2011 Optics + Photonics

Optical Engineering + Applications

Technical Summaries

spie.org/op

Conference Dates: 21–25 August 2011
Exhibition Dates: 23–25 August 2011
San Diego Marriott Marquis and Marina, San Diego Convention Center
San Diego, California, USA

Connecting minds for global solutions

Contents
8121: The Nature of Light: What are Photons? IV .............................. 2
8122: Tribute to Joseph W. Goodman .............................................................. 15
8123: Eleventh International Conference on Solid State Lighting .............. 20
8124: Nonimaging Optics: Efficient Design for Illumination and Solar Concentration VIII ............................................................. 33
8125: Optomechanics 2011: Innovations and Solutions .......................... 39
8126: Optical Manufacturing and Testing IX .................................................. 47
8127: Optical Modeling and Performance Predictions V ........................... 58
8128: Current Developments in Lens Design and Optical Engineering XII; and Advances in Thin Film Coatings VII ...................... 63
8129: Novel Optical Systems Design and Optimization XIV ...................... 68
8130: Laser Beam Shaping XII ................................................................. 74
8131: Optical System Alignment, Tolerancing, and Verification V .............. 81
8132: Time and Frequency Metrology III .................................................... 87
8133: Dimensional Optical Metrology and Inspection for Practical Applications ............................................................. 91
8134: Optics and Photonics for Information Processing V .......................... 100
8135: Applications of Digital Image Processing XXXIV .......................... 107
8136: Mathematics of Data/Image Pattern Coding, Compression, and Encryption with Applications XIV ................................. 121
8137: Signal and Data Processing of Small Targets 2011 ......................... 126
8138: Wavelets and Sparsity XIV ............................................................... 136
8139: Advances in X-Ray/EUV Optics and Components VI ..................... 148
8140: X-Ray Lasers and Coherent X-Ray Sources: Development and Applications ............................................................. 157
8141: Advances in Computational Methods for X-Ray Optics II .............. 169
8142: Hard X-Ray, Gamma-Ray, and Neutron Detector Physics XIII ............ 178
8143: Medical Applications of Radiation Detectors ..................................... 193
8144: Penetrating Radiation Systems and Applications XII ....................... 199
8145: UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy XVII .............................................................................. 204

8146: UV/Optical/IR Space Telescopes and Instruments: Innovative Technologies and Concepts V .................................................... 210
8147: Optics for EUV, X-Ray, and Gamma-Ray Astronomy V ................... 219
8148: Solar Physics and Space Weather Instrumentation IV ......................... 233
8149: Astronomical Adaptive Optics Systems and Applications V .............. 241
8150: Cryogenic Optical Systems and Instruments XIV ................................ 245
8151: Techniques and Instrumentation for Detection of Exoplanets V ........ 250
8152: Instruments, Methods, and Missions for Astrobiology XIV ............... 262
8153: Earth Observing Systems XVI ........................................................... 272
8154: Infrared Remote Sensing and Instrumentation XIX .......................... 290
8155A: Infrared Sensors, Devices, and Applications ................................... 301
8156: Remote Sensing and Modeling of Ecosystems for Sustainability VIII .............................................................................. 311
8157: Satellite Data Compression, Communications, and Processing VII .............................................................................. 319
8158: Imaging Spectrometry XVI ............................................................... 327
8159: Lidar Remote Sensing for Environmental Monitoring XII ................. 332
8160: Polarization Science and Remote Sensing V ..................................... 339
8161: Atmospheric Optics: Turbulence and Propagation ............................ 349
8162: Free-Space and Atmospheric Laser Communications XI .................... 354
8163: Quantum Communications and Quantum Imaging IX ..................... 362
8164: Nanophotonics and MacroPhotonics for Space Environments V ........ 371
8165A: Unconventional Imaging and Wavefront Sensing VII ..................... 377
8165B: Adaptive Coded Aperture Imaging and Non-Imaging Sensors V ....... 385
Conference 8121: The Nature of Light: What are Photons? IV
Monday-Thursday 22-25 August 2011 • Part of Proceedings of SPIE Vol. 8121
The Nature of Light: What are Photons? IV

8121-01, Session 1
A loophole in correlated photon statistics
A. F. Kracklauer, Private Consultant (Germany)

Experiments on correlated photon pairs, e.g., tests of Bell inequalities, are encumbered with the challenge of identifying valid pairs. Noise in the form of accidental coincidences between photons not produced as a correlated pair, must be excluded. Usually, this is thought to be achieved by both reducing the intensity of the pair-generation-stimulus so as to isolate genuine pairs with larger time buffer intervals, and then by selecting only pairs within as narrow a time window as is feasible (while retaining instrumental stability). Herein we present results of a study of a contravening phenomena, based on physically feasible models of photo detection, which surprisingly lead to enhanced corruption of the detection events using these two tactics. It will shown that to date taken data is compatible with the existence of this phenomena, so that done experiments must be considered inconclusive.

8121-02, Session 1
Toward an event-based corpuscular model for optical phenomena
H. De Raedt, F. Jin, Univ. of Groningen (Netherlands); K. F. L. Michielsen, Forschungszentrum Jülich GmbH (Germany)

We present an event-based corpuscular model (EBCM) of optical phenomena that does not require the knowledge of the solution of a wave equation of the whole system and reproduces the results of Maxwell’s theory by generating detection events one-by-one. The EBCM gives a cause-and-effect description for every step of the process, starting with the emission and ending with the detection of the photon. By construction, the EBCM satisfies Einstein’s criterion of local causality and allows for a realistic interpretation of the variables that appear in the simulation model. The EBCM is entirely classical in the sense that it uses concepts of the macroscopic world and makes no reference to quantum theory but is nonclassical in the sense that it does not rely on the rules of classical Newtonian dynamics. The key feature of our approach is that it uses adaptive processes to mimic the interaction of the particles with the optical components such as detectors, beam splitters etc. We demonstrate that one universal EBCM for the interaction of photons with matter suffices to explain the interference and correlation phenomena that are observed when individual photons are detected one by one. This EBCM gives a unified description of multiple-beam fringes of a plane parallel plate and single-photon Mach-Zehnder interferometer, Wheeler’s delayed choice, photon tunneling, quantum eraser, two-beam interference, double-slit, Einstein-Podolsky-Rosen-Bohm and Hanbury Brown-Twiss experiments. Of course, this model produces the frequency distributions for observing many photons that are in full agreement with the predictions of Maxwell’s theory and quantum theory.

8121-03, Session 1
Proposal for an interference experiment to test the applicability of quantum theory to event-based processes
K. F. L. Michielsen, M. Richter, T. Lippert, Forschungszentrum Jülich GmbH (Germany); B. Barbara, Institut NÉEL (France); S. Miyashita, The Univ. of Tokyo (Japan); H. De Raedt, Univ. of Groningen (Netherlands)

We propose a realizable single-particle Mach-Zehnder interferometer experiment in which the path length of one arm can change before each passage of a particle through the interferometer. We demonstrate that the analysis of the time-series produced by this experiment can be used to determine to which extent quantum theory provides a description of the observed detection events that goes beyond statistical averages. This is important because quantum theory postulates that it is fundamentally impossible to give an explanation that goes beyond the description in terms of frequency distributions to observe events. Although in practice, it may be impossible to give such an explanation, the present state of knowledge does not support the premise that it impossible in principle. Moreover, as there exist event-based, locally causal corpuscular models that reproduce the statistical results of quantum theory for this experiment if the path lengths are fixed during experiment (the simplest one being given in De Raedt H., De Raedt K. and Michielsen K., Europhys. Lett., 69 (2005) 861), this premise is untenable. We also show that the proposed experiment may be used to refute whole classes of event-based, locally causal corpuscular models for optical phenomena.

8121-05, Session 1
Controversy among giants and a simple test regarding the “photon” nature of light
W. T. Rhodes, Florida Atlantic Univ. (United States)

On reading Ulf Leonhardt’s book Measuring the Quantum State of Light shortly after its publication, I became interested in a conceptual tool described by Leonhardt designed to aid one in the understanding of the action of beam splitters in photon-starved systems. What intrigued me most about the model is that it suggested differences in the results of a low-light-level demonstration of the photon-by-photon development of Young’s fringes, depending on whether a lossless beam-splitter attenuator is placed directly after the source point or is placed directly before the two pinholes. At a meeting on quantum optics soon thereafter, I brought my observation to the attention of two giants in the area of the quantum state of light. One, without hesitation, declared me “Wrong.” The presence of controversy on this issue is interesting in itself. The availability of a simple experiment—which I shall describe in this talk—for testing the concept is potentially important.

8121-06, Session 2
Gauss’s Law for gravity and observational evidence reveal no solar lensing in empty vacuum space
E. H. Dowdye, Jr., Pure Classical Physics Research (United States)

An application of the Mathematical Physics of Gauss’s Law for gravity along with intense observational evidence, reveal that solar lensing does not occur in the empty vacuum space slightly above the plasma rim of the sun. The thin plasma atmosphere of the sun represents a clear example of an indirect interaction involving an interfering plasma medium between the gravitational field of the sun and the rays of light from the stars. There is convincing observational evidence that a direct interaction between light and gravitation in the empty vacuum space above the solar rim simply does not occur. Historically, all evidence of light bending has been observed predominantly near the thin plasma rim of the sun; not in the empty vacuum space far above the thin plasma rim. An application of Gauss’ law clearly shows that, if the light bending rule of General Relativity were valid, then a light bending effect due to the gravitational field of the sun should be easily detectable with current technical mean in Astrophysics at various analytical Gaussian spherical surfaces of
special relativity postulates. The deformed Minkowski metric presented with the special relativity addition of velocities in one dimension. They of a hyperbolic scator algebra. The proposed rules become identical immediately fulfilled. This representation is based on a transformation.

An alternative velocity addition scheme is proposed consistent with the relativistic velocities of electron and positron. This “action at a distance” force has mathematical descriptions, but the underlying phenomenon is really not well understood. Our intuitive understanding of how force is delivered through the action of an impulse comes from our everyday experience and is described by Newton’s Laws. If we extend this classical mechanical line of reasoning to these more mysterious forces, it leads to the derivation of a high velocity version of F = ma. The basis of this model is Newton’s notion that gravity could be attributed to multiple impacts of invisible bodies. In this model it is assumed that such an acceleration field is made up of tiny bodies that travel at the speed of light and that these bodies deliver energy to accelerated particles by elastic collisions. The result is a model that is similar to relativistic equations and predicts a maximum velocity for the accelerated particle.

8121-07, Session 2
The high-velocity version of classical mechanics
R. T. Dorn, Independent Researcher (United States)
A good understanding of the actual mechanism for the attraction between an electron and positron is necessary for the study of electron - positron phenomenon such as annihilation and pair production. This “action at a distance” force has mathematical descriptions, but the underlying phenomenon is really not well understood. Our intuitive understanding of how force is delivered through the action of an impulse comes from our everyday experience and is described by Newton’s Laws. If we extend this classical mechanical line of reasoning to these more mysterious forces, it leads to the derivation of a high velocity version of F = ma. The basis of this model is Newton’s notion that gravity could be attributed to multiple impacts of invisible bodies. In this model it is assumed that such an acceleration field is made up of tiny bodies that travel at the speed of light and that these bodies deliver energy to accelerated particles by elastic collisions. The result is a model that is similar to relativistic equations and predicts a maximum velocity for the accelerated particle.

8121-08, Session 2
Alternative realization for the composition of relativistic velocities
M. Fernández-Guasti, Univ. Autónoma Metropolitana-Iztapalapa (Mexico)
The reciprocity principle requests that if an observer, say in the laboratory, sees an event with a given velocity, another observer at rest with the event must see the laboratory observer with minus the same velocity. The composition of velocities in the Lorentz-Einstein scheme does not fulfill the reciprocity principle because the composition rule is neither commutative nor associative. In other words, the composition of two non-collinear Lorentz boosts cannot be expressed as a single Lorentz boost but requires in addition a rotation. The Thomas precession is a consequence of this composition procedure. Different proposals such as gyro-groups have been made to fulfill the reciprocity principle. An alternative velocity addition scheme is proposed consistent with the invariance of the speed of light and the relativity of inertial frames. An important feature of the present proposal is that the addition of velocities is commutative and associative. The velocity reciprocity principle is then immediately fulfilled. This representation is based on a transformation of a hyperbolic scator algebra. The proposed rules become identical with the special relativity addition of velocities in one dimension. They also reduce to the Galilean transformations in the low velocity limit. The Thomas gyration needs to be revised in this nonlinear realization of the special relativity postulates. The deformed Minkowski metric presented here is compared with other deformed relativity representations.

8121-09, Session 2
Relativity: a pillar of modern physics or a stumbling block
G. S. Sandhu, Independent Researcher (India)
Currently, the theory of relativity is being regarded as one of the main pillars of Modern Physics, essentially due to its perceived role in high energy physics, particle accelerators, relativistic quantum mechanics, and cosmology. Since the founding assumptions or postulates of relativity and some of the resulting consequences confound the logic and common sense, a growing number of scientists are now questioning the validity of Relativity. The advent of Relativity has also ruled out the existence of the 19th century notion of ether medium or physical space as the container of physical reality. Thereby, the Newtonian notions of absolute motion, absolute time, and absolute reference frame have been replaced with the Einsteinian notions of relative motion, relative time, and inertial reference frames in relative motion. This relativity dominated viewpoint has effectively abandoned any critical study or advanced research in the detailed properties and processes of physical space for advancement of Fundamental Physics. In this paper both special theory of relativity (SR) and general relativity (GR) have been critically examined for their current relevance and future potential. We find that even though Relativity appears to be a major stumbling block in the progress of Modern Physics, the issue needs to be finally settled by a viable experiment [Phys. Essays 23, 442 (2010)] that can detect absolute motion and establish a universal reference frame.

8121-10, Session 3
Planck’s constant h not only governs atomic shell energies, moreover, is also responsible for the neutrons and protons internal structure (charge and size)
E. H. Berloff, Leopold-Franzens-Univ. Innsbruck (Austria)
The discrepancy between the neutron’s inherent magnetic flux and the flux quantum lead to a new model for the internal structure of neutrons and protons. A highly charged core Mass X is surrounded by 4 tetrahedral arranged πo mesons. Nuclear forces are of repelling character. Coulomb forces keep the system in balance and attempts due to collisions enlarging the system are compensated by bubbling out electrons from the core mass X. The neutrons decay is core charge dependent. A core charge asymmetry gives the proton its macroscopic charge; it shrinks until the core charge reaches 47.e.

8121-11, Session 3
The physical origin of the uncertainty theorem
A. Giese, Consultant (Germany)
Elementary particles can be explained by an interpretation of quantum mechanics that is based upon that of Louis de Broglie, the discoverer of the wave properties of a particle. According to this, elementary particles can be described using a predominantly classical model. This model is derived from the presence of relativity in all matter, and furthermore from properties such as mass, spin and magnetic moment. According to this model an elementary particle is made up of a pair of sub-particles which orbit each other. The internal field which binds the sub-particles extends outward from the particle. It causes the particle to appear from the outside like a wave, and to undergo interference, for example when passing through a double slit. This understanding conforms to the approach of Louis de Broglie, who characterized the external part of the alternating field as a “pilot wave”. The problem with measuring the dynamic parameters of an elementary particle is that those parameters are determined by the reaction of its surrounding wave. This surrounding wave on the one hand extends
outward from the particle, but on the other hand it is locally concentrated around the position of the particle. This fact, the spatial delimitation, limits the determination of the wave parameters using the rules of the Fourier transform. Hence it reduces the information that can be obtained about the parameters to a degree described by the uncertainty relation. The properties of the particle itself, however, are not at all uncertain in this view.

This derivation of uncertainty does not support the very general consequences drawn from the uncertainty principle as used by contemporary QM.

To apply this understanding to the photon, we have to assume that the photon has a kind of core, like leptons and quarks. This gives rise to further questions which need to be discussed.

8121-12, Session 3
Microscope and spectroscopy results are not limited by Heisenberg’s Uncertainty Principle!
N. S. Prasad, NASA Langley Research Ctr. (United States)

A reviewing of many published experimental and theoretical papers demonstrate that the resolving powers of microscopes, spectrosopes and telescopes can be enhanced by orders of magnitude better than old classical limits by various advanced techniques including de-convolution of the CW-response function of these instruments. Heisenberg’s original analogy of limited resolution of a microscope, to support his mathematical uncertainty relation, is no longer justifiable today. Modern techniques of detecting single isolated atoms through fluorescence also over-ride this generalized uncertainty principle. Various nano-technology techniques are also making atoms observable and location precisely measurable. Even the traditional time-frequency uncertainty relation or bandwidth limit can be circumvented while doing spectrometry with short pulses by deriving and de-convolving the pulse-response function of the spectrometer just as we do for CW input.

8121-13, Session 3
Arising of the entangled photon in the one-dimensional high finesse nanocavity
V. F. Cheltsov, Moscow State Mining Univ. (Russian Federation); A. Cheltsov, Q-MOL LLC (United States)

This work is a continuation of papers presented by the author at the Optics and Photonics Symposium (2009) and is devoted to the case of the high finesse nanocavity with the average photon escaping rate $\Gamma = \eta c/\bar{\eta} < g$ -coupling constant. The case is of special interest as possible pretender for a qubit in quantum computers. The probability distribution to find photon in the $(\omega, r)$-space, investigated in the interval $0 < \omega / 4g < \eta 1$ has triplet structure with very low central peak and satellites at frequencies $\pm G(\omega \pm g)$. The latter emerge as result of emission from two upper atomic split sublevels. The peak is produced by ensuing reabsorptions of satellites by atom through its upper sublevels. Oscillating as $\cos(\omega t)$ and decaying fast, the peak is accompanied with the simultaneously arising satellites, when the peak disappears the satellites become stationary. The steady state is quenched with continuum of final states. The profile of structure consists of two identical components has the time-dependence $t^{-1/4}$ and the spectral width of satellites is by order less than the distance between them. These components with frequencies $(g \pm \omega)$ have the average photon energies equal to $1/2(\omega / 4g)$ where factor $1/2$ accounts for normalization condition. The satellites amplitudes reach maximum at $1/4g > 0.05$. The profile of this structure has been found to have the form $t^{-1/4} \exp(-1/4)$ with maximum attained for $1/4g > 0.05$ and average photon cavity life-time proportional to $4/n$. We named the structure "entangled photon".

8121-14, Session 4
Interplay between theories of quantum classical signals: classical representation of entanglement
A. Y. Khrennikov, Linnaeus Univ. (Sweden)

We present a model, prequantum classical statistical field theory (PCSFT), which provides a classical random signal representation of quantum correlations, including correlations for entangled quantum systems. This task is dedicated to Einstein’s vision of physics and specifically his hope for what quantum theory could and, in his view, should be. In particular, two of Einstein’s dreams about the future of quantum theory are realized in this book: reduction of quantum randomness to classical ensemble randomness and total elimination of particles from quantum mechanics (QM) — creation of a field model of quantum phenomena (cf., e.g., Einstein and Infeld). Thus, contrary to a number of the so-called “no-go” arguments and theorems advanced throughout the history of quantum theory (such as those of von Neumann, Kochen-Specker, and Bell), quantum probabilities and correlations can be described in a classical manner. There is, however, a crucial proviso. While this I argue that QM can be interpreted as a form of classical statistical mechanics (CSM), this classical statistical theory is not that of particles, but that of fields.

8121-15, Session 4
Understanding the masses of elementary particles: a step towards understanding the massless photon
K. O. Greulich, Fritz Lipmann Institute (Germany)

A so far unnoticed simple explanation of elementary particle masses is given by $m = Z * melectron/alpha$, where alpha ($= 1 / 137$) is the fine structure constant or coupling constant of quantum electrodynamics. $Z = 3(M-L/2) + S$, where $M = 1,...,12, 24, 26$ and $S = 1,2,3$ depending on the strangeness of the particle and $S = 0, L = 1$ for leptons and the nucleon. The mass at rest is identical to the gravitational potential of two Planck masses at a distance of the deBroglie wavelength of the particle. Photons can be described similarly when the planck masses are replaced by hypotheticmassless objects.

Literature:
Greulich, K.O. Calculation of the masses of all fundamental elementary particles with an accuracy of approximately 1% J Mod Phys 1, 300 - 302 (2010)
http://www.fii-leibniz.de/www_kog/ Then click “Physics”

8121-17, Session 4
Quantum points/patterns, part 1: from geometrical points to quantum points in sheaf framework
M. G. Zeitlin, A. N. Fedorova, Institute of Problems of Mechanical Engineering (Russian Federation)

We consider some generalization of the theory of quantum states, which is based on the analysis of long standing problems and unsatisfactory situation with possible interpretations of quantum mechanics. We demonstrate that the consideration of quantum states as sheaves can provide, in principle, more deep understanding of some phenomena. The key ingredients of the proposed construction are the families of sections of sheaves with values in the category of the functional realizations of infinite-dimensional Hilbert spaces with special (multiscale) filtration.

The questions we hope to answer are:
Return to Contents

8121-61, Poster Session

Shapiro Delay: a frequency dependent transit time effect; not a 4D space-time effect
S. Ghaazanshahi, California State Univ., Fullerton (United States); E. H. Dowdy, Jr., Pure Classical Physics Research (United States)

First noticed by Irvin L. Shapiro in 1964, the transit time required for a microwave signal to propagate through space, arrive at a satellite orbiting Venus or Mercury, required a measurable time delay for the reply signal to propagate back to the earth to be received at the antenna of the observatory. The time delay was noticeably affected by the relative position of the sun. Controlled measurements conducted by Shapiro determined that the time-tagged microwave signals had measurable effects that varied as a function of the impact parameter of the microwave beam relative to the sun. The delays observed to be in the 100's of microseconds when the impact parameter of the microwave beam was at a minimum. After repeated measurements, varying time delays were recorded and were referred to as the Shapiro delay. These measurements permitted a precise determination of the electron density profile of the solar wind as a function of the radial distance r from the sun. Significant findings reveal that, for all microwave signals propagating in the solar wind atmosphere of the solar system, the waves are subjected to a frequency dependent plasma index of refraction n that exceeds unity, i.e., n > 1.00000000. For optical, IR and UV wavelengths, the plasma index of refraction is practically n = 1.00000000 and these wavelengths are virtually unaffected by the widespread atmosphere of the expanding solar wind described by the electron density profile. Thus, the Shapiro delay is a frequency dependent transit-time effect and cannot be a space-time effect of General Relativity since it is independent of frequency.

8121-18, Session 4

Quantum points/patterns, part 2: from quantum points to quantum patterns via multiresolution
A. N. Fedorova, M. G. Zeitlin, Institute of Problems of Mechanical Engineering (Russian Federation)

It is obvious that we haven’t any unified framework covering a zoo of (mostly) discrepant interpretations of QM, as well as satisfactory explanation/understanding of main ingredients of a phenomena like entanglement, etc.

The starting point is an idea to describe the key object of the area, namely point objects (physical points). Usually, for the modeling of real physical point objects, one can consider equivalence between them and standard geometrical points.

As direct consequence, our dynamical variables (wave function or density matrix or the Wigner function) are described by means of point functions. It seems reasonable to have the rich structure for a model of the (quantum) physical point (particle) in comparison with the structureless geometrical point.

All above looks like Physical Hypothesis but it is more or less well known from the mathematical point of view. Some of the regular and unitary structures are well known (instantaneous unitary evolution). However, the structural notion of point function is not quite well known. It is quite surprising that from some mathematical points of view the point function is not well defined in contrast to the structureless point object.

It is obvious that the point function structure is not realizable in the framework of classical mechanics. It seems reasonable to have one more step: from point function to sheaf. It means that we have to study the structure of point function from the proper category describing space-time to other one properly describing structure dynamics of Quantum States/Patterns. The objects of this category are some filtrations on the Hilbert space of States.

Definitely, we need a proper analytical/numerical machinery to realise such approach. We present a family of methods which can describe the creation of nontrivial states (patterns), localized, chaotic, entangled or decoherent, from the basic localized (nonlinear) eigenmodes which are more realistic for the modeling of quantum dynamical process than the orthodox linear gaussian-like coherent states.

8121-62, Poster Session

Explanation of relativistic phenomena on the basis of interactions of particle energy, applied energy, and field energy
V. P. Fernando, Natural Philosophy Alliance (Canada)

The present dynamic theory identifies that in parallel with position related, gravitational energy finding expression in terms of the universal constant G, the energy of motion finds expression in terms of the universal constant c. Constant c, primarily is the determinant of structural configurations of energy of motion, internal energy of particles, and of photons, in a multiplicity of ways. The value c, enters into expression of relativistic phenomena as the ratio of energy of motion Mpc and particle energy Mc2. This ratio is $v/(c/(1-v^2/c^2))^{1/2}$. Gamma-factor arises because, energy of motion pc (applied to overcome the inertia M of the particle), itself has inertia $m = pc/c^2$, which classical mechanics has omitted to simplify physics of slow motion. By rectifying such omissions and defects in the classical conceptual framework, and discerning that interactions of gravitation as well as motion are regulated by two specific algorithms, all principal relativistic phenomena are explained dynamically. These algorithms show that the stability of configuration of a system is attained by induction of energy from the universal field. These algorithms also provide the insight that phenomena related to motions of photons, such as aberration, and physical basis Fresnel’s formula too are regulated by similar algorithms.

8121-63, Poster Session

Diffraction described by virtual particle momentum exchange: the “diffraction force”
M. J. Mobley, Arizona State Univ. (United States)

Particle diffraction can be described by an ensemble of particle paths
The much-discussed wave-particle duality permits operations that are pure wave or pure particle, with no ambiguity. As wave operations with passive components do not require energy, it is possible to make a number of zero energy devices. The most recent of these is Boolean logic. Like most optimists, I have never encountered a situation in which I am genuinely puzzled about whether any particular operation is done in the wave domain or in the particle domain (photons). Only recently did I figure out the types of computations that can be done in the wave domain - saving time, energy, speed, and so on. One approach that can be done in the wave domain is to find computations that do what nature does (Unitary Transformations). For two years now, I have known how to do logic in the wave domain, and was somewhat puzzled. After all, everyone knows that Boolean logic requires a nonlinear operation that, to my knowledge, requires a nonlinearity. As is often the case, what everybody knows is not true. So I have sought and will report here the solution. We can do Boolean logic in the wave domain, but not the way everyone has thought it should be done. Once again, we must formulate the question carefully if we seek to have nature provide us the answer. The solution is one of the many three-step processes found in technology. In this case it is of the form:

Particle (Input) → Wave (Lookup Table) → Particle (Detection)

As should be clear, the particle operations require energy dissipation, but the wave operation can be done at zero energy but only in optics.

The constancy of c everywhere requires space to be a stationary and complex tension field

C. Roychoudhuri, Univ. of Connecticut (United States); A. M. Barootkoob, Independent Consultant (United States)

If photons are perpetually propagating classical wave packets moving with the extreme velocity “c”, then it requires a sustaining complex cosmic tension field (C2TF), which is stationary everywhere. Then Michelson-Morley experiment should naturally produce null results except for minute Fresnel drags being within the Earth’s atmosphere. Further, if C2TF has a built-in weak dissipative property towards electromagnetic waves, its frequency should decrease slowly with the distance of propagation through the C2TF, which would eliminate the need for the hypothesis of “expanding universe”. We will present appropriate mathematical relations along with a suitable wave equation whose solution incorporates the Hubble constant that does not require Doppler shift. The success of this hypothesis would imply that stable particles are complex 3D resonant oscillations of the C2TF, eliminating the need to have the hypothesis of “wave-particle duality”.

The extraterrestrial casimir effect

R. C. Storti, Delta Group Engineering, P/L (Australia)

Application of the Electro-Gravi-Magnetic (EGM) Photon radiation method to the Casimir Effect (CE), suggests that the experimentally verified (terrestrially) neutrally charged parallel-plate configuration force, may differ within extraterrestrial gravitational environments from the gravitationally independent formulation by Casimir. Consequently, the derivation presented herein implies that a gravitationally dependent CE may become an important design factor in nanotechnology for extraterrestrial applications (ignoring finite conductivity + temperature effects and evading the requirement for Casimir Force corrections due to surface roughness).

Doppler phenomena determined by photon-cosmic field interactions

V. P. Fernando, Natural Philosophy Alliance (Canada)

The principle of conservation of energy in all interactions of matter or photons in motion, can be accounted for, only if an inflow or outflow of energy from the cosmic field is associated. This paper discarding the algorithm of gravitation, first traces out how energy from the cosmic field alters the frequency, hence time of an atomic clock in a GPS satellite orbit. Then by discerning an analogous algorithm, it demonstrates how inflow of energy from the cosmic field underlies Fresnel’s result when a photon passes through a moving medium. Michelson-Morley experiment was warranted by the mathematical finding based on kinematic concepts, of the second order difference in the frequency, between the two cases - observer at rest and the source of light moving, and vice-versa. The dynamic reality is that momentum mc of a photon cleaves into two parts (active and passive). When the observer is moving towards the source, the active part acquires the value m(c - v) and the other +mv, and when the observer moves away, the active part acquires the value m(c + v) and the other -mv. This renders the second order difference sought in the Michelson experiment to be redundant. Further, in the final result the velocity of light remains constant at c, instead the frequency changes, in conformity with Planck’s law E = hf, and confirms that there is an inflow and an outflow of energy respectively in the two cases, from the Cosmic Energy Field. An integral explanation of Doppler shift and Aberration is offered.

On information transmitted using a photon

S. C. Kak, Oklahoma State Univ. (United States); P. Verma, G. MacDonald, The Univ. of Oklahoma - Tulsa (United States)

We present new research providing the basis of transmission of information using polarization states of photons and its application in cryptography. Current quantum cryptography applications are based on the BB84 protocol which is not secure against photon siphoning attacks. Recent research has established that the information that can be obtained from a pure state in repeated experiments is potentially infinite. This can be harnessed by sending a burst of photons confined to a very narrow time window and whereas conventional view would be that such a narrow burst would carry a single bit of information. The proposed method represents an entirely new way of transmitting secret information, with potentially significant applications to cryptography and communications. While polarization shift-keying methods have been proposed earlier, our method is somewhat different in that it proposes to discover the polarization state of identical photons in a burst from a laser which codes binary information.
About luminiferous world ether

P. O. Demyanenko, National Technical Univ. of Ukraine (Ukraine)

In the physics of electromagnetic (EM), and specifically, light waves, uncertain situation takes place: the waves actually exist, but medium of their occurrence is not determined.

Persistent experimental investigations of demonstration of luminiferous ether physical properties were always ineffective. Taking it into account as well as an absence of any privileged coordinate system in the Universe to link ether, Einstein proposed generally to reject this concept and exclude it from science usage. EM waves herewith should be considered as definite self-contained physical objects.

With the lapse of time this situation became usual one, however it could not be satisfactory in world view context. Thus "waves" are the changes in medium's state (its disturbance), which propagate within the medium and carry the energy. This entire means that existence of waves beyond the medium is nonsense.

Analyzing the problems as to EM ether and waves, we propose the hypothesis, which can consistently associate all set of problems. In accordance with our hypothesis the concept of structure of our world (OW) should be revised. If we accept the structure of OW in accordance with our hypothesis, we do not need in certain "ether-medium" for providing the condition for exiting of EM waves. There these waves exist due to existence of properly arranged OW. Traditional concept of ether is not a “medium”, which can fill by itself usual 3D space (volume) in OW, but a separate entity, which could be considered as a constituent part of OW, but not a filling part. This concept allows determining OW with the time elapsed over it as a certain 3D-frontier between other changeless in time worlds.

The nature of light: What are photons?

A. Giese, Consultant (Germany)

The particles on which particle physics generally focuses are leptons and quarks. In accelerators, leptons, quarks, and those particles which are composed of quarks (e.g. mesons) are investigated.

Using the properties of particles, such as their mass, spin and magnetic moment, and from the relativistic behaviour of matter - which can be derived from the 'zitterbewegung' of the electron - we can draw up a model in which a particle is composed of a pair of sub-particles which orbit each other. This model conforms to the quantum mechanical concepts of Louis de Broglie. It replaces the idea of particle-wave duality, based upon Heisenberg's interpretation of QM, by the so-called pilot wave. The particle model allows the properties of particles to be described using concepts derived to a considerable extent from classical physics. This includes the precise determination of the mass and the magnetic moment of the particle without resorting to a Higgs field, vacuum polarization, or similar QM devices.

If we apply this particle model, which has been developed for leptons and quarks, to the photon, then this has some specific implications. A logical consequence of it is that the photon, too, must be composed of sub-particles orbiting each other. - The talk will discuss the aspects of the photon for which this model can help our understanding of it and those for which our understanding may be complicated.

Non-equilibrium mechanisms of light in the microwave region

J. H. J. Mortenson, General Resonance, LLC (United States)

A significant advance in quantum mechanics - the discovery of Einstein's hidden variables - was presented at the previous meeting. These discoveries are providing a richer and more classical understanding of interactions between light and matter. This New Physics has revealed that what was described in the past as the "photon", is not really an elementary particle of light. Previous definitions inadvertently limited various degrees of freedom and attributed the property of indivisibility...
to what is actually a collection of elementary light particles. The true elementary "particle" of light is the single wave of light, i.e., a single oscillation of electromagnetic energy.

Quantum chemists however, relying on prior incomplete photon concepts, hypothesized that photon energies equal to or greater than bond energies were necessary to produce chemical or material reactions. Light in the microwave region was therefore theorized to exert only thermal effects in such reactions. Numerous experiments with microwaves suggested otherwise, however, but no quantum mechanical framework existed to explain any non-thermal or non-equilibrium mechanisms. In the absence of a mechanistic explanation, the clear and reproducible experimental evidence was simply disregarded by many scientists.

The recent advances in quantum mechanics have now provided a firm mechanistic framework for the explanation of non-equilibrium and non-thermal effects by microwaves. These new-equilibrium mechanics include resonant absorption, resonant electron stimulation, and resonant acoustic transduction, thereby providing rational frameworks for many previously unexplained experimental results. This New Physics dramatically expands the reach of practical engineering applications beyond the previous limitations of photochemistry and into lower frequency regions of the electromagnetic spectrum.

8121-29, Session 8
Creation and fusion of photons
A. Meulenberg, Jr., S. Ramadass, Univ. Sains Malaysia (Malaysia)

Light, from a star, begins as a photon. Fusing with uncountable others, it forms a minuscule component of a spherical wave that eventually is better represented as a plane wave. Moving further through the universe, its energy density drops until it begins to recombine into photons. This paper seeks to learn about the interaction of light with light (and with matter) during this process. The Hanbury Brown Twist (HBT) Effect gives a model for the observed nature of stellar light that has traveled across the universe. What are the physical mechanisms underlying this model? Comparison is made with both laser light and that from atomic radiation. Keys to the 'coherence' length observed and measured in non-solar stellar light is the low convergence angle from the source and perhaps the distance from the source. How much interaction does light have with matter during its cross-universe transit? If it is not insignificant, then the thought that the HBT effect could be light interacting with light must be reexamined.

Maxwell did not believe in photons. Therefore his equations, based on the wave nature of light, did not include any nonlinearities, or boundary conditions, that could lead to photonic structures. His equations are complete, relativistically correct, and unchallenged after nearly 150 years. However, even though his far-field solution has been considered as the basis for photons, is probable that radiation from atomic electrons are not quite what many ‘classical’ models try to represent as the source of photons.

8121-30, Session 8
Birth of a two-body photon
R. T. Dorn, Independent Researcher (United States)

The two body photon model assumes that an electron and a positron have been accelerated to the speed of light. The tenets of relativity theory would lead one to believe this to be impossible. It has long been thought that a body cannot be accelerated to the speed of light because the relativistic mass would become infinite. This conceptual problem is addressed with the realization that it is not necessary to resort to the concept of a velocity dependent mass. Instead, the force could be considered to be velocity dependent. The relativistic equations of motion can be rearranged and interpreted such that the force varies with velocity instead of the mass. When the velocity reaches the speed of light, instead of dividing by zero and interpreting the equations as implying a nonphysical infinite mass, the equations show a finite mass with an applied force of zero. The equations can still take on the indeterminate form of 0/0, but standard mathematical analysis of this situation will show that the equations predict that a body can reach the speed of light. Furthermore, under the influence of an inverse square force, a body can be accelerated to the speed of light over very short distances and provide the initial conditions necessary for the birth of a two body photon.

8121-31, Session 8
A wave theory of the photoelectric effect
H. H. Lindner, Consultant (United States)

The author will demonstrate that the photoelectric and Compton effects are best explained by a wave theory of light and electrons. Light is a spreading wave in electromagnetic (EM) space. Electrons are not particles but are extended EM wave-structures. Electrons absorb and emit light in discrete wave-packets. Once emitted, the wave-packet begins to spread by diffraction like all radiation. The wave-packet that an electron absorbs is the product of superpositioning of the source waves and background EM radiation of all frequencies (vacuum fluctuations). This quantization is electronic, not luminal. Planck’s constant, h , is an electron-structure constant and does not refer to freely propagating light itself.

8121-32, Session 8
The conservation of light's energy, mass, and momentum
J. H. J. Mortenson, General Resonance, LLC (United States)

The discovery of Einstein’s hidden variables was presented at the previous “Nature of Light” meeting, and revealed that Max Planck’s famous quantum formula, “E = h ν”, was incomplete (“E” is energy, “h” Planck’s action constant, and “ν” frequency). Planck assumed the formula as a given to derive the black body radiation function. A minor mathematical irregularity led Planck to use an abbreviated quantum formula, rather than his original quantum relationship, “E = h t ν” (“h” is the energy constant for light, and “t” the measurement time variable). Unaware of the mathematical issue, many struggled with interpretation of the action constant in regards to energy, mass and momentum. Although Einstein described the conservation of energy and mass, his framework was necessarily incomplete because of the hidden energy constant. De Broglie attempted to provide a complete picture for the conservation of energy, mass and momentum, however he encountered the same difficulties, bemoaning that it was “impossible to consider an isolated quantity of energy”.

With the newly discovered energy constant such consideration is now possible. The paradox of light’s rest mass yields to simple calculation - 7.372 X 10^-1[-51] kg/oscillation - within the same order of magnitude as Luo’s calculated upper limits for photon mass. Bending of light by massive gravitational objects becomes a natural, mechanical consequence of the gravitational attraction between light’s mass and matter. Momentum of light (2.21 X 10^-42 kg m/sec oscillation) is readily determined, and the conservation of energy, mass and momentum for both matter and light emerges in a mechanical framework.

8121-33, Session 8
Analysis of spectrometric data and detection processes corroborate photons as diffractively evolving wave packets
N. Tifessa, Manchester Community College (United States); C. Roychoudhuri, Univ. of Connecticut (United States)

In a previous paper [Proc. SPIE Vol.6372-29 (2006), “Do we count...
indivisible photons or discrete quantum events experienced by detectors?"), we have proposed that photons are diffractively evolving classical wave packet as a propagating undulation of the Complex Cosmic Tension Field (C2TF) after the excess energies are released by atomic or molecular dipoles as perturbations of the C2TF. The carrier frequency of the pulse exactly matches the quantum condition $E = h \nu$ and the temporal envelope function creates the Lorentzian broadening of the measured spectral lines. In this paper we compare and contrast the QM prescribed natural line width of emitted spectra and the Doppler free laser absorption spectra to further validate our photon model. Since a diffractively spread out wave packet cannot deliver all of its energy to an angstrom size detector, the stimulation of a detecting molecule by multiple wave packets are required to deliver the required quantum of energy and influence the emission of a photo electron. QM does not bar level- (or, band-) transition in a quantum device achieved through energy exchange delivered simultaneously by multiple classical or quantum entities. Case examples will be cited to validate the assertions in this paper.

8121-34, Session 9

Beyond the paraxial approximation for OAM light waves
A. M. Guzman, C. Beetle, Florida Atlantic Univ. (United States)

We explore the limits of the paraxial approximation for OAM waves and possible consequences of the use of $L$ as a good quantum number instead of the total angular momentum $J$ of the radiation. Generalized Stokes parameters for the OAM of a light wave can be measured by the phase space tomographic reconstruction of its Wigner distribution. We propose simultaneous measurements of the Stokes parameters for polarization and the generalized Stokes parameters for OAM waves for Laguerre-Gauss modes as a function of the propagation distance, in order to measure deviations from the field quantization in the paraxial approximation.

8121-35, Session 9

Studies on reaction kinetics under coherent microwave irradiations
M. Sato, National Institute for Fusion Science (Japan)

A richer and more classical understanding of interactions between light and matter(1) were investigated at the microwave frequency. As the microwave processing uses monochromatic frequency and single phases electromagnetic oscillations, it remained us the word of “coherence”. The wave gets spatial modulation by the non-uniformity in the materials and decreases phase velocities to the order of electron thermal velocities. The energy transmits back and forth between the waves and electrons during each cycle of oscillation and a part of energy is left in collective motions of the electron “clouds” via Landau damping mechanism. When the build up time of collective motions is shorter than the relaxation time to thermal motion, a collective kinetic motions can give the thermodynamic work to the material that generates various thermally non-equilibrium reactions. It is the origin of so called non-thermal effects of microwave.

The reduction speeds of metal oxide powders ($\text{CuO} \rightarrow \text{Cu}_2\text{O}$), irradiating by 2.45GHz H-field, were measured to investigate an amount of kinetic energy transmits back and forth between the waves and electrons during each cycle of oscillation and a part of energy is left in collective motions of the electron “clouds” via Landau damping mechanism. When the build up time of collective motions is shorter than the relaxation time to thermal motion, a collective kinetic motions can give the thermodynamic work to the material that generates various thermally non-equilibrium reactions. It is the origin of so called non-thermal effects of microwave.

According to the literature(1), the periods of time getting the work energy was estimated to $t_\text{vac} = h / qQ = 4.4 \times 10^{-10}$ (sec), and the numbers of cycles to accumulate work energy $N = 4.4 \times 10^{-6} \times 2.45 \text{GHz} \times 104$ cycles. (1) Juliana H. J. Mortenson, “The elementary quantum of Light” Proc. of SPIE (2009) Vol. 7421 74210T-1

8121-36, Session 9

Light’s infinitely variable energy speed in view of the constant speed of light
J. H. J. Mortenson, General Resonance, LLC (United States)

The discovery of Einstein’s hidden variables was presented at the previous “Nature of Light” meeting, and revealed that Max Planck’s famous quantum formula was incomplete. His complete quantum formula revealed a previously hidden energy constant, time variable, and a sub-photonic elementary particle of light (the single oscillation). Einstein embraced Planck’s work, yet struggled with the conflict between Galilean relativity and Lorentzian constant light speed, prompting Einstein’s Special Theory of Relativity. Later, with the energy constant still hidden, De Broglie could not model a fundamental quantity of energy and resorted to phase and group velocities.

The energy constant now allows one to consider a sub-photonic light particle and its fundamental quantity of energy in regard to time, space, speed and velocity. What emerges is a remarkably fresh and yet classical perspective. Einstein envisioned light energy as being confined in space in volumetric packets. Einstein’s 3-D quantum model suggests that those discrete and localized packets are single oscillations of light. The length of one quantum packet is equal to the wavelength, along which its 6.626 X 10^-34 J of energy is distributed. The entire energy packet travels at the constant speed of light, according to Lorentz. The speed with which an entire packet of energy can be absorbed by matter varies, however, relative to the length of the packet, pursuant to Galileo’s relativity principle, and can be much faster than the constant speed of light. This is consistent with supraluminal information and sub-photonic transmission experiments, and provides realistic mechanisms for new optical and photonic engineering applications.

8121-37, Session 9

Investigation of the irradiance (optical field) originated from an elementary atomic dipole transition
E. H. Berloffa, Leopold-Franzens-Univ. Innsbruck (Austria)

The irradiance of an atomic dipole transition -screened at microscopic distances from its origin - reveals interesting details not always evident when dealing with light phenomena. The basis of this investigations are pure classical. The HERTZ vector- formalism was used (BORN & WOLF). The special features of the electromagnetic radiation behaviour of such an atomic transition solely became evident when generally made disregards were suspended. However, the complexity of the originating equations forced one to treat the problem numerically. All computations were done due to a dipole elongation of 0,1Å with an oscillation frequency corresponding to the YAG-laser wavelength, $\lambda = 1,064 \mu\text{m}$. Strikingly a Fourier analysis of the irradiance (Poynting vector) does not replicate this frequency, moreover, it reveals harmonics. Up to ~ 0,1 $\mu\text{m}$ the fourth harmonic dominates, second harmonic is also appearing albeit at a minor amount. Beyond 0,1 $\mu\text{m}$ fourth and second harmonic exchange their appearance. Up to 100nm from the dipole centre sixth and eighth harmonics are also present but at minor strengths.

Outside the source centre the optical field is perceived as light wave and practically, instead of the presumed YAG wavelength, we measure double this frequency, namely green light. This is consistent lines with supraluminal information and sub-photonic transmission experiments, and provides realistic mechanisms for new optical and photonic engineering applications.

8121-38, Session 9

Virtual and real photons
A. Meulenber, Jr., Univ. Sains Malaysia (Malaysia); P. G. Vaidya, Indian Institute of Science (India); S. Ramadass, Univ. Sains
Malaysia (Malaysia)

Maxwell did not believe in photons. However, his equations lead to electromagnetic field structures that are considered to be photonic by Quantum Electro Dynamics. They are complete, relativistically correct, and unchallenged after nearly 150 years. However, even though his far-field solution has been considered as the basis for photons, as they stand and are interpreted, they are better fitted to the concept of virtual rather than to real photons. Comparison between static-charge fields, near-field coupling, and photonic radiation will be made and the distinctions identified. The questions about similarities in, and differences between, the two will be addressed.

It is probable that radiation from atomic electrons is not quite what many so-called ‘classical’ models try to represent as the source of photons. The functional difference in Coulomb vs harmonic potentials makes for a major difference in the radiation field from the low angular-momentum electron orbitals (not so for the more circular orbits). Therefore, a third form of EM radiation (non-photonic) is suggested. It is possible that this is a portion of the evanescent wave phenomenon about all charged matter. As such it would be equivalent to virtual photons and yet still “fill the universe.” Feynman’s and Jackson’s failure to identify the differences can be partially forgiven for the excellence in their respective classic texts. We will try to rectify that situation and thereby establish a grounds for better understanding both kinds of photons and their physical (as distinct from just their mathematical) interaction with charged particles and each other.

8121-39, Session 10

Possible evidence for unmediated momentum transfer between light waves

W. R. Hodgins, Science for Humanity Trust, Inc. (United States); A. Meulenberg, Jr., Univ. Sains Malaysia (Malaysia) and Science for Humanity Trust, Inc. (United States); S. Ramadass, Univ. Sains Malaysia (Malaysia)

Dowling and Gea-Banacloche proved mathematically that “...under certain circumstances, it is possible to consistently interpret interference as the specular reflection of two electromagnetic waves off each other...” Combining experiment, model, and logic, we confirm this statement. Contrary to the supposition that electromagnetic waves/photons cannot interact, it is possible to interpret the results to indicate that out-of-phase waves and opposite polarity photons repel or, at least, cannot pass through each other. No energy is detected in the dark/null zones of wave interference. Because energy is absent, the exchange of momentum through the null zone must redirect/repel light waves into bright zones. Our Zero-Slit Experiment (ZSX) provides diffraction free interference in air between two portions of a divided laser beam. This experiment was initiated in the attempt to completely cancel a section of these two beams by recombining them in air when they are 180 degrees out-of-phase. We have been able to reduce the interference pattern to a double bright zone (with 3 null zones), but no further. This pattern is qualitatively identical to a pattern of interference for a beam and its reflection from a front-surface mirror plus its mirror image. Thus, visually and mathematically, it is impossible to distinguish the two images. It is not surprising that a photon can create its mirror image in a conductive surface in the same manner that a charge creates it mirror image. The fact that the second beam can accurately represent the radiation from moving charges has interesting implications.

8121-40, Session 10

Why does the wave particle dualism become evident, particularly at optical wavelengths?

K. O. Greulich, Fritz Lipmann Institute (Germany)

At radio wavelengths “photons” are not really needed. The description of this part of the electromagnetic spectrum as waves is completely satisfying. In turn, in the range of cosmic radiation, the description of photons as “particles” is sufficient. However, this may not be intrinsic basic physics but caused by the choice of detectors. Radio detectors are solid metal rods - antennae. The energy density and the wavelength of a radio photon are much smaller than those of the antenna. In the range of cosmic radiation, the detectors are essentially single atoms. The energy density of such a photon is much higher, the wavelength much smaller. The primary process of photon detection at optical wavelengths usually occurs at a single atom, a limited group of atoms or a band in a solid state detector. There, the energy density is comparable to the energy density of the detected photon. Depending on the detailed conditions, a wave or a beam of particles is perceived.

Literature:

8121-41, Session 10

Nature of EM waves as observed and reported by detectors for radio, visible, and gamma frequencies

M. Ambroselli, P. Poulos, C. Roychoudhuri, Univ. of Connecticut (United States)

Characteristic transformations measured by detectors dictate what conclusions we can draw in terms of the superposition of monochromatic waves with integer wavelength multiples of the round trip of the cavity. However, the non interference of waves implies that these wave-fields cannot sum themselves without matter interaction [1,2]. The summation has to be carried out either by a nonlinear medium whose output involves the wave-mixing and/or it is performed by the detector. The output of a femtosecond Titanium Sapphire oscillator is analyzed with the above mentioned framework in mind. The spectrum is obtained in mode-locked and non mode-locked operation via a grating spectrometer for different cavity detunings. The time dependence is measured via a fast photodiode to record the repetition rate. A frequency resolved optical gating (FROG) device is used to resolve the temporal shape of the femtosecond pulses. The data is examined from three viewpoints: a) the superposition takes place within the cavity, b) the superposition occurs at the detector, c) the superposition takes place with no medium. [1] C. Roychoudhuri, “Principle of non-interaction of

8121-43, Session 10
A deeper understanding of cavity ring down spectroscopy (CRDS) based on the principle of non-interaction of waves

N. S. Prasad, NASA Langley Research Ctr. (United States); C. Roychoudhuri, Univ. of Connecticut (United States)

Cavity Ring down spectroscopy (CRDS) has evolved into an important technological tool for sensitive detection of atmospheric trace gases and other chemical species. The technique usually constitutes in sending an isolated pulse through a very high finesse Fabry-Perot (FP) resonator and then comparing the exponentially decaying transmitted pulse trains without and with a gas in the cavity. This paper will explicitly apply the NIW-principle (Non-Interaction of waves) in understanding the physical evolution of the pulse train without and with intra-cavity gas. The key issue we will address is the effect of the input pulse width in comparison to the cavity round trip time. A single incident pulse will generate an output pulse train with decaying intensity given by ; T and R are the intensity transmittance and reflectance of the two FP mirrors. The incident pulse after entering the cavity, reverberates between the two mirrors, while generating the decaying pulse train both in reflection and transmission. At each reflection, the front end of the pulse, due to reflection, gets folded onto the oncoming rest of the pulse, creating a temporary time-varying superposition on itself. While the characteristics of the exiting pulse does not change due to this superposition, the absorption efficiency by the gas residing in the vicinity of the mirrors becomes enhanced as the gas molecules now respond to two coherent superposed beams. The volume and duration of this effect steadily increases as the width of the incident pulse increases. Obviously, wider the pulse, more efficient absorption will take place. However, if , then the output pulse train will be clearly overlapped and the detector will now respond to the superposed intensity of multiple pulses, which destroys the simplicity of analysis following the . Thus, an optimum pulse width is desirable for a given cavity. In this paper, an analysis of the influence of pulsewidth on absorption efficiency using NIW principle is presented.

8121-44, Session 10
Re-interpreting “coherence” in light of Non-Interaction of Waves, or the NIW-Principle

C. Roychoudhuri, Univ. of Connecticut (United States)

The Wiener-Khintchine, or the auto correlation, theorem plays a pivotal role in optical coherence theory. It's proof is derived from the time-frequency Fourier theorem (TF-FT) [see Proc. SPIE Vol. 6108-50(2006); “Reality of superposition principle and autocorrelation function for short pulses”]. The final step requires dropping the cross-products (interference terms) between the different filed amplitudes corresponding to different frequencies. The physical interpretation of this mathematical step implies non-interference (non-interaction) between different frequencies. We have already proposed the generic principle of Non-Interaction Waves (NIW) [see J. Nanophotonics., Vol. 4, 043512 (2010); “Principle of non-interaction of waves”, doi:10.1117/1.3467504]. Note that the NIW-principle also dictates that TF-FT cannot be a generic physical principle of nature [see SPIE Conf. Proc. Vol. 6667, paper #18 (2007); “Bi-centenary of successes of Fourier theorem! Its power and limitations in optical system designs”]. The limited assumption, incoherence of different frequencies, was used by Michelson to demonstrate the success behind his Fourier Transform Spectroscopy, which is correct when the detector possesses a long integrating time constant like a human eye, a photographic plate, or a photo detector circuit with a long LCR time constant. A fast detector gives heterogeneous signal; oscillatory transfer of photo electrons from the valence to the conduction band dictated by the various difference frequencies. The measured “incoherence”, as reduced visibility of fringes, is essentially dictated by the integration time constants of the detecting molecules and the electric circuit that extracts the photo electrons. So, the photo electron counting statistics is dominantly dictated by the intrinsic QM properties of detectors and the measuring circuits; some contribution, of course, comes from the fluctuating stimulating EM fields, which is classical. A sub-femto second detector can record good visibility fringes from almost any light sources! Can light ever be incoherent?

8121-45, Session 11
Appreciating the principle of non-interaction of waves (NIW-principle) by modeling Talbot diffraction patterns at different planes

M. Ambroselli, Univ. of Connecticut (United States); N. S. Prasad, NASA Langley Research Ctr. (United States); C. Roychoudhuri, Univ. of Connecticut (United States)

We demonstrate the NIW-principle by showing that dark fringes in the near-field Talbot diffraction patterns are not devoid of energy. A detector is simply incapable of absorbing any energy at the dark fringe locations because the local E-vector resultants are zero. The energy flow through the “dark fringe locations” is demonstrated by obstructing the “bright fringes” locations at the half-Talbot plane with an identical grating that generated this diffraction image. Then, by propagating the transmitted complex amplitudes through the dark fringes, we show that the Talbot plane can still receive more energy than that could have been recorded out of those same dark fringe locations at the half Talbot plane.

8121-46, Session 11
Time diffraction produced by a Talbot grating immersed in a dispersive medium

Q. Peng, Rensselaer Polytechnic Institute (United States); C. Roychoudhuri, Univ. of Connecticut (United States); S. De, Rensselaer Polytechnic Institute (United States)

We use a Talbot grating immersed in a dispersive medium and propagate a train of (i) perfectly mode locked “coherent” pulses, explicitly recognizing all the mode frequencies and (ii) externally amplitude modulated pulses from a CW laser having well stabilized single frequency but without using the mathematical Fourier frequencies of the pulse train envelope function. We explain the differences in the diffraction patterns in terms of the NIW-principle (Non-Interaction of Waves), which implies that the time-frequency Fourier theorem (TF-FT) cannot be a principle of nature. Hence we need to explain where TF-FT fails even though it has been so effective in so many branches of physics.

8121-47, Session 11
Visualizing the mode evolution process in passive and active cavities based on the NIW-Principle

N. S. Prasad, NASA Langley Research Ctr. (United States); C. Roychoudhuri, Univ. of Connecticut (United States)

This paper will present results of computer models depicting the evolution of diffractive processes through passive and active cavities (traditional stable resonator and single mode fiber) as the number of passes (or the length of propagation) increases. The objective is to visualize how the spatially stable eigen-modes evolve with propagation. Our core assumptions are the validity of the Huygens-Fresnel hypothesis of secondary wavelets and the recently articulated Non-Interaction
The Nature of Light: What are Photons? IV

8121-48, Session 11

Coherence and frequency spectrum of a Nd:YAG laser: generation and observation devices
M. Fernández-Guasti, H. Palafox, Univ. Autónoma Metropolitana-Iztapalapa (Mexico); C. Roychoudhuri, Univ. of Connecticut (United States)

The coherence of a Nd:YAG CW laser is analyzed using a Michelson interferometer. Fringe contrast is measured as the path difference is varied by changing the length of one arm. The fringe contrast, as expected, is maximum when there is no path difference between arms. However, the fringe contrast does not decrease monotonically. It decreases and then increases several times before fading away. This behaviour is reminiscent of the fringe contrast depending on aperture and the uncovering of the Fresnel zones. In order to evaluate the mode structure it is necessary to consider the geometric parameters and Q factor of the cavity, the medium gain curve and the type of broadening.

The non interference of waves principle requires that two (or more) modes competition or their interference can only take place though matter non linear interaction. Therefore, and in addition, it is important to consider the setup and type of detectors employed to monitor the frequency and/or time dependence. In as much as speckle is recognized as an interference phenomenon taking place at the detector plane, say the retina, the role of the sensing element in the detection of mode beats should also be decisive.

8121-49, Session 11

Visualizing superposition process and appreciating the principle of non-interaction of waves
M. Ambroselli, C. Roychoudhuri, Univ. of Connecticut (United States)

We demonstrate the dynamic evolution of superposition effects to underscore the importance of visualizing interaction processes. The model recognizes the principle of Non-Interaction of Waves. Recordable linear fringes, bisecting the Poynting vectors of the two crossing beams, have time evolving amplitude patterns in the bright fringes because the two superposed E-vectors oscillate through zero values while staying locked in phase. If a detector registers steady stable bright fringes, it must do so by time integration. The QM recipe to model energy exchange by taking the square modulus of the sum of the complex amplitudes has this time integration built into it. So, we will underscore the importance of assigning proper physical processes to the mathematical relationships: the algebraic symbols should represent physical parameters of the interactants and the mathematical operators connecting the symbols should represent allowed physical interaction processes and the guiding force.

This presentation will be based on a series of papers published in the last three proceedings of this conference. “The nature of light: What are photons?” by Prof. C. Roychoudhuri, besides the following publications:


8121-50, Session 12

The nature of light in Indian epistemology
S. C. Kak, Oklahoma State Univ. (United States)

Light was taken as a kind of a wind (collection of particles) within the Indian atomic theory of Vaisheshika which is ascribed to Kanada of 600 BC. According to Vaisheshika, the atom (anu) is the fundamental unit and it is indivisible because it is a state for which direct measurement cannot be defined. Since it cannot be described completely, it can neither be further divided nor can be spoken of as having parts. Further the motion it possesses is non-observable directly which makes the atom abstract in a conventional sense. Space and time are like two mediums through which all matter is observed and they form the matrix of reality. Kanada’s framework defies the usual categories of realist versus idealist, since for him matter in itself is a result of motion. Kanada’s emphasis on analysis of categories is also found in the complementary tradition of logic. The idea of tanmatra in the cosmology of Sankhya, which is viewed as a kind of potential out of which materiality emerges, has features similar to that of anu in the Vai eshika system. Kanada’s distinction between intrinsic and extrinsic motions and his claim that the atom, which has only intrinsic motion, is unobservable leads to the remarkable conclusions that intrinsic motion is different from the usual material motion because it is uniform in all directions.

8121-51, Session 12

Two-slit interference and wave-particle duality for single photons from Observer’s Mathematics point of view
D. Knots, B. Khots, Compressor Controls Corp. (United States)

When we consider and analyze physical events with the purpose of creating corresponding mathematical models we often assume that the mathematical apparatus used in modeling, at least the simplest mathematical apparatus, is infallible. In particular, this relates to the use of “infinitely small” and “infinitely large” quantities in arithmetic and the use of Newton - Cauchy definitions of a limit and derivative in analysis. We believe that is where the main problem lies in contemporary study of nature. We have introduced a new concept of Observer’s Mathematics (see www.mathrelativity.com), Observer’s Mathematics creates new arithmetic, algebra, geometry, topology, analysis and logic which do not contain the concept of continuum, but locally coincide with the standard fields.

We proved the following theorems:

Theorem 1 (Two-slit interference). Let $\Psi_1$ be a wave from slit 1, $\Psi_2$ - from slit 2, and $\Psi = \Psi_1 + \Psi_2$. Then the probability of $\Psi$ is a wave equals to 0.5.

Theorem 2 (Wave-particle duality for single photons). If $v$ is small enough, then $\lambda$ is a random variable.
Two types of arguing in physics: a critical discussion
A. I. Vistnes, B. Jagielski, Univ. of Oslo (Norway)

In quantum optics one kind of arguing is as follows: “Interference is a manifestation of the intrinsic indistinguishability of the photon paths.” (Quotation from Zou, Wang and Mandel, Phys. Rev. Lett. 67 (1991) 318-321). Arguments like this were used by Bohr and Einstein in the 1930s and has been in use ever since. The double slit experiment where the slits are located in a movable screen, is a classical example. Heisenberg’s uncertainty relation was then used in a coarse manner, and was based on very abstract thoughts. The alternative argument is based on diffraction, and offers a far more detailed picture where the interaction of light and matter is considered in detail instead of in a superficial way. We claim that the principle of “indistinguishability of the photon paths” may lead to explanations being in direct conflict with a more detailed interaction-based description. Two examples will be given: the Bohr-Einstein model of the double slit, and the Zou, Wang, Mandel coherence experiment from 1991 (reference given above). We conclude that detailed interaction-based arguments should be preferred instead of very abstract, nonspecific arguing in physics, and point out that some conclusions drawn so far in quantum optics may not be the full story.

Simple alternative model of the dual nature of light and its Gedanken experiment
F. Hénaout, Univ. de Nice Sophia Antipolis (France)

In this paper is presented a simple alternative model of the dual nature of light, based on the deliberate inversion of the original statement from P. A. M. Dirac: “Each photon interferes only with itself. Interference between different photons can never occur.” Such an inversion stays apparently compatible with the experimental results reported from different recent experiments. A Gedanken experiment having the capacity to test the proposed model in single photon regime is described, and its possible outcomes are discussed. The proposed setup could also be utilized to assess the modern interpretation of the principle of complementarity.

Beyond relativity and quantum mechanics: space physics
H. H. Lindner, Consultant (United States)

Relativity and Quantum Mechanics are the products of an esoteric metaphysics and epistemology imposed upon physics by Albert Einstein. Subjective idealism holds that the observers’ conscious experiences are the only reality and that science should only describe the observers’ experiences and measurements, not attempt to explain the nature and causes of things. Einstein eliminated ether theory from physics by reducing physics to mere description; eliminating the need for any physical explanation of fundamental phenomena. This program is the source of unreality, paradoxes and schisms in physics. Albert Einstein did not fully comprehend the nature of his own program nor adhere to it consistently; resulting in confusion. In order to understand the physical Cosmos, we need a revolution similar to the Copernican Revolution. We must again remove the observer from the center of physics and hypothesize about the nature and causes of Cosmic phenomena. When we do so, it becomes apparent that space itself is the causal nexus of all physical phenomena. Space physics requires the reinterpretation of all known phenomena, concepts, and mathematical models.

Did Michelson and Morley test the wrong phenomenon?
G. N. Mardari, The Johns Hopkins Univ. (United States)

Light is a combination of two types of phenomena. It propagates as an electromagnetic field (expressing the wave aspect), but also as a stream of photons (expressing the particle aspect). When we measure the speed of light, do we measure the speed of the waves, or the speed of the particles? Michelson and Morley tested the speed of light for invariance. According to their results, the speed of light does not exhibit the relativistic properties of a wave. Therefore, it must correspond to the speed of a particle (the photon). By implication, the nature of fundamental waves has not been tested yet. In classical physics, the electron is also described as a dual entity: a particle with an associated field. The speed of the electron is the speed of the particle. The speed of the waves must correspond to the rate of propagation of changes in the associated field. This conclusion implies that the speed of magnetic pulses cannot be identical to the speed of light. It must also violate the principle of invariance. Both of these predictions are verifiable.

Experiment versus theory: do physicists still know the difference?
C. Rangacharyulu, Univ. of Saskatchewan (Canada)

Physics is an experimental science, quite distinct from mathematics or philosophy. Almost all physical laws are simple generalizations of experimental observations with, perhaps, the exception of Newton’s laws. Newton’s laws were likely the first attempt to offer operational definitions to physical parameters and provide a mathematical basis to quantify experimental observations. At least for some time, there was a clear distinction between the experimental observations from the corresponding theoretical formulations to interpret the meanings of data. In modern times, the theoretical assumptions are very much part of the preparation of experiments and interpretation of results of measurements, which makes us question the very meaning of test of experiment against theoretical predictions. In this talk, I would provide a brief survey of the modern experiments where the interpretation of experimental data so heavily relies on the theoretical arguments, it becomes clear that we are begging the question rather than answering the question.
Appreciation of the nature of light demands enhancement over the prevailing scientific epistemology
C. Roychoudhuri, Univ. of Connecticut (United States)

The principle of Non-Interaction of Waves (NIW-principle) in the linear domain has been known in physics. But the prevailing Measurable Data Modeling Epistemology (MDM-E), achieving success over the last few centuries, obscured the identification of the NIW-principle. Measured data and the theory always matched except for a detector constant. So, we propose the Interaction Process Mapping Epistemology (IPM-E). IPM-E builds upon MDM-E and goes deeper by demanding the visualization of the interaction processes that give rise to the measurable data. IPM-E helps clarify the roots behind the famous QM "Measurement Problem" as an inherent limit in nature and hence cannot be solved by any mathematical theorems. All of our theories, irrespective of their magnitude of successes, are necessarily incomplete as they are founded on hypotheses containing incomplete information about the nature. IPM-E guides us to iteratively review and reconstruct successful theories to inch towards cosmic reality.

Quantum epistemology: the Växjö viewpoint
A. Y. Khrennikov, Linnaeus Univ. (Sweden)

This paper is about a series of meetings in Vaxjo and debates on foundations of quantum mechanics and its epistemology which took place during these meetings. The Växjö series of conferences played an important role in elaboration of epistemology of modern quantum mechanics, the epistemology of quantum physics enlightened by quantum information theory. One of the main lessons of this remarkable series is huge diversity of opinions on foundations. After all we can firmly declare that the common viewpoint that the community of people interested in quantum foundations can be split into orthodox Copenhagen School and a small group of outsiders who dream of the comeback of determinism does not match the real situation. It became completely clear that the group of orthodox Copenhagen School is very diverse. The degrees of their beliefs in completeness of quantum mechanics vary substantially. Many of the brightest followers of Copenhagen School have proposed original ideas on possibilities to go beyond current quantum. On the other hand, majority of people who does not believe in Bohr's claim about completeness of quantum mechanics do not at all dream of recovery of Laplacian determinism of particles. A variety of novel approaches to go beyond current quantum have been proposed, including various classical field-type models. In conclusion, we can say that the meetings in Växjö clearly demonstrated that nowadays limits and validity of boundaries of quantum mechanics is a hot topic attracting the attention of the whole quantum community and characterized by diversity of opinions. The Växjö interpretation of quantum mechanics, the realistic interpretation based on coupling of quantum probability to classical (Kolmogorovean or von Mises) probability, attracts a lot of attention.
8122-01, Session 1

High-resolution imaging through horizontal path turbulence

W. T. Rhodes, D. F. Pava, S. R. Malinda Silva, F. R. Dalgleish, G. Nootz, Florida Atlantic Univ. (United States)

Imaging through long-path turbulence, as in the case of horizontal-path imaging, has long presented special problems for the optical imaging community because the isoplanatic patch is diminishingly small. In this paper we describe a method based on Fourier telescope concepts that appears to provide a means of achieving diffraction-limited resolution with a large-aperture system. The scheme requires active illumination of the object. The basic concept will be presented along with preliminary experimental results.

8122-02, Session 1

Gigapixel synthetic-aperture digital holography

J. R. Fienup, A. E. Tippie, Univ. of Rochester (United States)

Building on the work of Goodman and Lawrence (1967), we have extended digital holographic imaging to gigapixel scales with 2-D aperture synthesis. Sub-pixel registration algorithms were required to mosaic together hundreds of arrays of data and phase-error correction algorithms were required to correct for system instabilities.

8122-03, Session 1

Illustrative EDOF topics in Fourier optics

N. George, X. Chen, W. Chi, Univ. of Rochester (United States)

No abstract available

8122-04, Session 1

Linear systems formulation of non-paraxial scalar diffraction theory

J. E. Harvey, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Goodman's popular linear systems formulation of scalar diffraction theory includes a paraxial (small angle) approximation that severely limits the conditions under which this elegant Fourier treatment can be applied. In this paper a generalized linear systems formulation of non-paraxial scalar diffraction theory will be discussed. Diffraction radiance (not intensity or irradiance) is shown to be shift-invariant with respect to changes in incident angle only when modeled as a function of the direction cosines of the propagation vectors of the usual angular spectrum of plane waves. This revelation greatly extends the range of parameters over which simple Fourier techniques can be used to make accurate diffraction calculations. Non-paraxial diffraction grating behavior (including the Woods anomaly phenomenon) and wide-angle surface scattering effects for moderately rough surfaces at large incident and scattered angles are two diffraction phenomena that are not limited to the paraxial region and benefit greatly from this extension to Goodman's Fourier optics analysis. The resulting generalized surface scatter theory has been shown to be valid for rougher surfaces than the Rayleigh-Rice theory and for larger incident and scattered angles than the classical Beckman-Kirchhoff theory. This has enabled the development of a complete linear systems formulation of image quality, including not only diffraction effects and geometrical aberrations from residual optical design errors, but surface scatter effects from residual optical fabrication errors as well. Surface scatter effects can thus be balanced against optical design errors, allowing the derivation of optical fabrication tolerances during the design phase of a project.

8122-05, Session 1

Fourier transforms by white-light interferometry: Michelson stellar interferometer fringes

J. B. Breckinridge, California Institute of Technology (United States)

The white-light compensated rotational shear interferometer (coherence interferometer) was developed in an effort to study the spatial frequency content of white-light scenes in real-time and to image sources of astronomical interest at high spatial frequencies through atmospheric turbulence. This work was inspired by Professor Goodman's studies of the image formation properties of coherent (laser) illuminated transparencies. The need for a coherent laser source to illuminate a transparency does not enable real-time processing. Real-time processing is possible using white-light interferometry. This paper reviews the image formation properties of the coherence interferometer and its applications to physical optics, optical processing and astrophysics (imaging of the surfaces of stars and search for exoplanets).

8122-06, Session 1

Coherence holography and photon-correlation holography: marriage between holography and statistical optics

M. Takeda, The Univ. of Electro-Communications (Japan); W. Wang, Heriot-Watt Univ. (United Kingdom); D. N. Naik, The Univ. of Electro-Communications (Japan)

Traditionally, holography and statistical optics have been regarded as mutually separated fields of optics. For a long time, this seems to have restricted synergy of knowledge in holography and coherence theory. Recently we proposed two new techniques of unconventional holography, called coherence holography and photon-correlation holography, which bridge the gap between the two fields. The principle of coherence holography is based on the fact that a coherence function obeys the same wave equation as the optical field. In coherence holography, a hologram is illuminated by spatially incoherent light, and a 3-D object is reconstructed as the 3-D distribution of a spatial coherence function rather than the field itself. Just as a computer-generated hologram can create a 3-D image of a non-existing object, a computer-generated coherence hologram can create an optical field with a desired 3-D distribution of spatial coherence function. Thus coherence holography opens up a new possibility of optical tomography and profilometry based on a synthesized spatial coherence function, and a coherence hologram also serves as a generator of coherence vortices. The principle of photon-correlation holography is based on the combination of the concept of coherence holography with that of Hanbury Brown and Twiss intensity interferometry. The principle and applications of coherence holography will be reviewed with particular emphasis on the space-time analogy in coherence theory, as well as the formal analogy between an optical field and its coherence function, which gives an insight into the methodology for coherence holography and the new concept of spatial frequency comb for dispersion-free optical coherence tomography and profilometry.
8122-07, Session 1

Optical information processing

D. Psaltis, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

No abstract available

8122-08, Session 1

Fourier filtering grows much better with age

H. J. Caulfield, Alabama A&M Univ. (United States)

Professor Goodman’s best known publication is certainly his book on Fourier Optics. That is still valid, but the use of Fourier transform filtering for pattern recognition has been limited. After almost 50 years of effort, it still led to an unfortunate dilemma. Fourier filtering applies a linear discriminant in parallel to each pixel in the input. Were it not for that linearity, it could not do the space-invariant (I am thinking images, but this applies to 1D and 3D signals as well). So unless we restrict applications to simple linearly discriminable target sets, The discrimination ability of Fourier filtering will be very poor.

All of that changed with the invention of what I call Margin Setting. It is not a new pattern recognition algorithm. Instead, it is a method that uses any pattern recognition algorithm to achieve much better discrimination with that discriminant type. Margin Setting itself will not be explained in this abstract. But I can describe some of what it does.

Here are its uses that I will show in my talk: Margin Setting accomplishes - Wonderful preprocessing for or against texture, spectral content, polarization, and the like
- Unchanged target locating ability
- Dramatically improved discrimination
- The evaluation of target parameters such as scale and pose
- Massive bandwidth reduction

I will suggest that these operations amount to a kind of Artificial Visual Perception. I will argue that Artificial Perception is key to future conscious machines and key to understanding

8122-09, Session 2

Volume holographic spectral-spatial imaging of biological tissue

R. K. Kostuk, The Univ. of Arizona (United States)

A volume holographic imaging system is described that is capable of both spatial and spectral imaging of biological tissue samples. The primary component of this system is a multiplexed volume holographic element. The holograms are highly Bragg selective (0.0180 in angle) and all wavefronts to be selected from multiple depths within the tissue sample. The high selectivity also allows for high lateral spatial resolution (<4µm). Two modes of operation of the system have been investigated. The first uses an LED with 20-40 nm spectral bandwidth. The spectral bandwidth determines the field of view of the system. The second mode of operation uses laser excited dyes deposited on the tissue sample. The dyes react with cancerous cells and act as markers to identify suspicious tissue areas. Several illumination systems have been implemented and a prototype endoscope version has also been demonstrated.

8122-10, Session 2

Retinal imaging using curved detectors

L. Hesselink, Y. Takashima, E. Perederey, Stanford Univ. (United States)

For almost a century ray optics programs have been used to trace rays through optical systems to optimize their performance. Images were either recorded on film or other suitable recording medium, or the optics were used by a human to enhance visual quality and resolution, with little room for post image processing to improve performance and quality. Design tradeoffs were typically made between performance, physical characteristics such as size and weight, and cost. With the advent of digital recording media, a new dimension is added to this tradeoff space: computation. Since only the final image is of interest to a human, an intermediate recorded image does not necessarily have to be esthetically pleasing or sharp. We can tradeoff optical imaging performance against post detection digital processing.

In this invited talk we describe how curved detectors can significantly reduce cost, size and weight at the expenses of additional post-recording processing. Examples of very large FOV simple lens systems will be presented.

8122-11, Session 2

Modern scalar diffraction theory

H. H. Arsenault, Univ. Laval (Canada); P. García-Martínez, Univ. de València (Spain)

Classical scalar diffraction theory used the Green Function approach to solve the wave equation, as described in Goodman’s classical Fourier Optics book. Arsac proposed a new approach based on Distribution Theory. More recently we attempted to derive the equations directly from relativistic Quantum Mechanics, based on the fact that the wave equation is equivalent to the expression for the invariance of the modulus of the light Energy-momentum four-vector.

8122-13, Session 2

Fourier optics in the mirror of digital computers

L. P. Yaroslavsky, Tel Aviv Univ. (Israel)

The paper by J. Goodman of 1967 on numerical reconstruction of holograms was, along with papers by A. Lohmann on computer generated holograms, was one of the first signs heralded the advent of new era in the evolution of imaging optics that nowadays culminated in a new imaging technology, computational imaging. Computers have become an integral part of optical imaging systems and even sometimes completely replace such optical devices as lenses and diffractive gratings. To do optics in computers, one needs discrete representation of optical signals and transforms. Optical transforms are represented in computers by their discrete versions. Particularly, Fourier optics is represented through different versions of Discrete Fourier Transform (DFT). Being discrete representation of the optical Fourier transform, DFT features a number of peculiarities that cast a new light on such fundamental properties of the Fourier Transform as sampling theorem and the uncertainty principle. In the paper, we formulate the Discrete Sampling Theorem, prove that signals with N samples with bounded DFT spectrum with K Ksgnl Kspctr>N and present examples of such “band-limited/space-limited” signals that remain to be so for whatever large N.

8122-14, Session 2

Reflections on speckle: old and new results

C. Dainty, National Univ. of Ireland, Galway (Ireland)

One of the first descriptions of speckle was by Karl Exner in 1877 and in the early 1900s Lord Rayleigh derived many of the statistics of speckle. But it was the invention of the laser in 1960 that triggered many publications re-discovering the phenomenon: the very high spatial coherence of the laser meant that speckle was visible in any situation involving an optically rough surface or random medium. In this early
8122-24, Session 2
Solar sails, optical tweezers, and other light-driven machines
M. Mansuripur, College of Optical Sciences, The Univ. of Arizona (United States)

Electromagnetic waves carry energy, linear momentum, and angular momentum. When light (or other electromagnetic radiation) interacts with material media, both energy and momentum are usually exchanged. The force and torque experienced by material bodies in their interactions with the electromagnetic field are such that the energy as well as the linear and angular momenta of the overall system (i.e., the system of field plus matter) are conserved. Radiation forces are now used routinely to trap and manipulate small objects such as glass or plastic micro-beads and biological cells, to drive micro- and nano-machines, and to contemplate and manipulate small objects such as glass or plastic micro-beads and biological cells, to drive micro- and nano-machines, and to contemplate and manipulate.

8122-15, Session 3
Exploring light-matter interaction processes to appreciate various successes behind the Fourier theorem
C. Roychoudhuri, Univ. of Connecticut (United States)

Goodman’s contribution to the theory & applications of Fourier optics is simply outstanding. When a scientific field becomes extremely matured in the world of application, it is obvious that it must have captured some of the real operational cosmic logics since working instruments must emulate (conform to) interaction processes in nature. Broad engineering successes also imply that it is time to ponder if the mathematical theory and the hypotheses behind it, have captured and reached the unchangeable final form, or the theory should be re-evaluated from its very foundation once again. I believe in perpetual iteration of all such successful theories since they are always incomplete since they are all formulated based on incomplete knowledge of the universe. And engineers are best prepared to stimulate such iterations since they always emulate nature’s interaction processes from many different angles for many different purposes.

This talk is derived from:

8122-16, Session 3
Singular beams in metrology and nanotechnology
J. Shamir, Technion-Israel Institute of Technology (Israel)

Optical singularities are localized regions in a light field where one or more of the field parameters, such as phase or polarization, become singular with associated zero intensity. Focused to a small spot, the electromagnetic field around the singularity is extremely sensitive to changes and can be exploited for metrology with high sensitivity and the study of physical processes on a nanometer scale. Metrological applications to be discussed include object positioning with an accuracy of at least 20 nm and nano-particle analysis. It is shown that sub-wavelength particles can be easily detected and characterized. On the physical side, aspects of a strong longitudinal field component are discussed. The excitation of plasmonic resonance in nano sized objects will be also addressed indicating the possibility of anomalous absorption effects.

8122-17, Session 3
Optical coherent processors in phase-space representations
J. Ojeda-Castaneda, Univ. de Guanajuato (Mexico)

In applied optics, often one is faced with a trade-off between two functions that are a Fourier transform pair. For an insightful analysis of the limitations, as well as for analyzing the proposals for overcoming this trade-off, it is convenient to use a phase-space representation. However, phase-space representations appear to be mathematically demanding. We recognize that coherent optical processors are useful for visualizing simultaneously the two domains of a Fourier transform pair. And hence, coherent optical processors are indeed helpful for understanding and for displaying Phase-Space representations.

Here, we explore the use of coherent optical processors for overcoming some classical optics trade-offs, which are associated to a Fourier transform pair. We show that certain complex amplitude masks are able to reduce the impact of focus errors on the modulation transfer function (MTF) /2/. Furthermore, based on the space-time analogy, we show that a similar procedure is useful for correcting residual time aberrations, which are present when electro-optic sinusoidal phase modulators generate temporal lenses /3/.

References

8122-18, Session 3
On propagation of optical coherence
B. E. A. Saleh, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

Joseph W. Goodman pioneered the use of linear systems to describe light propagation through optical components. In the 1980s this has motivated me to describe propagation of partially coherent light using
bilinear systems (second-term in a Volterra series description of a nonlinear system). More recently, I considered the propagation of the second-order optical coherence function through a linear optical system. Normally, this involves linear operations in a space of two positions (and/or two times). However, with one point fixed, the dependence on the other point can always be thought of as propagation through the linear system twice (forward and backward). This is described as a cascade of linear operations in a space of a single position (and/or single time). The familiar operations that describe propagation of the optical field through linear systems, such as diffraction and imaging (or dispersion of optical pulses), may therefore be directly applicable to the propagation of the coherence function, and can readily explain well-known phenomena such as the Van Cittert-Zernike theorem. This approach, which reduces the dimensionality of the space by a factor of two while requiring double passage through the system, is also applicable to linear systems with random components, such as phase screen. It can be used to interpret effects such as Anderson localization for optical beams traveling through a parallel array of waveguides with random coupling.

8122-19, Session 3

**Fourier optics and near-field superlens**

Y. Sheng, G. Tremblay, Y. Gravel, Univ. Laval (Canada)

Superlens of negative index material can collect the evanescent waves for ideal imaging with nano-metric resolution. Metallic near-field superlens of a sole negative permittivity, but a positive permeability at optical frequency is more realizable. The fundamental Fourier optics is applied to the near-field superlens with the transfer function defined as the transmission coefficient of the superlens for spatial components, which is computed with the transfer matrix of multilayer system, the surface plasmon polariton (SPP) resonance within the superlens layer, or with the SPP waveguide theory. The total transfer function is a product of that of the superlens with the free space propagation filters in the object and image layers. The impulse response of this linear system is the Fourier transform of the transfer function. However, when the nano-object structures as slits, holes, grooves and bumps are modeled as oscillating dipole sources, the space invariance condition can be not respected within the dimension of the dipoles, so that the superlens is usually characterized by imaging of two nano-silts. The scattered field over the surface of lossy earth has been studied by Sommerfeld in 1909 involving the Zenneck surface wave. In the 2D cases we find the close-form rigorous solution of the Sommerfeld integral by introducing two parameterizations of the integral spaces and choosing appropriate branch-cut integral paths. The results is in agreement with the recent experiment on the transient SPP and is useful not only for near field imaging, but also beam collimating, focusing and enhancement by nano-plasmonic structures.

8122-20, Session 3

**From fourier optics to integrative engineering**

T. Jannson, A. A. Kostrzewski, Physical Optics Corp. (United States)

This paper describes evolution of technical directions at Physical Optics Corporation (POC), from physical optics, in general, and Fourier Optics, in particular, to: integrative optics, integrating: optics, electronics, mechanics, and even further to: Integrative Engineering, integrating the above disciplines with QA and IA. This specific type of interdisciplinary system integration is a kind of Integrative, Interactive, Interdisciplinary, and Intelligence (I4) approach, leading to Small System Integration (SSI) at POC. This presentation describes the I4 transformation, including such examples as: Crush-Survivable Video Recorder and Data Transfer/Storage Avionics systems, (a kind of black box), 3600 FOV telescopic camera with Electronic Zooming, Self-sustainable CAISR sensor, conformable e-wearables and other devices representing defense and Homeland Security.

8122-21, Session 3

**Phase-sensitive coherence and the classical-quantum boundary in ghost imaging**

B. I. Erkmen, Jet Propulsion Lab. (United States); N. D. Hardy, D. Venkataraman, F. N. C. Wong, J. H. Shapiro, Massachusetts Institute of Technology (United States)

The theory of partial coherence has a long and storied history in classical statistical optics. The vast majority of this work addresses fields that are statistically stationary in time, hence their complex envelopes only have phase-insensitive correlations. The quantum optics of squeezed-state generation depends on nonlinear interactions producing baseband field operators with phase-insensitive and phase-sensitive correlations. Utilizing quantum light to enhance imaging has been a topic of considerable current interest, much of it involving biphotons, i.e., streams of entangled-photon pairs. Biphotons have been employed for quantum versions of optical coherence tomography, ghost imaging, holography, and lithography. However, their seemingly quantum features have been mimicked with classical-state light, questioning wherein lies the classical-quantum boundary. We have shown, for the case of Gaussian-state light, that this boundary is intimately connected to the theory of phase-sensitive partial coherence. Here we present that theory, contrasting it with the familiar case of phase-insensitive partial coherence, and use it to elucidate the classical-quantum boundary of ghost imaging. An object’s ghost image results from correlating the output from a high-spatial-resolution detector, whose illumination has not interacted with that object, with the output from a single-pixel (bucket) detector, whose illumination has undergone such an interaction. Ghost imaging has been done with pseudothermal (classical) and biphoton (quantum) light. We show, both theoretically and experimentally, that classical phase-sensitive light produces ghost images most closely mimicking those obtained with biphotons, and we derive the resolution, field-of-view, and signal-to-noise ratio of a standoff-sensing ghost image, taking into account target-induced speckle.

8122-22, Session 3

**Digital holography and tissue dynamics spectroscopy: on the road to high-content drug discovery**

D. D. Nolte, Purdue Univ. (United States)

Tissue dynamics spectroscopy (TDS) uses short-coherence-gated dynamic speckle from living tissue to detect sub-cellular motion as a novel imaging contrast agent. Tissue dynamics spectroscopy is a digital holographic imaging technique that uses wide-field illumination to extract sub-cellular motion as deep as 1 mm inside tissue as a function of three-dimensional location. Motility contrast presents an unexpected imaging approach that is well-matched to the problem of imaging the effects of broad classes of drugs, and allows us to explore how function defines cellular motion, and how altered function is detected as changes in motion.

Speckle images of tumor tissues shimmer due to cellular motility, and statistical properties of the dynamic speckle are obtained by capturing temporally fluctuating images at successive depths. Different perturbations on the cellular biochemistry show significantly different responses in the three frequency bands. These different responses represent distinct signatures that relate to the mode of action of the various perturbations. Differential changes in the fluctuation spectra (measured through the dynamic speckle) as a function of time of new distinct signatures that are specific to the modes of drug action. These signatures can be used to construct high-content screens of drug candidates. The label-free character of motion as a contrast agent, the sensitivity and specificity of motion to cellular function, and the three-dimensional access to tissue properties far from surface effects, make tissue dynamics spectroscopy an attractive new approach for high throughput label-free screening of drug candidates.
Computational photography: advances and challenges

E. Y. Lam, The Univ. of Hong Kong (Hong Kong, China)

In the mid-1990s when digital photography began to enter the consumer market, Dr. Goodman and I embarked on an exploration on how computation would affect the imaging system design. The field has since grown to be known as computational photography. In this paper I’ll describe some of its recent advances and challenges, and discuss what the future holds.
8123-01, Session 1

Optical design and lighting application of an LED-based sports lighting system
L. H. Boxler, Musco Sports Lighting, LLC (United States)

This paper describes both the optical development of an LED based sports lighting system and the results of the application of the system to an actual sport field. A traditional sports lighting fixture is generally composed of a single 1500 watt HID light source with faceted metal reflectors used to control the light distribution. The efficacy of the HID light source is equivalent or nearly equivalent to most LED light sources, putting LEDs at a large cost disadvantage in a high light output application such as sports lighting. To assess the feasibility and applicability of LEDs in a sports lighting application, an LED based sport light has been developed and installed on a small soccer field specified to have an average maintained illuminance level of 30 footcandles. An existing HID sport lighting system was also installed on the same size soccer field adjacent to the LED field with the same average footcandle level for comparison. Results indicate that LEDs can provide equivalent average illumination, however the LED system component and structural cost is substantially higher. Despite the high cost, it was found that improved optical control afforded by the optical design used in the system provides a significant improvement in spill light control and on field uniformity. The significant improvement in on field uniformity provides the opportunity to re-evaluate specifications with the possibility of specifying minimum light levels rather than average light levels while maintaining playability. This could provide an advantage for LED systems.

8123-02, Session 1

Design, simulation, and measurement of LED reading lamp with non-axisymmetrical reflector and freeform lens
W. Chao, Y. Chen, J. A. Whang, National Taiwan Univ. of Science and Technology (Taiwan)

With the rapid development of various types of digi-readers, such as i-Pad, Kindle, and so on, non-self-luminous type has an advantage, low power consumption. This type of digi-reader reflects the surrounding light to display so it is no good at all to read under dim environment. In this paper, we design a LED lamp for a square lighted range with low power consumption. The e-book is about 12cm x 9cm, the total flux of LED is 3 Lm, and the LED lamp is put on the upper brink of the panel with 6cm height and 45 degree tilted angle. For redistributing the energy, the LED lamp has a freeform lens to control the light of small view angle and a non-axisymmetrical reflector to control the light of large view angle and create a rectangular-like spot. In accordance with the measurement data, the proposed optical structure achieves that the power consumption of LED light source is only 90mW, the average illumination is about 200 Lux, the uniformity of illumination is over 0.7, and the spot is rectangular-like with precise light/dark cutting-off line. Our designed optical structure significantly increases the efficiency of light using and meets the environmental goal of low energy consumption.

8123-03, Session 1

Investigation of tunable LED lighting for general illumination employing preliminary activity recognition sensor network
M. Thompson, OSRAM SYLVANIA Inc. (United States)

Digitally controlled lighting systems equipped with colored LEDs can produce a range of different qualities of white light, adjustable to users’ requirements. Sensor networks allow lighting changes to be actuated in response to the location, activities, and paths of the occupants. We explore strategic control of RGBW LEDs forming white light, in response to an preliminary activity recognition sensor system, as well as the associated human factors. This paper reports and discusses the results of an ongoing research project applying the principles of tunable lighting, encompassing three main domains:
(a) Tunable LED light system with controls;
(b) Sensor network;
(c) Human factors studies
The main goal is to understand best practices in tunable lighting for general illumination, especially based on potential for energy savings and improved visual comfort.

We are interested on one hand in the integration of LED system, controls and sensor network (hardware and software domains) and on the other hand on how the visual system perceives changes in the spectral components of white illuminants. An experimental tunable LED system and sensor network was installed in an occupied office environment, where a series of human factors experiments were conducted to assess realistic visual performance under changing lighting conditions.

8123-05, Session 1

Optical system design for a reflector-based LED food lighting module
A. Bäuerle, Fraunhofer-Institut für Lasertechnik (Germany) and RWTH Aachen (Germany); C. Schnitzler, RWTH Aachen (Germany); R. Wester, Fraunhofer-Institut für Lasertechnik (Germany); M. Kirsten, BARO GmbH & Co. KG (Germany); H. Schlüter, Alux-Luxar GmbH & Co. KG (Germany); P. Loos, RWTH Aachen (Germany) and Fraunhofer-Institut für Lasertechnik (Germany)

We report on the development and experimental analysis of an LED lighting module for use in a high-end food lighting environment. Goods that are advertised in these lighting situations put high demands on color homogeneity and the rendering of certain color components. At the same time, energy regulations require the overall lighting fixture to be efficient. One possible approach is to use PVD coated metal reflectors that show up to 98% reflectivity across the visible spectrum but whose optical properties degrade if the surface curvature gets too high.

We present an adapted optical design that allows for homogeneous illumination in terms of both illuminance and colour by combining reflective elements. Within the optical setup, multiple elements of a low degree of deformation are combined to yield the desired illumination result, combining aspects of imaging and non-imaging optics. The selective texturing of reflector surfaces introduces scattering that enables the use of RGBW LEDs without any visible colour fringes. Using electronic controls, the spectrum of the light can be adjusted to yield optimum colour rendering without significant losses in efficiency. From a prototypical lighting module, energy efficiency and perceived quality of light are assessed in comparison with conventional light sources for various lighting situations.

Possible further applications for this setup include architectural and general lighting as well as process illumination.
Non-axisymmetrical freeform design for short LED street lamp
C. Jen, Y. Chen, J. A. Whang, National Taiwan Univ. of Science and Technology (Taiwan)

Based on energy savings trend, LED has been developing as the main force of the future lighting, especially the road lighting. For controlling the intensity distribution of LED, the concept of freeform design has been proposed in many articles with transmission or reflection components but mainly focus on axial symmetrical types or dual axial symmetrical types. We, in this paper, design a non-axisymmetrical freeform system applying in a short LED street lamp whose dimension is 10cm (W) x 10cm (L) x 7cm (H) that has an advantage, easy maintaining. For coordinate transformation and simplifying the non-axisymmetrical system, we create two virtual surfaces and design the slope of each discrete point on the freeform surface to control the light path between the two virtual surfaces and avoid the total internal reflection. The short street lamp has four LEDs to light 3m square and each LED light a triangle area. According to the simulation results, the uniformity of illumination is 1:3 and the optical efficiency is more than 80% that meet the legal requirements of street lamp. In short, to reduce manufacturing and maintenance costs, the proposed design is appropriate to use in the actual lighting on the road and to replace the traditional street lamps.

Phosphor-free white: the prospects for green direct emitters
C. Wetzel, Rensselaer Polytechnic Institute (United States)

No abstract available

Material properties of MOCVD-grown AlGaN layers influenced by the in-incorporation
T. Y. Lin, L. Li, Y. L. Chung, J. R. Jiang, National Taiwan Univ. (Taiwan); Y. Lee, Tung Nan Institute of Technology (Taiwan); S. Yao, Z. C. Feng, National Taiwan Univ. (Taiwan); D. Wuu, National Chung Hsing Univ. (Taiwan); I. T. Ferguson, The Univ. of North Carolina at Charlotte (United States)

AlGaN epilayers were grown on sapphire (0001) by MOCVD, with intermediate growths of low/high temperature AlN nucleation layers. Variable flow rates of TMIn, 0, 50 and 500 sccm were introduced. Three AlGaN samples were originally designed with similar Al composition of ~20%. Rutherford backscattering determined accurately Al content which decreased with increasing In-flow. Main photoluminescence bands spread over 310-350 nm with peaks in 320-335 nm. PL (10-300K) exhibited anomalous temperature dependent emission behavior of S-shaped shift, red-blue-red shifts. Carriers transfer between different luminescent centers. Abnormally high activation energy was obtained, indicating that excitons are not in the free states. Raman Scattering and spectral line shape analysis led to an optical determination of the electrical property free carrier concentration of AlGaN. Our results on In-doped AlGaN provide useful information for designing UV-LEDs.
Structural and optical properties of InGaN/GaN multiple quantum well light-emitting diodes prepared by metalorganic chemical vapor deposition

J. R. Jiang, M. H. Wang, Z. C. Feng, National Taiwan Univ. (Taiwan); B. Zhang, Huazhong Univ. of Science and Technology (China); Z. Zhou, Peking Univ. (China); A. G. Li, RAINBOW Optoelectronics Material Shanghai Co. Ltd. (China); X. Y. Li, B. L. Liu, Xiamen Univ. (China); D. Wuu, National Chung Hsing Univ. (Taiwan)

We have performed a comparative structural and optical investigation on typical industry-manufactured blue emission InGaN/GaN MQW LED wafers with different indium composition and structural parameters, grown by MOCVD. Structural and optical properties were studied by various advanced analytical techniques. The effects of indium compositions and QW parameters, determined by HRXRD and HRTEM, were studied. HRTEM also revealed the dislocation distribution and the so-called V-shape defects. PL, PLE and TRPL in 10-300K and under different excitation and detection wavelength, were employed to study comprehensively the MQW luminescence mechanism, localization effect, carrier recombination and transferring dynamics, corresponding to the HRTEM observations and correlating to the lighting efficiency and LED device performance, which are significant to find the key to design high efficiency LEDs.

Effects of voltage modulation of individual RGYB LEDs on the high power phosphor LED for color temperature and luminous efficiency

H. Chen, G. Wu, C. Yang, Y. Lo, J. Jhou, S. Li, National Yunlin Univ. of Science and Technology (Taiwan)

This study investigated the variations of color temperature and luminous efficiency for the high power phosphor Light-Emitting Diodes (LEDs) with the single LED of red, green, yellow and blue, respectively. First, the base voltages of white LEDs will be set up for the color temperature of 7500K (D75 cool white). Then we tuned individual voltages of RYGB LEDs to investigate the variations of color temperature and luminous efficiency for the high power phosphor Light-Emitting Diodes (LEDs) via a fiber optic combiner is constructed. Insufficient spectral device performance, which are significant to find the key to design high efficiency LEDs.

Encapsulation structure with reflective slope to improve light extraction for OLED lighting

C. Lee, J. Lee, Korea Electronics Technology Institute (Korea, Republic of); D. Choi, Hanyang Univ. (Korea, Republic of); M. Kwak, Korea Electronics Technology Institute (Korea, Republic of)

Recently, organic light emitting diodes (OLEDs) have attracted to solid-state lighting due to self-emitting property, high brightness at low current density, high efficiency and slim shape. To use illumination, properties of OLED are required to improve for efficiency and long life time. So we developed new encapsulation structure to improve light extraction for OLEDs and life time. Emitted light in OLEDs propagates all directions and materials have each other refractive index, so its external efficiency is low about 20% by total ref. To reduce this light loss, we designed new encapsulation structure. New encapsulation glass cap was excavated by wet etching in order to insert glass substrate. And it was worked to have two steps of reflective slope edges. A glass substrate that OLED was deposited was inserted in this cap and attach on first step of encapsulation glass cap. On the reflective slope, the reflective layer, aluminum was coated to improve reflectivity. Two reflective slope edges reflected the waveguided light from a glass substrate and an OLED. Also, to reduce reflective index by air between OLED and encapsulation glass, we filled up this gap with the suitable reflective index material. Also this material performed a role to improve lifetime. As adopted this cap, brightness and lifetime was increased about 20% and 15% than the cap of general structure.

Light-extraction improvement of GaN LEDs using nano-scale top transmission gratings

A. Ellaboudy, G. Chavoor, X. Jin, S. Trieu, California Polytechnic State Univ., San Luis Obispo (United States) and Peking Univ. (China); C. Xiong, X. Kang, B. Zhang, G. Zhang, Peking Univ. (China)

Gallium Nitride (GaN) light emitting diodes (LEDs) embody a large field of research that aims to replace inefficient, conventional light sources with LEDs that have lower power, high luminosity, and longer lifetime. The conventional GaN LEDs have only a few percent light extraction efficiency. A common way to solve this light trapping issue is to etch a periodic structure at the light extraction surface and/or at the bottom reflective layer of the LED. In this paper, we present a Finite-Difference Time-Domain GaN LED model. The LED structures are: 200nm p-GaN, 50nm MQWs, 400nm n-GaN, 200nm n-GaN 2PhC grating. The CW light source is placed in the center of MQWs. The time monitor is above the LED to collect output power. Three design parameters define the grating layer: grating height, grating width, and grating period. First, we fix the grating height at 200nm, select the 50% filling factor, and sweep the grating period from 100 to 1000 nm. We find that the n-GaN grating layer has the highest light extraction output at a period around 700nm. Compared to the non-grating case, it has 27% light extraction improvement, which is agree with published experimental data of Peking University. Then, we sweep the above three parameters and all their possible permutations. And the light extraction improvement design optimization charts are developed. Some nano-grating structure improve light extraction of the LED devices, but some gratings actually lower the light extraction rate compared to the non-grating case.

Multi-functional colorimeter designed for color analyses

F. Sametoglu, O. Celikel, TÜBITAK National Metrology Institute (Turkey)

A multifunctional colorimeter is designed for measuring colorimetric properties of reflective and transparent materials. In order to illuminate samples, a special light source based on mixtures of a high power cool-white (CW) and a near-ultraviolet (n-UV) light emitting diodes (LEDs) via a fiber optic combiner is constructed. Insufficient spectral
power distribution of CW LED over 380 nm - 410 nm are improved by using the mixture of light. A barium-sulphate coated integrating sphere capable of meeting standard measurement conditions of d/8° and 0°/45° for colorimetric analysis is designed. The integrating sphere has a sample port (18 mm in diameter) and three illumination/measurement ports (each of which has 9 mm in diameter). The mixture of light is transferred from the light source to the illumination port of the sphere by using a fiber optic cable having core diameter of 1 mm. Collimators are used at the illumination port for illuminating samples. Light reflected or transmitted from the sample is measured by means of a designed detector composed of a RGB-photodiode and stray light reduction tube. Photocurrents generated at outputs of RGB-photodiode are converted to voltages by using a three-channel transimpedance amplifiers having gain selection switches from 1×10^4 to 5×10^4.

A special detector composed of RGB-photodiode and diffuser is also designed for measuring hemispheric and photometric properties of emissive surfaces like television or computer monitors. Design details and optical characterization of the colorimeter are presented herein.

8123-46, Poster Session
Improving reliability of LED package by inorganic gas barrier thin film
Y. Lu, Y. Lee, C. Sung, Lextar Electronics Corp. (Taiwan)

Research on inorganic thin film developed as gas-barrier protection for LED package is reviewed. The Si3N4, SiO2, Al2O3 and SiO2+TiO2 inorganic thin film gas barrier coated on the surface of LED packages were prepared by sputter method, their structure characterization and luminescent properties were also investigated. These kinds of compounds show different water/vapor permeation in different thickness vary from 20nm to 100nm. One of the interesting results of this work is that the inorganic thin film could prevent water react with phosphor or silver layer from air, which provides the potential as a long life package in LED packing technology. Performance of gas barrier had been checked by different reliability tests. The reliability tests include (i) High temperatures and high humidity life test (Ta=60°, RH=90%),(ii)Resistance to soldering heat (Tsol=260°,10sec, Pretreatment: 85°,85%RH,24hrs).

It was demonstrated that samples with inorganic gas barrier show better optical performance than uncoated sample. The life decay analyses showed that the uncoated sample has cut down over 25% after 2000hrs. However, Si3N4 thin film coated sample could successfully suppressed optical intensity decay less than 10% after 2000hrs. Furthermore, the deviation of CIE distribution also could be improved from 0.011 to 0.003. This result shows that Si3N4 is an attractive candidate as a potential gas barrier in LED packing technology. The present results provide important information on the optimization of LED package reliability by coating inorganic thin film on the surface of package.

8123-47, Poster Session
Efficiency droop improvement in GaN-based light-emitting diodes by graded-composition electron blocking layer
C. Wang, National Chiao Tung Univ. (Taiwan); S. Chang, National Chiao Tung Univ. (Taiwan); Epistar Corp. (Taiwan); W. Chang, J. Li, H. Kuo, T. Lu, S. Wang, National Chiao Tung Univ. (Taiwan)

Carrier overflow out of the active region as well as inefficient injection and transportation of holes have been identified to be the major reasons of efficiency droop. To reduce the carrier overflow, an AlxGa1-xN electron blocking layer (EBL) was adopted in common LED structures. However, the polarization-field induced band bending and the valance band offset (Ev) at the interfaces of GaN and EBL are considered to retard the injection of holes. We have designed a graded-composition electron blocking layer for InGaN/GaN LED. The simulation results showed that the triangular barrier of conventional EBL at valance band could be balanced, while the slope of conduction band could be increased by increasing the band gap of AlxGa1-xN along [0001] direction. As a result, the hole concentration in MQWs was significantly increased, while the electron distribution within the GEBL region and p-GaN was enormously decreased over 2 orders, indicating the GEBL can effectively improve the capability of hole transportation across the EBL as well as the electron confinement. Furthermore, the LED structure with GEBL was realized by MOCDV. The L-I-V characteristics of GEBL LED showed better electrical characteristics due to the improvement in hole-injection and the higher-efficiency p-type doping in GEBL, as compared to the conventional LED. More importantly, the efficiency droop was reduced from 34% in conventional LED to only 4% in GEBL LED at 200 A/cm².

8123-48, Poster Session
InGaN-GaN MQW LEDs with current blocking layer formed by Mg-H bonds
C. Chen, L. Hsia, J. Chao, J. D. Guo, Lextar Electronics Corp. (Taiwan)

For most of the Sapphire-based LEDs, both n- and p-type electrodes are formed on the same side because sapphire substrate is an insulating material. The p-type electrode area consists of a thick wire-bonding pad and extended finger electrode on the top side. In such a structure, the thick p-pad metal inevitably blocks part of the light output and reduces the light extraction efficiency. In addition, due to the not-so-good conductivity of the thin transparent layer, there often exists current crowding effect around the p-pad. This may further reduce the quantum efficiency and device reliability as well. To increase LED external quantum efficiency is one of the important topic in LED technology.

In this work, we demonstrate an enhancement of the light output power of GaN light emitting diodes (LEDs) by using Mg-H bonds as current blocking layer (CBL). The formation of Mg-H bonds is achieved by annealing the SiNx film on the p-GaN surface and then removing it. Through annealing process, the region that deposited with SiNx film will increase in the resistivity of the metal-semiconductor contacts and the p-type neutral regions. The forward voltage of Mg-H CBL-LED slightly increased 0.03V and the light output power improved 2.54% enhancement than the without CBL reference. The formation of Mg-H will form a current-blocking layer that improve the current horizontal spreading in the transparent layer, is applied to InGaN-GaN LEDs to enhance the external quantum efficiency.

8123-49, Poster Session
Optical and electrical properties of GaN-based light emitting diodes grown on micro and nano-scale patterned Si substrate
C. Chiu, C. Lin, National Chiao Tung Univ. (Taiwan); D. Deng, Hong Kong Univ. of Science and Technology (Hong Kong, China); H. Kuo, National Chiao Tung Univ. (Taiwan); K. Lau, Hong Kong Univ. of Science and Technology (Hong Kong, China)

We investigate the optical and electrical characteristics of the GaN-based light emitting diodes (LEDs) grown on Micro and Nano-scale Patterned silicon substrate (MPLEDs and NPLEDs). The transmission electron microscopy (TEM) images reveal the suppression of threading dislocation density in InGaN/GaN structure on nano-pattern substrate due to nanoscale epitaxial lateral overgrowth (NELOG). The plan-view and cross-section cathodoluminescence (CL) mappings show less defective and more homogeneous active quantum well region growth on nano-porous substrates. From temperature dependent photoluminescence (PL) and low temperature time-resolved photoluminescence (TRPL) measurement, NPLEDs has better carrier confinement and higher radiative recombination rate than MPLEDs. In terms of device performance, NPLEDs exhibits smaller electroluminescence (EL) peak wavelength blue shift, lower reverse leakage current and decreases efficiency droop compared with the MPLEDs. These results suggest the feasibility of using NPSI for the growth of high quality and power LEDs on Si substrates.
The study of measurement method for the junction temperature and thermal resistance in LED lightings

J. Park, H. Lim, LED-IT Fusion Technology Research Ctr. (Korea, Republic of); J. Jang, Yeungnam Univ. (Korea, Republic of)

The forward voltage, light emission and lifetime of LED lightings are closely related with the junction temperature. Recently, the alternative techniques for measuring junction temperature of LED packages have been reported, which include optical and electrical test method. Based on electrical test method, we propose how to evaluate the LED junction temperature of LED lightings by examining relation between the forward voltage variation and the junction temperature. In case of LED lighting, it is very difficult to measure junction temperature because of high voltage, high current and too many variables as compared with single LED package. In this study, LED lighting is placed in a temperature chamber and connected to precise current source (or LED drive) and measurement equipment to be able to measure a voltage and current simultaneously. K factor was experimented in condition of typical driving current at different temperatures ranging between 298 and 368 K. At room temperature, the corresponding forward voltage value was measured. And after the LED lighting continuously operated over one hour, the unchangeable forward voltage was measured. From these results, the junction temperature can be easily calculated by using formula based on EIA/JESDS1-2 standard. The measured junction temperature in this method is expected to provide useful information to predict adequate lifetime of LED lighting.

LEDs on curved ceramic substrate with primary optics for modification of luminous intensity

A. Wei, Power Lens Technology Inc. (Taiwan); J. Sze, Instrument Technology Research Ctr. (Taiwan); J. Chern, Power Lens Technology Inc. (Taiwan)

A conventional LED chip is mounted on a flat substrate, leading to mere the forward emission (luminous intensity distribution with the angular spread 180°). To realize a LED bulb with the backward emission, a common method is exploiting diffuse surfaces. However, the output-coupling luminous flux is reduced around 10 %. In this study, a curved substrate is used to efficiently achieve the forward and the backward emission. Meanwhile, the required curved substrate is realized by a ceramic printed circuit board (PCB), resulting in a cost-efficient chip-on-board (COB) structure. Further, such a COB LED luminary can be packaged with primary optics. With proper design of the primary optics, the luminous intensity can be adjusted to fit the applications of streetlightings. One example has been designed, fabricated and measured. The fabricated single unit is mounted on a heat-sink, while the measured luminous intensity distribution is shown as a bat-wing with the beam-angle of 132.6°. To realize a streetlight, 21 units have been assembled with related electronics and mechanics recently. The measurement of the designed streetlight is on-going and the reports of the results will be provided soon.

Energy-saving approaches to solid state street lighting

A. Zukauskas, P. Vitta, R. Stanikunas, A. Tuzikas, I. Reklaitis, A. Stonkus, H. P. Vaivekicius, Vilnius Univ. (Lithuania)

Commercial high-power light-emitting diodes (LEDs) have already attained luminous efficacy comparable to that of high pressure sodium (HPS) lamps, which are widely used in street lighting. However in comparison with slowly and inefficiently dimmed yellowish HPS lamps, LEDs offer efficient dynamic dimming and more appropriate color. We consider a solid-state street lighting concept based on three energy saving aspects, namely, savings due to improved visual performance under white solid-state light sources, weather sensitive luminance regulation, and intelligent lighting tracking of pedestrians and vehicles at low traffic density. Potential energy savings due to improved visual performance were estimated from the psychophysical investigation of human reaction time measured using an off-axis visual stimuli placed under various light sources (HPS lamp, warm white and daylight phosphor converted LEDs, and RGB LED cluster). Measurements of road luminance under different road surface conditions were collated with the statistical data for night time in Lithuania (60% dry, 10% wet, and 30% snowy). The intelligent vehicle/pedestrian tracking was tested using a statistical data for night time in Lithuania (60% dry, 10% wet, and 30% snowy). The intelligent vehicle/pedestrian tracking was tested using a statistical data for night time in Lithuania (60% dry, 10% wet, and 30% snowy). The intelligent vehicle/pedestrian tracking was tested using a statistical data for night time in Lithuania (60% dry, 10% wet, and 30% snowy).

Effects of pitch and shape for diffraction grating in LED fog lamp

H. Chen, J. Lin, National Yunlin Univ. of Science and Technology (Taiwan); J. Wu, Ming Chuan Univ. (Taiwan); S. Ma, Feng Chia Univ. (Taiwan); C. Yang, National Yunlin Univ. of Science and Technology (Taiwan)

The characteristics of light-emitting diodes (LEDs) that make them energy-efficient and long-lasting light source for general illumination have attracted a great attention from the lighting industry and commercial market. As everyone know LEDs have the advantages of environmental protection, long lifetime, fast response time (µs), low voltage and good mechanical properties. Their high luminance and the wide region of the dominant wavelengths within the entire visible spectrum mean that people have high anticipations for the applications of LEDs. People also found wide application in solid state lighting, like as street lighting, back lighting, sign lighting, lamp lighting and so on. A high brightness LEDs would like to used for the illumination on both street and automobile. The output lighting from reflector in the traditional fog lamp was required to fit the standard of the ECE regulation. Therefore, this study investigated the effects of pitch and angle for a diffraction grating in LED fog lamp. The light pattern of fog lamp must be satisfied ECE automobile technical regulations, so a design of diffraction grating to shift the lighting was required. We used two 1W LEDs (Cree XLamp XPE LEDs) as the light source in the fog lamp for the illumination efficiency. Then, an optimal simulation of diffraction grating was done for the pitch and angle of the diffraction grating at the test plane of 25 meters. The best pitch and angle was 2mm and 60 degree for the grating shape of triangle type.

Investigation of GaN-based light emitting diodes on thermal stress

Y. Cho, H. Lim, M. Park, J. Jang, LED-IT Fusion Technology Research Ctr. (Korea, Republic of)
We have investigated the degradation of the optical power and the I-V characteristics of InGaN/GaN light-emitting diodes (LEDs) during the thermal stress on golden hot plate. We have analyzed the effect of high temperatures on the degradation of high brightness LEDs: a set of thermal stress tests have been carried out on LEDs produced by different manufacturers. At each step of the ageing tests, LEDs have been set on golden hot plate for a complete electro-thermal analysis of their properties. Thermal treatment has been found to induce output power decrease, modification of the spectral properties of the devices and operating voltage increase. The degradation of the optical properties has been found to be thermally activated: ageing tests carried out at different temperature levels: 25 to 250 °C at a constant current, the optical power was significantly reduced. The experimental results showed that the power loss, wavelength peak shift, and spectrum intensity reduction increase as the temperature increase.

In this paper, we have proposed a new concept of LED by which we can estimate the lifetime of blue LEDs with high accuracy. Two kinds of LEDs from different manufacturers were analyzed in this study using proposed LEDs. Optical and electrical characteristics such as light-output degradation and reverse leakage current of high-power blue LED were investigated and analyzed.

8123-55, Poster Session

Atomic distribution of transition metals in III-nitrides
R. W. Nicholas, M. H. Kane, The Univ. of Oklahoma (United States)

Understanding atomic distributions on the order of nanometers is becoming increasingly essential to solid-state electronic device design. The local composition of any singular constituent can have a great effect on a host of materials properties. Atom probe tomography is currently the only characterization technique that can provide direct physical detection of ionic species of atoms. This work presents the first case of GaMnN thin films that are characterized utilizing the state of the art local electrode atom probe (LEAP) to determine the atomic ordering of Mn in an effort to help understand room-temperature ferromagnetic exchange mechanisms in wide bandgap dilute semiconductors. The distribution of Mn on the atomic scale was found to be random in nature with no evidence for the predisposition of Mn to form dimers, trimers or clusters that may lead to room-temperature ferromagnetism that has been observed in the samples. This is attributed to surface segregation of Mn during the growth process, leading to a concentration of Mn well below the solubility limit near the buffer layer where data was collected. This work proves consistent with previous magnetic analysis in that most isolated Mn atoms will result in paramagnetic behavior. This behavior, coupled with the effects of ferromagnetic clusters yields previously observed superparamagnetic behavior. Atom probe tomography corroborates where in the sample these clusters lie, aiding in the ultimate goal of understanding the structure-property-growth condition relationships for the tailoring of specific MOCVD processes that will lead to the ability to selectively control spintronic device functionalities.

8123-56, Poster Session

Growth of novel buffer layers for III-nitride LEDs by pulsed electron deposition
N. Arefin, R. W. Nicholas, R. Dooly, M. H. Kane, The Univ. of Oklahoma (United States)
Pulsed electron beam deposition (PED) allows for the growth of high crystalline quality films at much lower growth temperatures than metal organic chemical vapor deposition and molecular beam epitaxy. PED also represents a potential replacement to pulsed laser deposition especially for very high bandgap materials, as PLD has higher setup costs due to the requirement of excimer lasers. The low temperature growth of PED also allows for the integration of dissimilar materials, which inhibits interdiffusion, backetching, and chemical reactions during the growth process. This approach may alloy for the implementation of III-nitrides with lattice-matched oxide substrates, or for the integration of chemically soluble buffer layers which can be removed to improve thermal management or light extraction. In this work, we have explored the epitaxial deposition of GaN films on chemically soluble buffer layers (ZnO, CrN) using PED. The as-grown films were characterized using X-ray diffraction, atomic force microscopy, and transmission electron microscopy. The results show that this technique may provide a new avenue for integration of III-nitrides on lattice matched but chemically reactive substrates.

8123-57, Poster Session

Self-assembled microlens on LED using hydrophilic effect
G. J. Su, H. Wei, National Taiwan Univ. (Taiwan)

In this paper, we propose a self-assembled microlens arrays (MLAs) on top of light emitting diodes (LEDs) based on hydrophilic effect by UV Ozone treatment. A SU-8 mask with opening is used to obstruct the UV Ozone treatment and produce zones which are more hydrophilic on LEDs with SU-8 base layer on it. After hydrophilic zones are produced and the SU-8 mask is removed, the substrate with hydrophilic zones is dipped in and out of diluted SU-8 solution with slow and constant velocity. Finally, MLA is formed after UV curing and baking. There are several influence parameters, including diameter of hydrophilic zone, contact angle, and viscosity of diluted SU-8. Larger diameter, longer UV Ozone time, and more concentrated of diluted SU-8 induce longer focal length. Optical measurement revealed a good optical performance from the fabricated MLAs. By this approach, the fabrication is low cost and low time-consuming.

8123-58, Poster Session

Study on colony image acquisition and analysis system
W. Wang, Henan Polytechnic Univ. (China)

In this paper, colony image acquisition system design and construction are discussed and presented. To make colony image of stable and good quality, camera chosen, lighting design and colony plate should be considered. Recently, many researchers and developers have made efforts for this kind of systems. By investigation, some existing systems have some problems since they belong to a new technology product. One of the main problems is image acquisition. In order to acquire colony images with good quality, an illumination box was constructed as: the box includes front lighting and back lighting, which can be selected by users based on properties of colony dish. With the illumination box, lighting can be uniform; colony dish can be put in the same place every time, which make image processing easy. A digital camera in the top of the box connected to a PC computer with a USB cable, all the camera functions are controlled by the computer.

8123-59, Poster Session

Optimal design of light distribution of LED luminaries for road lighting
W. Lai, W. Chen, X. Liu, Chongqing Univ. (China)

No abstract available
8123-12, Session 3

Photo-recycling effects in LED lighting
C. Sun, National Central Univ. (Taiwan)
No abstract available

8123-13, Session 3

From dark to bright: novel daylighting applications in solid state lighting
H. G. Adler, OSRAM SYLVANIA Inc. (United States)
The term “daylighting” is used in various ways, on one hand in a more architectural sense, i.e. using existing daylight to illuminate spaces, and on the other, more recently, for using light sources to replicate daylight. The emergence of solid state lighting (SSL) opens up a large number of new avenues for daylighting. SSL allows innovative controllability of intensity and color for artificial light sources that can be advantageously applied to daylighting. With the assistance of these new technologies the combination of natural and artificial lighting could lead to improvements in energy savings and comfort of living beings. Thus it is imperative to revisit or even improve daylighting research so that lighting and building networks of the future with their sensor, energy (e.g. HVAC) and lighting requirements can benefit from the new emerging capabilities. The current talk will review existing daylighting concepts and technology and discuss new ideas. An example of a tunable multi-color SSL system will be shown.

8123-48, Session 3

Intensity shaping and the application efficiency of indoor OLED lighting
P. Y. Ngai, J. Fisher, M. M. Lu, Acuity Brands Lighting, Inc. (United States)
Most indoor lighting is uniform, targeted for the most demanding visual tasks, a practice driven by limitations of conventional lighting systems, resulting in waste. It has been shown that discrete low-luminance tiles of OLED lighting can achieve a practical overhead lighting system that precisely tunes illumination for user requirements, resulting in energy savings, increased comfort, and enhanced flexibility. In this paper, the application efficiency of OLED lighting is further explored by evaluating how intensity shaping can vary photometric performance, create more targeted lighting effects, and increase the types of lighting applications for which OLED can be considered. Several non-Lambertian distributions are considered, along with multiple configurations of OLED panels.

8123-49, Session 3

Toward mass production of OLED lighting
C. Lee, C. Chen, C. Yang, C. Fang, T. Chang, AU Optronics Corp. (Taiwan)
Toward mass production of OLED lighting, differential application field, satisfying performance and competitive cost structure are all very important. In this article, from manufacture point of view, challenges and potential approaches to achieve such performance and cost structure will be discussed. Besides, comparison of OLED lighting with other light sources in some specific application field will be also described.
assumed to be responsible for the polymerization of the unidentified molecules. Further investigations are in progress to determine the unidentified molecules.

8123-16, Session 4

The analysis of thermal effect on color performance for white LEDs
C. Chen, H. Wu, C. Sun, National Central Univ. (Taiwan)

For general phosphor converted LED packaging, the chromatic performance of an LED changes with the increasing temperature. In this paper, we try to analyze and predict the thermal effect on the phosphor and the blue die. Our experimental results show that the output power, correlated color temperature, and color coordinate of white LEDs will vary as the temperature rises. The output power of the blue and yellow light will decay with rising temperature. In addition, the spectrum of the blue die is red-shift and the phosphor is blue-shift with the rising temperature. According to the various emission spectra of the bare chip, the ability of blue light absorbed by YAG phosphor will change. In the study, we introduce a concept “ absorbability” to analyze properties in white LEDs, which are combined with the excitation spectrum of YAG phosphor and the emission spectrum of blue bare chip. Then, we combine the thermal effect with the absorbability to minimize the deviation of correlated color temperature and color coordinate of white LEDs with the rising temperature. Finally, we can predict the variance of color performance with various operation temperatures in the white LED packaging combined with different bare chips.

8123-60, Session 4

Methods for estimating junction temperature of AC LEDs
A. Jayawardena, Y. Liu, N. Narendran, Rensselaer Polytechnic Institute (United States)

Light-emitting diodes operating on alternating current (AC) are gaining popularity in lighting applications. The junction temperature of an LED has significant influence on its performance, including light output, luminous efficacy, service life, and reliability. Since junction temperature cannot be measured directly, most methods presently used with DC LEDs are indirect and provide estimations of junction temperature. Although there are many proven methods for estimating the junction temperature of DC LEDs, only a few methods have been proposed for AC LEDs. In the study presented in this paper, three different methods were investigated and analyzed to understand their accuracies in estimating AC LED junction temperature. In one method, a low reference current pulse was used to measure the voltage across the AC LED junction that estimated the junction temperature. In the second method, an active cooling system was used to recover the initial current (rms) and estimate the junction temperature. In the third method, the peak wavelength value of the spectrum was used to estimate the junction temperature. Results from all three methods were compared and analyzed to determine their accuracies. The details of the methods and the associated results will be presented and discussed.

8123-18, Session 5

Compact collimators for high-brightness LEDs using dielectric multilayers
H. J. Cornelissen, Philips Research Nederland B.V. (Netherlands); H. Ma, C. Ho, M. Li, Technische Univ. Delft (Netherlands)

A novel method is presented to inject the light of millimeter-sized high-brightness LEDs into light guides of sub-millimeter thickness. Use is made of an interference filter that is designed to pass only those modes that will propagate in the light guide by total internal reflection. Other modes are reflected back to the LED cavity and recycled, leading to an increased brightness.

A collimator has been designed and made that is only 1mm thick, with a diameter of 6.5mm. It creates a beam of 26deg Full Width at Half Maximum. Presently, collimators with these characteristics have a thickness of 10-20mm and a diameter of 20-30mm and require careful mounting and alignment. The new collimator contains a 4.5micron thick interference filter made of 54 layers of Nb2O5 and SiO2 layers. The filter is optically coupled to the LED with Silicone adhesive which makes the configuration very robust. A cylindrical lightguide, tapered from 6.5mm to 2.5mm diameter and 1mm thick captures the light that passes the filter, folds the light path and redirects the beam. Measurements on collimator prototypes show good agreement with the designed characteristics. This promising approach enables much more compact collimators optics that offer material cost savings and design freedom.

8123-19, Session 5

Freeform lens design for LED illumination with high uniformity and efficiency
W. C. Chen, H. Y. Lin, National Taiwan Univ. (Taiwan)

In this paper, design examples related to LED illumination are presented. We design a freeform lens according to the initial LED light source intensity distribution so that the light rays emitted from a LED through the lens can achieve high uniformity and efficiency on the prescribed target plane. Because the model is of rotational symmetry, we consider just a 2-D lens shape and then sweep to get the 3-D result. Here a procedure based on the Snell’s law and “edge-ray principle” for designing the freeform lens is proposed. First of all, we analyze the LED intensity distribution and subdivide it into parts. Then we calculate the zones on the target plane where the subdivided light rays should be distributed to. Finally we use an analytic approximate method to construct the freeform lens. After constructing the freeform lens, we simulate for the optical model by using the ray-tracing software LightTools®. The simulation results are very close to our expectation, that is, most light rays are distributed to the zones as designed. And it also shows that the Cree XLamp XR-E LED light source through the freeform lens can achieve 93% uniformity and 90% efficiency including Fresnel losses for a 1 m distance away and 1 m radius of circular illumination plane. This method utilizes simple processes and the model can be easily constructed; so they can be very useful for designing LED illumination. As long as variables such as the distance and range of the illumination plane are prescribed, the lens of secondary optics can be designed to achieve high uniformity and efficiency for LED illumination.

8123-20, Session 5

Sapphire side wall shaping by laser scribing
Y. Chen, F. Wenffy, L. Hsia, J. Chao, J. D. Guo, Lextar Electronics Corp. (Taiwan)

To increase LED light extraction efficiency is the one of the important topic in LED technology. Due to the difference of reflective index between GaN, sapphire and air, most of emitting light will be trapped in substrate materials. Therefore, there are many solutions that used to solve the problem such as surface texture, and pattern sapphire substrate. In this paper, we will discover a method to increase the light extraction efficiency in sapphire base LED. In this method, the laser scribing was used to shape sapphire side wall to form the regular trapezoid and pours trapezoid shape. We found that the regular trapezoid can make more light escape from sapphire side wall when the angle from side wall to the bottom side of sapphire substrate is about 131°. On TO-can, the regular trapezoid and pours trapezoid can improve ~5% and ~10% light output enhancement individually compared with straight sapphire side wall on p-GaN roughness LED structure. But interestingly, the efficiency of blue light Transfer to white of the regular trapezoid sapphire shaping is better than pours trapezoid shaping in white light on L/F type. The detail mechanism will be reported in this talk.
8123-21, Session 5

Using Taguchi method to design LED lamp for zonal lumen density requirement of ENERGY STAR

J. Yu, Y. Chen, J. A. Whang, National Taiwan Univ. of Science and Technology (Taiwan)

In recent trend, LED begins to replace traditional light sources since it has many advantages, such as long lifespan, low power consumption, environmentally mercury-free, broad color gamut, and so on. According to the zonal lumen density requirement of ENERGY STAR, we design a triangular-prism structure for LED light tube. The optical field distribution of the current LED light tubes consists of the array of LED and the semi-cylindrical diffuser in which the intensity distribution of LED is based on Lambertian and the characteristics of diffuser are BTDF: 63%, transmission: 27%, and absorption: 10%. We design the triangular-prism structure at the both sides of the semi-circular diffuser to control the wide-angle light and using the Taguchi method to optimize the parameters of the structure that will control the 15% of total flux to light the area between 90 degree and 135 degree and avoid the total internal reflection. According to the optical simulation results, the 85% of total flux is within 90 degree and the 15% of total flux is between 90 degree and 135 degree that match completely with the Solid-State Lighting (SSL) Criteria V.1.1 of ENERGY STAR.

8123-22, Session 5

Profiling the optical distribution of a white organic light emitting diode as a lighting source

H. Yang, National Taipei Univ. of Technology (Taiwan); J. Su, National Taiwan Univ. of Science and Technology (Taiwan); L. Chen, Natioanl Taipei Univ. of Technology (Taiwan); Y. Lien, National Taipei Univ. of Technology (Taiwan); S. Peng, National Taiwan Univ. of Science and Technology (Taiwan); Y. Chen, National Taipei Univ. of Technology (Taiwan)

The optical distribution of a white organic light-emitting diode (WOLED) was experimentally investigated and profiled by using a microscopic goniometer equipped with optical power meter. WOLED has become a potential planar lighting source due to its unique planar device structure consisted of multiple organic layers sandwiched by cathode and anode electrodes on glass substrate. The optical field distribution of a WOLED planar lighting source is expected to be different from that of conventional LED as a point lighting source. It is crucial for understanding its optical distribution of a planar lighting source to design lighting source system by WOLED. The optical distribution of a WOLED with 1cm x 1cm lighting area was profiled by a microscopic goniometer in which we are able to pinpoint any spot in lighting area and measure its microscopic optical power independently. The profile of its optical distribution can be established by combining individual microscopic optical power from measured spots across the lighting area. The optical distribution of a WOLED is generally observed as uniform distribution by naked eyes. Our experimental result revealed that the optical distribution of a planar WOLED lighting area behaves like Gaussian distribution rather than uniform distribution as observed by naked eyes. It is also indicated that the optical profile of a WOLED planar lighting source is analogous to a point lighting source in microscopic point of view.

8123-23, Session 5

Freeform reflector design for LED street lighting

C. Li, P. Schreiber, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); A. Walkling, C. Schierz, Technische Univ. Ilmenau (Germany); M. Schwede, V. Guehne, JENOPTIK Polymer Systems GmbH (Germany)

Faceted freeform reflectors were designed for intelligent street lighting with LED cluster arrays for main traffic roads. Special attention was paid to achieve highly efficient illumination on both wet and dry road surfaces. CIE reflection tables W4 and C2 were applied in the simulation for these two conditions, respectively. The design started with plane facets, then to avoid artifacts from the images of the individual LEDs - plane facets were replaced with cylindrical facets. To get further more flexibility for the design and optimization, freeform facets were employed, modeled by extruding two different conic curves together. Besides of achieving well-proportioned road luminance distribution, the basic shapes of the reflectors were also formed to control stray light caused by multiple reflections within the reflector and by reflecting the light from neighbor clusters within the cluster array. The merit functions useful transmission of light to the road as well as overall and lengthwise uniformity according to road illumination standards. Due to the large amount of variables, the optimization was carried out sequentially facet by facet. The design loops included compromising with manufacturing limitations for plastics molding and thorough analysis of conformity with DIN EN 13201 standards for ME road lighting classes. The calculated reflector profiles are realized by plastic injection molding.

8123-24, Session 6

High-reflectance and low-resistance nano-patterned Pt alloy contact to p-type GaN

C. Chang, C. Liu, National Central Univ. (Taiwan)

A self-formed nano-network meshed Pt layer formed on the epitaxial (0001) GaN substrate upon thermal annealing. EBSD analysis shows that, while the meshed Pt layer was forming on the GaN surface, Pt atoms rearranged themselves in (111)-preferred orientation on (0001) GaN. The (111) Pt/(0001) GaN interface represents the most energy-favored stacking configuration.

In this talk, we will report a high transmittance (in visible range) and low-resistance p-GaN contact for high-power LEDs by using this unique meshed Pt layer. Besides using the meshed Pt layer as the transparent conducting layer for the horizontal LED chips, we also combine the meshed Pt layer with the Ag reflector as the high reflective and low resistance p-GaN contact-scheme for the vertical LED chips (thin-GaN LED). In addition, we found that by alloying the Pt layer with Au or Ag, the de-wetting of the Pt alloy thin film can be more controllable on the GaN surface. The de-wetted Pt alloy layers were found to have good ohmic contact with p-GaN. All the optical and electrical characterizations of LEDs with the meshed Pt contact layer would be presented in this talk.

8123-25, Session 6

Improvement of GaN-based light emitting diodes using p-type AlGaN/GaN superlattices with a graded Al composition

S. J. Lee, S. Han, C. Cho, Gwangju Institute of Science and Technology (Korea, Republic of); H. Shim, Y. Kim, Samsung Electro-Mechanics (Korea, Republic of); S. Park, Gwangju Institute of Science and Technology (Korea, Republic of)

We investigated the effect of graded Al composition in the p-type AlGaN/GaN superlattices (SLs) of InGaN/GaN multiple quantum well (MQW) light-emitting diodes (LEDs) to improve their performance. The InGaN/GaN MQW LEDs with p-type AlGaN/GaN SLs were grown on a c-plane (0001) sapphire substrate by metalorganic chemical vapor deposition (MOCVD). The LEDs with grading I and grading II consisted of Al compositions in p-type AlGaN barriers that varied from 0 to 16% and from 16 to 0%, respectively. The integrated electroluminescence (EL)
intensity of LEDs with grading I and grading II was higher by 10% and 7.6% than that of LEDs without grading at 350 mA, respectively. The external quantum efficiency (EQE) of LEDs with grading I and grading II was increased by 9.5% and 6.5% at a current density of 30 A/cm², respectively, compared to that of LEDs without grading. The improvement of output power and EQE of LEDs with Al composition grading can be attributed to the increased hole injection by the reduced AlGaN barrier heights and the suppression of the potential spikes between AlGaN and GaN in SLs. These results indicate that a graded AlGaN layers in p-type AlGaN/GaN SLs alleviate the efficiency drop mostly at low current density.

8123-26, Session 6
High-quality vertical light emitting diodes fabrication by mechanical lift-off technique
S. Hsu, Tamkang Univ. (Taiwan)

For the past decade, wide band gap GaN-based semiconductors have attracted much attention due to the important applications of high brightness light emitting diodes in solid state lighting. These devices were grown heteroepitaxially onto foreign substrates like sapphire and SiC and led to the shortage of high quality GaN substrates. The sapphire is the most commonly used substrate because of its relatively low cost, but also has the limitation of high-power performance due to its poor electrical and thermal conductivity. In the last decade, a laser lift-off (LLO) and chemical lift-off (CLO) technique have been used to fabricate the freestanding GaN membrane for high performance optoelectrical devices. However, the LLO and MLO may induce some damages at elevated temperature in GaN epilayer, i.e., decrease the lighting performance during lift-off process. Here, we demonstrate the fabrication of mechanical lift-off (MLO) high quality thin-GaN with hexagonal inverted pyramid (HIP) structure for vertical light emitting diodes (V-LEDs).

In this experiment, the high quality thin-GaN LED devices are fabricated by Au-Si wafer bonding and MLO process. Si material is chosen due to its high thermal conductivity which helps to quickly dissipate heat generated by LEDs. The density of threading dislocations was supposed to be efficiently reduced by re-growth GaN epilayer on HIP structure. The stress relaxation of the transferred GaN films is studied by varying the bonding thickness in the range from 5 µm to 50 µm. The residual stress states of the transferred GaN thin films are characterized by Raman spectroscopy measurement. Finally, the PL and EL spectrum of MLO V-LEDs are also measured to prove the improvement of lighting performance.

8123-27, Session 6
Single-chip phosphor-free white LEDs
X. Guo, B. L. Guan, Beijing Univ. of Technology (China)

With the realization and rapid development of GaN light-emitting-diodes (LEDs), white LEDs using GaN-based materials have attracted a lot of attentions and interests both in research and in industrial applications, such as for indicators, backlights, and especially in general illumination. To date, there are two leading approaches to achieve white LEDs. One is to put red, green and blue LEDs (RGB-LEDs) together in space and mix these three primary colors to produce white light. The other approach is to use blue or UV LEDs to excite one or more phosphors covered on them to give white light. LEDs using this approach are called phosphor-converted LEDs (pc-LEDs). Although RGB-LEDs have high efficacy, instantaneous color and intensity controllability, the practical implementation has numerous challenges, including the spatial light mixing and complicated feedback control system. For the pc-LEDs, their lifetime is limited by the phosphors covered on them. The power or the efficacy of pc-LEDs usually decreases due to the wavelength conversion occurred in the phosphor from the blue region to the yellow region, degrading the efficacy of LED itself. Moreover, some phosphors result in some environmental problems both in preparation and in use of this kind of white LEDs, such as the use of chlorine and cadmium.

In this study, the single-chip phosphor-free white light source made of two different LEDs was investigated. An InGaN/GaN LED and an AlGaNp LED are integrated together by wafer-bonding technology. By choosing two complementary wavelengths with a certain power ratio, the combination of EL lights from the two LEDs yields white light located on the chromaticity diagram near to the standardized Illuminant C.
offer a touch screen to select graphically-illustrated presets, these rigid assumptions lead to user frustration. Most attempts to integrate sensor feedback into commercial systems exploit simple motion sensors to activate all lighting in a space when one occupant moves. This is generally an energy-wasteful choice and, is not much better than the converse: turning off all the lights when the occupant doesn’t move for a while.

The inherent control flexibility implied by solid-state lighting - united with the rich details offered by sensor networks - prompts us to rethink lighting control. In this research, we focus on both modulated photonic and geometric methods of measuring the work surface illuminance and ambient light, as detected by our sensor network, for controlling solid-state lighting networks. We discuss these techniques, including the lessons learned from our prior research. We present a new method for measuring the illuminance of an arbitrary luminaire at the work surface, without user disruption, by decomposing the modulated light into its fundamental and harmonic components. We fully derive and provide the results of this method, including its performance in our latest adaptive lighting testbed.

8123-31, Session 7

Addressing the variables in LED product design to ensure product reliability

P. F. Keebler, F. D. Sharp, Electric Power Research Institute, Inc. (United States)

Continuing developments in LED lighting are leading to more lighting products for illumination in LED fixtures for the residential, commercial, and industrial facilities. Most of the research in the past ten years has been aimed at developing LEDs with higher brightness, higher efficiencies, good color performance and longer life. Many efforts have been accomplished to develop LED driver circuits to drive LED arrays, even drivers that are dimmable. Manufacturers are increasing their level of concern with the performance and life of the whole LED product with a renewed emphasis on reliability. Reliability for LED products not only involves thermal management, fixture design, and driver loading but also how products respond to electrical disturbances that occur in the building electrical environments where the products must function. EPRI research has demonstrated that the immunity of LED lighting systems to common everyday electrical disturbances is critical to establishing the reliability needed to ensure expected performance and for their survival during product life. Test results showing the application of voltage surges, transients, and sags among other disturbances will be presented. This paper will discuss the application of the results of EPRI research in this area, the test protocol associated with EPRI system compatibility concept, examples of how applying the concept has identified reliability problems in LED products, and how the reliability of these LED systems can be easily improved.

8123-32, Session 7

Statistical approach to color rendition properties of solid state light sources

A. Zukauskas, R. Vaisekauskas, A. Tuzikas, P. Vitta, Vilnius Univ. (Lithuania); M. S. Shur, Rensselaer Polytechnic Institute (United States)

Versatility in composing the spectral power distribution of solid-state light sources offers vast possibilities in color rendition engineering. In particular, the use of narrow-band spectral components allow for controlling two principle color rendition properties of illumination, color fidelity and chromatic contrast. We present the results of this work and its implications on the assessing and optimization of color rendition properties of solid-state light sources using a recently introduced statistical approach to color quality of illumination. The method relies on the computational grouping of a large number of test color samples (e.g., the Munsell palette of 1269 samples) depending on the color shifts in respect of the experimentally established just perceived differences of chromaticity and luminance. The method allows for introducing single-format and easy-to-understand color rendition indices, such as Color Fidelity Index (percentage of the test samples having the color shifts smaller than the perceived color differences) and Color Saturation/Dulling Indices (percentage of the test samples having the color shift vectors with a perceivable increase/decrease in chromatic saturation). Within this approach, practical solid-state lamps, such as phosphor converted light-emitting diodes (LEDs) and polychromatic LED clusters were attributed to several distinct types, such as high-fidelity, color saturating, or color dulling light sources. Optimization of spectral power distributions of solid-state lamps in respect of different color rendition properties was performed and light sources with dynamically tailored color rendition properties were developed. The statistically assessed color rendition properties were validated using a psychophysical investigation.

8123-33, Session 8

Thermal analysis of mid-UV LEDs light sources

S. Graham, Georgia Institute of Technology (United States); A. M. Khan, Univ. of South Carolina (United States); V. Adivarahan, Nitek, Inc. (United States)

The development of mid-UV solid state light sources hold promise for applications such as biological sensors and water purification. Due to their wavelength of emission, these devices are often grown on sapphire or AlN substrates and then flip chip bonded to a submount and then a power electronics or optoelectronics package to dissipate the heat. Maximizing the thermal dissipation is critical to improving the efficiency and reliability of these devices. However, very little has been done to elucidate the thermal response of mid UV-LED emitters. In this work, a combination of forward voltage thermometry, Raman spectroscopy, and IR thermography are used to analyze the thermal response of mid-UV LED light sources made using micro-pixel LEDs. Transient thermal analysis using structure function modeling and transient forward voltage temperature measurements provide insight into the packaging thermal resistance. Corresponding light out put was measured using an ocean optics spectrometer. Combined with finite element analysis, a detailed description of the parameters impacting heat dissipation from these devices is presented along with methods to reduce thermal resistance.

8123-34, Session 8

Study of transient thermal measurement for high-power LED package

W. Liu, C. Liu, T. Yang, National Central Univ. (Taiwan)

A transient thermal measurement system is developed to measure the transient behavior of the junction temperature of LED in the very early operation stage. For the typical LED package, heat would be generated from the LED chip and conducting to the first-level Cu substrate via the Ag-epoxy TIM (Thermal Interface Material) interface, then, dissipated into the heat sink via the thermal paste. Using the current-developed transient thermal measurement system, we can study the thermal-dissipation characteristics of every heat-transferring path or interfaces in the LED package. In this research, we investigated the transient behavior of the junction temperature of the studied LED package using the Cu substrates with various dimensions. The Cu substrate varies with the diameter (1.0 to 2.5 cm) and thickness (0.4 to 3.0 mm). From preliminary results on the transient behavior of the junction temperature of the studied LED package, we found that the heat transferring rate highly depends on the dimension of the Cu substrate. Also, in the steady-state condition (after 100–seconds current driving), the junction temperature decreases with the thickness of Cu substrates with a constant diameter. Yet, the junction temperature does not have a linear proportional relation with the diameter...
of the Cu substrate. The lowest junction temperature occurred at the middle range of diameter of the Cu substrates (about 1.5 cm in diameter). In this talk, we will report the established transient thermal measurement system and the analytic results to understand the detail characteristics of every heat-transferring path or interfaces in the LED package.

8123-35, Session 8
Evaluating the junction temperature of AC LEDs by DC and AC methods
H. Fu, K. Tai, C. Wang, P. Chou, Industrial Technology Research Institute (Taiwan); Y. Zong, Y. Ohno, National Institute of Standards and Technology (United States)

Alternating-current (AC) driven light-emitting diodes (LEDs) have become the trend of solid-state lighting (SSL) products. The junction temperature is an important index of LEDs reliability and efficiency. In other words, with proper thermal management of AC LEDs lighting products, the high performance of SSL products will be achieved. In order to obtain the junction temperature, we study and compare two published evaluating methods differentiating between the measurements of DC and AC in this paper. The first method is in which a low reference current having a pulse width was applied and the corresponding voltage across the device was measured and correlated to the junction temperature. The second method is using an active heat sink for recovering the root mean square (RMS) current of the first half cycle to estimate the junction temperature. The experimental evidence showed different aspects and variations of evaluating the AC LEDs junction temperature. The variations of evaluating junction temperature were caused by the switch time and phase of different source measurements in the first method and the capture time of the first half cycle in the second method. With proper capture time, the rising junction temperature in the second method might be negligible.

8123-36, Session 8
Measuring the junction-to-ambient thermal resistance of a LED lamp directly and accurately
K. Shih, K. Hua, Lawrence Technological Univ. (United States)

The junction temperature of a LED determines its life expectancy and light conversion efficiency. It is critically important to measure the junction to ambient thermal resistance of a LED lamp directly and accurately. With this information we can easily predict the thermal behavior of a LED lamp at any drive current and ambient temperature. However, it is difficult to measure LEDs that are packaged into an enclosure without taking the system apart. Some lamp makers use time consuming, expensive computer based modeling program to calculate the junction temperature of a LED inside a LED lamp. Other lamp manufacturers use indirect measurement methods to estimate the junction temperature. Because these methods are NOT direct measurement of the LED junction temperature under the real working condition; their results are not verifiable. This paper describes a method that measures the junction to ambient thermal resistance of an assembled LED lamp directly and accurately while under its real working condition. This measurement method not only reduces the time and cost to characterize the thermal behavior of a lamp, but also drastically improves the accuracy of the measurement.

8123-37, Session 8
Measurement of thermal resistance of first-level Cu substrate used in high-power multi-chips LED package
C. Yang, C. Liu, National Central Univ. (Taiwan)

Thermal dissipation is the one of key issues for the application of high-power LEDs package. To achieve an excellent thermal system for high-power LED, an effective thermal substrate is required. Currently, high thermally conductive Cu substrate is used as the first-level dissipation substrate. However, there is no systematical study on investigating the effect of the dimensions on the thermal performance of first-level Cu substrate.

Thermal resistance of the first-level Cu dissipation substrate (RCu) with different Cu thickness is investigated in this work. Using the “constant-forward-voltage” method, the thermal resistances of the first-level Cu dissipation substrates (RCu) were measured against different Cu thickness. In the initial increase in the Cu thickness (up to 0.6 mm), RCu decreases with the Cu thickness. As the Cu thickness over 0.6 mm, RCu starts to slightly increase with the Cu thickness. The thermal resistance (RCu) of the Cu substrate is composed of the z-direction thermal resistance (Rz) and the two-dimensional horizontal spreading resistance (Rs). The initial increase in RCU should attribute to the decrease in both Rz and Rz with the Cu thickness. After the initial increase in RCU, the RCu would increase and be dominated by the Rz increase with the Cu thickness. Intriguingly, a minimum RCU value occurs at the Cu thickness of about 0.6 mm. Also, in this study, we discuss the possible inaccuracy factors of the “constant-forward-voltage” method.

8123-38, Session 9
Electroluminescence emission from hybrid light emitting diode of p-ZnO/(InGaN/GaN) multiquantum wells/n-GaN
Y. Choi, T. Park, S. Kim, G. Jung, S. Park, Gwangju Institute of Science and Technology (Korea, Republic of)

We report on the fabrication and characteristics of hybrid light-emitting diodes (LEDs) which consist of antimony (Sb) doped p-ZnO, (InGaN/ GaN) multiquantum wells (MQWs), and n-GaN. The Sb-doped p-ZnO films with a hole concentration of 1.18x10^18/cm^3 and mobility of 0.71 cm^2/V.s were deposited on InGaN/GaN MQWs to fabricate hybrid LEDs by metalorganic chemical vapor deposition (MOCVD). After the growth of hybrid LEDs structure, a rapid thermal annealing (RTA) was carried out in an N2 ambient gas for 1 min to activate Sb-doped p-ZnO. The forward voltage and series resistance of hybrid LEDs were measured as 3.0 V and 11.8 Ω, respectively. An electroluminescence (EL) emission at a wavelength of 468 nm is observed from the hybrid LEDs. The EL intensity of hybrid LEDs increases as injection current increases, showing that the Sb-doped p-ZnO layer acts as a hole injection layer in the hybrid LEDs. Furthermore, the EL peaks are red-shifted as the injection current is increased, indicating that the compressive strain in MQWs is relaxed due to Sb-doped p-ZnO layer. Micro-Raman spectra show that the tensile strain of ZnO nanorods in p-ZnO:Sb layer is expected to compensate the compressive strain in MQWs, reducing the strain induced piezoelectric field in MQWs.

8123-39, Session 9
Growth and characteristics of titanium oxide nanoparticles-coated nonpolar a-plane GaN by spin coating method
J. Kim, Korea Univ. (Korea, Republic of) and Korea Electronics Technology Institute (Korea, Republic of); J. Son, K. Baik, Korea Electronics Technology Institute (Korea, Republic of); J. H. Park, Korea Univ. (Korea, Republic of); S. Hwang, Korea Electronics Technology Institute (Korea, Republic of)

Non polar a-plane (11-20) GaN structure which was coated TiO2 nanoparticles by spin coating method has been successfully grown on r-plane (1-102) sapphire substrates to improve light extraction efficiency and crystal quality. It was found that average size of titanium oxide nanoparticles is approximately 500 nm from scanning electron
microscopy (SEM). From photoluminescence (PL) results at 13 K of Si-doped GaN samples, basal plane stacking faults (BSFs) and near band edge (NBE) emission peaks were observed at 3.434 eV and 3.484 eV, respectively. We also found the temperature-induced band-gap shrinkage from temperature dependence PL, which was fitted well with empirical Varshini’s equation. The room temperature PL intensity of TiO2 coated multiple quantum wells (MQWs) sample was 20 % higher than that of reference sample. High-resolution x-ray diffraction analysis of films showed a anisotropy of strain with in-plane orientation. The full width at half maximum (FWHM) along the GaN [0001] and [1-100] directions were 564 arcsec and 490.8 arcsec, respectively. A small deviation of FWHM values compared with reference sample at in-plane crystal direction is attributed to relatively uniform in-plane strain. An improvement of crystal quality was also demonstrated by calculation of lattice constants, strain and PL results.

8123-40, Session 9

Tridoping and fabrication of ZnO homojunction by RF magnetron sputtering
B. Lakshmi Narayanan, G. Subramaniam, T. Balasubramanian, G. Nammalvar, National Institute of Technology, Tiruchirappalli (India)

The present study deals the novel approach of tridoping into ZnO to realize low resistive p-ZnO thin film and hence to fabricate the ZnO homojunction by RF magnetron sputtering. The tridoping i.e. simultaneous doping of two potential acceptors (As & N) and a donor (Al) has been achieved by As back diffusion from GaAs substrate and different AlN doped ZnO targets(0.5, 1 & 2 mol%). The diffused arsenic from GaAs substrate into ZnO film has been confirmed by Rutherford backscattering depth profile analysis. The grown films have been characterized by Hall measurement, X-ray diffraction (XRD), room temperature and low temperature Photoluminescence (PL). The Hall measurement showed that the low resistivity of 8.6x10^-2 Ωcm and high hole concentration of 4.7x10^20 cm^-3 for the 1% AlN concentration. The obtained resistivity is much lower than that of monodoped and codoped ZnO films. The Hall measurement results have been well justified by XRD and PL analysis. The presence of dopants in the film has been confirmed by Energy dispersive spectroscopy. The fabricated homojunction with the low resistive film (i.e. best tridoped film) has been characterized to determine the junction parameters.

8123-41, Session 9

Intense white luminescence from amorphous silicon oxycarbide (a-SiCxOy) thin films
S. Gallis, Univ. at Albany (United States) and IBM Corp. (United States); V. Nikas, H. Suhag, M. Huang, A. E. Kaloyeros, Univ. at Albany (United States)

Strong room-temperature white luminescence emitted from amorphous silicon oxycarbide (a-SiCxOy) films grown by thermal chemical vapor deposition (TCVD) is reported in this study. The emission spectra from the films cover a broad spectral range, from blue-violet to near infrared, depending on excitation energy. Furthermore, the effects of carbon concentration (8.4 at.% < C < 25 at.%) in the material and post-deposition annealing treatments (O2 and forming gas 5% of H2 ambient up to 1100oC) on the white luminescence are studied. It was found that photoluminescence (PL) intensity was well correlated with Si-O-C/ Si-C-O bond density, determined from the Fourier transform infrared spectroscopy (FTIR) analysis. For samples with very low C concentration (<5 at%), PL was shown to quench to close to zero values after annealing in O2 ambient in atmospheric pressure, even at 500 °C, while it remained unaffected in the films with higher C content. Interestingly, it was found that white PL could be significantly enhanced when the samples were excited at higher pump energy, under ultraviolet laser light (325nm) and the emitted light was visible with naked light even in a bright room environment. The findings suggest that C- and Si-related oxygen defect centers may play the role of luminescence sources in the strong white light emission observed from amorphous silicon oxycarbide films and they may be responsible for the thermal stability of a-SiCxOy against oxidation.
Illumination devices for uniform delivery of light to the oral cavity for photodynamic therapy

C. Canavesi, Univ. of Rochester (United States); W. J. Cassarly, Synopsys, Inc. (United States); T. H. Foster, Univ. of Rochester Medical Ctr. (United States); J. P. Rolland, Univ. of Rochester (United States)

To date, the lack of delivery mechanisms for light to the oral cavity remains a barrier to the treatment of oral cancer with photodynamic therapy (PDT). The greatest impediment to medical practitioners is the current need to shield the normal tissues of the oral cavity, a costly and time-consuming procedure. In this research, we present the design of illumination devices to deliver light to the oral cavity for PDT, which will facilitate administration of PDT in the clinic. The goal for such an illumination device, as indicated by our clinical collaborators at Roswell Park Cancer Institute in Buffalo, NY, is to limit exposure of healthy tissue and produce an average irradiance of 100 mW/cm² over the treatment field, with spatial non-uniformities below 10%. Furthermore, the size of the device must be compact to allow use in the oral cavity. Our research led to the design and fabrication of two devices producing spatial non-uniformities below 6% over a treatment area of 0.25 cm² by design. One device consisted of an appropriately-sized reflector, inspired by solar concentrators, illuminated by a cylindrical diffusing fiber optimally located within the reflector; another was a solid lightpipe with a combination of optimized tapered and straight components.

Construction of freeforms in illumination systems via Cartesian oval representation

D. Michaelis, P. Schreiber, C. Li, A. Bräuer, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Freeforms in illumination systems are directly constructed by adapting some ideas of Oliker and co-workers [1]. The freeform is created by a set of primitive surface elements which are generalized Cartesian ovals including the optical response of the residual system. Hamiltonian theory of ray optics can be used to determine the family of primitives, which is in particular a simple task if the freeform is the exit or the entrance surface of the illumination system. For simple optical systems an analytical description of the primitives is possible. Contrarily, for more complex optics a conventional ray-tracer is additionally utilized to determine the required system’s information, like the optical path lengths or mixed characteristics. To this end, a discrete set of rays is traced through the residual systems and the required relations are interpolated to obtain a quasi-analytic representation of the primitives.

For sources with a pronounced extension as well as ray divergence the inevitable “smearing out” effect [2] can be reduced by anticipating the corresponding blurring in the illumination task. To this end, the freeform construction method for point or collimated sources is combined with a linear chi-square algorithm.

The potential of this approach is demonstrated by some examples, e.g. freeform optics including collimating or deflection elements.


Design, manufacturing and measurements of a metal-less V-groove RXI collimator

D. Grabovickic, Univ. Politécnica de Madrid (Spain); J. C. Miñano, P. Benítez, Univ. Politécnica de Madrid (Spain) and Light Prescriptions Innovators, LLC (United States)

A metal-less RXI collimator has been designed. Unlike to the conventional RXI collimators, whose back surface and central part of the front surface have to be metalized, this collimator does not include any mirrored surface. The back surface is designed as a grooved surface providing two TIR reflections for all rays impinging on it. The main advantage of the presented design is lower manufacturing cost since there is no need for the expensive process of metalization. Also, unlike to the conventional RXI collimators this design performs good colour mixing. The first prototypes of V-groove RXI collimator have been made of PMMA by direct cutting using a five axis diamond turning machine. The experimental measurements of the RXI collimator are presented.

Uniform light distribution by using microlenses with various focal lengths

I. Hsu, G. J. Su, National Taiwan Univ. (Taiwan)

The increasing demands for non-self-emissive portable display devices jointly stimulate the needs for additional front light units to provide extra illumination to compensate for the ambient light in dim environment. The advantages of light emitting diodes (LED), such as high efficiency and small size, make it an ideal source for the compact unit, but direct LED lighting is impractical. Secondary optics is commonly adopted in illumination occasions to ensure the output from the LED dies meet the overall specification. Considering an oblique incidence situation, light mapping redistribution is inevitable. In this paper, we propose a beam shaping method adopting microlens array with various focal length to achieve uniform light distribution. The design is based on edge ray principle, which considers each microlens individually. Microlenses with various focus were made by photore sist thermal reflow process to verify the novel design.

The hybrid SMS-DSF method of nonimaging optical design

J. C. Bortz, N. E. Shatz, SAIC (United States)

The recently developed hybrid simultaneous-multiple-surface, dual-surface-functional (SMS-DSF) method of nonimaging optical design combines the discrete SMS method with the DSF method to obtain improved optical performance relative to the discrete SMS method alone. We review the hybrid SMS-DSF method and present a new variation that uses differential ray tracing to further enhance optical performance.

Fundamental bounds for antenna harvesting of sunlight

H. Mashaal, J. M. Gordon, Ben–Gurion Univ. of the Negev (Israel)
The tantalizing prospect of using antennae for solar power conversion received preliminary consideration, but was not pursued in earnest due to the daunting challenges in suitable materials, fabrication procedures, and the rectification (conversion to DC power) of frequencies approaching 1 PHz (10^15 s^-1). Recent advances in nanomaterials and nanofabrication technologies have prompted revisiting the solar antenna strategy. Coherence theory informs us that even ostensibly incoherent radiation is partially coherent on a sufficiently small scale. Based on a generalized broadband analysis, it will be shown how the partial coherence of sunlight, exhibiting transverse partial coherence on a scale of two orders of magnitude larger than its characteristic wavelengths, impacts the potential of harvesting solar energy with an aperture antenna (a coherent detector), and a fundamental bound will be established. These results quantify the tradeoff between intercepted power and averaged intensity with which the effect of increasing antenna size (and hence greater system simplicity) can be evaluated.

8124-07, Session 2

On the challenge of flux concentration at grazing incidence for neutrons and x-rays

B. Khaykovich, D. E. Moncton, Massachusetts Institute of Technology (United States); N. Ostroumov, Ben-Gurion Univ. of the Negev (Israel); M. V. Gubarev, NASA Marshall Space Flight Ctr. (United States); D. Feuermann, J. M. Gordon, Ben-Gurion Univ. of the Negev (Israel)

Concentrator designs for thermal neutrons and x-rays are severely constrained by the requirement of grazing incidence, i.e., the exceedingly small angles for total external reflection at mirror surfaces. The etendue limit for flux concentration must be tempered by this extreme limitation, and the design principles of nonimaging optics must be reconsidered. We establish fundamental limits to flux concentration for certain classes of neutron and x-ray optics, and thereby provide perspective for the performance of established designs. Examples of tailoring mirror contours for progressively higher concentration are presented. A basic bound for the potential of nesting mirror designs to improve flux concentration is also derived, against which the performance of published corresponding systems can be compared. Based on these observations, we present concepts for improving the attainable target flux density from neutron and x-ray sources.

8124-08, Session 3

Principles of thermodynamically efficient concentrators

R. Winston, W. Zhang, L. Jiang, Univ. of California, Merced (United States)

No abstract available

8124-09, Session 3

New vistas in solar concentration with gradient-index optics

P. Kotsidas, V. Modi, Columbia Univ. (United States); J. M. Gordon, Ben-Gurion Univ. of the Negev (Israel)

Certain classes of gradient-index lenses can achieve both perfect imaging and flux concentration at the etendue limit. Although useful in microwave technology, eponymous Luneburg lenses have been viewed as esoteric idealizations for visible and near-infrared radiation due to the paucity of suitable materials and fabrication methods. We show that the classic Luneburg problem was constrained in subtle, implicit ways that can be relaxed. With the extra degrees of freedom, we demonstrate new gradient-index profiles that can accommodate both realistic, readily-available materials and existing manufacturing technologies, while compromising neither perfect imaging nor maximum concentration (confirmed by raytrace simulation) - thereby opening new vistas for solar concentration and other visible and near-infrared applications. Specifically, the broader genres of solutions identified here permit a far smaller range of refractive indices than previously believed, with minimum required refractive index values well above unity, at arbitrary lens f-number, with remarkable insensitivity to dispersion losses when compared to conventional lenses. A variety of lens shapes are considered, from fully spherical, to hemispherical and truncated versions thereof.

8124-10, Session 3

Solar thermal system for lunar ISRU applications: development and field operation at Mauna Kea, HI

T. Nakamura, Physical Sciences Inc. (United States)

Physical Sciences Inc. (PSI) has been developing the optical waveguide (OW) solar power system. Figure 1 shows a schematic representation of the system. In this system solar radiation is collected by the concentrator array which transfers the concentrated solar radiation to the optical waveguide (OW) transmission line made of low loss optical fibers. The OW transmission line directs the solar radiation to the thermal receiver for thermochemical processing of lunar regolith for oxygen production on the lunar surface. Key features of the proposed system are:

1. Highly concentrated solar radiation (~4 x 10^3) can be transmitted via the flexible OW transmission line directly to the thermal receiver for oxygen production from lunar regolith;
2. Power scale-up of the system can be achieved by incremental increase of the number of concentrator units;
3. The system can be autonomous, stationary or mobile, and easily transported and deployed on the lunar surface; and
4. The system can be applied to a variety of ISRU processes.

This paper discusses development of the ground-based solar thermal power system and its application to (i) surface stabilization of the native soil and (ii) carbothermal oxygen production. Both experiments were conducted at the ISRU analog test, Mauna Kea, HI during January - February, 2010. The experiment for surface stabilization of the native soil was conducted in collaboration with Northern Center for Advanced Technology (NORCAT), Ontario, Canada, and experiment for carbothermal oxygen production was conducted in collaboration with Orbital Technologies Corporation (ORBITEC), Madison, WI.

8124-11, Session 3

Spiral nonimaging optical designs

P. Zamora, P. Benitez, J. C. Miñano, Univ. Politécnica de Madrid (Spain); J. F. Vilaplana, Light Prescriptions Innovators Europe, S. L. (Spain)

Faceted optical elements such as Fresnel or TIR lenses usually have manufacturing constrains that limit their geometry. Manufacturing technologies as injection molding or embossing specify their production limits for minimum radii of the vertices or draft angle for demolding, for instance. In some demanding nonimaging applications, these restrictions may limit the optical efficiency of the system or affect the generation of undesired artifacts on the illumination pattern.

We present a novel concept, in which the surfaces are not obtained from the usual revolution symmetry with respect to a central axis (z axis), but they are calculated as free-form surfaces in such a way that they describe a spiral trajectory around z axis (each facet converting into the adjacent one after each turn). The main advantage of this new concept lies in the manufacturing process: a molded piece can be easily separated from its mold just by applying a combination of rotational
movement around axis z and linear movement along axis z. By applying this “spiral” movement, demolding is possible even for designs whose cross section shows negative draft angles, allowing for maximum efficiency and avoiding the light incidence on the corner radii by design. This family of spiral designs may have many different applications. Nevertheless we will focus on non-imaging optics, especially on illumination and photovoltaic concentration. Several new spiral designs, which rotational-symmetric equivalent cannot be manufactured with conventional techniques will be presented, demonstrating its ease of manufacturing and its optimum optical properties with computer ray-trace simulated results.

8124-12, Session 4
Angular dependence of surface relief gratings for solar and lighting applications
T. M. de Jong, Technische Univ. Eindhoven (Netherlands); D. K. G. de Boer, Philips Research Nederland B.V. (Netherlands); C. W. M. Bastiaansen, Technische Univ. Eindhoven (Netherlands) and Queen Mary Univ. of London (United Kingdom)

Inexpensive and compact solar concentrators can be designed using transmission gratings that diffract sunlight into total internal reflection when applied on top of a light guide. In order to couple the incoming light efficiently into the light guide, the gratings should combine a large diffraction angle with a high diffraction efficiency and low angular and wavelength dispersion. Similarly, such gratings can be useful for out-coupling from light guides and in solid state lighting applications. We study the design and fabrication of gratings that fulfill these requirements. Rigorous Coupled Wave Analysis is used for a numerical study of the influence of various parameters on the diffraction efficiency and the angular dependence of the grating. We show that for sub-wavelength grating periods highest diffraction efficiencies will be achieved when the grating is produced as a surface relief structure. For such surface relief gratings we demonstrate the presence of specific regions in the full space of conical angles of incidence where highly efficient in-coupling occurs. The distribution of the diffraction efficiency over angular space can be varied by adjusting the grating geometry. For slanted gratings the efficiency regions corresponding to positive orders are promoted at the cost of those corresponding to negative orders or vice versa. Two-dimensional, crossed gratings result in a distribution of the diffraction efficiency over a wider angular range. Our theoretical results are supported by experiments. We used the photoresist SU-8 to show that gratings with the desired dimensions can be fabricated by interference holography and demonstrated the desired properties.

8124-13, Session 4
Evaluation and comparison of different designs and materials for Fresnel lens-based solar concentrators
L. Fu, R. Leutz, H. P. Annen, Concentrator Optics GmbH (Germany)

Optics with high optical efficiency and reliability are the key components for CPV modules as well as high efficiency solar cells and a high accuracy tracker. The present paper describes the optical design, simulation and materials, including a direct comparison of geometrically identical lens designs for three materials.

As primary optical element (POE), a rotationally symmetric nonimaging Fresnel lens with centerline prisms of variable height and constant step size was chosen. The lens area of 150 x 150 mm² results in a geometrical concentration ratio of 790X. The lenses are assembled in a 5x4 parquet. Concentrator Optics designed and fabricated parquets of identical focal length and lens size in three materials: PMMA, SOG, and thermostable silicone on glass. These parquets are called the Triple Primaries, and serve as test samples and off-the-shelf products. Tests are under way for accelerated aging and optical performance. All primaries are hot embossed or cast.

The Fresnel lenses focus impinging sunlight onto secondary optical elements (SOE). The challenge in designing SOE lies in the combination of requirements on maximum light homogenization, additional concentration and acceptance half-angle, manufacturing complexity and mounting effort. Two SOE designs were developed. The first design is a domed kaleidoscope providing very homogeneous distribution of the sun light on the cell surface even in case of tracking errors. The second design uses an aspherical half-egg shape and has significant advantages in terms of manufacturing effort and costs. Both SOEs are blank-molded in glass.

POE and SOE are designed as optical train. Therefore, optical tests are run to determine manufacturing quality and optical efficiency of the primary lenses and secondaries. The laboratory tests are compared with the simulation results.

Acknowledgment: This study is part of the Triple Primaries project, initiated as research project for various primary and secondary optics in combination with cells, by Concentrator Optics, Azur Space Solar and Isuzu Glass.

8124-14, Session 4
Limiting acceptance angle to maximize efficiency in solar cells
E. D. Kosten, H. A. Atwater, California Institute of Technology (United States)

Within a detailed balance formalism, the open circuit voltage of a solar cell can be found by taking the band gap energy and accounting for the losses associated with various sources of entropy increase. Often, the largest of these energy losses is due to the entropy associated with spontaneous emission. This entropy increase occurs because non-concentrating solar cells generally emit into 2 pi steradian, while the solid angle subtended by the sun is only 6.85x10^{-5} steradian. Thus, for direct normal irradiance, non-concentrating solar cells with emission and acceptance angle limited to a narrow range around the sun could see significant enhancements in open circuit voltage and efficiency. With the high degree of light trapping we expect given the narrow acceptance angle and the ray optics brightness theorem, the optimal cell thickness will result in a discrete modal structure for most materials. Thus, limiting the acceptance and emission angle can be thought of as coupling to only a subset of radiating modes, or, alternatively, as altering the modal structure such that some radiating modes become bound modes. We have shown the correspondence between the ray optics picture and the modal picture, by deriving the ray optics results for light trapping under angular restrictions using a modal formulation. Using this modal formulation we can predict the light trapping and efficiencies for various thin structures under angular restriction. We will discuss these predicted efficiencies and various options for implementing broadband and angle-specific concentrators.

8124-15, Session 4
Investigation of scattering profiles for passive solar light collectors
A. N. Bharathwaj, B. Srinivasan, Indian Institute of Technology Madras (India)

We explore the use of light scattering off diffuser elements to enhance the collection efficiency in a passive solar collection system. A passive solar collection system is an optical alternative for the existing systems which use mechanical components for sun tracking in turn leading to uniformity in the light output. It consumes no power, is rugged, portable and a cost efficient solution for solar light collection systems and is based on manipulating the angular distribution of the incident solar radiation. One major drawback of the passive solar systems is the poor collection
efficiency at off-axis illumination. The off axis rays don’t contribute to the collection efficiency and hence the poor performance. To counter this, we investigated the use of scatterers to enhance the performance at off-axis case. It was observed through simulations using ASAP that the Light uniformity improved by 50% when incorporating an arbitrary profiled scattering surface. The scattering surface scattered off the off-axis rays such that it was suitable for light collection.

We also tried out different shapes for the scattering surface and simulation results showed a curved scattering medium offered a 11% increased performance and was much more suited to the collection needs as the off-axis rays are always normally incident on it. This lead to the trial of exploring other possible surface profiles for the scattering mediums commercially available in ASAP environment. Preliminary experiments are underway to establish the link between the scattering profile and the angular distribution of the scatter radiation and also on the development of a passive solar light collection system.

8124-17, Session 5

**Static high-irradiance solar concentration by gradient-index optics**

P. Kotsidas, V. Modi, Columbia Univ. (United States); J. M. Gordon, Ben-Gurion Univ. of the Negev (Israel)

Novel solutions for realistic gradient-index (GRIN) lenses are presented, that create the possibility of nominally stationary photovoltaic concentrators capable of daylong averaged flux concentration levels of order 10^3. One transfers the burden of precision solar tracking from massive units on which numerous solar modules are mounted, to miniaturized mechanical components inside modules that are completely stationary. The best optical properties for this aim would appear to be perfect imaging - a case where imaging and nonimaging objectives coalesce because perfect imaging is non-trivially synonymous with attaining the fundamental limit to concentration. Our GRIN profiles surmount limitations of classical Luneburg solutions that resulted in GRIN lenses being deemed physically unattainable idealizations for sunlight. To wit, while preserving perfect imaging, our GRIN profiles eliminate the need for refractive indices near unity, markedly reduce the range of refractive indices required, and permit arbitrary focal length. They are also amenable to realistic materials and fabrication technologies. Raytrace simulations confirm that they offer an unprecedented solution to this problem - even accounting for chromatic aberration and misalignment. Eliminating massive precision tracking of large photovoltaic arrays in favor of precision cm-scale lens tracking inside the modules opens the possibility of rooftop CPV. The perception that high solar concentration is inseparably linked to massive trackers is supplanted here by a different paradigm.

8124-18, Session 5

**High-efficiency Köhler photovoltaic concentrators with external light confinement**

P. Zamora, P. Benitez, J. C. Miñano, M. Buljan, Univ. Politécnica de Madrid (Spain)

We present a novel and advanced optical design for a CPV concentrator in order to increase module electrical efficiency by means of lowering reflected light on the solar cell surface, based on a confinement cavity. If we are able to minimize this reflection on the cell surface, the amount of light absorbed by the device will thus be greater. This reduction in light reflection is achieved by designing an external confinement cavity ad hoc for the system.

External confinement cavities have been proposed in the past, but they had always had difficulties of integration with classical secondary optical elements, generally presenting kaleidoscopic homogenization. However, the recent invention of high-performance Köhler concentrators (as it is the case of Fresnel-Köhler (FK) and Fresnel-RXI Köhler (FRXI) concentrators), fully compatible with the use of external cavities, will allow for this practical integration. The external cavity is added to the concentrator secondary element (SOE).

We will be able to achieve very high single-module electrical efficiencies if we apply this external confinement cavity to high optical efficiency CPV modules. For example, for a FK concentrator module (presenting a proved measured peak electrical efficiency over 30%, close to 33% @Tcell=25°C), the addition of an external cavity leads to a total peak electrical efficiency of around 35% @Tcell=25°C.

8124-19, Session 5

**Linear Fresnel lens Concentrators, revisited**

W. Zhang, R. Winston, Univ. of California, Merced (United States)

No abstract available

8124-20, Session 6

**Nested aplanatic optics**

A. Goldstein, D. Feuermann, Ben-Gurion Univ. of the Negev (Israel); G. D. Conley, H2Go, Inc. (United States); J. M. Gordon, Ben-Gurion Univ. of the Negev (Israel)

Dual-mirror aplanatic optics can provide efficient, ultra-compact, high-irradiance solar concentration, recently developed for concentrator photovoltaics. However, inherent limitations place the focus inside the optic and therefore mandate a terminal dielectric concentrator to extract the concentrated sunlight to the solar cell outside the optic, with the
affiliated need for an optical bond to the cell. Can a modified design strategy site the focus outside the optic - and hence eliminate the need for a terminal concentrator and optical bond - without compromising concentrator compactness, low shading losses, or even the pragmatic advantage of the primary and secondary mirrors being coplanar toward facilitating the alignment of optical components? We show how judiciously nested dual-mirror aplanats can satisfy all these objectives, with sample performance evaluations based on raytrace simulation.

8124-21, Session 6

Integrating tracking in concentrating photovoltaics using laterally moving optics

F. Duerr, Y. Meuret, H. Thiernpont, Vrije Univ. Brussel (Belgium)

In this work the concept of tracking-integrated concentrating photovoltaics (CPV) is studied and its capabilities are quantitatively analyzed. In contrast to the clear separation between static CPV modules and external solar trackers, the here introduced general concept of a tracking-integrated concentrating photovoltaic system is to transfer part of this external solar tracking functionality to the concentrating optics within the module. This tracking integration can only be achieved through the introduction of additional degrees of freedom, such as relative movement between the optics and solar cells. This design strategy desists from ideal concentration performance to reduce the external mechanical solar tracking effort in favor of a compact installation, possibly resulting in lower overall cost. The proposed optical system relies on the use of two laterally moving plano-convex lenses to achieve high concentration over a wide angular range. Its optical design is based on an extended Simultaneous Multiple Surface (SMS) algorithm. This extended design algorithm is presented and used to design tracking-integrated optical systems comprising two movable plano-convex lenses and thus two curved optical surfaces. In comparison to a single meniscus lens, also consisting of two curved optical surfaces comprising a laterally moving receiver, the additional moving optics helped to raise the concentration performance considerably. This design approach enables a strong reduction of the external solar tracking effort along with high concentration ratios for both, line and point concentration systems. Ray tracing simulations show that this novel system design outperforms its conventional concentrating photovoltaic counterparts.

8124-22, Session 6

Optical characterization of nonimaging focusing heliostat

K. Chong, Univ. Tunku Abdul Rahman (Malaysia)

The greatest challenge in designing a heliostat capable of focusing the sunlight onto a small receiver throughout a year is to optimize astigmatism. A novel nonimaging focusing heliostat consisted of many small movable element mirrors that can be dynamically maneuvered in a line-tilting manner has been proposed for the astigmatic correction in a wide range of incident angle ranging from 0 deg to 70 deg. In this article, a comprehensive analysis of the new heliostat with total reflective area of 25 m^2 and slant range of 25 m using ray-tracing method has been carried to analyze the optical performance including solar concentration ratio, spacious uniformity of solar flux distribution, spillage loss, and variation in flux distribution with time and day. The optical analysis of the heliostat in the application of solar power tower system has embraced the cases of 1×1, 9×9, 11×11, 13×13, 15×15, 17×17 and 19×19 arrays of concave mirrors attached to the heliostat frame provided that the total reflective area remains the same. To achieve a smooth simulated result of solar flux distribution, a total number of 8.11 x 10^9 rays per heliostat are traced in the simulation. The simulated result has shown that the maximum solar concentration ratio at a high incident angle of 65 deg can be improved from 1.76 suns (single mirror) to 104.99 suns (9×9 mirrors), to 155.93 suns (11×11 mirrors), to 210.44 suns (13×13 mirrors), to 246.21 suns (15×15 mirrors), to 259.80 suns (17×17 mirrors) and to 284.73 suns (19×19 mirrors).

8124-23, Session 6

Optimum design and efficiency improvement for organic luminescent solar concentrators

C. Wang, L. S. Hirst, R. Winston, Univ. of California, Merced (United States)

No abstract available

8124-24, Poster Session

Optical characterization of solar furnace system using fixed geometry nonimaging focusing heliostat and secondary parabolic concentrator


A novel solar furnace system has been proposed to be consisted of a Nonimaging Focusing Heliostat (NIFH) and a smaller parabolic concentrator. In this design, the primary NIFH heliostat consists of 11×11 array of concave mirrors with focal length equal to target distance and dimension 1×1 m^2 each to form a total reflective area of 121 m^2 while the secondary parabolic concentrator has a focal length of 30 cm. To simplify the design and reduce the cost, fixed geometry of the primary heliostat is adopted to omit the requirement of continuous astigmatic correction throughout a year. The overall performance of the novel solar furnace configuration can be optimized if the heliostat's spinning-axis is fixed in the orientation dependent on the latitude angle so that the annual variation of incidence angle is the least, which ranges from 33 deg to 57 deg. A comprehensive optical analysis of the novel solar furnace system has been carried using ray-tracing method for different target distances such as 50 m and 100 m, where the target distance is defined as the distance between the central point of heliostat and the vertex of parabolic reflector. To obtain a smooth flux distribution plot, a total number of 2.41 x 10^10 rays per heliostat are traced in the simulation. The simulated results have shown that the maximum solar concentration ratio ranges from 20,529 suns to 26,074 suns for the target distance of 50 m, and ranges from 40,366 suns to 43,297 suns for the target distance of 100 m.

8124-25, Poster Session

A hemispherical static concentrator with double-aspheric compensated lens array for continued collecting sunlight

W. Chen, Y. Chen, J. A. Whang, National Taiwan Univ. of Science and Technology (Taiwan)

Natural light is an inexhaustible and environmentally friendly energy. The solar energy exposed to the earth everyday is about three thousand times to the global energy consumption. Therefore, it would be a considerably large energy saving if we collect and guide the sunlight for lighting. Currently, there are two types of solar concentrators for collecting sunlight purpose, namely, active and static. The former is more efficient, but needs costly active sun-tracking system for supplement; the latter is cheaper, but is limited for certain time slots. In static systems, a hemispherical concentrator can gather the sunlight with longer time, but the collected flux is not stable and the energy density of optical fiber is lower than the illuminance of sunlight. We, in this paper, propose a hemispherical static concentrator that consists of double aspheric
compound lens array. The double layers of lenses are designed with large tolerance for continued collecting sunlight and the apertures of lenses are larger than optical fiber for increasing the energy density. According to the simulation results, we get uniform distribution of collected flux from 10 a.m. to 4 p.m. that is less than 10% change. Moreover, the energy density of optical fiber is about 50 Lm/cm² in summer when the illuminance of sunlight is about 120,000 Lux.

8124-26, Poster Session

**Effect of scattering of cover glass for silicon and dye-sensitized solar cells**

H. Chen, W. Lu, Y. Lo, S. You, National Yunlin Univ. of Science and Technology (Taiwan)

The study would investigate the effect of the scattering model on the photoelectric conversion efficiency for the silicon solar cell and dye-sensitized solar cell (DSSC). We will examine the accuracy of optical simulation of these solar cells by the A class standard measurement of AM1.5G at the light source of 1000 W/m². The scattering lighting of DSSC always is occurred by the particle size of the titanium dioxide (TiO2) and the distribution of the layer. Anyway, the silicon solar cell would absorb the lighting by the energy band of the silicon. Therefore, Mie scattering theory is a useable model to describe the scattering mechanism and then bidirectional scattering distribution function (BSDF) could descrip the scattering status for the silicon solar cell and DSSC. The regular pattern of the cover glass including the type, size, deep and smooth would effected the scattering model of the silicon solar cell and DSSC for the absorption efficiency. We found the absorption efficiency would be enhanced at the scatter pattern of big deep and smooth round. The scattering pattern at the front always was better than at the back for the cover glass at the efficiency of lighting absorption. The absorption efficiency of DSSC would be higher than the silicon solar cells at the same scattering pattern. The optical simulation and measurement data showed the scattering pattern would improve the absorption efficiency of 2% to 5% for silicon solar cell and 5% to 8% for DSSC.
8125-32, Poster Session

Automated semi-spherical irradiance meter

M. Tecpoyotl-Torres, G. Vera-Dimas, J. J. Escobedo-Alatorre, Univ. Autónoma del Estado de Morelos (Mexico); J. Varona-Salazar, Univ. Bonaterra (Mexico); R. Cabello-Ruiz, A. Zamudio-Lara, Univ. Autónoma del Estado de Morelos (Mexico)

In previous work, we have developed a semi-spherical irradiance meter, based on a mobile arm, where the detector was located, that showed an acceptable performance. However, the number of the discrete points under analysis was limited by the mechanical arrangement.

In this work, a new approximation is developed based on the obtained experience, the suggestions given by a manufacturer of illumination sources interested in our work, and based on the recent advances in other areas related to measurement prototypes.

In this new approximation the mechanical stage has been improved. The detector is located on a rectangular ring (which is assumed as joined two mobile branches in order to compensate the weights), who described trajectories of 170°. The illumination source is located at the center of the mobile support, which rotates 360°. The movement of the system is determined by two step motors. The mechanical arrangement has the enough rigidity, in order to support the precision required for the acquisition stage, based on a DSPIC. Measurements of illumination sources with different sizes can be possible by using adjustable lengths of the base and the ring.

The advantages of the new meter are: Its low costs (as it is built with recyclable materials), a reliable detection based on a single photodetector, which has demonstrated its effectiveness. The received power by the detector is useful to obtain the irradiance profile of the lighting source under test.

8125-33, Poster Session

Alignment protocol for effective use of hard x-ray quad collimator for micro-crystallography

S. Xu, N. Venugopalan, R. Sanishvili, R. F. Fischetti, Argonne National Lab. (United States)

In October 2009, a quad, mini-beam collimator was implemented at GM/CA CAT that allowed users to select between a 5, 10, or 20 micron mini-beam or a 300 micron scatter guard for macromolecular crystallography. Initial alignment of each pinhole to the optical axis of each path through the mini-beam collimator is preformed under an optical microscope using an alignment jig. Next, the pre-aligned collimator and its kinematic mount are moved to the beamline and attached to a pair of high precision translation stages attached to an on-axis-visualization system for viewing the protein crystal under investigation. The collimator is aligned to the beam axis by two angular and two translational motions. The pitch and yaw adjustments are typically only done during initial installation, and therefore are not motorized. The horizontal and vertical positions are adjusted remotely with high precision translational stages. Final alignment of the collimator is achieved using several endstation components, namely, a YAG crystal at the sample position to visualize the mini-beam, a CCD detector to record an X-ray background image, and a PIN diode to record the mini-beam intensity. The alignment protocol and its opto-mechanical instrumentation design will be discussed in detail.

8125-34, Poster Session

Stably joint optical tables


We present a simple and practical method for joining pneumatically floated optical tables. To demonstrate our method we joined two optical tables in an uncentered T-shape. We then used a Michelson interferometer to compare the stability of the entire T-structure versus a single unconnected table. The measurements demonstrate that the rigidity of the joint and unjointed tables are comparable. We also found the optimal master-slave leg configuration by calculating the stress on the joint and confirmed the calculations by Michelson interferometry. The vibration damping for the T-structure against the unjoined tables was measured finding comparable results. This method can significantly reduce costs of large optical tables and will be useful to extend existing optical tables without manufacturer modification.

8125-35, Poster Session

Compact dynamic microfluidic iris array

C. Kimmle, U. Schmittat, C. Döring, H. Fouckhardt, Technische Univ. Kaiserslautern (Germany)

In a first step a variable iris based on microfluidics has been realized. Light attenuation is achieved by the absorption of an opaque liquid (f.e. black ink). The modulation can be achieved by fluid displacement via a transparent elastomer (silicone) half-sphere. The silicone calotte is hydraulically pressed against a polymethylmethacrylate (PMMA) substrate, such that the opaque liquid is squeezed away, this way opening the iris. With this approach we can reach a dynamic range of more than 60 dB. The system has response times in the ms to s regime.

Depending on the design of the silicone structure either a single iris or an iris array can be realized. So far the master for the silicone structure has been fabricated by precision mechanics. In experiments the aperture diameter has been changed continuously from 0 to 8 mm for a single iris and 0 to 4 mm in case of a 3 x 3 iris array.

In a second step we have combined such an iris array with a PMMA lens array to a compact module, the distance of both arrays equaling the focal length of the lenses. This way even spatial frequency filter arrays could be realized.

We also show the possibility to extend the iris array concept to an array with many elements (f.e. 100 x 100), using lithographic techniques for the master. Such arrays could be used e.g. in light field cameras.

8125-36, Poster Session

Thermo-opto-mechanical analysis of a cubesat lens mount

J. Champagne, College of Optical Sciences, The Univ. of Arizona (United States) and Space Dynamics Lab. (United States)

Small satellites called cubesats have given students at universities and high schools the opportunity to conduct experiments in space in the past decade. This has mostly been possible due to low cost and quick development times. A popular cubesat payload has been optical imaging systems for the study of planet Earth from space. Due to budget, space, and time constraints, commercial photographic lenses of the double-Gauss type are prime candidates for cubesat optics. However, photographic objectives are not designed to operate in a space
environment and modifications are usually necessary. One method of improving optical performance of the objective over large temperature variations is by replacing the stock lens mount with a different material. This paper describes the thermo-opto-mechanical analysis of several lens mount materials for a double-Gauss imaging system suitable for a cubesat.

8125-37, Poster Session

The design and verification of a robust secondary mirror adjustment mechanism for airborne optical remote sensing instruments

P. Huang, Y. Cheng, Instrument Technology Research Ctr. (Taiwan)

Optical system architecture of Cassegrain telescope is usually applied for spaceborne and airborne optical remote sensing instruments. The optical system has to overcome the intense shock and vibration during launch process, and successfully survive and keep the optical performance for mission operations. Therefore, it's adopted for most design to fix the primary mirror and adjust the orientation and position of the secondary mirror to meet the optical performance specification.

In order to achieve the required optical performance, the adjustable support mechanism for secondary mirror shall be designed with five degrees of freedom for secondary mirror adjustment. And the precision of adjustable mechanism has to achieve the level of micrometer and arc-second. In addition to the adjustment function, the mechanism shall be robust enough to survive under the vibration condition of 15G without deformation and damage.

This work presents a developing design of adjustable support mechanism of secondary mirror for airborne optical remote sensing instruments. And several reference planes and shims have been designed in this mechanism. The shims and one of the structural parts can be released and are properly grinded to the desired thickness.

The proposed mechanism has been verified by an experimental model. The reassembled accuracy is 5 arc-second and 2 µm. Furthermore, the adjustable orientation and position accuracy can achieve 5 arc-second and 2 µm respectively, depending on the grinding and measurement precision. The accuracy can drive the optical system performance to diffraction limit. After verification, we confirm the proposed design of adjustable support mechanism can be applied to airborne optical systems, and has the good potential in spaceborne applications.

8125-38, Poster Session

On the accuracy of framing-rate measurements in ultra-high-speed rotating mirror cameras

M. Conneely, H. O. Rolfsnes, C. Main, D. McGloin, P. A. Campbell, Univ. of Dundee (United Kingdom)

Rotating mirror systems based on the Miller Principle are a mainstay modality for ultra-high speed imaging within the range 1-25 million frames per second. Importantly, the temporal accuracy of measurements made with such systems is sensitive to the frame rate reported during data acquisition. The purpose for the present investigation was to examine the validity of reported frame rates in a widely used commercial system (a Cordin 550-6Z model) by independently measuring the framing rate at the instant of triggering. In the event, we found a small but significant difference between such measurements: the average discrepancy (over the entire spectrum of frame rates used) was found to be 1.15 ± 0.95%, with a maximum difference of 2.33%. The principal reason for this discrepancy was traced to non-optimized sampling of the mirror rotation rate within the system software. This paper thus serves three purposes: (i) we highlight a straightforward diagnostic approach to facilitate scrutiny of rotating-mirror system integrity; (ii) we raise awareness of the intrinsic errors associated with data previously acquired with this particular system and model; and (iii), we recommend that future control routines address the sampling issue by implementing real-time measurement and reporting at the instant of triggering.

8125-01, Session 1

Optomechanical design for cost-effective DEMVAL systems

A. Ison, Sandia National Labs. (United States)

Sticker shock for opto-mechanical hardware designed for advanced optical DEMVAL systems can lead to program loss. In opto-mech design it is important to manage this risk through easily manufacturable and inexpensive hardware for lower budget programs. The optical and opto-mech design teams must work closely to optimize the system design for manufacture, and assembly. This often results in unique/creative design solutions. Outlined are some novel optomechanical structure concepts, with 5 degrees of freedom, used to design a low cost optical system. The concepts discussed include inexpensive magnetic kinematic mounts, fixture rings for lens preloading, simplistic drop-in lens housing designs, and adjustable tooling ball metering rods which accommodate alignment in 5 degrees of freedom.

8125-02, Session 1

A tip/tilt mirror with large dynamic range for the ESO VLT Four Laser Guide Star Facility

N. Rijnveld, R. Henselmans, TNO Science and Industry (Netherlands)

A critical element in the Four Laser Guide Star Facility (LGSF) for the ESO Very Large Telescope (VLT) is the Optical Tube Assembly (OTA), consisting of a stable 20x laser beam expander and a tip/tilt mirror, the Field Selector Mechanism (FSM). This paper describes the design and performance testing of the FSM. The driving requirement for the FSM is its dynamic range: a stroke of ±6.1 mrad with less than 1.5 µrad RMS absolute accuracy.

The FSM design consists of a Zerodur mirror, bonded to a plate spring and strut combination to allow only tip / tilt motion. Two spindle drives actuate the mirror, using a stiffness based transmission to dramatically increase resolution. Absolute accuracy is achieved with two differential inductive sensor pairs.

A complete prototype of the FSM is realized to optimize the control configuration and measure its performance. Friction in the spindle drive is overcome by creating a local velocity control loop between the spindle drives and the shaft encoders. Absolute accuracy and low pointing jitter is achieved by using a cascaded low bandwidth control loop with feedback from the inductive sensors.

The absolute accuracy is measured with an autocollimator. The results show good agreement between the measured and predicted performance. The FSM complies to the dynamic range requirement, while being realized with mostly low cost off-the-shelf products.

8125-03, Session 1

Design and development of the fibre cable and fore optics of the HERMES Spectrograph for the AAT

S. Case, L. Gers, J. Brzeski, Australian Astronomical Observatory (Australia)

We report on the development of the fibre slit of the High Efficiency and Resolution Multi Element Spectrograph (HERMES), Discussed is the the fibre positioning and mounting techniques of 400 fibres, the mounting and alignment of the slit relay optics and coupling between the fibres and
the relay optics using an index matching gel solution. An investigation into stress sources was undertaken in the development of the fibre v-groove subassembly to ensure the focal ratio degradation (FRD) of the fibre array minimized, by employing low-shrinkage adhesives. Thermal effects on FRD due to changing the temperature of the slitlet component were also investigated, and it was concluded that there are negligible effects with this change in temperature (~1% change in output numerical aperture).

The relay optics magnify the group of ten fibres by a factor of two. This is mounted in high precision v-groove mounts. These optics are also mounted to high precision and each of the systems is aligned to each individual fibre v-groove assembly. There are 40 of these subassemblies, which are located in a way that can be described by a spherical surface in space.

8125-04, Session 1
Design and development of a fast-steering secondary mirror for the Giant Magellan Telescope
M. K. Cho, National Optical Astronomy Observatory (United States); A. Corredor, C. Dribusch, The Univ. of Arizona (United States); K. Park, Y. Kim, Korea Astronomy and Space Science Institute (Korea, Republic of); I. Moon, Korea Research Institute of Standards and Science (Korea, Republic of)

The Giant Magellan Telescope (GMT) will be a 25m class telescope which is one of the extremely large telescope projects in the design and development phase. The GMT will have two Gregorian secondary mirrors, an adaptive secondary mirror (ASM) and a fast-steering secondary mirror (FSM). Both secondary mirrors are 3.2 m in diameter and built as seven 1.1 m diameter circular segments conjugated 1:1 to the seven 8.4m segments of the primary. The FSM has a tip-tilt feature to compensate image motions from the telescope structure jitters and the wind buffeting. The support system of the lightweight mirror consists of three axial actuators, one lateral support at the center, and a vacuum system. A parametric study and optimization of the FSM mirror blank and central lateral flexure design were performed. This paper reports the results of the trade study. The optical image qualities and structure functions for the axial and lateral gravity print-through cases, thermal gradient effects, and dynamic performances will be discussed for the case of a lightweight segment with a center thickness of 140 mm weighing approximately 105 kg.

8125-05, Session 2
Training of optomechanical engineers at the University of Rochester
V. L. Genberg, Sigmadyne, Inc. (United States)

The University of Rochester is well known for the Institute of Optics as well as a strong mechanical engineering program. In recent years, there has been collaboration between the two departments on a variety of topics. This summer, a new faculty member will further the collaboration with a joint appointment in both departments. There is a new cross-listed course in Optomechanics, which is described in this paper. An additional course in Precision Engineering and Testing will soon be offered. As yet, there is no formal specialization in Optomechanics, but many students create their own program from available courses. Students have the opportunity to participate in the several research areas which cross discipline boundaries. A design team of students is building a 16" telescope which they hope can become the basis of an intercollegiate design contest. In addition to full semester courses, there is a summer program of short courses available to working engineers.

8125-06, Session 3
Optomechanical design of an ultrahigh-resolution inelastic x-ray scattering spectrometer at the Advanced Photon Source
D. Shu, S. Stoupin, R. Khachatryan, K. Goetze, T. Roberts, Y. Shvyd’ko, Argonne National Lab. (United States)

A prototype of a novel ultrahigh-resolution inelastic x-ray scattering spectrometer has been designed and tested at undulator-based beamline 30-ID, at the Advanced Photon Source (APS), Argonne National Laboratory. This state-of-the-art instrument is designed to meet challenging mechanical and optical specifications for producing ultrahigh-resolution inelastic x-ray scattering spectroscopy data for various scientific applications.

The optomechanical design of the ultrahigh-resolution inelastic x-ray scattering spectrometer as well as the preliminary test results of its precision positioning performance are presented in this paper.
Work supported by the U.S. Department of Energy, Office of science, Office of Basic Energy Sciences under Contract No. DE-AC02-06CH11357.

8125-07, Session 3
Design and development of an optical system with SiC support structure
I. K. Moon, H. Yang, H. Rhee, J. Song, Y. Lee, Korea Research Institute of Standards and Science (Korea, Republic of)

A support structure of the optical system comprises a series of substructures which are interconnected to support the optical components and their mechanisms. The main structure employing lightweight cylindrical shape of SiC main frame is optimized for high image quality and low weight constraint. To fulfill the optical and mechanical performance requirements extensive finite element analyses using I-DEAS and optical analyses with PCFRINGE has been conducted for the structure of optical system. Analyses include static deformation (gravity and thermal), frequency, dynamic and response analysis, and optical performance evaluations for minimum optical deformation. Image motion is also calculated based on line of sight sensitivity equations integrated in finite element models. A parametric process was performed for the design optimization to produce highest fundamental frequency for a given weight, as well as to deal with the normal concerns about global performance. Alignment and test plan for an optical system will be discussed as well.

8125-08, Session 3
High-precision optical systems with inexpensive hardware: a unified alignment and structural design approach
E. G. Winrow, Sandia National Labs. (United States)

High precision optomechanical structures have historically been plagued by high costs for both hardware and the associated alignment and assembly process. This problem is especially true for space applications where only a few production units are produced. A methodology for optical alignment and optical structure design is presented which shifts the mechanism of maintaining precision from tightly tolerated, machined flight hardware to reusable tooling. Using the proposed methodology, optical alignment error sources are reduced by the direct alignment of optics through their surface retroreflections (pips) as seen through a theodolite. Optical alignment adjustments are actualized through motorized, sub-micron precision actuators in 5 degrees of freedom. Optical structure hardware costs are reduced through the use of simple shapes (tubes, plates) and repeated components. This approach
produces significantly cheaper hardware and more efficient assembly without sacrificing alignment precision or optical structure stability. The design, alignment plan and assembly of a 4" aperture, carbon fiber composite, Schmidt-Cassegrain concept telescope is presented.

8125-09, Session 3
RF-mechanical performance of the Haystack radio telescope
K. B. Doyle, MIT Lincoln Lab. (United States)

The Haystack radio telescope is being upgraded to support imaging radar applications at 96 GHz requiring diffraction-limited performance over an elevation range of 10 - 40 degrees. The Cassegrain antenna includes a 120-foot diameter primary reflector that is comprised of 432 reflector panels and a 10-foot diameter monolithic subreflector that is mounted on a hexapod assembly. Mechanical performance requirements of the antenna are based on meeting an RF waveform error requirement of 210 µm rms that account for fabrication, alignment, and environmental errors. Fabrication errors include the manufacturing of the primary reflector panels and the machining of the subreflector. Alignment errors include mounting the panels to the subframes, and the mounting of the subframes to the antenna backstructure. Environmental contributions include the effects from gravity, thermal gradients, and diurnal thermal variations. Details of the reflector fabrication and alignment along with the environmental performance modeling are discussed to meet overall system mechanical requirements.

8125-10, Session 3
Optomechanical tolerancing with Monte Carlo analysis
V. L. Genberg, G. J. Michels, Sigmadyne, Inc. (United States)

Mechanical tolerances within an optical system can consist of a wide array of variables including machining tolerances, variability in material properties, uncertainty in applied loads, and discrete resolution of actuation hardware. This paper discusses methods to use integrated modeling and Monte Carlo techniques to determine the effect of such tolerances on optical performance so that the allocation of such tolerances is based upon optical performance metrics. With many random variables involved, statistical approaches provide a useful means to study performance metrics. Examples include the effect of mount flatness on surface RMS and Zernike coefficients and the effect of actuator resolution on the performance of an adaptively corrected deformable mirror. Tolerances impacting line-of-sight errors are also addressed.

8125-12, Session 4
Deformation analysis of tilted primary mirror for an off-axis beam compressor
J. H. Clark III, U.S. Naval Observatory (United States); F. E. Penado, Northern Arizona Univ. (United States); J. Dugdale, U.S. Naval Observatory (United States)

The Navy Prototype Optical Interferometer (NPOI) array, located near Flagstaff, Arizona, collects and transports stellar radiation from six primary flat collectors (siderostats) through a common vacuum relay system to a beam combiner station where the beams are combined, fringes obtained and modulated, and data recorded for further analysis. The siderostats are capable of redirecting a 38 cm diameter stellar beam to the vacuum relay system, which has the capacity of redirecting only a smaller 12.5 cm diameter beam. We have determined the number of observable stellar objects for the current system configuration in which any portion of the beam greater than 12.5 cm is wasted to be approximately 6,000. The original design of the array, however, includes space for a beam compressor, tilted up at 20 degrees relative to the horizon, and positioned between each siderostat and the vacuum relay system. The effect from the addition of beam compressors is to increase the number of potential stellar observables to 65,000. This is due to the 9-times increase in collection area. A set of off-axis beam compressors were procured in 2004; however, they were found to have unacceptably high mechanical sample imagery characteristics. These compressors were investigated and mitigation techniques discussed in a previous paper. The present paper addresses the analysis of the actual primary mirror, which is almost 2-1/2 times thicker than originally requested. The deflection due to gravity effects on its surface figure versus tilt angle is analyzed and compared with allowable deformations, and the results presented and discussed.

8125-13, Session 4
Vibration analysis using digital image processing for in vitro imaging systems
Z. Wang, S. Wang, C. Gonzalez, Abbott Point of Care Inc. (United States)

In this paper, we propose a novel method for an optical microscope imaging system in-plane rigid-body vibration self measurement by processing digital images taken from a dot patterned calibration target. The method utilizes the system’s own imaging system without additional sensors. This paper presents a method for analyzing vibrations within a biological sample imaging system is provided. By imaging a target having one or more identifiable features in fixed positions while the target is stationary using an imaging system, the in-plane coherent spacing of the identifiable features can be determined. By imaging the target a plurality of times during operation of the imaging system and comparing the stationary images to the operational images, the incoherent displacements of the identifiable features of the target can be identified. By evaluating the incoherent displacements of the identifiable features, one or more vibration frequencies associated with those incoherent displacements can be found. In some embodiments, the method may further include the step of determining which component in the imaging system is a source of one or more of the vibration frequencies. Then power spectrum density (PSD) analysis is performed for both intra and inter frame incoherent movements. From the PSD plots, the vibration sources can be identified. It also gives a descriptive statistics of the vibration displacement distribution of the random vibration contents. This study helps microscope imaging system design retrofit, vibration source identification and vibration geometric moments measure. An example for analyzing a biological sample is provided.

8125-14, Session 4
Strength of glass from hertzian line contact
W. Cai, B. Cuerden, R. E. Parks, J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

Glass optics are frequently mounted using line contact interfaces with cylindrical or toroidal metal interfaces. The Hertzian line contact that results can create a large stresses in the glass, including a tensile stress that occurs at the surface near the interface. For contacts with short radii, analysis shows this tensile stress can easily be greater than the strength of the glass, providing reason for concern. However, we show by finite element modeling and by sample testing that for most cases, the effects of this stress are benign. Cracks caused by this stress concentration will propagate only as deep as the stress field, which is typically only a few microns. At this level, such cracks do not have any effect on the optical element, and have an insignificant effect on the strength of the element. This leads to a prediction, which we have verified, that sharp-edged metal interfaces can be used for many applications without risk of fracturing the glass elements due to the resulting stress concentration.
8125-15, Session 5

Analysis of lens mount interfaces

K. A. Chase, J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

Lenses are typically mounted into precision machined barrels, and constrained with spacers and retaining rings. The details of the interfaces between the metal and the glass are chosen to balance the accuracy of centration and axial position, stress in the glass, and the cost for production. This paper presents a systematic study of sharp edge, toroidal, and conical interfaces and shows how to control accuracy, estimate stress, and limit production costs.

Results are presented from computer models, finite element simulations, and experimental testing.

8125-16, Session 5

Analytic results for high-precision and cryogenic lens holders

A. Boesz, Kayser-Threde GmbH (Germany); F. U. Grupp, Univ.-Sternwarte München (Germany); N. Geis, Max-Planck-Institut für extraterrestrische Physik (Germany); R. Bender, Univ.-Sternwarte München (Germany)

The optical system of EUCLID Near Infrared Spectrometer & Photometer (NISP) is composed of 4 lenses, bandpass filters and grisms. The lenses are made of different materials: the corrector lens (fused silica) directly behind the dichroic and the lenses L1 (CaF2), L2 (LFSG15), and L3 (LF5G15) that are mounted in a separate lens barrel design. Each lens has its separate mechanical interface to the lens barrel, the so called adaption ring.

The adaption ring shall provide the necessary elasticity caused by the different CTE of the lens and ring materials, as well as shall allow the high position accuracy of the lenses relative to the lens barrel and the optical axis.

The design drivers for the adaption ring are high precision, cryogenic operation temperature (120 -150K) and the large dimension of the lenses (170 mm). The design concept of the adaption ring is based on solid state springs which shall both provide sufficient protection against vibration loads at ambient temperature as well as high precision (< ±10µm) and stability at cryogenic temperatures.

Criteria for the solid state spring design shall be low radial forces at cryogenic conditions to avoid any refractive index and polarization variations. The design shall be compliant to the large temperature differences between assembly and operation, the high precision and non-deformation requirements of the lenses as well as to the deviating CTEs of the selected lens materials.

The paper describes the selected development approach including justification, thermal and structural analysis as well as preliminary test results.

8125-17, Session 5

A parametric finite-element model for evaluating segmented mirrors with discrete, edgewise connectivity

J. A. Gersh-Range, Cornell Univ. (United States); W. R. Arnold, Jacobs Engineering Group Inc. (United States); M. A. Peck, Cornell Univ. (United States); H. P. Stahl, NASA Marshall Space Flight Ctr. (United States)

Since future astrophysics missions require space telescopes with apertures of at least 10 meters, there is a need for on-orbit assembly methods that decouple the size of the primary mirror from the choice of launch vehicle. One option is to connect the segments edgewise using mechanisms analogous to damped springs. To evaluate the feasibility of this approach, a parametric ANSYS model has been developed. This model constructs a mirror using rings of hexagonal segments and a set of geometric parameters that includes the mirror diameter, the size of the gap between segments, the number of rings, the mirror curvature, and the aspect ratio. The connectivity determines whether the mirror is monolithic or segmented: for a monolithic mirror, the edges of adjacent segments are connected continuously, while for a segmented mirror, the edges of adjacent segments are connected at discrete locations corresponding to the mechanism locations. The mechanism properties and placement are additional parameters.

To compare the performance of the segmented mirror to that of the equivalent monolith, the model determines the mode shapes, natural frequencies, and disturbance response of each mirror. As an example, this paper presents the case of a mechanism that is analogous to a set of four collocated single-degree-of-freedom damped springs. The results of these parameter studies suggest that such mechanisms can be used to create a 15-m mirror that behaves similarly to a monolith, although fully predicting the segmented mirror performance would require incorporating measured mechanism properties into the model.

8125-18, Session 5

A tool for bonded optical element thermal stability analysis

G. L. Klotz, Klotz Optical and Mechanical Engineering and Technologies (United States)

An analytical tool is presented which supports the opto-mechanical design of bonded optical elements. Given the mounting requirements from the optical engineer, the alignment stability and optical stresses in bonded optical elements can be optimized for the adhesive and housing material properties. While a perfectly athermalized mount is desirable, it is not realistic. The tool permits evaluation of element stability and stress over the expected thermal range at nominal or worst case. A tool for bonded optical elements can be optimized for the adhesive and housing material properties. While a perfectly athermalized mount is desirable, it is not realistic. The tool permits evaluation of element stability and stress over the expected thermal range at nominal or worst case. The tool is based on a simple stress-strain analysis using Hooke's Law in the worst case plane through the optical element centerline. The optimal bondline is determined for the selected adhesive, housing and given optical element materials using the basic athermalization equation.

The tool was originally developed to analyze the pointing stability of a circumferentially bonded fiber optic ferrule. It is, however, equally useful for evaluating any thick, or thin, optical element. Edge bonded windows, filters, mirrors and prisms, whether circular, or rectangular, can be easily evaluated for alignment stability and maximum stress. The tool is currently designed to run in Microsoft Excel. Future versions of the tool will include an extended adhesive, housing and optical element material properties library and run in MATLAB.

8125-19, Session 6

Application of modal testing to characterize ground based telescope elastic motion and its effect on image quality

J. Lukens, B. C. Steele, Quartus Engineering Inc. (United States); G. Gates, N. Kaiser, J. S. Morgan, Univ. of Hawai‘i (United States)

No abstract available
8125-20, Session 6

**Thermal stress failure criteria for a structural epoxy**

P. Côté, N. Desnoyers, INO (Canada)

Representative failure data for structural epoxies can be very difficult to find for the optomechanical engineer. Usually, test data is only available for shear configuration at room temperature and fast pull rate. On the other hand, the slowly induced stress at extreme temperature is for many optical systems the worse-case scenario. Since one of the most referenced epoxy for optical assembly is the 3M Scotch-weld EC-2216 B/A Gray, better understanding its behavior can benefit a broad range of applications.

The objective of this paper is two-fold. First, review data for critical parameters such as Young’s modulus and coefficient of thermal expansion. Secondly, derive failure criteria from correlation between a thermal stress experiment and finite element model.

Instead of pulling out a standard tensile specimen, it is proposed to test thin bondline geometry to replicate the optical device usage. Four test plates are assembled at the Institut National d’Optique (INO) in Quebec City, Canada with bondlines of 75um and 150um. To detect the failure of the epoxy, the low level vibration signature of a cantilever Invar plate is monitored as temperature changes. Following the finite element analysis, a failure criterion is found to better match the experimental results than generic lap shear data.

8125-21, Session 6

**Acquisition, simulation, and test replication of weapon firing shocks applied to optical sights**

K. D. Ball, D. A. L. Gardner, Qioptiq Ltd. (United Kingdom)

As part of a capability improvement programme, a requirement was placed to develop a comprehensive understanding of the transient inertial shock loads exerted on visible and IR weapon systems through standard field operation. The knowledge was intended to aid in the development of new techniques for mechanical analysis simulations and representative ‘in house’ testing.

Weapon integrated sight systems have experienced huge technological advancement in recent years current systems give the user thermal and image intensified capabilities combined with high recognition and detection range. To satisfy customer requirements system designs must incorporate complex electronics, innovative optical materials and advanced mounting techniques, all of which are susceptible to failure under operational loads. Failures can be direct mechanical breakdown, permanent deformation, or interference / momentary non-conformance resulting from amplification of load through excitation of a component's natural frequency.

This paper describes the non-intrusive mechanical field data acquisition and subsequent analysis and test integration techniques, performed on complex opto-mechanical weapon mounted systems. These systems when mounted in tactical configuration with a wide range of military equipment are subjected to variable random vibration and shock loading; consistent with standard operational requirements. As a result of the multi-directional field data acquisition, innovative techniques have been developed enabling the synthesis of the transient recordings for the purpose of finite element analysis. Further investigations have revealed new possibilities in applying accurately controlled ‘in-house’ loading for low cost representative test purposes.

8125-22, Session 6

**Novel optical refraction index sensor**

N.紧凑Leon (Mexico)

The optical industry is increasing rapidly in recent years. The refraction parameter is a feature of any material and therefore there is a lot of research to development an instrument capable of measuring it. Amount the techniques in the state of the art, we can find the Fresnel method, the Christianson method, and some interferometric methods. However, these methods have demonstrated to be confident when the analyzed material is monolayer. The complexity of the measuring increases as long as the numbers of layers are presented in the material. The setup consisted of a diode laser, a focusing lens, a z-axis-scanner, a photo-detector, an electronic and software system to interpret the signals.

This work describes a novel optical refraction index sensor which is based on the analysis of double reflection lecture detection. This process initially identifies the thickness of a semitransparent solid or liquid material by the retro-reflection of a laser diode at 633nm, 800nm, 915nm and 980nm as a function of distance along the device under test. For the index detection, a lens is attached in a Z-axis-scanner to find the focusing point. This feedback signal brings how depth is penetrated the beam and also how far traveled the beam path. As we know, the refractive index is indirectly related to the traveled beam path at different materials, the data of the thickness at each layer is treating with a geometrical analysis of the beam velocity and all data can provides us of the refractive index at each material. The system is compact, robust and reliable.

8125-23, Session 6

**Adhesive bond cryogenic lens cell margin of safety test**


The Near Infrared Camera (NIRCam) instrument for NASA’s James Webb Space Telescope (JWST) has an optical prescription which employs four triplet lens cells. The instrument will operate at 37K after experiencing launch loads at –293K and the optic mounts must accommodate all associated thermal and mechanical stresses, plus maintain an exceptional wavefront during operation.

Lockheed Martin Space Systems Company (LMSSC) was tasked to design and qualify the bonded cryogenic lens assemblies for room temperature launch, cryogenic operation, and thermal survival (25K) environments. The triplet lens cell designs incorporated coefficient of thermal expansion (CTE) matched bond pad-to-optic interfaces, in concert with flexures to minimize bondline stress and induced optical distortion. A companion finite element study determined the bonded system’s sensitivity to bondline thickness, adhesive modulus and adhesive CTE. The design team used those results to tailor the bondline parameters to minimize stress transmitted into the optic.

The challenge for the Margin of Safety (MOS) team was to design and execute a test that verified all bond pad/adhesive/optic substrate combinations had the required safety factor to generate confidence in a very low probability of optic/bond failure during the warm launch and cryogenic survival conditions. Because the survival temperature was specified to be 25K, merely dropping the test temperature to verify margin was not possible. A shear/moment loading device was conceived that simultaneously loaded the test coupons at 25K to verify margin.

This paper covers the design/fab/SEM measurement/thermal conditioning of the MOS test articles, the thermal/structural analysis, the test apparatus, and the test execution/results.
8125-24, Session 7

A few observations about mounting moderately sized mirrors

M. I. Kaufman, National Security Technologies, LLC (United States)

Most of the mirror mounting literature has focused on small (less than 0.1 meters) or large (greater than 1 meter) mirrors. We will examine the theory and practice of mounting moderately sized mirrors (between 0.1 and 1 meter). Two examples will be taken from optical diagnostic systems designed for the National Ignition Facility (NIF). One of the examples will be for a mirror with a poor aspect ratio (i.e. diameter to thickness ratio greater than 15:1).

8125-25, Session 7

Lens mount with ring-flexures for athermalization

H. Kihm, H. Yang, Y. Lee, Korea Research Institute of Standards and Science (Korea, Republic of); J. Lee, Cheongju Univ. (Korea, Republic of)

We present a new athermal lens mounting scheme made of cascaded ring flexures. Two circular grooves are concentric at the adhesive injection hole and fabricated monolithically on a lens cell or a barrel itself. The ring flexure can accommodate six degree-of-freedom motions by controlling dimensional parameters. We evaluate thermo-elastic deformations by interferometric measurements and verify the results with finite element analyses. Also we compare the athermal performances from a simple elastomeric mount and a ring-flexured mount. This lens mounting scheme would be a promising candidate for environmentally challenged optical systems like space and military applications.

8125-26, Session 7

Mounting small optics for cryogenic space missions


The Near Infrared Camera (NIRCam) instrument for NASA's James Webb Space Telescope (JWST) includes numerous optical assemblies. The instrument will operate at 57K after experiencing launch loads at ~293K and the optic mounts must accommodate all associated thermal and mechanical stresses, plus maintain an exceptional wavefront during operation. Lockheed Martin Space Systems Company (LMSSC) conceived, designed, assembled, tested, and integrated the mirror and lens assemblies for the NIRCam instrument. This paper covers the design, analysis, and test of the instruments key optical assemblies.

8125-27, Session 7

Design considerations of a slit diaphragm flexure used in a precision mirror gimbal

B. C. Cox, National Security Technologies, LLC (United States)

Two precision mirror gimbals were designed using slit diaphragm flexures to provide two-axis precision mirror alignment in space-limited applications. Both gimbals are currently in use in diagnostics at the National Ignition Facility: one design in the Gamma Reaction History (GRH) diagnostic and the other in the Neutron Imaging System (NIS) diagnostic. The GRH gimbal has an adjustment sensitivity of 0.1 mrad about both axes and a total adjustment capability of +/- 6 degrees; the NIS gimbal has an adjustment sensitivity of 0.8 mrad about both axes and a total adjustment range of +/- 3 degrees. Both slit diaphragm flexures were electro-discharge machined out of high-strength titanium and utilize stainless steel stiffeners. The stiffener-flexure design results in adjustment axes with excellent orthogonality and centering with respect to the mirror in a single stage; a typical two-axis gimbal flexure requires two stages. Finite element analyses are presented for both flexure designs and a design optimization of the GRH flexure is discussed.

8125-28, Session 8

Backlighting for alignment of optics in first diffraction order path

A. Amphawan, Univ. of Oxford (United Kingdom)

In a typical Fourier transform by a convex lens, the first diffraction order deviates from the axis of the zeroth diffraction order. When the angle of deviation of the first diffraction order with respect to the zeroth diffraction order is very small, launching a laser beam into an optical fiber located on the axis of the first diffraction order presents a challenge. To facilitate this, a backlighting technique is proposed. The step-by-step alignment procedure for this is described. It is evident that the backlighting technique improves the power coupling efficiency into the optical fiber.

8125-29, Session 8

Large stable aluminum optics for aerospace applications

D. Vukobratovich, Raytheon Missile Systems (United States); J. Schaefer, Raytheon ELCAN Optical Technologies (United States)

Aluminum mirrors offer the advantages of lower cost, shorter fabrication time, more rugged mounting, and same material athermalization when compared to classical glass mirrors. In the past these advantages were offset by controversial dimensional stability and high surface scatter, limiting applications to IR systems. Raytheon developed processes to improve long term stability, and reduce surface scatter. Six 380 mm aperture aluminum mirrors made using these processes showed excellent stability, with figure changes of less than 0.01 wave RMS (1 wave = 633 nm) when cycled 10 times between -51 and +71 deg. C. The VQ process developed at ELCAN reduces surface scatter in bare aluminum mirrors to below 20 angstroms RMS, and has been used in hundreds of production mirrors up to 300 mm aperture. These processes were employed in the fabrication of two lightweight single arch 600 mm aluminum mirrors. The two mirrors were produced in four months, with a mounted surface figure of 0.22 waves RMS and surface roughness of 20 angstroms. Mounted fundamental frequency was 218 Hz, and no figure distortion was observed at preload levels four times higher than design. Subsequently the mirrors performed well when subjected to severe environmental loadings in a Raytheon test system. This technology is being extended to ultra-lightweight sandwich mirrors, which are competitive with other technologies in many aerospace applications such as UAV surveillance systems and satellite optics.

8125-30, Session 8

Comparative analysis of the efficiency of several open-back mirror lightweighting approaches using machining parameters now available for a Zerodur blank of 1.2m aperture

T. B. Hull, L-3 Communications Tinsley Labs. Inc. (United States); A. R. Clarkson, G. Gardopee, L-3 IOS Brashear (United States); R. Jedamzik, A. Leys, SCHOTT North America, Inc.
We evaluate several open-back mirror lightweighting approaches now offered in Schott Zerodur® realizing more aggressive figures-of-merit than in the past. A f/1.3 mirror 1.2 meters in diameter has been selected, since significant lightweighting often is required of a mirrors around this size for both spaceborne and terrestrial telescope applications, and methods applied are well illustrated for this size. Each lightweighting approach will be taken to its current limit and is required to meet a common free-free natural frequency, and to be compatible with machining parameters now available. We will also recognize optical processes, and constrain the results for the same expected magnitude of residual substructure print-through, as well as considering optical testing. Other mirror parameters, including facesheet and core thickness, cell size and cell wall thickness, and even partially closing the back are adjusted to achieve this stiffness and other constraints. The resulting relative mass and thickness then become figures-of-merit. We will also evaluate the relative machining time as an index of relative cost and duration of the lightweighting process. We expect that these figures-of-merit can be extrapolated to somewhat smaller or larger mirror diameters, and that the more aggressive machining parameters now available will extend the use of open-backed mirrors into the domain where expensive closed-back sandwich-mirrors were previously required.

8125-31, Session 8

**Optimal window engineering**

A. E. Hatheway, Alson E. Hatheway Inc. (United States)

Mechanical engineers are sometimes called upon to come up with specifications for a minimum price and minimum mass (weight) window. Usually the shape of the window is known, the spectral pass-band is known and the allowable contributions to image blur is known. This paper presents an engineering method for quantifying the trade-off between price and mass in a window.
8126-01, Session 1

Optical manufacturing and testing requirements identified by the NASA Science Instruments, Observatories and Sensor Systems Technology Assessment

H. P. Stahl, NASA Marshall Space Flight Ctr. (United States)

In August 2010, the NASA Office of Chief Technologist (OCT) commissioned an assessment of 15 different technology areas of importance to the future of NASA. Technology assessment #8 (TA8) was Science Instruments, Observatories and Sensor Systems (SI OSS). SIOSS assess the needs for optical technology ranging from detectors to lasers, x-ray microscopes to microwave antenna, in-situ spectrographs for on-surface planetary sample characterization to large space telescopes. The needs assessment looked across the entirety of NASA and not just the Science Mission Directorate. This paper reviews the optical manufacturing and testing technologies identified by SIOSS which require development in order to enable future NASA high priority missions.

8126-02, Session 1

Technologies for producing segments for extremely large telescopes

D. D. Walker, Zeeko Ltd. (United Kingdom); R. Evans, S. Hamidi, P. Harris, H. Li, M. Parry-Jones, OpTIC Glyndwr Ltd. (United Kingdom); G. Yu, Glyndwr Univ. (United Kingdom)

We describe a new process-chain being used to produce eight 1.4m hexagonal mirror segments for the European Extremely Large Telescope project. The first is a reference sphere for metrology, and the others are prototypes of a cluster of aspheric segments near the edge of the 42m telescope pupil. OpTIC Glynd r has created a new pilot plant in North Wales, based around the integration of a highly bespoke full-aperture test-tower designed and built in-house, with a Zeeko 1.6m polishing machine, and supported by independent profilometry. The existing 1.2m and 600mm Zeeko machines are being used for process development and optimization, which is continuing through the segment programme. The process chain starts with direct aspherising of the hexagonal segments on the Cranfield BoX ultra-precision grinder, and continues through smoothing, polishing, form-corrective and edge-rectification using the Zeeko CNC platform. The paper describes the development of the technology and progress to date, and anticipates how the process-chain is expected to evolve through the seven segments to increase both process speed and surface quality.

8126-04, Session 1

ZERODUR for stress mirror polishing

R. Jedamzik, T. Westerhoff, C. Kunisch, SCHOTT AG (Germany)

Stress mirror polishing is considered for the generation of the aspherical shaped primary mirror segments of the thirty meter telescope (TMT). For stress mirror polishing it is essential to precisely know the elastic response of glass ceramic substrate materials under a given deformation load. In the past it was experimentally shown that glass ceramics do not respond instantaneously to loading and unloading conditions, this effect was called “delayed elasticity”.

Recently it was shown that it is possible to use a model to predict the characteristic thermal expansion behaviour of individual ZERODUR batches for a given temperature profile. A similar approach will be used to predict the elastic behaviour of ZERODUR under time dependent loads.

In this presentation the delayed elasticity effect of ZERODUR® is reviewed. The elastic response of the material to load conditions is shown and discussed. First results of a model approach based on experimental results and tools that have been built up for the modelling of the thermal structural relaxation effect of ZERODUR® will be presented.

8126-05, Session 1

Design and fabrication of a 3m class light weighted mirror blank for the E-ELT M5

R. Jedamzik, V. Seibert, A. Thomas, T. Westerhoff, SCHOTT AG (Germany); M. Müller, M. Cayrel, European Southern Observatory (Germany)

In the recent past SCHOTT has proven its capability for the manufacturing of large light weighted ZERODUR® mirror blanks for telescope projects like for example the GREGOR solar-telescope. In 2010 SCHOTT was awarded with a study to develop a design for the M5 mirror blank of the ESO E-ELT.

The tip and tilt M5 mirror of the European Extremely Large Telescope (E-ELT) requires a demanding approach in light weighting. The approximately 3 m x 2.5 m elliptical plano mirror is specified to a weight of less than 500 kg with high Eigenfrequencies and low deformation under different inclination angles.

The study was divided into two parts. The first part targeted on an optimized lightweighted design with respect to performance and processability with the help of finite element modelling. In the second part of the study a concept for the processing sequence including melting, cold-processing, acid etching and handling of the M5 blank was developed. With the fabrication of a prototype section SCHOTT demonstrated its capability to manufacture the demanding features including pockets with 350 mm depth, thin walls and sloped pocket bottoms.

This presentation shows the results of the design work, processing concept and demonstrator fabrication.

8126-06, Session 1

Optical finishing properties of silicon-infiltrated silicon carbide

E. J. Gratrix, M Cubed Technologies, Inc. (United States); F. Tinker, Aperture Optical Sciences, Inc. (United States); P. B. Mumola, P. B. Mumola, LLC (United States)

Silicon Carbide (SiC) has been considered to be a leading candidate material for future lightweight telescopes and opto-mechanical structures based on its high specific stiffness and thermal stability. A number of companies have successfully demonstrated processes to manufacture complex, net-shape, lightweight mirror substrates with apertures exceeding one meter. The cost of optical finishing such mirrors has nonetheless continued to be an obstacle to the widespread adoption of SiC as a mirror material with the exception of niche cryogenic applications. Nearly all current processes for producing SiC mirror substrates yield surfaces that are unsuitable for optical polishing unless they are first coated with CVD-SiC or CVD-SiC. The cost of CVD coating and the non-uniformity of this relatively thick layer of material unfortunately add to the optical finishing cost. This paper addresses the material removal and polishing characteristics of Si-infiltrated SiC and compares these properties to those of CVD-SiC. The results indicate that high quality optical surfaces, with micro-roughness on the order of 1.0 nm rms, can be obtained without the need for CVD cladding while preserving the thermal and structural advantages typical of SiC.
8126-52, Session 1

European ELT mirrors development

E. Ruch, J. Carel, H. Leplan, F. Poutriquet, Sagem Défense Sécurité (France)

Sagem • Reosc has been awarded by ESO several contracts for the manufacturing and testing of seven prototype segments of the E-ELT primary mirror, the design of the 6 meters convex secondary mirror and the active support system, the large thin shell for the adaptive M4 mirror and the design of the extremely lightweighted tip tilt M5 mirror.

The main purpose of the development efforts are to assess the segment feasibility and define a baseline process for the serial production of more than one thousand of these segments. The paper will present the results achieved so far on the different prototypes segments and compared them to the requirement of the future E-ELT segments.

The presentation will also address the manufacturing and the testing of the prototype thin shells of 2.5 meter diameter and 2 mm thin that have been recently delivered to ESO. We will present the technical results that have been achieved.

8126-07, Session 2

Piezoelectric deformable mirror based on monolithic PVDF membranes

G. A. Finney, Kratos Defense & Security Solutions, Inc. (United States); K. D. Spradley, Advanced Optical Systems, Inc. (United States); B. S. Farmer, NeXolve Corp. (United States)

Deformable mirrors using polyvinylidene fluoride (PVDF) membranes in a bimorph configuration have been previously studied by numerous investigators. Kratos Defense and Security Solutions in partnership with Advanced Optical Systems, Inc. and Mantech NeXolve Corporation, have been evaluating the utility of unimorph PVDF films for fabrication of deformable mirrors. Actuation using a unimorph film is based upon creating a gradient in the piezoelectric response of the film through a proprietary process. This property eliminates the requirement to bond multiple films to generate curvature and improves the optical quality of the films. Analytical approximations to describe the behavior of the film under applied loads and voltages have been developed. To assist in the development and design of the films, a multiphysics design tool has been developed by tightly integrating several commercial software packages. This tool has then been used to model the performance of the films and extract significant material parameters from experimental results. This paper reports on these initial results and characterization of this novel material.

8126-08, Session 2

Progress on 4m class ZERODUR mirror production

T. Westerhoff, R. Jedamzik, A. Klein, C. Klein, SCHOTT North America, Inc. (United States)

The first monolithic ZERODUR 4 m class mirror was ordered by the German Max Planck Institute for Astronomical Physics in 1968. The technological ability to actively compensate the bending of the mirror substrate under gravity initiated the development from heavy non active thick mirror substrates to ever thinner thicknesses starting with the NTT, the New Technology Telescope of ESO.

The thinner the mirror substrates are becoming the more demanding are the requests on homogeneity of material properties to ensure best performance over the clear aperture at every spot.

In this paper we present results on material properties achieved for the 4 m class mirror substrates recently delivered by SCHOTT. The CTE homogeneity, the internal quality regarding striae, bubbles and inclusions as well as stress birefringence data are reported. Improvements in CNC processing and overall manufacturing process for the very thin 4 m class blanks are discussed.

8126-09, Session 2

Open-source data analysis and visualization software platform

D. W. Kim, B. Lewis, J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

Optical engineering projects often require massive data processing with many steps in the course of design, simulation, fabrication, metrology, and evaluation. A Matlab-based data processing platform has been developed to provide a standard way to manipulate and visualize various types of data that are created from optical measurement equipment. The operation of the software platform via the graphical user interface is easy and powerful. Data processing is performed by running modules that use a proscribed format for sharing data. Complex operations are performed by stringing modules together using macros. While numerous modules have been developed to allow data processing with the least effort, the greatest power of the platform is provided by its flexibility. A developer’s toolkit is provided to allow development and customization of modules, and the program allows a real-time interface with the standard Matlab environment. This software, developed by the Large Optics Fabrication and Testing group at the University of Arizona, is now publicly available. We present the capabilities of the software and provide some demonstrations of its use for data analysis and visualization. Furthermore, we demonstrate the flexibility of the platform for solving new problems.

8126-10, Session 2

Measuring the residual stress of transparent conductive oxide films on PET by the double-beam shadow Moiré interferometer

H. Chen, K. Huang, Y. Lo, H. Chiu, G. Chen, National Yunlin Univ. of Science and Technology (Taiwan)

The purpose of this research was to construct a measurement system which can be fast and accurately analyze the residual stress of the flexible electronics. In which, representative transparent conductive oxide (TCO) films, such as tin-doped indium oxide (ITO), gallium-doped zinc oxide (GZO) films and aluminum-doped zinc oxide (AZO) films, were deposited by RF magnetron sputtering using corresponding oxide targets on PET substrate. As we know that the shadow moiré interferometry is a suitable way to measure the large deformation. So we set up a double beam shadow moiré interferometer to measure and analyze the residual stress of TCO films on PET. In this measurement system, a beam splitter splits one beam into two beams to pass through a reference grating with the identical incident angle and create a deformation shadow grating on the object surface. Then we used CCD to retrieve moiré pattern which is created by shadow grating and reference grating. The feature was to develop a mathematical model and combine the image processing software. By the LabVIEW graphical software, we could measure the distance which is between the left and right fringe on the pattern to solve the curvature of deformed surface. Hence, the residual stress could be calculated by the Stoney correction formula for the flexible electronics. We also had done the error analysis for the system whose relative error could be under 2%. Therefore, shadow moiré interferometer is an accurate, fast, and simple system for the residual stress on TCO/PET films.

8126-11, Session 3

MicroFinish Topographer: surface finish metrology for large and small optics

R. E. Parks, Optical Perspectives Group, LLC (United States)
The MicroFinish Topographer (MFT) is a temporal phase measuring interferometer attachment to the Point Source Microscope that uses 4D Technology 4Sight software for data analysis. The MFT is designed to set directly on a large optic to measure the surface roughness. Tip, tilt and focus adjustments allow breaking out the fringes and finding maximum contrast with the help of the software. Tests have shown the MFT gives the same roughness values even on non-isolated samples as do traditional surface roughness profilers. Results of these tests will be given.

The convenience of making in situ roughness measurements led to the obvious question of whether the same device could measure roughness on small samples, something smaller in diameter than the 120 mm diameter support ring for the large optics version. This is easily done by turning the unit over and placing smaller samples on a support plate that kinetically holds the sample above the 10x Mirau objective. The close coupling of the sample to the objective eliminates the need for vibration isolation in all but the worst environments. Again, results of measurements made on the MFT will be shown alongside those from other profilers.

The suite of well designed and coordinated hardware and software make surface roughness measurement quick and easy on the widest possible range of sample sizes without the need for replicas or vibration isolation hardware.

8126-12, Session 3

Infrared reflection deflectometry system for optical surface measurement in grinding stage: the IR SCOTS

T. Su, W. Park, R. E. Parks, P. Su, J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

A rapid, robust and accurate system for measurement of specular surface has been adopted at the Steward Observatory Mirror Lab in University of Arizona. This system, called SCOTS (software configurable optical test system), is based on reflection deflectometry and is similar to a reversed traditional Hartmann test. It uses an LCD screen to illuminate the surface under test; a camera captures reflected light for surface slope analysis. In comparison to interferometry, SCOTS provides similar results with a simpler optical system and a larger dynamic range. By using an infrared source (in this case an electrically heated alloy wire), the same idea can be applied to make measurements of ground surfaces which are diffuse reflectors in visible wavelength. A linear stage is used to scan the alloy wire through the field, while an infrared camera is used to collect data. This IR system could be applied early in the grinding stage of fabrication of the large telescope mirrors to minimize the surface shape error imparted during processing. This advantage combined with the simplicity of the optical system (no null optics, no high power carbon dioxide laser) would improve the efficiency and shorten processing time.

8126-13, Session 3

Phase-shifting Zernike interferometer wavefront sensor

S. Rao, J. K. Wallace, E. Serabyn, Jet Propulsion Lab. (United States)

A phase-shifting Zernike interferometer measures the electric field in the pupil plane of an optical instrument, with advantages over a traditional Shack-Hartmann sensor. When operated as a long-stroke interferometer, it measures the absolute phase across the pupil as a function of wavelength. A common-path, all-reflective design makes it minimally sensitive to vibration, polarization, and wavelength. We describe the optical system, review the theory of operation, and review results from a laboratory demonstration of this novel instrument.

8126-14, Session 3

Flexible null interferometry of the aspherical surface

H. Chang, C. Liang, C. Liang, National Central Univ. (Taiwan)

A novel optical testing method is developed to test the surface deformation of the asphere without using any additional holograms or null optics. The principle optical testing method is based on the geometrical null utilizing merely 4 axes of geometrical motions. The optical null of the tested aspherical surface is achieved at the partial surface of an axial symmetrical surface. By adapting the vibration insensitive phase shifting algorithm, we are able to extract the phase of the interferogram reflected from an asphere during the rotational scanning motion in the presence of mechanical vibration induced from the stages. The azimuthal phase stitching method is used to stitch the tangential phase after interferogram measurement to form a complete asphere surface profile. The four motions geometrical null principle is illustrated and the preliminary measurement results are shown.

8126-15, Session 3

Dynamic surface roughness profiler

B. T. Kimbrough, N. Brock, 4D Technology Corp. (United States)

A dynamic profiler is presented that is capable of measuring surface roughness while mounted directly to optical polishing equipment or while resting directly on large optics. Utilizing a special CCD camera incorporating a micro-polarizer array and a proprietary 460nm LED source, quantitative measurements were obtained with exposure times of <100 usec. The polarization-based interferometer utilizes an adjustable polarizer to optimize fringe contrast and signal to noise for measurement of optical surfaces ranging in reflectivity from 1 to 100%. A new phase calculation algorithm is presented that nearly eliminates phase-dependent errors resulting in shot noise limited performance. In addition to its vibration immunity, the systems light weight, <5 kg, compact envelope, 24 x 24 x 8 cm, integrated alignment system, and multiple mounting options facilitate use in both directly resting on large optical surfaces and directly mounted to polishing equipment, stands, gantries and robots. In this paper we present measurement results for both on-optic and stand-mounted configurations. A fully automated tripod mounting system for on-optic measurements is demonstrated. Measurement results presented show an RMS repeatability <0.005 nm and an RMS precision < 0.1nm which are achieved without active vibration isolation.

8126-16, Session 4

Cryo stability of HB-Cesic optics

M. R. Kroedel, ECM GmbH (Germany)

For large future space optics the requirements are more and more challenging with respect to mass, size and stability. In the past two years ECM tested together with his partners extensively the cryo stability of HB-Cesic material under various conditions.

In this paper we will report the test configuration and results from sample testing up to two large measurement and qualification campaigns of HB-Cesic optics.

The first mirror was a 600 mm mirror, which was polished directly without any overcoatings and the second mirror was an 800 mm mirror with a silicon layer on the optical surface. Both mirrors were tested to cryogenic temperatures of 10 to 100 K.
8126-17, Session 4

Analysis of fine-grinding techniques in terms of achievable surface qualities

O. W. Fähnle, K. Hauser-Bergen, FISBA OPTIK AG (Switzerland)

In Optical Fabrication of e.g. glass lenses or tungsten carbide tools for hot glass molding processes, two goals have to be achieved: the desired surface shape and the required surface quality (level of surface roughness and sub-surface damage (ssd)) have to be generated. To that aim, abrasive processes, e.g. grinding and polishing, are applied subsequently. In particular, the fine grinding has to leave a mini-mum level of ssd since this determines the time needed for the subsequent costly polishing process. In this paper we report on an analysis of three different fine grind-ing techniques in terms of achievable surface qualities: fixed abrasive cnc grinding, traditional loose abrasive grinding and fluid jet grinding, where a fine grinding slurry is accelerated by a nozzle and guided onto the surface to be machined (a similar ap-proach to Fluid Jet Polishing). To detect the level of ssd, two non destruc-tive methods were applied. A traditional one where the sample under test consists of two optically contacted parts and intensity-detecting Total Internal Reflective Microscopy (TIRM). Experimental studies have been carried out. A.o. the generated surface qualities have been analyzed if these techniques are set up with the same abrasive grain sizes. In addition, the level of ssd is detected if they are set up to generate the same level of surface roughness. While in FJP wear is caused by the kinetic energy of the impinging particles, in cnc and traditional grinding, there is a macroscopic contact between tool and surface causing a higher level of ssd.

8126-18, Session 4

Fabricating and testing of complex optical elements with high precision

H. Wang, V. Giggel, G. Derst, T. Koch, Carl Zeiss Jena GmbH (Germany)

The very strong requirement for the super precision optics for the microlithography has been driving the development of optical fabrication and testing technologies since last twenty years. These technologies are basis for manufacturing high-end optics. In addition to the requirements on reasonable costs for manufacturing arbitrary surface shapes, the optics with lambda/100 quality, aspheric and freeform optics mean always challenges with both fabrication and test, because experienced optical technicians should know exactly what they measure at first and then decide how to achieve the required quality using different iterative processes. These iterative processes are based on the commercial available figuring and polishing machines and Zeiss CCP (computer controlled polishing) technology. The testing has been performed using both commercial available interferometers and Zeiss self developed metrologies. The materials used cover all types of typical optical materials, in particular the CaF2 and fused silica.

8126-19, Session 4

Analytical process design for chemo-mechanical polishing of aspheres

F. Klocke, O. Dambon, D. Waechter, Fraunhofer-Institut für Produktionstechnologie (Germany)

This work deals with the chemo-mechanical sub-aperture polishing using spiral tool path and pressure inflated membrane tools. The choice of machining parameters is often based on empirical try-outs and iterative corrections. However, an economic manufacturing of glass aspheres in small lot sizes requires first part right strategies. To get there, an analytical process design, which chooses the best process parameters in regard to the geometry, material and initial quality of samples, based on knowledge instead of experiments is essential. This work contributes to gain efficiency in polishing aspheres from ground to polished quality by a systematic investigation of process parameters and by presenting a method for calculating the effect of major input parameters on the local distribution of material removal. It is based on Preston's equation and takes into account the influence of the input parameters on the spot size, local relative velocity, pressure and dwell-time. The analytical methods enable the prediction of the effect of changing parameters on the edge and center effects as well as general deviations in the radius of curvature, when polishing aspheres. In the second place, they enable the control of shape deviations by varying process parameters dynamically. The necessary experimental investigations, the mathematical model and application examples for controlling the radius of curvature and the edge effect will be presented. In conclusion, the analytical methods for choosing appropriate process parameters will help increasing significantly the efficiency in chemo-mechanical polishing of glass aspheres and can be even applied to free-forms.

8126-28, Poster Session

The slow tool servo diamond turning of optical freeform surface for astigmatic contact lens

C. Chen, Instrument Technology Research Ctr. (Taiwan); Y. Cheng, Instrument Technology Research Ctr. (Taiwan) and National Tsing Hua Univ. (Taiwan); W. Hsu, H. Chou, Instrument Technology Research Ctr. (Taiwan); P. Wang, National Tsing Hua Univ. (Taiwan); D. P. Tsai, Instrument Technology Research Ctr. (Taiwan) and National Taiwan Univ. (Taiwan)

Three ultra-precision machining processes namely fast tool servo, slow tool servo and diamond milling, are frequently used to produce optical freeform surface. Though slow tool servo has the advantages of no extra attachment and fast setting-up, the complicated three dimensional tool shape compensation and tool-path generation are major reasons for resulting in poor form accuracy, pre-matured tool failure and poor surface finish. This research aimed to develop a model of three dimensional tool shape compensation for generating 3D tool path in slow tool servo diamond turning of asymmetrically toric surface such as in astigmatic contact lens.

The toric surface can be used to correct the astigmatism. The disposable contact lens can’t make with toric surface in the past. Because of the progress of the freeform optics machining technology, the astigmatic contact lens has been manufactured by casting method recently. For the casting method, the plastic optical mould made by plastic injection method was used to generate the contact lens. The nickel plating steel mould with toric surface of plastic injection will be manufactured by slow tool servo diamond turning in this research. The form accuracy of freeform surface was measured by UA3P with user define function and the form error has also been corrected. Finally, the form error of both x and y direction and fully surface are less than 0.3µm and 0.5µm, respectively. The surface roughness is less than 5nm.

8126-29, Poster Session

The fabrication of high filling factor double side micro lens array with high alignment accuracy

Y. Cheng, Instrument Technology Research Ctr. (Taiwan) and National Tsing Hua Univ. (Taiwan); C. Chen, W. Hsu, Instrument Technology Research Ctr. (Taiwan); P. Wang, National Tsing Hua Univ. (Taiwan); D. P. Tsai, Instrument Technology Research Ctr. (Taiwan) and National Taiwan Univ. (Taiwan)

Laser has the advantage of monochromaticity, coherence, divergence
8126-42, Poster Session

Mirror segments for large mirror systems of weak optical signals detectors for UV spectral range

P. Schovanek, M. Hrabovsky, M. Palatka, M. Pech, D. Mandat, L. Nozka, A. Dejnka, Institute of Physics of the ASCR, v.v.i. (Czech Republic); J. Jankuj, Meopta - optika, s.r.o. (Czech Republic); M. Vujtek, Palach? Univ. Olomouc (Czech Republic)

Authors introduce some results of high quality segments testing for the construction of the large-area light-weight mirror systems for UV detectors of weak optical signals. For this category of the optical components an increase of demands on technology production is typical. This is caused by various reasons.

1. Width to diameter ratio is 1:100 for this type of segments. For astronomical mirrors this ratio is about 1:10. This is the reason why the manufacturing technology of the light-weight segment surfaces was changed. Similarly, usually used testing methods of the shape of the optical surfaces are changed. The shapes of the surfaces are evaluated by the minimal spot diameter of the reflected beam which contains 95% of the incident signal energy.

2. Processing technology of working surfaces was enhanced because of the UV light wavelength. The technology must respect the fact that the amount of diffused light in the short UV wavelength region is increasing in the dependence on the surface roughness of the mirror.

3. Surface reflectivity is not the only important parameter of the optical reflecting thin film systems in this kind of applications. Surface roughness and homogeneity of thin films are taken into account of testing methods also.

8126-43, Poster Session

Manufacturing process optimization of phase plates for depth extension microscope systems

C. Hsu, H. Sung, Y. Chen, W. Cheng, C. Liang, C. Chang, Industrial Technology Research Institute (Taiwan)

Extended depth of focus (EDoF) technology can be used for imaging systems by merging phase coding design and digital signal processing. This paper presents an application of EDoF in the microscope platform, comparing the phase plate component fabrication in different conditions by ultra-precision diamond machining and the performance of the EDoF. A cubic phase plate component is an illustration of diamond machining about the peak-to-valley (PV) error of the cubic surface and the performance of the EDoF. In addition to cubic phase plate, we also design other phase plates such as axial symmetric and non-symmetric plates to evaluate the feasibility by the process and experiment on the microscope platform. Because the sag variation of the component is very small for this phase plate, how to determine the optimal cutting conditions which can stabilize the quality of the fabricated phase plate is very important. So the SPDT (single point diamond turning) was applied to the manufacture of a variety of optical components for its high precision. In the paper, the effect of cutting conditions such as feed rate, pitch and depth of cut are investigated. And the results are as following, the average roughness height of the surface without subsequent polishing was found below 20 nm. The accuracy of the symmetric and non-symmetric phase plate was found between 0.2 µm and 1µm. Therein the symmetric plate was suited to commercialization. The purpose of this study is to compare the relationship between PV error of cubic surface and imaging restoration quality, which maybe a good benchmark in this field.

8126-44, Poster Session

An intuitive concept for manufacturing and inspecting of aspherical components

H. Chou, Instrument Technology Research Ctr. (Taiwan)

In this paper we propose an intuitive concept for manufacturing and inspecting of aspherical components. Two types, parabolic and cylinder, of plano-convex and plano-concave aspherical lenses were made by LOH 120S form generation machine. Three form error measurement methods were used known as coordinate measuring machine (CMM), interferometer with CGH null lens and inspection with combined pair lenses. Ultra high accuracy CMM from Brown & Sharpe Co., CGH cylinder null and CGH aspheric null from Diffraction International and OWI 150 ASPH CGH interferometer from Optotek GmbH play the roll for measurement. CMM was used as a surface profiler to inspect the surface shape, and the software GRAPHWER was also used as analysis tool to examine asphere numerical datum. The difference between theoretical and practical is as a surface polishing revised reference. The finished plano-convex and plano-concave aspherical lenses can be combined to be a plane lens. The individual and combined lenses were inspected on OPTOTECH OWI 150 ASPH CGH interferometer. The compared interference patterns has shown with the Diffraction International CGH Aspheric Null “ASPHERIC 1” and CGH Cylinder Null “H80F2C”. Through the procedure, the combined plano-convex and plano-concave aspherical lenses should be a perfect match plane lens and the individual lenses might be an aspherical test standard element for quick inspection.

8126-45, Poster Session

Verification program for a high-precision large cryogenic lens holder

A. Boesz, Kayser-Threde GmbH (Germany); N. Geis, Max-Planck-Institut für extraterrestrische Physik (Germany); F. U. Grupp, R. Bender, Univ.-Sternwarte München (Germany)

The Near Infrared Spectrometer and Photometer (NISP) of EUCLID requires high precision large lens holders (170 mm) at cryogenic temperatures (120K - 150K). The four lenses of the optical system are made of different materials: fused silica, CaF2, and LFS915 that are mounted in a separate lens barrel design. Each lens has its separate mechanical interface to the lens barrel, the so called adaption ring. The performance of the lens holder design shall be verified by an adapted test facility including an optical metrology system. The characterization of the lens deformation and displacement (decenter, tilt) due to thermally induced loads are driven by the require submicron precision range and at the operational thermal condition. The surface deformation of the lens and its holder is verified by interferometric measurements, while tilt and position accuracy are...
measured by fibre based distance sensors. The pre-selected distance measurement sensors have the capability to measure in a few nm range with submicron resolution at ultra high vacuum, in vibration environments and at liquid nitrogen temperatures and below.

The calibration of the measurement system is of crucial importance; therefore the sensors shall be mounted on a stiff well characterized reference structure made of Zerodur.

The verification program is currently under development at KT under an MPE contract. The paper presents the vacuum chamber design, the metrology system, the used Ground Support Equipment and the attained performance of the high precision lens holder design.

8126-46, Poster Session
Flexible manufacturing of large asphers for VLT’s Optical Tube Assemblies
G. P. Gubbels, R. Henselmans, C. van Drunen, TNO Science and Industry (Netherlands)

For the ESO Very Large Telescope TNO is making four Optical Tube Assemblies for the Four Laser Guide Star system. Each OTA is a large Galilean beam expander, which expands a 15 mm diameter, 25W CW 589 nm input laser beam to a 300 mm diameter output beam. The L2 lens is a 380 mm conical convex lens with a radius of curvature of 637 mm and conic constant k = -0.41776.

The paper describes the deterministic polishing and flexible metrology tool (NANOMEFOS) that are used in TNO’s value chain for high-accuracy asphere and freeform production. NANOMEFOS enables the universal non-contact measurement of asphers and freeforms up to 500 mm diameter with a high accuracy, equivalent to normal interferometers and with interferometric axial and lateral resolution (or better!). Besides flexibility NANOMEFOS is also an absolute measurement system giving it the advantages of coordinate measuring machines combined with interferometric accuracy.

In this paper we describe e.g. the research that was needed for good spiral polishing in order to prevent mid-spatial generation on our (size limited) Zeeko FJP600 polishing robot.

The initial error after grinding and pre-polishing was almost 6 µm. This data was obtained by measuring more than 2 million data points in about 15 minutes (data spacing 0.4 mm). Such high point density and absolute measurement data cannot be achieved in such short time with any other state of the art 3D metrology instruments. This high point density is especially useful to reveal mid-spatials that are inherent to corrective (local) machining processes. The final result after 5 polishing runs was about 300 nm PV and 27 nm rms. Principally the amount of polishing runs could have been less, but that was not possible because of the used polishing cloth that had a lifetime of about 5 hours.

8126-47, Poster Session
New approach for pre-polish grinding with low subsurface damage
J. B. Johnson, D. W. Kim, College of Optical Sciences, The Univ. of Arizona (United States); R. E. Parks, College of Optical Sciences, The Univ. of Arizona (United States) and Optical Perspectives Group, LLC (United States); J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

For an optical surface to be properly prepared, the amount of material removed during polishing must be greater than the volume of grinding damage. An intermediate stage grind between loose abrasive figuring and polishing can reduce the total volume of subsurface damage. This results in less time and expense needed during the polishing phase. We investigated the grinding rate and subsurface damage depth for Trizact diamond tile pads. Trizact shows a sizeable reduction in the overall subsurface damage compared to loose abrasives. This understanding of the abrasive behavior allows us to create a better grinding schedule that more efficiently removes material and finishing with less overall damage than traditional loose abrasives.

8126-48, Poster Session
Optical contacting of low-expansion materials
G. Kalkowski, M. Rohde, C. Rothhardt, S. Risse, R. Eberhardt, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

We report on direct bonding of glass to glass for optical and precision engineering applications. Fused silica (SiO2) and ultra-low-expansion (ULE) glass materials with coefficients of thermal expansion of about 5*10-7/K and 1*10-8/K at room temperature, respectively, were investigated. Large glass wafers of up to 150 mm diameter and about 1.5 mm thickness were bonded to massive glass substrates of up to 20 mm thickness.

Successful bonding was achieved after extensive chemical cleaning and low pressure plasma surface activation, using a commercial wafer bonding equipment. High quality (optically transparent) bonds with a very low fraction of aerial defects were obtained at relatively low temperatures under compressive forces of several tens of KN in a high vacuum environment. Typically, only small unbound locations occurred at the rim, where insufficient pressure had been applied in the bonding process.

Bonding strengths were estimated from destructive “razor-blade” testing of bonded wafer pairs /1/ and resulted in bond energies up to about 2 J/ m² for bonding temperatures of only 250° Celsius. For surface activation, N2-plasma was found to give slightly stronger bonds than O2 plasma. Under nominally identical bonding conditions with respect to temperature and pressure, N2 plasma was found to give slightly stronger bonds than O2 plasma. Although influences of surface roughness cannot be fully excluded, ULE materials also appear to bond slightly stronger than fused silica, in general.

This work was supported by BMBF/DLR (Germany) under contract No. 50YB0814.

8126-49, Poster Session
A novel packaging method for stable microsphere coupling system
S. Yan, W. Zhang, North Univ. of China (China)

A novel method to enhance the robustness of the microcavity coupling system (MCS) is presented by encapsulating and solidifying the MCS with a low refractive index (RI) curable UV polymer. The process is illustrated in detail for a typical microsphere with a radius R about 240µm. Three differences of the resonant characteristics before and after the package are observed and analyzed. The first two differences refer to the enhancement of the coupling strength and the shift of the resonant spectrum to the longer wavelength, which are both mainly because of the microsphere surrounding RI variation. Another difference is the quality factor (Q-factor) which decreases after the package due to the polymer absorption. Moreover, Experimental results demonstrate that the packaged MCR has much better robust performance than the un-package sample.

The enhancement of the robustness greatly promotes the microcavity research from fundamental investigations to application fields.

8126-50, Poster Session
The photoanisotropy in the holographic media on the basis of silver halide emulsion
V. G. Shaverdova, S. S. Petrova, A. L. Purtseladze, V. I.
The experimental results of the induced photoanisotropy in the media on the basis of small and super small grained color-sensitive silver halide emulsions are presented. It was shown that in the given layers after the irradiation of the polarized light with wave-length actinic for the given sensitizer and of the following specific development the photoinduced anisotropy was visualized. It turns out that weakly expressed anisotropy of the latent image multiplied more than on the two order of magnitude. The high stability, the possibility of working in the red region and with low power energy sources, with wide controlled characteristics are represented the main advantage of such media. As it was shown in this investigation, value of the photo anisotropic parameters can change in wide-ranging after the specific physicochemical treatment: hypersensitizing, specific worked out developers, thermal treatment, fixing (in case of need). Each of the procedure has such essential value, that the separated examination was needed. Some technological regimes which reduced to the optimization of the parameters of the photo anisotropy are presented. Quantitative measurements have been spent on the spectrosensitometer, by the polarized radiation of a photometric lamp spread out in a spectrum. The measurements energy of the wavelength were spent in the focus of the device by means of the thermoelectric receiver having possibility to move smoothly on a scale of wavelength. Complex birefringence was measured on modernized spectrophotometer. The exposure and spectral characteristics of photoanisotropy was given. It was shown the possibility of carry out polarization-holographic diffraction elements on this material.

8126-51, Poster Session  

**Development of high-performance, stable, and moisture-resistant polarization-sensitive materials**

I. Chaganava, G. A. Kakauridze, B. N. Kilosanidze, G. Datukishvili, Institute of Cybernetics (Georgia)

Existing high-performance stable polarization sensitive materials based on bisazoxydes introduced into water-soluble polymer matrices (particularly, on the basis of modified azodye Mordant Pure Yellow M) require a protection against external moisture. By-turn this decreases the advantage of such materials and limits the field of their application. There are developed new stable polarization sensitive media on the basis of the hydrophobic components which does not require an additional protection from moisture. The lipophilic bisazoxyde tolidine derived ortho-tolidinebisazophenol chromophoric component is specially synthesized which is liposoluble analogue of water-soluble Mordant Pure Yellow M. Materials was obtained on the basis of this bisazoxyde introduced in different polymers. These moisture resistant materials at the same time can be applied as a protective layer that improves the efficiency of the materials. The difference between the nature of the solubility of media effectively isolates the recording layers from each other. To increase the thermal stability of the material we have synthesized media by the introduction bisazoxyde into the chemical composition of macromolecules main chain of thermally stable, transparent, hydrophobic and amorphous polymer with a linear structure. The kinetic of inducing photoanisotropy of the obtained materials was investigated. The study of photoanisotropic properties of the obtained main chain materials showed the possibility of their work both in a stable and dynamic regime. The different types of polarization holographic gratings with high diffraction efficiency of 30-50% were recorded on the obtained materials by laser beams in the wavelength range of 441 - 486 nm.

8126-22, Session 5  
**Electronic speckle pattern interferometric testing of JWST primary mirror segment assembly**

K. Z. Smith, D. M. Chaney, Ball Aerospace & Technologies Corp. (United States); B. N. Sair, NASA Goddard Space Flight Ctr. (United States)

The James Webb Space Telescope (JWST) Primary Mirror Segment Assembly (PMSA) was required to meet NASA Technology Readiness Level (TRL) 06 requirements in the summer of 2006. These TRL06 requirements included verifying all mirror technology systems level readiness in simulated end-to-end operating conditions. In order to support the aggressive development and technology readiness schedule for the JWST Primary Mirror Segment Assembly (PMSA), a novel approach was implemented to verify the nanometer surface figure distortion effects on an in-process non-polished beryllium mirror surface. At the time that the TRL06 requirements needed to be met, a polished mirror segment had not yet been produced that could have utilized the baseline interferometric optical test station. The only JWST mirror segment available was a finished machined segment with an acid-etched optical surface. Therefore an Electronic Speckle Pattern Interferometer (ESPI) was used in coordination with additional metrology techniques to perform interferometric level optical testing on a non-optical surface. An accelerated, rigorous certification program was quickly developed for the ESPI to be used with the unfinished optical surface of the primary mirror segment. The ESPI was quickly implemented into the PMSA test program and optical testing was very successful in quantifying the nanometer level surface figure deformation changes in the PMSA due to assembly, thermal cycling, vibration, and acoustic testing. As a result of the successful testing, the PMSA passed all NASA TRL06 readiness requirements.

8126-23, Session 5  
**Cryogenic optical testing results of JWST aspheric test plate lens**

K. Z. Smith, T. C. Towell, Ball Aerospace & Technologies Corp. (United States)

The James Webb Space Telescope (JWST) Secondary Mirror Assembly (SMA) is a circular 740mm diameter beryllium convex hyperboloid that has a 23.5nm-RMS / 27 RMS on-orbit surface figure error requirement.
The radius of curvature of the SMA is 1778.9113mm±0.45mm and has a conic constant of -1.6598×0.0005. The on-orbit operating temperature of the JWST SMA is 22.5K. Ball Aerospace & Technologies Corp. (BATC) is under contract to Northrop Grumman Aerospace Systems (NGAS) to fabricate, assemble, and test the JWST SMA to its on-orbit requirements including the optical testing of the SMA at its cryogenic operating temperature. BATC has fabricated and tested an Aspheric Test Plate Lens (ATPL) that is an 800mm diameter fused silica lens used as the Fizeau optical reference in the ambient and cryogenic optical testing of the JWST Secondary Mirror Assembly (SMA). As the optical reference for the SMA optical test, the concave optical surface of the ATPL is required to be verified at the same 20K temperature range required for the SMA. In order to meet this objective, a state-of-the-art helium cryogenic testing facility was developed to support the optical testing requirements of a number of the JWST optical testing needs, including the ATPL and SMA. With the implementation of this cryogenic testing facility, the ATPL was successfully cryogenically tested and performed to less than 10nm-RMS ( /63 RMS) surface figure error levels for proper reference backout during the SMA optical testing program.

8126-24, Session 5

The design of MTF test system based on point light source

R. Fu, Nanjing Univ. of Science & Technology (China)

The MTF test system consists of point light source, off-axis parabolic mirror, image acquisition system, stepping motor control system and the computer. The white light passes through a group of high-precision microscope and forms a point light source which is located in the focus point of an off-axis parabolic reflector modules, the light is reflected by the off-axis parabolic reflector and becomes parallel light beam. The focus length of the off-axis parabolic mirror is 1000mm. A sample lens is merged in the light beam, it can converge the light on its focus point and form the Airy circle. The Airy circle was enlarged by the high-precision microscope and is obtained by the CCD camera through delay lens. The stepper motor controls the position of the high-precision microscope and CCD through a two-dimensional mobile platform, so as to insure the Airy circle is in the focus of the high-precision microscope. The image acquired by the CCD is transferred to the computer through image capture devices card. After image preprocessing, the data passed to the calculation module of MTF information processing, and finally get the MTF of the lens.

The results of this test system in the middle-frequency part show more consistent, but a moderate low-frequency part of the curve down, high-frequency part, they fall very quickly. The following factors are response on possible deviation, the deviation caused by optical imaging system, the deviation caused by CCD, the deviation caused by Stepping Motor.

8126-25, Session 5

The optical metrology system for cryogenic testing of the JWST primary mirror segments

J. B. Hadaway, The Univ. of Alabama in Huntsville (United States); D. M. Chaney, L. B. Carey, Ball Aerospace & Technologies Corp. (United States)

The James Webb Space Telescope (JWST) primary mirror is 6.6 m in diameter and consists of 18 hexagonal mirror segments each approximately 1.5 m point-to-point. Each primary mirror segment assembly (PMSA) is constructed from a lightweight beryllium substrate with both a radius-of-curvature actuation system and a six degree-of-freedom hexapod actuation system. With the JWST being a near to mid-infrared observatory, the nominal operational temperature of a PMSA is 45 K. Each PMSA must be optically tested at 45 K twice, first to measure the change in the surface figure & radius-of-curvature between ambient & cryogenic temperatures and then to verify performance at cryo following final polishing. This testing is conducted at Marshall Space Flight Center’s (MSFC’s) X-Ray & Cryogenic Facility (XRCF). The chamber & metrology system can accommodate up to six PMSAs per cryo test. This paper will describe the optical metrology system used during PMSA cryogenic testing. This system evolved from systems used during the JWST mirror technology development program. The main components include a high-speed interferometer, a computer-generated holographic null, an absolute distance meter, a tiltable window, and an imaging system for alignment. The optical metrology system is used to measure surface figure error, radius-of-curvature, conic constant, prescription alignment, clear aperture, and the range & resolution of the PMSA actuation systems.

8126-26, Session 5

Nanometer profile measurement of large aspheric optical surface by scanning deflectometry with rotatable devices

M. Xiao, S. Jujo, S. Takahashi, K. Takamasu, The Univ. of Tokyo (Japan)

High accuracy mirrors and lenses with large dimension are widely used in the huge telescopes and other industry filed. For measuring near flat surface and spherical optical surfaces, interferometers are widely used because of their high accuracy and high efficiency. Scanning deflectometry is also used for measuring optical near flat surface with uncertainty of sub-nanometer. However, for measuring aspheric surface with large departure from perfect spherical surface both of these methods are difficult to use. The key problem for scanning deflectometry is that high accuracy autocollimators usually have limited measuring range which is less than 1000 arc-second, so it cannot be used for measuring surface with large slope. We have proposed a new method for measuring large aspheric surface with large slope based on scanning deflectometry method. Rotatable devices are used to enlarge the measuring range of autocollimator. We proposed a method to connect the angle data which are cut by the rotation of the rotatable devices. The error caused by the rotation is propagated. The uncertainty propagation analysis of our proposed method is done. The simulation result shows that when measuring a large aspheric surface with a diameter over 300 mm and with a slope of 10 arc-degrees the uncertainty is less than 30 nanometers. Numerical simulation is also done to show that the analysis match the analysis well. For the verification of our proposed method, experimental devices are set up. A spherical optical surface with diameter of 35 mm and curvature radius of 5000 mm is measured. Measuring range of autocollimator is successfully enlarged by our proposed method. Experimental result shows that the standard deviation of 10 times measurement is less than 20 nm which is larger than the theoretical value. Random drift and systematic error is found in the experiment result. Temperature drift is considered to be the main reason for the systematic error.

8126-20, Session 6

A complete qualification methodology for coatings of precision glass molding tools

K. Georgiadis, O. Dambon, F. Klocke, Fraunhofer-Institut für Produktionstechnologie (Germany)

The demand for complex-shaped optical components is rapidly rising, driven by their significant advantages over traditional optics. Precision glasses molding, a replicative process where a glass blank is heated and isothermally pressed between high precision molds, is the technology of choice for the production of complex-shaped optical components. However, significant thermal, mechanical and chemical loads during the process limit the lifetime of the molds. Protective coatings can significantly extend their lifetime and are therefore necessary in order
Commercialising corrective polishing technology to maintain a global competitive edge in the first 10 years of Zeeko

R. R. Freeman, Zeeko Ltd. (United Kingdom)

Zeeko launched its first aspheric polishing machine in 2001 4 years after the MRF machine had been introduced and so well received by the global optics industry. Having entered the market second, in order to succeed the Zeeko solution had to offer functionality and performance that the market leader was unable to provide. Initially product sales were slow but this paper tells the story of the way that the early launch of a genuine free-form software solution coupled with the combining of multiple ablation solutions (Bonnet “Classic” polishing, ZeekoJet polishing, pitch polishing and Grolishing) on one platform helped Zeeko establish a competitive offering. Having successfully positioned its more universal technology in the market place, machines, software and metrology began to evolve in a most interesting way. The paper describes this evolution in detail examining the innovation and technological developments that real life applications drove into the product offering. It describes developments on the software side, with the creation of a “Metrology Toolkit” that provided multiple and universal import/ export interfaces for metrology data and CAD data for a wide array of different metrology and CAD packages. The introduction of various stitching solutions is described to provide pseudo 3-D surface data maps for use by the corrective polisher as well as the handling of difficulties such as interferometer image distortion that had to be accommodated as optical metrology stepped from the analogue to the digital domain. The paper finally concludes with evolution and the introduction of on-machine metrology solutions for large optics fabrication that have been seamlessly integrated with the controls system of the polisher itself.

8126-30, Session 6

From Herschel to Gaia: 3-meter class SiC space optics

M. Bougoin, J. Lavenac, BOOSTEC S.A. (France)

Herschel and Gaia are two cornerstone missions of ESA which embark 3 - meter class optics. These instruments require so high thermal and mechanical stability that the SiC technology turned out to be indispensable. The Boostec SiC material has been selected first for its high specific stiffness and thermal stability. But it also shows a perfect isotropy of all its physical properties and it is remarkably more stable than the glass-ceramics in time and also against space radiations. This SiC material has furthermore been fully qualified for application at cryogenic temperature (Herschel and also JWST NIRSpec). The Boostec manufacturing technology of very large size SiC components includes i) manufacturing 1.5 - meter class monolithic sintered parts and then ii) assembly based on a brazing process. The former one is a near net shaping process which allows manufacturing at reasonable costs and also within short time.

Herschel is one of the six telescopes made of Boostec SiC which are successfully operating in space. It includes a 3.5 m primary mirror, a secondary mirror and an hexapod. It weighs only 315 kg and its WFE is kept below 6 μm rms despite an operating temperature of 70 K. Gaia is made of more than 280 SiC parts of 80 different types. The most challenging of them is undoubtedly its highly stable structure, the 3 meters torus. This quasi octagonal and hollow shaped ring is made of 19 SiC elements brazed together. It weighs only 200 kg. All the Gaia hardware has been successfully manufactured and it is now being integrated and tested at Astrium facilities.

8126-53, Session 6

Fluid jet and bonnet polishing of optical moulds for applications from visible to x-ray

A. T. H. Beaucamp, Zeeko Ltd. (United Kingdom) and Chubu Univ. (Japan); R. R. Freeman, Zeeko Ltd. (United Kingdom); A. Matsumoto, Y. Namba, Chubu Univ. (Japan)

Electroless Nickel (ENi) and binderless Tungsten Carbide (WC) are widely used to make replication moulds for optics ranging from consumer camera lenses to highaccuracy X-ray mirrors. Aspheric shape generation is generally performed by diamond turning in the case of Nickel, and micro-grinding in the case of Tungsten Carbide. Both machining methods fail in general to meet the ultra-precision criteria required by an increasing number of applications. A 7-axis CNC machine equipped with sub-aperture fluid jet and precessed bonnet polishing technology was used to develop deterministic finishing processes on both Electroless Nickel and Tungsten Carbide. Corrective polishing to less than λ/20 (<31nm PV) form error can be achieved, as well as the ability to smooth surface texture down to 1nm Ra or less.

8126-31, Session 7

Recent developments on swing arm optical CMM: self-calibration and measuring optical surfaces in grinding stage

P. Su, Y. Wang, C. J. Oh, R. E. Parks, J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

The Swing arm Optical CMM (SOC) is an important metrology technique for highly aspheric surface testing because of its versatility. It is configurable for measuring concave, convex and plano surfaces, it can make in situ measurements, and it has high precision performance rivaling full aperture interferometric tests. Errors in the SOC bearing that have odd symmetry are self-calibrated due to the test geometry. In the past, even bearing errors were calibrated against a full aperture interferometric test. Recently, we developed a dual probe self calibration mode for the SOC. Data from the dual probes can be used to calibrate the swing-arm air bearing errors since both probes see the same bearing errors while measuring different portions of the test surface. With the dual probe model, the SOC can be fully self-calibrated without requiring any external reference.

Until recently, the SOC has only been used for measuring polished surfaces due to limitations imposed using the interferometric probes. To enlarge the measurement range of the SOC, we have developed a systematic data reduction model and calibration procedure for a laser triangulation (LT) probe. The calibrated probe is insensitive to the surface angle variation during the measurement. With the LT probe, the SOC
has been used to measure highly aspheric optical surfaces during their grinding stage. Initial measurement results from a ground surface with an aspheric departure of 1.8mm and angular variation of the normals of more than 1 degree show that the SOC with the LT probe can make measurements with an accuracy better than 0.25micron rms and is limited by the calibration of the probe scaling effect.

8126-32, Session 7

**Total integrated scatter from moderately rough surfaces with arbitrary correlation widths and incident angles**

J. E. Harvey, N. Choi, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); S. Shroeder, A. Duparre, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Surface scatter effects from residual optical fabrication errors can severely degrade optical performance. The total integrated scatter (TIS) from a given mirror surface is determined by the ratio of the spatial frequency banded-limited or “relevant” rms surface roughness to the wavelength of light. For short-wavelength (EUV/X-ray) applications, even state-of-the-art optical surfaces can scatter a significant fraction for the total reflected light. In this paper we present parametric plots of the TIS for optical surfaces with arbitrary roughness, surface correlation widths and incident angles. Surfaces with both Gaussian and ABC or K-correlation power spectral density (PSD) functions have been modeled. These parametric TIS predictions provide insight necessary to determine realistic optical fabrication tolerances necessary to satisfy specific optical performance requirements.

8126-33, Session 7

**Extended range roughness measurements in non-ideal environments**

K. Creath, 4D Technology Corp. (United States) and College of Optical Sciences, The Univ. of Arizona (United States)

This paper describes recent research into developing extended range dynamic interferometry where the range can be extended to enhance surface roughness measurements made in non-ideal environments. These techniques do not require expensive vibration isolation systems. Since this is ongoing research, we will be providing an up-to-date review of the techniques and experiments showing recent results.

8126-34, Session 7

**High-speed and -accuracy measurement of optical rotation by liquid crystal modulators**

M. Tanaka, Y. Nakashima, H. Amamiya, Atago Co., Ltd. (Japan); Y. Otani, Utsunomiya Univ. (Japan)

Optical characteristics of material that has optical activity have been used for the concentration measurement of the saccharide and amino acid for a long time. Some principal of optical rotation measurement techniques have been proposed by a rotating polarizer method, a Faraday cell method. A high-speed and high-accuracy measurement of optical rotation is proposed by dual liquid crystal polarized modulators which are pecialized multi-stacked cells with over-drive method for high speed drive.

8126-35, Session 7

**Instantaneous measurement Fizeau interferometer with high-spatial resolution**

D. Sykora, Zygo Corporation (United States)

Surface and wavefront metrology in vibration prone and turbulent environments often require that multiple phase shifts be encoded onto the interference signal within a single shuttered camera frame, typically of 100 μsec integration time, to adequately freeze the environmental disturbance and acquire quality signal data. The use of full-sensor single camera architectures mitigates critical alignment and signal balancing required of alternative simultaneous multi-image detection. Localized spatial phase shifting has been implemented in this full-sensor technique to extract the phase at each pixel through introduction of a carrier fringe. We report here on a new instantaneous Fizeau-type interferometer optimized for light-efficient single-frame carrier fringe acquisition that avoids the troublesome phase sensitivity to birefringence of polarization-based approaches. Fully coherent optics designed to perform with large slope differentials between interfering wavefronts provide maximized spatial resolution and instrument transfer function (ITF) beyond 250 cycles/aperture at all zoom settings. Results are documented for measurement of an etched phase step and custom periodic artifact. ITF beyond 500 cycles/aperture is also reported for an optional configuration where temporal phase shifting interferometry is enabled.

8126-36, Session 8

**Air-driving fluid jet polishing**

Z. Yu, C. Kuo, C. Chen, W. Hsu, Instrument Technology Research Ctr. (Taiwan); D. P. Tsai, Instrument Technology Research Ctr. (Taiwan) and National Taiwan Univ. (Taiwan)

The fluid jet polishing (FJP) is widely used for modern optical fabrication in recent years. FJP was originated from the demand for steep concave or complex aspherical elements and the inability of the conventional polishing for those elements. However, FJP method has to pump the slurry in a high pressure, in order to have the energy for material removal. In this study, we proposed an air-driving FJP system which draws slurry utilizing an air/water mixer. The air-driving FJP system is mainly composed by an air/water mixer, compressed air, pressure and flow rate regulators, and a nozzle. The high speed air flow in the air/water mixer draws out the slurry from the slurry tank, and the slurry is guided to mix with air flow inside the nozzle cavity. Then, the combined fluid slurry is emitted from the nozzle. The air-driving FJP system was preliminarily tested on N-BK7 and ZERODUR® plates with different air pressure and dwell time.

The test results show that the air-driving system could get a Gaussian-like removal shape with 3 kg/cm2 compressed air source and the depth of removal is about 100 nm within 5 seconds dwell time. The compressed air improves the kinetic energy of each abrasive, and makes it more efficient in material removal. Furthermore, the Gaussian-like removal shape is more convenient for tool path planning and surface waviness control of corrective polishing.

8126-37, Session 8

**Optical bonding reinforced by femtosecond laser welding**

F. Lacroix, Institut Franco-Allemand de Recherches de Saint-Louis (France); D. Hélie, R. Vallée, Univ. Laval (Canada)

Since a few years micro-welding by femtosecond (fs) laser pulses of dielectrics has demonstrated a great potential for micro-optical manufacturing. However, fs laser micro-welding of dielectrics created some variation of the refractive index which can be considered as optical defects for an optical component. We have demonstrated the capability
to realize bonding of large optical components with or without optical coating by direct bonding reinforced by fs laser micro-welding.

The first step consists in creating a direct optical bonding free of any impurity between the two pieces to join. In a second step, the contact field is sealed by fs laser welding. This technique creates a sealed direct bonding surface free of any adhesive between the two substrates which can be as different as silicon and fused silica or BK7 and fused silica windows. Even though direct bonding is mechanically strong, it does not resist well to elastic or plastic deformation. Different thermal dilatation of the assembled pieces might be catastrophic for direct contact bonding. By fs laser sealing of the direct contact bonding surface, we reinforce the effective bond of the two pieces, which now can support thermal shock. This bond is free of any impurity, any adhesive, any organic vapour and there is no risk of coloration by ageing of an organic adhesive.

This technique may be used to create a sandwich of doped and undoped materials to realize laser active media which can be pumped by wave guide effect in the un-doped material and which is reinforced against thermal lens effect.

8126-38, Session 8
Incorporating VIBE into the precision optics manufacturing process
J. DeGroote Nelson, A. Gould, C. Klinger, R. A. Wiederhold, M. Mandina, Optimax Systems, Inc. (United States)

The VIBE process is a full-aperture, conformal polishing process incorporating high frequency and random motion designed to rapidly remove sub-surface damage in a VIBE pre-polish step and eliminate mid-spatial frequency (MSF) errors in a VIBE finishing step. The VIBE process has potential to be introduced in two areas of today’s modern optics manufacturing process. The first instance is replacing the conventional pre-polishing step with the rapid VIBE pre-polish step. Results will be discussed in this paper that show 10 - 50x higher removal rates compared to conventional polishing for a variety of optical materials. High removal rates combined with the compliant lap results in damage-free surfaces that have the same form that was generated by the CNC generation process for spherical and non-spherical surfaces. The second potential area to incorporate VIBE into today’s modern optics manufacturing process is as a finishing step after deterministic sub-aperture polishing to remove mid-spatial frequency errors. By selectively altering the compliant properties of the VIBE pad, and adjusting the frequency of the VIBE motion, VIBE finishing can reduce the mid-spatial frequencies caused from sub-aperture polishing processes while maintaining the desired corrected surface form. This paper will serve as an in-depth review of the VIBE process and how it complements other modern CNC optics manufacturing technologies, as well as highlighting recent VIBE advances specifically in the area of conformal optic fabrication.

8126-39, Session 8
Computer-aided manufacturing for freeform optical elements by ultraprecision micromilling
S. Stoebenau, R. M. Kleindienst, M. Hofmann, S. Sinzinger, Technische Univ. Ilmenau (Germany)

The successful application of computer-aided manufacturing (CAM) is a key issue for the fabrication of freeform optical elements. Different classes of freeform surfaces demand for specific CNC-code programming techniques. Two strategies have been exploited and will be presented in our contribution. The first strategy is adopted to handle freeform surfaces that can be described analytically by polynomial equations. As a versatile example used e.g. in integrated optical microsystems, the fabrication of an astigmatic biconic lens by ultraprecision micromilling is investigated. We took advantage of the direct programming capabilities arising from state-of-the-art machine controls. The tooling trajectories are calculated by the control unit during the machining process. The calculations comprise the solution of the polynomial equations that define the shape and the local slope necessary for a tool cutting edge radius compensation. The second strategy is a more classical implementation of the CAM process. Herein, the preliminary results from the optical designing process are transferred into a CAD/CAM software module by means of a solid model. As this procedure doesn’t necessarily need a closed analytical description of the surface it is the most general solution. The solid model in combination with a very precise knowledge about the cutting edge geometry allows for a premachining calculation of the tooling trajectories. As an example for this strategy, a freeform element integrating different optical functionalities (laser beam deflection and shaping) has been fabricated. We present the design strategies, the fabrication process and finally the characterization concerning surface quality, shape accuracy and optical performance.

8126-40, Session 8
Calibration and optimization of computer-controlled optical surfacing for large optics
D. W. Kim, College of Optical Sciences, The Univ. of Arizona (United States); H. M. Martin, The Univ. of Arizona (United States); J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

Precision optical surfaces can be efficiently manufactured using a computer controlled optical surfacing (CCOS) process. Most of the CCOS processes are based on the dwell time control of a fabrication tool on the workpiece according to the desired removal and tool influence function (TIF), which is the material wear function by the tool. Some major topics to improve current CCOS processes were investigated to provide new solutions for the next generation CCOS processes. A rigid conformal (RC) lap using a visco-elastic non-Newtonian medium was newly invented. It conforms to the aspheric surface shape, yet maintains stability to provide natural smoothing. The smoothing removes mid-to-high frequency errors while a large tool runs over the workpiece to remove low frequency errors. A parametric smoothing model was also introduced to predict the smoothing effects. A parametric edge TIF model to represent measured edge TIFs was developed and demonstrated. This model covers the non-linear removal behavior as the tool overhangs the workpiece edge. These new tools and models were applied to a new process optimization technique called non-sequential optimization. The non-sequential approach performs a comprehensive dwell time optimization using multiple TIFs for the entire CCOS runs simultaneously. An overview of these newly implemented CCOS features will be presented with some actual CCOS run results.

8126-41, Session 8
Centration of optical elements
E. Milby, J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

Axisymmetric optical components such as lenses are frequently centered with the use of rotary air bearings, guided by optical instrumentation that uses reflected or transmitted light. When the position of the element is adjusted to null the error from the optical test, the element is potted in place using an adhesive. This paper systematically explores methods of adjusting the elements and potting them in place with a goal of defining the accuracy that can be expected. Analysis of the performance is supported with experimental data.
8127-01, Session 1

Design of nonparaxial optical systems with refractive and diffractive elements on a base of the local thin optics model

M. A. Golub, Tel Aviv Univ. (Israel)

Whereas quality optical systems demand essentially nonparaxial geometrical optics, diffraction calculations are often restricted to paraxial approximation and thin lens model of Fourier optics. However main and ghost nonparaxial diffraction orders must be considered in the frame of polychromatic interference and diffraction of physical optics. Straightforward calculation of numerically approximated diffraction integrals between each pair of sequential optical surfaces suffers from accumulated sampling and aliasing errors, and seems not practical for complex and diffraction limited optical systems. The problem is not only in limited capabilities of modern computers and high space-bandwidth product but in optimizing a solution before deep understanding of a model. We built and implemented a model of cascaded optical systems combining modern optical design with ideas of photonic structures, by exploiting geometrical optics at large number of smooth optical surfaces and diffraction on a single diffractive surface. Non-paraxial estimations for an impact of wavelength change, mismatch of diffractive groove depths, phase nonlinearity, and staircase approximation were derived. Finally, we developed (a) generalized ray-tracing method for diffractive, refractive and reflective surfaces based on finding a local focus position by direct calculation of local wavefront curvatures; (b) separated ray-tracing for several diffractions orders with subsequent superposition of their complex amplitudes with complex weight coefficients derived from diffraction efficiencies and phases; (c) equivalent lens method for multi-lens systems; (d) closed form analytical solutions for diffraction efficiency at resonance domain surface relief photonic structures with period slightly exceeding the wavelength. Applied optical systems were successfully modeled.

8127-02, Session 1

Reverse optimization in physical optics modeling

G. N. Lawrence, Applied Optics Research (United States); A. W. Yu, NASA Goddard Space Flight Ctr. (United States)

In reverse optimization, one begins with a nominal design assuming that is perfectly manufactured and perfectly aligned. The parameters of the design are then adjusted so that the performance matches experimentally determined performance. Reverse optimization is a means of determining the internal details of the system. Reverse optimization can identify the internal root causes of the effects and provide the exact prescription ready for immediate implementation in system improvement.

In the late 80's reverse optimization using geometrical ray tracing was applied to the alignment of complex, highly asymmetric mirror systems using a Hartmann sensor and a lens design optimization program that employed ray tracing and damped least squares (DLS) optimization. All models of misalignment were found by misaligning the ideal system to find the best fit to the experimental data. A full prescription of all misalignments could be found and all corrections applied simultaneously.

With the great advances in computer speed, we can now apply the reverse optimization method to full physical optics systems including full diffraction at all steps, laser gain, nonlinear optics, resonant oscillations, etc. The targets for DLS optimization may consist of specific performance measures and wavefront or irradiance maps that may consist of many millions of points. Wavefront and irradiance maps are often available from widely available beam diagnostic instruments.

With many millions of targets, some reformulation of the DLS mathematics is in order to skip explicit intermediate steps, speed the calculations, and remove memory redundancy with on-the-fly calculation. Some simple examples will serve to illustrate the capability of the reverse optimization method.

8127-03, Session 1

Optical modeling of the NASA high output maximum efficiency resonator (HOMER) laser

G. N. Lawrence, Applied Optics Research (United States); D. B. Coyle, D. Poullos, A. W. Yu, NASA Goddard Space Flight Ctr. (United States)

The NASA High Output Maximum Efficiency Resonator (HOMER) laser is intended for the DESDynl mission (Deformation, Ecosystems Structure and Dynamics of Ice), under design by the NASA-GSFC. This device employs a zigzag amplifier, complex diode side pumping, a graded reflectivity mirror (GRM), and an unstable resonator configuration. For modeling the zigzag amplifier, a 3D exact pixel matching algorithm has been developed that can consider misalignments resulting from full complexity in the 3D volume. In spite of the many millions of points in the volume, the exact pixel matching algorithm facilitates rapid calculation. We report progress to incorporate thermal modeling, detailed diode side pumping, GRM, and unstable resonator convergence into the model.

Central issues in the modeling include methods of streamlining the calculations and efficient handling of the gigabyte data that require 64 bit code and a high degree of multithreading. The system is studied for pitch and yaw stability of the end mirrors, detailed defects and failures of individual diode pumps, and other real-world errors in the system that could affect long term performance.

8127-04, Session 1

New phase retrieval for single-shot x-ray Talbot imaging using windowed Fourier transform method


We propose a new phase retrieval technique using a Windowed Fourier Transform (WFT) method for single-shot X-ray Talbot imaging. The WFT method has been studied to improve the noise robustness of the Fourier Transform (FT) method. In the WFT method, the phase map is retrieved from the spectrum corresponding to the carrier fringe, and the spatial resolution increases as the window function narrows. However, the spatial resolution is limited because an undesired pattern is superposed on the retrieved phase map when the width of window function is narrower than a certain size.

In our proposed method, we introduce an additional step to remove the undesired pattern from the phase map. In the case of the narrow window function, the WFT spectrum including the phase information is overlapped by other extended spectra. This overlap interferes with the retrieved phase and causes the undesired pattern. The additional step removes the overlaps from the desired spectrum analytically. By using the additional step, the high-resolution phase map can be obtained because the window function can be narrower than that of the original WFT method.

In this presentation, we demonstrate phase retrieval of a fringe pattern obtained by the two-dimensional X-ray Talbot interferometer using the proposed WFT method. The differential phase maps of a complex shaped object along both x- and y- axes were retrieved from a single fringe pattern. Compared to the previous FT method, differential phase maps were obtained in high resolution with an effective noise reduction.
8127-05, Session 1

Lambert's multiple reflection model revisited
C. F. Hahlweg, Helmut-Schmidt Univ. (Germany)

In last years paper on the idea of Lambertian reflection we gave a partial translation of an almost lost chapter by Johann Heinrich Lambert on multiple reflection in dioptric systems as a gimmick. The problem of multiple reflections in optical systems and appropriate counteractive measures is of special interest in scatterometric devices, but also in high dynamic range imaging. The present paper is dedicated to a deeper discussion of the model proposed by Lambert. This leads - besides the use of ray tracing methods for direct simulation - to a system theoretical approach including the Fourier optical consequences. Further a revision and completion of the translation will be given in the appendix.

8127-06, Session 1

Fourier planes vs. Scheimpflug principle in microscopic and scatterometric devices
C. F. Hahlweg, Helmut-Schmidt Univ. (Germany)

Scatterometric methods usually concentrate on gathering and analyzing scatter distributions in power domain. The analysis is mainly based on the relation between scatter distribution and fourier tranform of the reflection function of the surface under consideration. Imaging scatterometers in principle gather the fourier image of the illuminated spot, which in microscopy would be the primary diffraction image. Therefore imaging scatterometers can be used as microscopes as well, which requires an additional positive lens or equivalent mirror. It is obvious that combined designs are interesting in surface inspection: because of the loss of phase information in both direct and scatter image, there is still non-redundant information besides the intersection set of both images. For the design and adjustment of such combined devices it is of high interest to identify the fourier images. While a more or less paraxial dioptric device in orthogonal view has well defined fourier planes, in an off-axis device with paraboloid or elliptical mirrors the fourier image is concerned by the Scheimpflug relations, further by a significant vignetting effect, which have to be considered in design and alignment. In the present paper we discuss theory and practical applications and design and adjustment strategies.

8127-23, Session 1

System gain optimization in direction detection lidar system
L. Wu, Y. Zhao, Y. Zhang, Y. Zhang, J. Wu, Harbin Institute of Technology (China)

This paper presents an equivalent direct detection receiver model by statistical method which simplifies the random impulse responses of electrons counting of returned signal, background radiation and dark current as a Gaussian random process with high enough gain. An investigation based on Gaussian distribution of system output in ICCD scannerless range-gated Lidar system is conducted with the calculations of error probability, absolute error and relative error. As the unique manipulated variable, optimized system gains are calculated separately based on the Gaussian model of the random process to achieve the lowest error probability, the lowest absolute error and relative error. The simulations show that the values of optimized gains tend to increase along with the target distance, although the increasing speeds are different. To meet multiple requests, an evaluation model based on cost function is constructed with different weights. The simulation shows that the evaluation model is capable of setting optimized gains for different circumstances and the settings of the weights are vital to the performance of Lidar system.
Conference 8127:
Optical Modeling and Performance Predictions V

8127-11, Session 3

A compliant static deformable mirror for wavefront error cancellation

F. E. Penado, Northern Arizona Univ. (United States); J. H. Clark III, U.S. Naval Observatory (United States); J. Dugdale, Lowell Observatory (United States)

The Navy Prototype Optical Interferometer (NPOI) array, located near Flagstaff, Arizona, transports the stellar radiation from six primary collectors through a 9-reflection vacuum relay system, resulting in six separate combinable wavefronts. A total of 54 reflection mirrors (6 collectors x 9 reflections each) is required for all six primary collectors. Ground-based optical interferometry requires very high quality, ideally flat, relay mirrors. In practice, the manufacturing methods available will not produce flat mirrors, so for fabrication purposes the surface error of each of the 54 mirrors is specified to be no greater than 32 nm peak-to-valley. However, once mounted in the 9-element optical train, the errors from each mirror do not necessarily cancel one another, but can actually add and increase the resultant wavefront distortion for that path. This leads to fringe contrast reduction, reduced ability to fringe track, and a reduction in the limiting magnitude of observable objects. In a previous paper, it was shown that it is possible to mitigate the resultant wavefront distortion by using a phase-shifting interferometer combined with a single compliant static deformable mirror and control system. In that work, the mirrors tested showed a fairly uniform, concentric concavity deformation, which a single, centrally located actuator may significantly improve. In this paper, we extend the previous analysis to consider an off-center actuator acting on a mirror having an equivalently deformed surface resulting from the superposition of manufacturing errors of several flat relay mirrors. This initial shape applied to a single mirror was determined from the resultant wavefront distortion of a 7-reflection optical relay system using phase-shifting interferometer data. Finite element analysis results indicating how resultant wavefront error in the initially deformed mirrors can be collectively cancelled are presented and discussed.

8127-12, Session 3

BigBoss Telescope

M. J. Sholl, Univ. of California, Berkeley (United States)

BigBOSS is a proposed DOE-NSF Stage IV ground-based dark energy experiment designed to study baryon acoustic oscillations (BAO) and the growth of large-scale structure with an all-sky galaxy redshift survey. The project involves modification of existing facilities operated by the National Optical Astronomy Observatory (NOAO). Design and systems engineering of a 3 degree field of view transmissive corrector, atmospheric dispersion corrector, and 5000 actuator fiber positioning system are presented. Areas discussed include overall systems engineering budgets, survey plan, optical performance, throughput, thermal design and stray light.

8127-13, Session 3

Method for integration strain analysis as applied to the James Webb Space Telescope integration process

K. Dziak, K. M. Patterson, ITT Corp. Geospatial Systems (United States); C. L. Buttaccio, MSC.Software Corp. (United States)

When assembling a telescope structure for optimal performance in a zero gravity environment, it is desirable to assemble the structure in such a manner as to minimize residual stress and strain in the structure in its final zero gravity operating environment. Since satellite telescopes are assembled in a gravity field, it is impossible to eliminate all residual strain because the structures are deformed in the gravity field during assembly. The release of deformation that occurs during launch to zero gravity imparts residual strain in the telescope structure that can cause stress and optical misalignments. This paper describes a finite element method for predicting the impacts of these residual strains for low stiffness systems that undergo significant deformations during the 1g integration process.

8127-14, Session 4

Effects of accelerations and surface conditions on a pre-designed lightweight primary mirror

C. Chan, Instrument Technology Research Ctr. (Taiwan)

The effects of self-weight on the ground and acceleration force during launch process on the primary mirror of a Cassegrain telescope have both been studied in the paper. Finite element method and Zernike polynomial fitting are applied to the ZERODUR® primary mirror with a pre-designed lightweight configuration on the back. The relation between several selected surface treatment conditions and the mirror characteristic strength as well as the safety factors under various launch accelerations have been investigated. It is found that the surface treatment on the mirror surface needs to be at least ground using a D251 or finer tool to keep the load safety factor of the primary mirror structure of the telescope higher than 1.5 aerially.

8127-15, Session 4

Line-of-sight jitter analysis for the LLCD space terminal telescope

K. E. Nevin, K. B. Doyle, MIT Lincoln Lab. (United States)

An earth-based ground terminal and a lunar orbiting space terminal are being developed as part of NASA's Lunar Laser Communications Demonstration program. The space terminal is designed to minimize mass and power requirements while delivering high bandwidth data rates using a four-inch aperture telescope and a 0.5 watt beam. Design challenges for the space terminal include meeting pointing stability requirements of 5 urad and diffraction-limited wavefront error requirements. The use of efficient optomechanical analysis simulations were used to drive the material selection and mounting methods for the space terminal cassegrain telescope. This included the analysis of the primary mirror that was designed to meet system LOS jitter, thermal and assembly distortion, and stress requirements subject to operational vibration and thermal disturbances while surviving the non-operational launch load environment.
8127-16, Session 4

Integrated modeling of jitter MTF due to random loads

V. L. Genberg, Sigmadyne, Inc. (United States); K. B. Doyle, MIT Lincoln Lab. (United States); G. J. Michels, Sigmadyne, Inc. (United States)

Space borne astronomical telescopes are subjected to random dynamic disturbances from the host spacecraft that create line-of-sight (LoS) jitter errors, which decrease image quality. Special software tools and techniques have been developed to determine the degradation in image quality as measured by the modulation transfer function (MTF) and to identify regions of the telescope to be redesigned in order to minimize the LoS jitter response. A general purpose finite element program is used to find the natural frequencies and mode shapes of the telescope. Each of the optical surfaces for each mode shape is then decomposed into average rigid body motion and elastic deformation. Automated calculation of the LoS equations based on the optical prescription of the telescope provides the LoS response due to expected random loads. The percent contribution of each mode shape to the total LoS jitter is reported. This identifies regions of the telescope structure to be redesigned to minimize the response of the telescope. The LoS error due to the random input is then decomposed into drift and jitter and the remaining errors that result from a specified sensor integration time. The random jitter is converted to a jitter MTF response function which may be used to modify the MTF function of the nominal optical system yielding the resulting optical system MTF in the operational random environment.

8127-17, Session 4

Dynamic suppression design of metering structure for James Webb Space Telescope optical testing

K. M. Patterson, D. A. Hostetter, C. L. Buttaccio, ITT Corp. Geospatial Systems (United States)

In precision optical testing, it is desirable to provide a unified metering structure between the optical test source and the test article to limit the effects of incoming vibration sources. In this manner, the entire optical test structure may be vibration isolated as a single unit. Cryogenic temperature requirements and the size requirements for testing the James Webb Space Telescope make it cost prohibitive to develop a single rigid optical metering structure. This paper demonstrates the advantages and challenges of supporting the James Webb Space Telescope on a flexible, support from above, metering structure.

8127-18, Session 5

20 years of Hubble Space Telescope optical modeling using Tiny Tim

J. E. Krist, Jet Propulsion Lab. (United States); R. N. Hook, European Southern Observatory (Germany)

Optical modeling is typically done during the design phase by experienced engineers, but for astronomers using the Hubble Space Telescope (HST), knowledge of the point spread function (PSF) is often critical to analyzing their data obtained from orbit. Astronomers unfamiliar with optical simulation techniques need access to PSF models that properly match the conditions of their observations (i.e., instrument, filter, stellar color, field position), so any HST modeling software needs to be both easy-to-use and have detailed information on the telescope and instruments. The Tiny Tim PSF simulation software package has been the standard HST modeling software since its release in early 1992. A stand-alone, freely-available program written in C, Tiny Tim can compute PSFs for all of the HST imaging instruments. The user simply answers a few basic questions (PSF size, field position, filter, object spectrum, subsampling) and Tiny Tim will compute the PSF using simple far-field propagation. We discuss the evolution of Tiny Tim over the years as new instruments and optical properties have been incorporated (optical surface error maps derived from phase retrieval, field dependent CCD charge diffusion, optical distortions, etc.). We also demonstrate how Tiny Tim PSF models have been used for HST data analysis.

8127-19, Session 5

Improved integrated modeling of thermo-optic effects

G. J. Michels, V. L. Genberg, Sigmadyne, Inc. (United States)

Accurate optical analysis of the thermo-optic effects in transmissive media requires representation of complex distributions of refractive indices that relate to the thermal profile within the optical media. Such complex refractive index representations must be available to the ray tracing calculations while such calculations are performed along the ray path. The process begins with a thermal analysis to determine the temperatures throughout each optic in the system. Once the temperature profile is known, the refractive index profiles can be determined and supplied to the optical analysis. This paper describes an interface between Sigmadyne/SigFit and a user defined gradient index lens commonly available in commercially available optical analysis software. The interface consists of a dynamic link library (DLL) which supplies indices of refraction to a user defined gradient index lens as ray tracing calculations are being performed. The DLL obtains its refractive index description from a database derived from the thermal analysis of the optics. This process allows optical analysis software to perform accurate ray tracing analysis for an arbitrary refractive index profile induced by the change in the index of refraction due to temperature changes (dn/dT). The process is demonstrated with ORA/CODEV as the optical analysis software and MD Nastran as the finite element thermal analysis software. The DLL will provide more accurate results than current approaches involving the application of an integrated OPD map to the lens entrance surface.

8127-20, Session 5

Concurrent engineering of an infrared telescope system

D. A. Thomas, J. Geis, J. Lang, L. Peterson, F. Roybal, J. Tanzillo, The Aerospace Corp. (United States)

Complex products are best developed in a collaborative design environment where engineering data and CAD/CAE results can be shared across engineering discipline boundaries within a common software interface. This paper provides an example of an infrared telescope and spectrometer system designed in a Simulation Driven Engineering (SDE) software environment by an integrated team consisting of mechnical, structures, thermal, optics, and controls engineers.

8127-21, Session 5

High precision thermal, structural, and optical analysis of an external occulter using a common model and the general purpose multi-physics analysis tool Cielo

E. J. Cady, M. Chainyk, A. Kissil, M. B. Levine, G. J. Moore, Jet Propulsion Lab. (United States); C. C. Hoff, Cielo Software Engineering (United States)

The design and analysis of external occulters has relied on numerous feature rich commercial toolsets which do not share the same finite element basis, level of mesh discretization, data formats and compute...
platforms. Accuracy requirements, design change turnaround time and
design space investigations are challenges in the current process.
Cielo is an open, object-based, multidisciplinary, high-performance
compute environment that addresses these major shortcomings.
Funded through the Jet Propulsion Laboratory’s internal Research and
Technology Development program, Cielo combines state-of-the art best
practices from industry and academia and offers high-performance
computing and third-party software development to create an extensible
framework. Cielo is MATLAB-hosted, can run on serial and massively
parallel architectures, includes native high-performance modules for
thermal, structural, and optical aberration analyses, and offers plug-in
technologies for finite element methods development and utilization of
external numerical libraries. Cielo works from a common model with
multi-physics attributes. The ASCII data input format is based on Nastran
which is the industry standard.

We outline the optical performance requirements of the occulter with
special attention to in plane deformations of the occulter petal edges.
We present steady state and transient thermal analyses on a detailed
finite element model resulting in high precision temperature fields which
are directly used for subsequent structural deformation analyses without
interpolation or data transfer. We compare the results of Cielo with
results from commercial off the shelf tools and demonstrate the need of a
detailed model for both thermal and structural analysis to predict quality
edge deformations which can be used to demonstrate how the design
meets stringent accuracy requirements.

8127-22, Session 5

Uncertainty quantification in high-fidelity integrated structural-thermal-optical models for simulation-based verification and validation

L. D. Peterson, S. C. Bradford, J. E. Schiermeier, G. S. Agnes, S.
A. Basinger, D. C. Redding, Jet Propulsion Lab. (United States);
D. E. Womble, Sandia National Labs. (United States)

Flight system certification using an integrated system model would
challenge conventional tools, because of the necessary realism,
credibility and speed. When a simulation is provided to a decision
maker, it is important that errors in the prediction be minimized and
quantified to the extent practical and necessary for the application. But
these requirements conflict: high fidelity models can be too slow and
computationally expensive for uncertainty quantification.

This paper will present the use of the high performance Sierra mechanics
tools for overcoming this limitation. For this study, the Sandia-developed
Sierra thermal tool Aria and the solid mechanics tool Adagio are coupled
to the JPL MACOS optics analysis tool. Unlike conventional tools,
where results would be passed from a separate thermal to structural
to optical code, this toolset creates a truly coupled multiphysics
simulation. The thermal-structural-optical mapping is done automatically
within the simulation. This allows iterators such as DAKOTA to apply
efficient, directed search algorithms for uncertainty quantification.
Moreover, the thermal, structural and optical meshes can be different,
allowing independent convergence of the meshes. These simulations
can be scaled from desktop workstations to very large clusters with
many thousands of processors, so that many model iterations can be
computed in a timely fashion.

We will demonstrate these tools on an especially designed benchmark
problem. We will examine the relative convergence rates of thermal,
structural and optical discretization meshes for this problem, assess the
use of adaptive meshing and mesh error estimation, and compare various
methods for uncertainty quantification.
AZO film deposited by DC Magnetron Sputtering. Substrate heating process is better than vacuum annealed process for properties of the films were studied by UV-VIS-NIR spectrophotometer, 450. The optical, electrical, grain size and surface structure properties of the films were studied by UV-VIS-NIR spectrophotometer, Hall effect measurement equipment, x-ray diffraction, and scanning electron microscopy. The resistivity, carrier mobility, carrier concentration, and grain size of AZO films were 1.92x10^-3 Ω-cm, 6.38 cm²/Vs, 5.08x10^20 #/cm³, and 31.48 nm respectively, in vacuum annealing of 450 °C. The resistivity, carrier mobility, carrier concentration, and Grain size of AZO films were 5.08x10^20 #/cm³, and 31.56 nm respectively, when substrate temperature was at 250 °C. Substrate heating process is better than vacuum annealed process for AZO film deposited by DC Magnetron Sputtering.

Testing and design of a low-cost large scale solar simulator
Q. Meng, Sr., Chang’an Univ. (China) and Xi’an Jiaotong Univ. (China); W. Yuan, Xi’an Jiaotong Univ. (China)

To simulate solar radiation at the earth’s surface, a new economical multiple-lamp solar simulator was designed. The solar simulator is comprised of 188 reflector sunlight dysprosium lamps whose light spectrum is very similar to air mass 1.5 (AM1.5) solar spectrum terrestrial standards. Lamps are configured in a hexagonal pattern with 15 columns of 12 or 13 lamps at a lamp-to-lamp spacing and column-to-column spacing of 295mm. Without altering the radiation spectral distribution, the average irradiance on target irradiated area can be adjusted over a wide range between 150 and 1100W/m² by means of the variation of lamps number or/and lampl-to-irradiated area distance. At the height of 2.0m the solar simulator provides 2m×1.5m irradiated area with over 1000 W/m². Measurement of irradiance indicates that the multiple-lamp simulator conforms to Class B of ASTM (American Society for Testing and Materials) Standard (ASTM E927-2005) in regard to spectrum match, irradiance uniformity and stability. To enlarge the effective irradiated area, two large mirror-like stainless steel plates was mounted on both of the long sides of the solar simulator. The radiation characteristics of simulator are improved and the optimized effectively irradiation surface is expanded up to 81.6%.

8128-17, Poster Session

The influence of thermal effects on the optical and electric properties of Alumina-doped zinc-oxide films prepared by DC Magnetron Sputtering
C. Tang, J. Wang, C. Lin, Y. Li, C. Jaing, Minghsin Univ. of Science and Technology (Taiwan)

Al-doped ZnO (AZO) films have wide range of applications in optical and optoelectronic devices. AZO films have advantage in highly transparent, stability to hydrogen plasma and low cost to alternative ITO film. AZO film was prepared by direct-current (DC) magnetron sputtering from ceramic ZnO:Al2O3 target. The AZO films were compared in two different conditions. The first is substrate heating process, in which AZO film was deposited by different substrate temperature with room temperature,150 °C, and 250 °C. The second is vacuum annealing process, in which AZO film with deposited at room temperature have been annealed at 250 °C and 450 °C. The optical, electrical, grain size and surface structure properties of the films were studied by UV-VIS-NIR spectrophotometer, Hall effect measurement equipment, x-ray diffraction, and scanning electron microscopy. The resistivity, carrier mobility, carrier concentration, and grain size of AZO films were 1.92x10^-3 Ω-cm, 6.38 cm²/Vs, 5.08x10^20 #/cm³, and 31.48 nm respectively, in vacuum annealing of 450 °C. The resistivity, carrier mobility, carrier concentration, and Grain size of AZO films were 5.08x10^20 #/cm³, and 31.56 nm respectively, when substrate temperature was at 250 °C. Substrate heating process is better than vacuum annealed process for AZO film deposited by DC Magnetron Sputtering.

8128-18, Poster Session

The research of relationships between residual stress and columnar angles in oblique deposition of magnesium fluoride thin films
C. Jaing, Minghsin Univ. of Science and Technology (Taiwan); M. Liu, W. Cho, National Central Univ. (Taiwan); C. Tang, Minghsin Univ. of Science and Technology (Taiwan); Y. Liou, Chienkuo Technology Univ. (Taiwan); J. Wang, Minghsin Univ. of Science and Technology (Taiwan); C. Lee, National Central Univ. (Taiwan)

A report on the relationships between residual stress and columnar angles in oblique deposition of magnesium fluoride thin films is presented. MgF2 films were prepared on fused quartz and BK7 glass substrates using a resistive heating Mo boat at both substrate temperatures of room temperature and 220 °C. The various deposition angles with respect to the substrate normal were acquired by rotating the substrate holder. The morphology of the cross section and the columnar angles with respect to the substrate normal in columnar microstructures of the MgF2 films were investigated using a JEOL JSM-6700 SEM. A phase-shifting Twyman-Green interferometer along with the phase-reduction algorithm was applied to measure the variations of substrate curvatures before and after the MgF2 films were deposited on BK7 glass substrates, which had a 25.4 mm diameter and a thickness of 1.5 mm. Therefore the residual stress in the MgF2 films was calculated by utilizing Stoney’s expression and the variations of substrate curvatures. The MgF2 films have obviously columnar microstructures from SEM pictures without respect to substrate temperatures. The columnar angles of the MgF2 films increase with the deposition angles. However, the columnar angle of the MgF2 film, deposited at a substrate temperature of room temperature, is not equal to that at 220 °C when the MgF2 films are prepared at the same deposition angle. Also, the trend of stress behavior of the MgF2 films, deposited at a substrate temperature of room temperature, is different from that at 220 °C due to the generation of thermal stress.

8128-19, Poster Session

The design of beam shaping focusing lens applied in solar energy concentration
S. Ma, C. Lee, Feng Chia Univ. (Taiwan); Y. Lee, J. Wu, Ming Chuan Univ. (Taiwan); C. Tseng, Feng Chia Univ. (Taiwan)

In this paper, we proposed a new configuration of concentrator in solar PV system. A special optical system in the concentrator used in focusing sun light to solar cell is composed of an aspherical surface and a specific diffusing surface. The uniform-squared light pattern is obtained on the solar cell, the shape and size of light pattern can be modulated by the parameters of the diffusing surface. In order to decrease the weight of the lens, the concentrator in fresnel lens type is built at last. Besides, the optical efficiencies formed by the aspherical concentrator and Fresnel concentrator are about 92% and 77%, the concentrations are about 720mW/mm² and 640mW/mm², and the acceptance angles are about 0.35° and 0.30°, respectively. The tolerance in assembling the component of the concentrator is also discussed in detail.
Opto-mechanical design of one binocular with tunable lens

A. Santiago-Alvarado, F. Iturbide Jimenez, Univ. Tecnologica de la Mixteca (Mexico); S. Vazquez-Montiel, J. Munoz Lopez, Instituto Nacional de Astrofisica, Optica y Electronica (Mexico); M. Campos Garcia, Univ. Nacional Autonoma de Mexico (Mexico)

The optical systems of multiple focusing are traditionally designed and manufactured with rigid lenses and frames that can be moved such as zoom systems used in cameras, binoculars, video camera, etc. Moreover, tunable lenses are more suitable because they are compact, lightweight and allow a wide range of focusing by changing its shape. In this paper, we propose the design and development of opto-mechanical system of a binocular, using tunable lens; to perform the mechanical design of the mount is require an esthetic and ergonomic studies coupled with stress-strain analysis. In this paper, we proposed the opto-mechanical design of one binocular with tunable lenses eyepiece. The tunable liquid lens is composed of a cylindrical metallic mount with a compartment for two transparent elastic surfaces filled with water. Finally, the opto-mechanical behavior of the proposed binoculars is presented.

Cryogenic lens design case study: Gemini Planet Imager spectrograph

S. Thibault, Univ. Laval (Canada)

Making a lens design working at cryogenic temperature is a real challenge. Both optical and mechanical designer must work together to prevent problems during operation. The Gemini Planet Imager (GPI), currently under construction will be a facility instrument for the 8-m Gemini South telescope. The science instrument is a cryogenic integral field spectrograph based on a lenslet array. The integral field nature of the instrument allows for a full mapping of the focal plane at coarse spectral resolution. With such a data cube, artifacts within the PSF such as residual speckles can be suppressed. Additionally, the initial detection of any candidate planet will include spectral information that can be used to distinguish it from a background object: candidates can be followed up with detailed spectroscopic observations. The optics between the lenslet array and the detector are essentially a standard spectrograph with a collimating set of lenses, a dispersive prism and a camera set of lenses in a folded assembly. This paper describes by a step by step process from the first preliminary design to the final cryogenic system for both optical and mechanical design. We also discussed the assembly procedure (room temperature vs cryogenic compensation), the test support equipments and finally the laboratory optical performances over the field of view.

Eliminating dewar Narcissus artifacts induced by moving optics in infrared staring focal plane sensors

P. M. McCulloch, C. Olson, T. D. Goodman, L-3 Communications Sonoma EO (United States)

Lens designers must consider Narcissus artifacts during the design and optimization of lenses for staring infrared imagers. The traditional Narcissus effect occurs when the focal plane sees its own reflection from an optical surface, and many design metrics such as YNI or marginal ray angle-of-incidence have been proposed to control self-reflections. However, staring infrared imagers have multiple cold surfaces within the dewar assembly. The cold stop, cold filter, dewar window, and coating features all contribute to Narcissus-like artifacts on the focal plane.

Although non-uniformity correction (NUC) can remove static artifacts, lenses with focus or zoom groups create a dynamic Narcissus artifact that cannot be eliminated by such correction alone. Dynamic Narcissus artifacts often manifest as bright or dark rings apparent to the human eye, although they may lie near the noise floor of the imager. Additionally, strong field curvature of an imaged Narcissus artifact can further complicate the identification of its source and obscure its predicted contribution to the final image.

We present a detailed experimental case study showing how a simple pupil ghost metric compares to traditional Narcissus metrics in a lens exhibiting dewar Narcissus and how the metric can be used for optimization to eliminate the artifact.

Development of multi-spectral lenses for thermal imaging technique

S. N. Bezdidko, Open Joint-Stock Co. (Russian Federation); E. I. Morozova, The Freelancers, Moscow (Russian Federation); Y. A. Roy, Open Joint-Stock Co. (Russian Federation)

The modern level of development of optoelectronic devices requires the creation of devices, providing maximum information content in different weather conditions, day and night. The solution to this problem is possible only through the creation of optoelectronic devices operating in various ranges of the optical spectrum simultaneously (multi-spectral optoelectronic devices).

One of the problems in the development of multi-spectral optoelectronic devices is the creation of a common optical system that provides for the integration of information of optical channels in a single integrated optical scheme.

The report presents the results of work on the creation of thermal lenses, working simultaneously in two regions of the spectrum of 3-5 microns and 8-12 microns, shows the results of the specific development of such lenses and their aberration characteristics.

Optical transmittance of high-efficiency cavity with photon recycling

C. Lin, X. Lee, W. Chien, C. Sun, National Central Univ. (Taiwan)

In this paper, a high-efficiency cavity providing extreme high energy transmittance with photon recycling is reported and demonstrated. The cavity contains a diffuser and the high reflectivity surfaces. The optical efficiency of the cavity is calculated by a formula with considering photon recycling. Furthermore, various kinds of diffusers are applied to change the optical transmittance as well as the light pattern. When the reflectivity of the inner wall of the lighting cavity was about 96 %, the optical efficiency of the cavity is higher than 90 % with use of several diffusers. The lighting patterns are formulated and discussed incorporated with the cavity efficiency. The experimental measurement as well as the calculation is demonstrated in the paper.

Optical design of the adjustable flashlight based on a power white-LED

J. Cai, Y. Lo, C. Sun, National Central Univ. (Taiwan)

In the paper, we design an adjustable flashlight, which can provide the spotlight and the floodlight in different modes. For most users, there two illumination modes are requested mostly. In such two modes, one is high density energy of the light pattern and the other is the uniform light pattern in a wide view field. In designing the adjustable flashlight, we first
build a precise optical model for the high-power LED produced by CREE in mid-field verification to make sure the accuracy of our simulation. Typically, the lens is useful to be the key component of the adjustable flashlight, but the optical efficiency is low. Here, we apply a so-called total internal refraction (TIR) lens to the flashlight. By defocusing the TIR lens, the flashlight can be quickly changed into the beam size and energy density to various applications. We design two segments of the side of the TIR lens so that they can be applied to the two modes, and the flashlight provides a high optical efficiency for each mode. The illumination of the center of light pattern at 2 m away from the lamp is also higher than using the lens in the spotlight and the floodlight. It provides good lighting functions for users.

8128-06, Session 2
High energy-efficiency B+R LED beam shaping with micro-lens diffuser for agricultural lighting
Y. Chang, X. Lee, C. Sun, National Central Univ. (Taiwan)

Fluorescent lamps and incandescent lamps are common lighting sources for an agricultural lighting. However, the spectral characteristics and the property of arbitrary radiation of the traditional light source make the lighting not effective in energy consumption. In the application of agricultural lighting with high energy efficiency, a beam shaping technology to condense most of lights onto the planted areas is desired. In this paper, a beam shaping of a LED luminaire with a reflector and a micro-lens array is proposed and demonstrated. The LED luminaire can not only effectively shape the lighting pattern into a rectangle of the planted areas but also can mix blue and red light uniformly for complete photosynthesis. In the paper, the design and corresponding experimental results will be presented and discussed. The parameters including illumination uniformity, optical utilization factor and optical efficacy of the luminaire will be presented.

8128-07, Session 3
Range-balancing the large binocular telescope
A. Rakich, Large Binocular Telescope Observatory (United States)

The Large Binocular Telescope (LBT) consists of two 8.4 m telescopes mounted on a common alt-az gimbal. The telescope has various modes of operation, including prime-focus, bent- and direct-Gregorian modes. The telescopes can feed independent instruments or their light can be combined in one of two interferometric instruments, giving an interferometric baseline of over 22 m.

With all large telescopes, including the LBT, collimation models or modeled values for hexapod positions, are required to maintain reasonable optical alignment over the working range of temperatures and telescope elevations. Unlike other telescopes, the LBT has a highly asymmetric mechanical structure, and as a result the collimation models are required to do a lot more “work”, than on an equivalent aperture asymmetric mechanical structure, and as a result the collimation models are required to maintain values for hexapod positions, are required to maintain.

LBT has been phasing in science operations over the last 5 years, with first light on the prime-focus cameras in 2006, and first light in Gregorian mode in 2008. In this time, the generation of collimation models for LBT has proven to be problematic, with large departures from a given model, and large changes in pointing, being the norm. A refined approach to generating collimation models, “range balancing”, has greatly improved this situation. The range-balancing approach to generating collimation models has delivered reliable collimation and pointing in both prime focus and Gregorian modes which has led to greatly increased operational efficiency. The details of the range-balancing approach, involving the separation of pointing and coma rotations, are given in this paper.

8128-08, Session 3
Advanced optical design for DNA sequencing systems
K. Sobolev, A. Joobeur, ASML (United States); C. Uhrich, Complete Genomics, Inc. (United States); D. Aziz, Midbar West, Inc. (United States)

Latest advances in DNA sequencing techniques require development of high NA immersion microscope systems with large field of view, increased resolution and very tight distortion correction.

This paper discusses optical design and tolerance analysis of NA 1.0 immersion microscope system with field of view size over 1 mm to be used for four color fluorescence spectroscopy. Described microscope system includes immersion objective lens and four tube lens setup corrected for wide wavelength range from 490 nm to 712 nm. We will discuss critical aspects of designing this kind of optical system including special glass selection required for chromatic correction.

The first part of the paper describes overall system configuration, its differences from conventional microscope system, and how these differences affect image quality requirements.

In the second part we describe optical design difficulties associated with large field of view, wide spectral range and tight distortion correction. The most important aspects optical design is choosing design form and glass selection to successfully correct chromatic aberrations including axial and lateral colors, spherochromatic aberration and other field varying chromatic aberrations. Since application requirements limit glass selection to low fluorescence glass types the glass optimization is especially difficult.

8128-10, Session 3
Development and experimental verification of an intraocular scattering model
C. Jiang, T. Jhong, Y. Chen, C. Sun, National Central Univ. (Taiwan)

It is well-known that the scattering behavior in human eyes causes the disability glare effect. The main contributions of ray scatter in human eyes are composed of volumetric scatter in cornea, volumetric scatter in crystalline lens, and surface diffusion at retina fundus. In order to simulate the disability glare effect, a rigorous intraocular scattering model was built into a biometry-based human eye model. The eye model employed empirical anatomic and optical data of ocular parameters and had the functionality of age and accommodation. The resulting visual acuity and chromatic dispersion matched the behavior in real human eyes.

The first part of the scattering model was to add scattering particles in the crystalline lens, where the particle parameters such as the refractive index, size, and obstruction area were calculated from the data in the literature. The second part was the construction of the retina diffuseing surface. The retina fundus was considered as a Lambertian surface and had the corresponding reflectance at visible wavelengths. The volumetric scattering in cornea was also simulated by adding scattering particles. The particle parameters were varied until the veiling luminance of the eye model matched the values calculated from the CIE disability glare general formula with age 40 and zero p-value for black iris. By replacing the transparent lens with a cataractous lens, the disability glare formula of cataracts was generated. The MTF of the intraocular scattering model showed nice correspondence with the data measured by a double-pass experiment.

8128-11, Session 4
Novel plasma-enhanced sputter process for new applications
P. Biedermann, Evatec Ltd. (Switzerland)
Emerging applications in 3D and laser optics necessitate increasingly complex optical thin film stacks. Typical designs include multiple band pass filters or thick multilayers where conventional coating techniques cannot satisfy yield requirements for economical volume production whilst still maintaining the highest environmental and optical tolerances. A novel plasma enhanced sputtering process controlled by a combination of Plasma Emission Monitoring (PEM) and in situ Broadband Optical Monitoring has been investigated with the goal of achieving the coating stability and surface roughness associated with coating flux energy levels of around 20eV reported for Ion Beam Sputter (IBS) whilst still maintaining the advantageous high coating rates for conventional sputter processes. Coating set up and results will be presented for spectral and mechanical stability, run to run repeatability, and surface scatter and compared with those achieved by conventional sputter techniques.

8128-12, Session 4

Unexpected absorption in anti-reflection coatings used in infrared systems
C. Panetta, P. Fuqua, C. Chu, J. Barrie, The Aerospace Corp. (United States)

Infrared (IR) optical systems require a range of exotic materials, many with fairly large indices of refraction. The mismatch in the index between the optical element and the surrounding medium can result in reflection losses that approach 50%. Anti-reflection (AR) coatings are applied to these elements in order to improve the optical transmission and minimize artifacts through a system. There have been several instances of significant, unexpected, transmission loss in IR systems, with that loss being attributed to either initial AR coating problems or subsequent degradation of the coatings. Likely candidates for the loss mechanism are water trapped into the optical coatings during deposition and water being incorporated into coating voids or grain boundaries during exposure to ambient humidity. Five different AR coatings have been procured from four different manufacturers to study the cause of the observed losses, with this paper reporting on the preliminary results of lab tests to characterize the different samples.

8128-13, Session 5

Design of a free-form lens system for short distance projection
B. Yang, Univ. of Shanghai for Science and Technology (China)

As a digital image display device, projectors have been widely used in conference rooms and classrooms. With the development of high resolution image source devices and longer life-time light sources such as LED, projector becomes a good solution for home theatre applications now. Projector has many advantages compared with large screen LCD TV. It is compact, cheaper and consumes less power. Traditional projector lens has a very small projection angle so a long working distance is needed to form a big screen display. Such long working distance limits the application of projectors at home. In this paper we present a free-form lens system design for short distance projection. The difficulties of the optical design of such short distance projector lens lies in the distortion control and high order aberration correction. Free-form surface shape and non-rotational symmetrical structure provide us more freedoms for optimization. The catadioptric structure is also used to reduce the overall length of the whole system. The designed projector lens system consists of two parts. The first part is a rotationally symmetrical lens system which corrects the basic aberrations. The second part contains 2 free-form lenses and a reflector which eliminate the distortion and further corrects the basic aberrations. We achieve 40–60inch projected image size at a display screen which is 150–250mm away from the lens system. The object NA is 0.15 and the image source used is a 0.45inch WXGA DMD. The maximum distortion for all fields at all distances is less than 2%.

8128-14, Session 5

Progress in the SMS design method for imaging optics
L. Wang, Univ. Politécnica de Madrid (Spain); P. Benitez, J. C. Mirano, Univ. Politécnica de Madrid (Spain) and Light Prescriptions Innovators, LLC (United States); J. Infante Herrero, G. Biot, Univ. Politécnica de Madrid (Spain)

The Simultaneous Multiple Surfaces (SMS) was developed as a design method in Nonimaging Optics during the 90s. Later, the method was extended for designing Imaging Optics. The application of the SMS method for imaging optics was first introduced for the design of an ultra-high numerical aperture RX lens composed by two aspheric surfaces. More recently the extension to up to four aspherics was developed. Different from traditional optical design methods based on multi-parametric optimization techniques, SMS method is a direct construction method for selected ray-bundles, meridian or skew ray-bundles. This gives the SMS method an additional interest since it can be used for exploring solutions far from the paraxial approximation where the multi-parametric techniques can get lost because of the multiple local minima. Different SMS algorithms can be utilized, depending on the ray-bundles selected for the design. For instance, in three-surface designs, three meridian ray-bundles (3M) or one meridian and two skew ray bundles (1M-2S) can be selected for the calculation, the latter proving a better sampling of the phase space. In this work, we will compare different SMS algorithms for a new lens structure that combines 2 reflecting surfaces and 2 refracting surfaces in one solid piece, for a design of 720mm focal length, 1/6 and 0.650 diagonal field of view. With this catadioptric lens structure we have achieved designs with excellent performance (RMS spot size <12 µm), with total system length less than 35 mm, and the results obtained with the different algorithms will be presented.

8128-15, Session 5

Distributed wavefront coding for wide angle imaging system
H. Zhang, M. Lariviére Bastien, S. Thibault, Univ. Laval (Canada)

The emerging paradigm of imaging systems, known as wavefront coding, which employs joint optimization of both the optical system and the digital post-processing system, has not only increased the degrees of design freedom but also brought several significant system-level benefits. The effectiveness of wavefront coding has been demonstrated by several proof-of-concept systems in the reduction of focus-related aberrations and extension of depth of focus. While the previous research of wavefront coding has been mainly focused on the imaging system with small or modest field of view (FOV), we present a preliminary study of the wavefront coded applied to panoramic optical systems. Unlike the traditional wavefront coded systems which only require the constancy of modulation transfer function over an extended focal range, the wavefront coded panoramic systems emphasize particularly on the mitigation of significant off-axis aberrations such as field curvature, coma, and astigmatism. We first analyze the limits of using a traditional generalized cubic polynomial pupil phase mask for wide angle system. The results show that a traditional approach can work when the variation of the off-axis aberration is modest. Consequently we proposed to study how a distributed wavefront coding approach where the phase mask is not in the pupil plane can be used for wide angle lens. Some cases are discussed theoretically, designed with Zemax, and illustrated graphically.
Progressive addition lens design by optimizing NURBS surface

Y. Liu, National Taiwan Univ. (Taiwan); W. Hsu, Y. Cheng, Instrument Technology Research Ctr. (Taiwan); G. J. Su, National Taiwan Univ. (Taiwan)

Progressive addition lenses (PAL) are used to compensate presbyopia, which is induced by losing accommodation of elder eyes. These eyes need different optical power provided by eye glasses while watching objects at different distance. A smaller optical power is required in further distance and a larger one in nearer zone. A progressive addition lens can provide different power requirements in one piece of lens. This paper introduces a whole process of PAL production, from design, fabrication, to measurement. The PAL is designed by optimizing NURBS (Non-uniform rational B-spline) surface. Parameters of merit function are adjusted to design lenses with different specifications. The simulation results confirm that the power distributes as expected and cylinders are controlled under its adding power. The effect for presbyopic eyes has also been examined.

Imaging analysis for an eye model wearing designed PALs shows the feasibility of our design. Besides, sample lenses have been fabricated and measured. We used precise-machining to produce the molds for plastic injection. Then, the samples were produced by injecting polycarbonate to the molds. Finally, Ultra Accuracy 3D Profilometer was used to measure the sample PALs. Examinations show that our designs are achievable and feasible in practice use.
8129-01, Session 1

3D image capture through the use of an astigmatic projected pattern

G. C. Birch, J. S. Tyo, J. Schwiegerling, College of Optical Sciences, The Univ. of Arizona (United States)

Three-dimensional displays have become increasingly present in consumer markets. However, the ability to capture three-dimensional images cheaply and without major modifications to current cameras is uncommon in commercial systems. Our goal is to create a modification to a common commercial camera that allows a three dimensional reconstruction. We desire such an imaging system to be inexpensive and easy to use. Furthermore, we require that any three-dimensional modification to a camera does not reduce its resolution. The purpose of this project is to enable inexpensive three-dimensional image capturing devices, and in doing so close the loop between consumer three-dimensional display and capture.

We present a possible solution to this problem. A commercial digital camera is used with an astigmatic projector system to capture images of a scene. By using an astigmatic projected pattern we are capable of creating two different focus depths for horizontal and vertical features of the projected pattern, thereby encoding depth into the projected pattern. By carefully choosing a pattern we are able to exploit this differential focus in image processing. Wavelet transforms are performed on the image that pick out the projected pattern. By taking ratios of certain wavelet transforms we are able to correlate the distance an object at a particular transverse position is from the camera to the wavelet transform ratios.

We will present information regarding construction, calibration, and images produced by this system. The nature of linking a projected pattern design and image processing algorithms will be discussed.

8129-02, Session 1

3D imaging with a single-aperture 3-mm objective lens: concept, fabrication, and test

S. Bae, R. Korniski, Jet Propulsion Lab. (United States); H. Shahinian, Skull Base Institute (United States); H. Manohara, Jet Propulsion Lab. (United States)

A technique for achieving a full-color 3D image using a single camera is presented. Unlike a typical 3D-imaging system comprised of two independent cameras each contributing one full-color viewpoint, here two full-color viewpoints in a single-lens camera are created utilizing a form of spectral multiplexing from a series of different scene illuminations. The spectral multiplexing works with a bipartite-filter composed of a complementary pair of multiple bandpass filters, coupled with a series of spectral illumination bands (SIBs) each matched to the bandpasses of one or the other filter. When the bipartite-filter is mounted at the pupil of the objective, it divides the single pupil into two, and makes the openings of the pupils depend on the SIBs. A color image is then realized by mixing the series of SIBs that contain a combination of red, green, and blue (RGB) colors collected from each of the viewpoint. We believed that the technique was advantageous in miniaturizing a 3D camera. We applied this technique to fabricating a 3D camera composed of 3-mm lenses. In this paper, we will present the details of the concept, materials, and method used for building the camera and the results validating the concept.

8129-03, Session 1

Wide and narrow dual image guidance system for ground vehicle on fast focusing and stereo matching operation

A. Akiyama, Kanazawa Technical College (Japan); N. Kobayashi, Kanazawa Institute of Technology (Japan); E. Mutoh, Kawasaki Heavy Industries Ltd. (Japan); H. Kumagai, Tamagawa Seiki Co., Ltd. (Japan); H. Ishii, Nihon Univ. (Japan)

We have developed the wide and narrow dual image guidance system for ground vehicle on fast focusing and stereo matching operation. The wide focusing catches the averaged distance information of the outside world. The wide image stereo matching operation extracts the feature image area of objects from the focused wide images. The next narrow focusing on the extracted feature image area finds its fine distance information. Further finer distance information comes from the narrow focused image stereo matching operation.

The fast focus image is derived from the calculating the developed wavelet focus measure value of the horizontal high pass image and the vertical high pass image of the Daubechies wavelet transformed image. The highest wavelet focus measure value among them gives the best focus image directly. This focusing operation works finely similar to the other differential image techniques.

We used the stereo matching operation to find the direction of the local points on the wide focused image to make the further narrow focusing. The narrow focusing makes the clear distance image realizing the object edge or the good contrast of the object surface. Further narrow image stereo matching gives us the volume information of the focused image area.

For this operation we equipped the view control and focus control function each color video camera and mounted them on the 2 axis space direction set equipment system. Further the developed wide and narrow dual image guidance system is placed on the ground vehicle to find the appropriate direction and surface to move.

8129-04, Session 1

Reflective autofocus image system with MEMS deformable mirrors and freeform design

W. Chang, G. J. Su, National Taiwan Univ. (Taiwan)

In this paper we proposed an miniature auto-focus image system without moving parts. We had presented a 2-Mega-Pixel auto-focus module by combining reflective optics and MEMS deformable mirror. This design can be further improved. We expanded 2-Mega-Pixel image plane to 8-Mega-Pixel image plane and corrected the aberration by adding one more lens as a stop. For the concern of the cost, we distributed the optical power of the adding lens to the fixed mirror and the deformable mirror, and we designed them as freeform surfaces to compensate aberrations. Finally, a 8M pixel auto-focus image system whose FOV is ±26° can be achieved. The MTF at full spatial frequency is above 25%.

8129-05, Session 1

Continuous optical zoom module based on two deformable mirrors for mobile device applications

Y. H. Lin, G. J. Su, National Taiwan Univ. (Taiwan)
Conference 8129:
Novel Optical Systems Design and Optimization XIV

In recent years, optical zoom function of the mobile camera phones has been studied. However, traditional systems use motors to change separation of lenses to achieve zoom function, suffering from long total length and high power consumption, which is not suitable for mobile phones use. Adopting MEMS polymer deformable mirrors in zoom systems have the potential to reduce thickness and have the advantage of low chromatic aberration. In this paper, we proposed a 2X continuous optical zoom systems for mobile phones, using two deformable mirrors, suitable for 2-Mega-Pixel image sensors. In our design, the thickness of the zoom system is about 10 mm. The smallest EFL (effective focal length) is 4.5mm at field angle of 52° and the f/# is 3.5. The longest EFL of the module is 9mm and the f/# is 5.

8129-06, Session 2
Development of low-coherence light sheet illumination microscope for fluorescence-free bioimaging
Z. Xu, T. E. Holy, Washington Univ. School of Medicine in St. Louis (United States)

Light Sheet Illumination Microscopy is an imaging modality featuring the novel arrangement with the illumination axis perpendicular to the detection axis. In this technology a well defined light sheet is generated and aligned precisely to the focal plane of the microscope objective and thus only the thin in-focus layer of the sample is illuminated and imaged, thereby avoiding out-of-focus light. Besides the inherent optical sectioning function, other advantages include fast imaging speed, high longitudinal resolution and decreased light-induced heating or toxicity. Though promising, this microscopy is currently restricted in imaging fluorescently labeled tissue; in inspection of intact tissue using scattered light the acquired images suffers from intense speckles because of the severe coherence in the illumination. This work aims to build a microscope capable of achieving the intrinsic images of the fluorescence-free sample with reduced or eliminated speckles, by developing a low coherence light sheet illumination. To diminish the spatial coherence the sample is illuminated with tens of independent sub-beams (without inter-coherence) illuminating the field of view of the microscope with diverse incident angles. The temporal coherence is dramatically reduced by employing a supercontinuum laser with a broad spectrum as the original light source. The new microscopy significantly extends the functionality of Light Sheet Illumination Microscopy and will enable many new bioimaging applications.

8129-07, Session 2
Design considerations for biomedical optical imaging systems
R. Liang, Carestream Health, Inc. (United States)

Designing an efficient system for biomedical imaging requires a solid understanding of special requirements of optical systems for biomedical imaging and optical components used in the systems. This presentation will discuss some special considerations when designing optical systems for biomedical imaging.

8129-08, Session 2
Retinal tracking system for jumping spiders
C. Canavesi, Univ. of Rochester (United States); S. Long, Univ. of Massachusetts Amherst (United States); D. Fantone, Univ. of Rochester (United States); E. Jakob, Univ. of Massachusetts Amherst (United States); R. Jackson, Univ. of Canterbury (New Zealand); D. P. Harland, AgResearch Ltd. (New Zealand); J. P. Rolland, Univ. of Rochester (United States)

We present an optical system for tracking the retinal movement of a jumping spider as a stimulus is presented to it. The system, designed using only off-the-shelf optical components and one custom aspheric plate, consists of three sub-systems that share a common path: a visible stimuli presentation sub-system, a NIR illumination sub-system and a NIR retinal imaging sub-system. A 25 mm clearance was maintained between the last element and the spider to ensure a more stable positioning of the spider in the system. The stimuli presentation system relays an image from a display to the spider eye, matching the 15 arcmin resolution of the two principal eyes of the spider and producing a virtual image at a distance of 250 mm from the spider, with a visual full field of view of 55 degrees. When viewing a stimulus, the jumping spider moves its retinas, which cover a field of only 0.6 degrees, and directs them to view different places in the visual field. The retinal imaging system was designed to use a NIR camera to track changes of 0.5 degrees in the field of view seen by the spider. By tracking retinal movement across the images that are presented to spiders, we will learn how they search for visual cues to identify prey, rivals, and potential mates.

8129-09, Session 2
SOI strip waveguide microring resonator for homogeneous biosensing
S. Malathi, N. Mangal, Indian Institute of Science (India); S. S. Cochin Univ. of Science & Technology (India); R. V. Honnunar, S. Talabattula, Indian Institute of Science (India)

We report the simulation and analytical results obtained for homogenous of eukl sensing of protein on silicon-on-insulator(SOI) strip waveguide based microring resonator. The strip waveguides provide higher optical mode confinement. The radii of the rings are 5µm and 20µm; the waveguide dimensions are 300x300 nm and a gap of 200 nm exists between the ring and bus waveguide. The protein analyte is uniformly distributed over a thickness which exceeds the evanescent field penetration depth of 100nm. The SOI platform was considered following the analysis of the penetration depth of evanescent field which was found to be the least compared to polymer and silicon rich nitride (SRN) based waveguides. A lesser penetration depth of the evanescent field allows it to interact more with the bio-layer in comparison to its surroundings which ultimately results in better sensitivity. Moreover, the difference in the effective index and propagation constant of the ring and bus waveguide are taken into consideration by including a detuning parameter of 1 - 2/2. The Q-factor for the devices is ~9500 and ~1800 while the finesse is ~180 and ~90 for 5µm and 20µm respectively. The sensitivities of the resonators are 27.5 nm/RIU and 5 nm/RIU respectively. The analytical and simulated results corresponding to the effective index Neff of the fundamental mode for our device were found to be comparable.

8129-10, Session 3
Scalability of a cross-platform multi-threaded non-sequential optical ray tracer
A. W. Greyynolds, Ruda-Cardinal, Inc. (United States)

Design optimization increases the computational workload of engineering calculations by orders-of-magnitude. Multiple-core computers are now the norm so that all computational intensive algorithms should be transparently multi-threaded if possible. Ray tracing is still the work-horse of optical engineering where it’s usually sequential for image analysis and non-sequential for illumination or stray light calculations. The question is how well do various implementations scale with the number of threads/coresprocessors. The GelOE optical engineering software implements multi-threaded ray tracing with just a few simple cross-platform OpenMP directives. Timings as a function of the number of threads are presented for two quite different ZEMAX non-sequential sample problems running on a dual-boot 12-core Apple computer and compared to not only ZEMAX but also FRED (plus single-threaded ASAP and CodeV). Also
discussed are the relative merits of using Mac OSX or Windows 7, 32-bit or 64-bit mode, single or double precision floats, and the Intel or GCC compilers. It is found that simple cross-platform multi-threading can be more efficient than the Windows-specific kind used in the commercial codes and who’s the fastest ray tracer depends on the specific problem. It should be noted that besides ray trace speed, overall productivity also depends on other things like visualization, ease-of-use, documentation, and technical support which are not rated here.

8129-11, Session 3
Modeling the role of phosphor grain packing in compact fluorescent lamps
N. Pannier, M. Filoche, B. Sapoval, Ecole Polytechnique (France); T. Le Mercier, V. Buissette, Rhodia (France)

A ray-tracing method is performed to study the optical properties of phosphor powder coating in fluorescent. The phosphor particles are represented as micron-size spheres. These are substantially larger than the wavelengths of the visible and the ultraviolet light to be modelled as rays. The mercury discharge is represented by a UV source, sending a large number of rays in randomly chosen direction at a wavelength of 254 nm. Each ray interacting with a phosphor particle can be reflected, refracted, absorbed and transmitted. The direction of refracted rays is calculated using Snell’s law. The ratio of reflected to incident intensity of non polarized light is computed employing Fresnel’s equation. Ideal absorption spectrum and excitation spectrum for three rare-earth phosphors are used.

We investigate the role of grain size, of the distribution of sizes, of the thickness of the phosphor layers and of their packing density. This last parameter seems to play a crucial role in the system efficiency. Reducing the density of the phosphor layer decreases accordingly the probability for an ultraviolet ray to be absorbed, and consequently the emission of visible light. On the other hand, increasing the density dramatically raises the number of obstacles in the output path of a visible ray. This behaviour suggests that there might be an optimal density for which the power of visible light received on the top side is maximal. Our results are in good agreement with previous simulations and experiments.

8129-12, Session 3
Simulation and optimization of a sub-micron beam for macromolecular crystallography using SHADOW and XOP at GM/CA CAT at the APS
Z. Liu, S. Xu, D. W. Yoder, R. F. Fischetti, Argonne National Lab. (United States)

The small, high intensity and low convergence beams available on beamlines at 3rd generation synchrotron sources have been a boon to macromolecular crystallography. It is now becoming routine to solve structures using a beam in the 5 – 20 micron (FWHM) range. However, many problems in structural biology suffer from poor S/N due to small (a few microns) crystals or larger inhomogenous crystals. In additional, theoretical calculations and experimental results have demonstrated that radiation damage may be reduced by using a micron-sized X-ray beam. At GM/CA CAT we are developing a sub-micron, low convergence beam to address these issues. The sub-micron beam capability will be developed on the existing beamline 23-ID-D where the minimum beam size available to users is currently 5 microns in diameter. The target goals are a beam size of ~0.8 micron (FWHM) in diameter, with a beam convergence of less 0.6 milli-rads, a flux greater than 5x1010 photons/sec, and an energy range from 5 to 35 keV. Four optical systems will be compared: 1) a single set of highly demagnifying Kirkpatrick-Baez (K-B) mirrors, 2) multiple Fresnel Zone Plates (FZP), 3) a set of K-B mirrors focusing to a secondary source that is imaged by another set of K-B mirrors, and 4) a set of K-B mirrors focusing to a secondary source that is imaged by a FZP. Here we will present the results of a design optimization based on ray trace simulations (SHADOW), flux calculations (XOP), and experimental results on 23ID.

8129-14, Session 3
Hearing at the speed of light: using interferometry to detect sound
M. G. Heyns, V. L. Hamilton, J. A. Hart, J. A. McKay, Franklin W. Olin College of Engineering (United States); V. Doherty, Eidolon Optical, LLC (United States)

In this study, a unique dual beam laser interferometer capable of detecting sound through solid resonant media has been developed. The system detects the vibrations of a specular surface induced by acoustic frequencies in the spoken register by using laser interferometry for real-time reproduction of the audio signal over large ranges. The system utilizes a unique optical configuration and conventional signal processing techniques to increase the signal to noise ratio, sensitivity, and range of the interferometer. The configuration allows for a clear and distinctive interference fringe pattern at greater than normal range. Numerical calculations, simulations, and experimental results verify the feasibility and applicability of this novel interferometer.

8129-15, Session 3
Innovating spectrometry studies at undergraduate level using a linear CCD array
A. Garg, R. Sharma, V. Dhingra, Acharya Narendra Dev College (India)

Students are less enthused in performing various spectrometry experiments in a conventional optics laboratory at the undergraduate level. In order to motivate students towards spectrometry, the present development focuses on innovating spectrometry experiments in undergraduate optics laboratory by integrating a linear CCD (Charge Coupled Device) for optical intensity capture using LabVIEW programme and a Digital Storage Oscilloscope with NI LabVIEW Signal Express. In the first step, students can calibrate wavelength in terms of pixels position using a standard light source. Then this calibration can be used to display and measure the colour spectrum, emission spectrum of various light sources. Various experiments performed include characterizing various LEDs in terms of wavelengths emitted for use in measurement of Planck's constant experiment, measuring characteristics wavelengths in emission spectra of hydrogen lamp (for calculating Rydberg's constant) and sodium lamp.

8129-27, Session 3
Determination of off-axis aberrations of imaging systems using on-axis measurements
J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

No abstract available

8129-16, Session 4
Ultra-compact telephoto lens design with SMS method
L. Wang, Univ. Politecnica de Madrid (Spain); P. Benitez, J.
The Simultaneous Multiple Surfaces (SMS) was developed as a design method in Nonimaging Optics during the 90s. Later, the method was extended for designing Imaging Optics. The application of the SMS method for imaging optics was first introduced for the design of an ultra-high numerical aperture RX lens composed by two aspheric surfaces. More recently the extension to up to four aspherics was developed. Different from traditional optical design methods based on multi-parametric optimization techniques, SMS method is a direct construction method for selected ray-bundles, meridian or skew ray-bundles. This gives the SMS method an additional interest since it can be used for exploring solutions far from the paraxial approximation where the multi-parametric techniques can get lost because of the multiple local minima.

In this work, we propose a new lens structure that combines 2 reflecting surfaces and 2 refracting surfaces in one solid piece, for a design of 720mm focal length, f/6 (aperture diameter 129 mm) and 0.665 diagonal field of view. The difficulty in these Catadioptric-type designs is to maintain high performance with small overall system length, which is very important in some space-limited applications like UAV (Unmanned Aerial Vehicle). The lens surfaces are rotational symmetric and calculated with SMS method to have good control of non-paraxial rays. We have achieved designs with excellent performance (RMS spot size <12 um), with total system length less than 35 mm. Compared to traditional designs, the solid lens designs are much more compact, easy to assemble and thus cost-saving.

### 8129-19, Session 4

**Optical design of automotive headlight system incorporating digital micromirror device**

Y. Fang, National Kaohsiung First Univ. of Science and Technology (Taiwan)

In this research we propose a new integral optical design for an automotive headlight system with an advanced light-emitting diode and digital micromirror device (DMD). In recent years, the popular adaptive front-lighting automobile headlight system has become a major emphasis of research that manufactures will continue to focus great efforts on in the future. Traditionally, automobile headlights have all been designed as a low beam light module, whereas the high beam light module still requires using accessory lamps. In anticipation of this new concept of integral optical design, we have researched and designed a single optical system with high and low beam capabilities. To switch on and off the beams, a DMD is typically used. Because DMDs have the capability of redirecting incident light into a specific angle, they also determine the shape of the high or low light beam in order to match the standard of headlight illumination. With collocation of the multiviewpoint reflection lens design, a DMD can control the light energy distribution and thereby reinforce the resolution of the light beam.

### 8129-20, Poster Session

**Blocking probability analysis with and without wavelength convertors in all-optical WDM networks**

A. Wason, Rayat & Bahra Institute of Engineering & Bio-Technology (India); R. S. Kaler, Thapar Univ. (India); R. Kaler, Bahra Group of Institutes, Patiala Campus (India)

The blocking probability of a lightpath request (or a call) is an important performance measures of a wavelength-routed all optical networks. This blocking probability calculation was based on the availability and non-availability of wavelength converters. The model can also be used to evaluate the blocking performance of realistic networks such as NSFNet topology and hence used to improve its performance of those network topologies. Results show that these
models work better without wavelength converters than with wavelength converters. Also, when the load applied to the network is increased the blocking probability of that network is decreased, both with and without wavelength conversion. Hence, these models can be applied for the better performance of those networks where the load applied is higher. The results have proved that blocking probability also decreases with the increase in the number of wavelengths. The comparison of both the models (with wavelength converters and without wavelength converters) have also been made and analysis can be made on the basis of results that the performance of the model without wavelength converters gives better output than the model with wavelength converters.

8129-21, Poster Session

Laser-based study of geometrical optics at school level

A. Garg, V. Dhingra, R. Sharma, A. K. Singh, D. Joshi, K. Sandhu, P. Wadhawan, P. Chakravarty, V. Sharma, Z. Khan, Acharya Narendra Dev College (India)

Students at the school level from grade 7 to 12 are taught various concepts of geometrical optics but with little hands-on activities. Light propagation through different media, image formation using lenses and mirrors under different conditions and application of basic principles to characterization of lenses, mirrors and other instruments has been a subject which although fascinates students but due to lack of suitable demonstrating setups, students find difficulty in understanding these concepts and hence unable to appreciate the importance of such concepts in various useful scientific apparatus, instruments and devices. Therefore, students tend to cram various concepts related to geometrical optics instead of understanding them. As part of the extension activity in the University Grants Commission major research project “Investigating science hands-on to promote innovation and research at undergraduate level” and University of Delhi at Acharya Narendra Dev College SPIE student chapter, students working under this optics outreach programme have demonstrated various experiments on geometrical optics using a five beam laser ray box and various optical components like different types of mirrors, lenses, prisms, optical fibers etc. The various hands-on activities includes demonstrations on laws of reflection, image formation using plane, concave and convex mirrors, mirror formula, total internal reflection, light propagation in an optical fiber, laws of refraction, image formation using concave and convex lenses and combination of these lenses, lens formula, light propagation through prisms, dispersion in prism, defects in eye- Myopia and hypermetropia and basic working of some optical instruments like camera and telescope. Students have been evaluated through pre and post tests in order to measure the improvement in their level of understanding.

8129-22, Poster Session

Optical sensor for the determination of adulteration in petrol: design and development

K. Kishor, R. K. Sinha, A. D. Varshney, V. Kumar, Delhi Technological Univ. (India)

In this paper, we report design and development of optical sensor for the determination of adulteration in petrol using optical time-domain reflectometer (OTDR). OTDR is generally used to find out faults in optical fibers but we effectively use this technique for the determination of the percentage of adulteration in petrol. This OTDR method enables detection of adulteration in petrol very accurately. The OTDR measurement method reported in this paper is easy to carry out and also a cost effective tool for the determination of adulteration in petrol.

In this experiment, we transmit several pulses of different wavelengths in optical fiber at the one end and measured the back reflection from other end of the optical fiber which is dipped in the given sample of the petrol. On the basis of back reflection recorded, we determine the percentage of adulteration in petrol comparing reflections from pure petrol. These measurements have been repeated several times with different percentage of adulteration in petrol. We found that the result obtained is very accurate, and method is highly sensitive even for the very low percentage of adulteration in petrol. It is reported that this optical-fiber based sensors for determination of adulteration in petrol is very economical, user friendly and most important eco-friendly.

8129-23, Poster Session

Variation of optical polarization in reflected light by redistribution of electric charge in metals

J. G. Suárez-Romero, E. Hernandez-Gomez, Instituto Tecnológico de Querétaro (Mexico)

We report in this work the observation of changes in the difference of the phase delay of the parallel and perpendicular components of an optical beam when it is reflected by a metal surface which is altered with electric charge. A quasimonochromatic linearly polarized beam is directed to a piece of steel where it is reflected, the polarization of the reflected beam is in general elliptical. The module of each polarization component and their difference of phase are measured with an ellipsometer. The piece of metal is grounded for first measurements, when static charge is induced on the metal the phase delay of the components changes obtaining a rotation of the elliptical polarization.

The metallic surface is polished to obtain specular reflection only. The incidence angle is 75 grad approximately; this angle is the principal angle of incidence. The azimuthal angle of the incident beam is set such that a circularly polarized reflected beam is obtained. When the piece of steel is altered with static charge the circular polarization gets elliptical. Given that the module of the reflectance components of the material does not change the only way is a change in the phase of the reflectance components. An interesting application of this effect is the rotation of the polarization of a beam without a reduction of its intensity.

8129-24, Poster Session

Optical design for LED dental lighting with imaging optic technique

Y. Kwon, H. Lim, S. Bae, LED-IT Fusion Technology Research Ctr. (Korea, Republic of); J. Jang, Yeungnam Univ. (Korea, Republic of)

Because of a lot of merit, LED is started to replace halogen lamp in many illumination applications like as indoor lighting, outdoor lighting, automotive lighting and so on. Especially, LED has no heat radiation, more comfortable than halogen lamp as medical luminaire. There are some products to replace conventional halogen lamp in market already. But have issues of low efficiency and dim pattern boundary. For solve the problem, we developed LED dental lighting as this research. We did a research as follows.

First of all, selected optimum LEDs and mixed it for higher CRI, target CCT and illuminance.

The following step is optical module design. Light directional characteristics of dental lighting must be concentrated to illuminate a part. Because this part is oral cavity, The feature of illumination pattern is rectangular. For uniformity of illuminance and clearer pattern boundary at reference distance, we designed it as direct type (no use reflector) by imaging optic technique. First, Image is rectangular feature, so object must be the same feature with magnification in general imaging optics. But the emitting surface feature of LED (1W grade) is square or circular generally. For that reason, made object as rectangular source with rectangular lightguide. This optical component was designed for higher efficiency by illumination optic technique. Next, we designed optical lenses based on imaging optic technique for image object feature using Code V, set to high NA for light efficiency in this design. Fundamentally,
Finally, this product is luminaire so illumination simulation and result analysis were executed by LightTools as illumination design software.

8129-25, Poster Session

**Broadband optical antenna with a disk structure**

I. Wang, The Hong Kong Polytechnic Univ. (Hong Kong, China)

Broadband optical antennas are of interest as they can transmit more information like traditional microwave UWB antennas. This paper presents a design of broadband optical antennas with a concentric disk structure. An equivalent circuit for the optical antenna with a disk structure is introduced. The broadband radiation at optical frequencies was demonstrated via the computer simulation.

8129-28, Poster Session

**Design and evaluation of wide field-of-view optical antenna**

P. Deng, X. Yuan, Y. Zeng, M. Zhao, Huazhong Univ. of Science and Technology (China)

The free space optical communication systems should utilize optical antennas with beam tracking mechanisms. However, the narrow field of view and optical aberration of antennas degrade the tracking performance of the system. To overcome the problems, we investigate the wide field of view optical antenna technology. The optical antenna consists of fish eye lens, compensating lens and a 125 mm diameter catadioptrics telescope with off-axis aspheric surface mirrors. The structures and performances of the optical device elements are numerically analyzed so that their design can make positive contribution in enlarging the field of view and reducing the optical aberration. The optical antenna of free space optical communication has been optimum designed. The proposed optical antenna could not only provide a wide field of view with approximately 60 degree and expand the range for tracking mechanism, but also mitigate the optical aberration and improve tracking accuracy for free space optical communication systems in turbulent atmosphere.
8130-01, Session 1

Beam shaping in the MegaJoule laser project
J. Luce, Commissariat à l’Énergie Atomique (France)

The LMJ (Laser Mega-Joule) is dedicated to inertial confinement fusion. To perform this type of experiment, 160 square beams are frequency converted and focused into a target filled with a deuterium tritium mixture. This means to achieve 10^15 W/cm2 laser intensity at 351 nm per bundle of 4 beams. The laser architecture can be divided into 4 blocks: a fiber source featuring gaussian beam, E: 1nJ, 1053nm, t: 5ns, 1000 flies; a pre-amplifier module (square beam, E: 1J); a four pass main amplifier boosters (E: 15kJ/beam) and then converting, focusing final optics (: 351nm, E: 8kJ/beam).

We propose to review the technics used to shape these beams along their propagation through the LMJ. Going upstream from the target to the laser source, specific optics are designed to meet the beam shaping requirement. A focusing grating and a pseudo-random phase concentrate the energy into the target. A deformable mirror controls and compensates the spatial phase defect occurring during the propagation through the main slab amplifiers. A liquid crystal cell shapes the beam in order to compensate the gain profile of the main amplifiers. It also protects the growth of damages that take place in the final chain optics. At last, a phase mirror shapes a square flat top mode from a gaussian beam within a regenerative amplifier.

All these optical components have one common principle: they control the phase of the laser field.

8130-02, Session 1

High peak power laser beam control with adaptive optics
A. V. Kudryashov, Active Optics NightN Ltd. (Russian Federation)

Some peculiarities of the use of adaptive optical elements and the whole system to correct for the aberrations of some high peak power TIS and glass lasers are presented. As a corrector we used bimorph multi electrode deformable mirror while as a sensor - Shack-Hartmann wavefront sensor.

8130-03, Session 1

Advances in MEMS deformable mirror technology for laser beam shaping applications
S. Cornelissen, P. Bierden, Boston Micromachines Corp. (United States)

Adaptive optics has made advances in the past years to move the technology into a broader range of applications and uses. This includes the extension of the technology from traditional astronomical and biological imaging systems to the fields of beam control for laser communication, laser machining and pulse shaping. In this talk I will describe ongoing work at Boston Micromachines and our collaborators in the field of micromachined deformable mirrors (DMs) for these applications. A MEMS mirror has been designed and fabricated for the use as a spatial and temporal shape controller for pulsed lasers. The design of the device, specifications, and potential applications of this device will be discussed. Also discussed will be the implementation of metric based control of wavefronts and the characteristics of MEMS devices required for high speed, high precision control.

8130-04, Session 1

Improve temporal contrast by cross-polarized wave generation at a sub-petawatt laser facility
N. Xie, W. Huang, X. Wang, L. Sun, Y. Guo, Q. Li, China Academy of Engineering Physics (China)

Temporal contrast is a key factor affecting the application of ultraintense and ultrashort pulse laser facilities. In this study, we attempt to improve temporal contrast for ultraintense and ultrashort pulses in a 300 TW laser facility by cross-polarized wave (XPW) generation, which is a new technique developed recently to improve temporal contrast for ultrashort pulses effectively. Preliminary experiments were carried out to study the XPW generation efficiency and the enhancement of temporal contrast in the front end system of the ultraintense and ultrashort laser facility. i.e. the super intense laser for experiment on the extremes (SILEX-I), with a wavelength of 800 nm. The results show that the relationships between the efficiency of cross-polarized wave generation and crystal orientation/ input intensity are in good agreement with theoretical predictions. Prepulses and the amplified spontaneous emission (ASE) pedestal are suppressed significantly and the temporal contrast is improved by two to four orders of magnitude. Higher and stabler contrast should be obtained if the extinction ratio of the polarizer-analyzer pair and energy stability of input pulses are improved. To amplify the temporally cleaner pulses, a double chirped-pulse amplification (CPA) system is designed and output energy of 300 mJ will be achieved for the front end system.

8130-05, Session 2

Generation of pure TEMp0 modes using a friendly intra-cavity laser beam shaping technique
T. Godin, E. Cagniot, M. Fromager, Ecole Nationale Supérieure d’Ingenieurs de Caen et Ctr. de Recherche (France); N. Passilly, FEMTO-ST (France); M. Brunel, Univ. de Rouen (France); K. Ait-Ameur, Ecole Nationale Supérieure d’Ingenieurs de Caen et Ctr. de Recherche (France)

The authors present a variant of the Fox & Li method [1] performing intra-cavity laser beam shaping for resonators containing an arbitrary number of amplitude and phase diffractive optics. This one consists in modeling just a single round-trip as a cavity equivalent sequence, and then propagating the desired resonant field through it. Consequently, this new approach, which preserves the ease of implementation of the original method (equivalent sequence of lenses) while removing its main drawbacks (random starting field distribution and hundreds of round-trips), is workable within an optimization process (Adaptive Simulated Annealing) iterating upon the features of the cavity until the input and the output fields match as much as possible. As an illustration, the problem of forcing a laser to oscillate on a single high-order transverse mode, which is a challenge in today’s research world [2], has been considered. In particular, from numerical simulation, we deduce a simple model for generating such modes with a pi-phase plate inserted into a plano-concave cavity. This model has been tested experimentally within an active cavity with a diode-pumped Nd:YVO4 laser and an excellent agreement with numerical predictions has been found: a phase aperture located quite close to the concave mirror, and whose normalized radius is so that 2π corresponds to a zero of a p-order Laguerre polynomial, was sufficient to generate single cylindrical TEMp0 modes (p = 1, 2, 3) as long as its radius is correctly chosen. The laser based the optimized features was perfectly stable, whatever the order of the generated mode [3].

Laser beam shaping is particularly challenging with Laser Guide Stars (LGS) and large telescopes. In Adaptive Optics (AO), LGS elongation becomes significant with TMT (30 m) and E-ELT (42 m). It significantly reduces performance of Shack-Hartmann and curvature wavefront sensors. To determine the dimension of the laser source, we need to know: Na layer column abundance, centroid height, Na concentration and Na layer thickness. The LGS spot elongation is a function of the vertical sodium layer thickness and the orthogonal offset of the observer of the laser beam. R. Ragazzoni (2004) suggested that LGS elongation might be reduced by distribution of launch optics around the telescope primary or secondary, all beams focusing and combining at the required elevation of 93 km.

Although TMT and E-ELT deal with the same parameters with respect to AO LGS, they apply them differently. For TMT (B. Ellerbroek, 2010), there will be 6 laser guide star wavefront sensors. Both center and side launch configurations have been considered, but the former is preferred due to cost and current progress.

For E-ELT, LGS spot elongation was analyzed for over year with nocturnal as well as seasonal NA variation. The orthogonal offset is 21 m. Assuming a laser of sufficient power, a telescope could observe at low latitudes for more than 250 days per year. Six laser guide stars and three natural guide stars are foreshadowed with the launch position at the edge of the aperture preferred. Elongation then depends on the sodium density profile. Performance of the two telescopes will be compared for system complexity as well as anticipated performance.

Spatial and temporal shaping for large mode area fiber laser system

Y. Deng, China Academy of Engineering Physics (China)

With the development of high-power laser technology, a focus density about 1022W/cm2 can be achieved in laboratory, and scientists are aiming for much higher level. As fiber lasers have many advantages over the traditional solid state lasers, for example high efficiency, high reliable, high stability, low thermo effect and etc, high energy Peta Watt (PW) laser facilities will adopt fiber laser front end. In order to scale output energy of fiber laser system, it maybe comprise much amplification stage. Also the nonlinear effect such as SBS, SRS etc. will happen when the power is very high. For the purpose of reducing nonlinear effect still with high power and high energy, they adopt large mode area fiber amplifier. An increase of the core size and decrease of the NA in large mode area (LMA) double cladding fibers can substantially reduce the power density still with single transverse mode, which is beneficial to high power fiber laser systems. But when a seeded laser pulse was coupling into a large mode area fiber amplifier, the model noise will be found, which mostly caused by large mode area fiber’s fabrication. And as there are much stage fiber amplification, the amplified spontaneous emission (ASE) will greatly depress laser pulses’ signal to noise ratio (SNR). The low signal and noise ratio level of the fiber laser front end system has many disadvantages for PW laser facilities.

In order to suppress mode noise and to enhance pulses’ SNR, we study the spatial and temporal shaping for large mode area fiber laser system. For spatial pulse shaping, we used method of mode area adapting to suppress mode noise. For purpose of temporal pulse shaping, a method of nonlinear polarization rotation caused by Optical Kerr effect in fiber was used. By spatial and temporal pulse shaping methods, cleared pulses with a strictly single mode in spatial and a cleaned pulse without ASE pedestal were obtained.

With the development of high-power laser technology, a focus density about 1022W/cm2 can be achieved in laboratory, and scientists are aiming for much higher level. As fiber lasers have many advantages over the traditional solid state lasers, for example high efficiency, high reliable, high stability, low thermo effect and etc, high energy Peta Watt (PW) laser facilities will adopt fiber laser front end. In order to scale output energy of fiber laser system, it maybe comprise much amplification stage. Also the nonlinear effect such as SBS, SRS etc. will happen when the power is very high. For the purpose of reducing nonlinear effect still with high power and high energy, they adopt large mode area fiber amplifier. An increase of the core size and decrease of the NA in large mode area (LMA) double cladding fibers can substantially reduce the power density still with single transverse mode, which is beneficial to high power fiber laser systems. But when a seeded laser pulse was coupling into a large mode area fiber amplifier, the model noise will be found, which mostly caused by large mode area fiber’s fabrication. And as there are much stage fiber amplification, the amplified spontaneous emission (ASE) will greatly depress laser pulses’ signal to noise ratio (SNR). The low signal and noise ratio level of the fiber laser front end system has many disadvantages for PW laser facilities.

In order to suppress mode noise and to enhance pulses’ SNR, we study the spatial and temporal shaping for large mode area fiber laser system. For spatial pulse shaping, we used method of mode area adapting to suppress mode noise. For purpose of temporal pulse shaping, a method of nonlinear polarization rotation caused by Optical Kerr effect in fiber was used. By spatial and temporal pulse shaping methods, cleared pulses with a strictly single mode in spatial and a cleaned pulse without ASE pedestal were obtained.
8130-38, Session 2

**Intra-cavity vortex beam generation**

A. Forbes, CSIR National Laser Ctr. (South Africa) and Univ. of KwaZulu-Natal (South Africa); D. Naidoo, CSIR National Laser Ctr. (South Africa); K. Ait-Ameur, Ecole Nationale Supérieure d'Ingénieurs de Caen et Ctr. de Recherche (France)

No abstract available

8130-11, Session 3

**Annular ring zoom system using two positive axicons**

F. M. Dickey, FMD Consulting LLC (United States); J. D. Conner, U.S. Photonics Inc. (United States)

The production of an annular ring of light with a variable diameter has applications in laser material processing and machining, particle manipulation, and corneal surgery. This can readily be accomplished using a positive and negative axicon pair. However, negative axicons are very expensive and difficult to obtain with small diameters. In this paper, we present a design of an annular ring zoom system using two positive axicons. One axicon is placed a distance before a primary lens that is greater than some prescribed minimum, and the second axicon is placed after the primary lens. The position of the second axicon determines the ring diameter. The ring diameter can be zoomed from some maximum design size to a zero diameter ring (spot). Experimental results from a developmental system will be presented.

8130-12, Session 3

**Evaluation of DMD-based high-precision beam shaping using sinusoidal-flat-top beam profile generation**

J. Liang, R. N. Kohn, Jr., M. F. Becker, D. J. Heinzen, The Univ. of Texas at Austin (United States)

We evaluated system performance of a high-precision beam shaper using a digital micromirror device (DMD) as a binary-amplitude spatial light modulator followed by a telescope with an adjustable pinhole low-pass filter. Beam shaping quality was measured by comparing intensity and wave-front conformity to the target function, and by energy conversion efficiency. We demonstrated various flattop beam profiles with narrow spatial frequency content. For a raw camera image, we achieved 0.81-1.12% intensity root-mean-square (RMS) error and a nearly uniform wave front for both coherent and incoherent light sources of different visible and infrared wavelengths. Diffraction efficiency analysis determined optimized operation wavelength ranges for different orders. Experiments achieved 19.8% Gaussian-flattop power conversion efficiency using a 781 nm laser diode. This paper extends beam-shaping experiments to target functions with arbitrary spatial frequency content. Analyses of intensity errors were conducted for output beam profiles consisting of pure sinusoids on a flat-top beam. Pattern design errors were predicted by the spectral content of binary DMD patterns produced by an error diffusion algorithm. We also investigated the impact of input profile and pixel location on digitization error and estimated the best possible performance of iterative pattern refinement by numerical simulation.

In addition, sinusoidal-flattop profiles with different frequencies were chosen for system evaluation. As an example, experiments demonstrated 1.5-2% RMS error over a 1.23×1.23 mm² square region for a 0.66 mm period sinusoidal-flattop beam. We expect that the error of any target profile with band-limited spatial frequency content can be estimated by superposition of the single-frequency results.

8130-13, Session 3

**Generation of flat top focusing with second order full Poincaré beams**

W. Cheng, W. Han, Q. Zhan, Univ. of Dayton (United States)

Two-dimensional flat-top beam shaping with spatially variant polarization can be obtained using Full Poincaré (FP) beams under low numerical aperture focusing condition. FP beams are a new class of beams that span the entire surface of Poincaré sphere. In this work, we report the flat-top focusing with second order FP beams generated through linear combination of orthogonally polarized fundamental Gaussian (LG00) and second order Laguerre Gaussian (LG02) beams. The fundamental Gaussian produces a solid spot and the LG02 produces with a donut distribution around the x-polarized solid spot. One problem of using higher order LG beam is the larger dark center area of LG02 mode that causes ripples in the resultant profile of combination with fundamental Gaussian. This is solved by slightly defocusing the y-polarized LG02 beam with respect to the x-polarized component to axially separate the focal points of the two orthogonally polarized components. A preferred flat-top profile can be found at a position between the two focal points where the intensity and size of the two components are comparable. Due to the use of the second order FP beam, the edge roll-off is much steeper compared with the case of first order FP beam. The theoretical beta-value is calculated to be 5.88 and experimentally it is found to be 6.65 for an incident beam diameter of 7.0 mm. Another significant advantage is that this beam shaping technique is insensitive to the input beam size, which has been confirmed experimentally.

8130-14, Session 3

**Synthetic design and integrated fabrication of multi-functional hybrid beam shapers**

R. M. Kleindienst, R. Kampmann, S. Stoebenau, S. Sinzinger, Technische Univ. Ilmenau (Germany)

Novel applications in the fields of optical beam shaping, imaging and sensing require the implementation of more and more complex optical functions. In general for this purpose optical systems are modularly extended by adding conventional optical components. This approach automatically comes along with an increasing system size and weight as well as potentially higher assembly and maintenance costs. Hybrid optical freeform components can help to overcome this tradeoff. They merge several optical functions within fewer but more complex optical surfaces, e.g. elements comprising shallow refractive/reflective and high frequency diffractive structures. However, providing the flexibility and precision essential for their realization is one of the major challenges for both optical components design and fabrication.

In our contribution we present a reflective hybrid beam shaper offering beam deflection, transformation and splitting capabilities. Dividing our work into three main parts, we first report on the applied design, simulation and optimization methods. To synthesize the reflective basic shape, composed of a 90°-beam deflection, a Gaussian-to-tophat beam shaping function and an aberration controlled Fourier lens function, we used wave optical and ray tracing calculations respectively. Furthermore we optimized the reflective structure, realizing the beam splitting function, were optimized by rigorous computations. In the second part we present an integrated machining technique suitable for rapid prototyping as well as the fabrication of molding tools for low cost mass replication of this hybrid beam shaper. To produce the different feature sizes with an optical surface quality we successively combine mechanical machining modes with precisely aligned ps-laser ablation. In the concluding part the shape accuracy and surface quality are demonstrated with profilometric measurements and experimental investigations of the optical performance proving the applied fabrication methods and design-synthesis.
8130-15, Session 3

Experimental realization of high-efficiency switchable optical OAM state generator and transformer

Y. Li, J. Kim, M. J. Escuti, North Carolina State Univ. (United States)

We introduce a high efficiency method to control orbital angular momentum (OAM) state of light by using switchable q-plates and switchable forked polarization gratings (FPGs). We successfully fabricated both elements and realized fast electric-optical switchable controlling on OAM state, whereas the methods by previous works offered either fixed or slow modification. We recently introduced FPG with special photo-aligned liquid crystal architecture that modify Pancharatnam-Berry phase, as an highly efficient OAM state controller. Q-plate is another well known OAM state generator, which converts circularly polarized light into a fixed OAM state associated with its q charge. We now report on our experimental implementation of electrically switchable FPGs and switchable q-plates based on liquid crystal cell. The special designed anisotropy is obtained by photo-alignment and liquid crystal technology. For FPGs, high-quality patterning is achieved by polarization holography. In both elements, external electric field applied on the cell can fast switch the element between OAM generating (on) mode and transmissive (off) mode. The electric-optical behavior is characterized. Converting efficiency and switching time of both elements are measured. As compact optical elements, switchable q-plates and switchable FPGs are highly efficient and flexible. They are the ideal units to compose multistage OAM state controlling system, which could benefit a lot to the realization of extreme high capacity information applications, among many others.

8130-16, Session 4

Comparing flat top and Gaussian focal beam shapes when micromachining steel

T. E. Lizotte, O. P. Ohar, Hitachi Via Mechanics (USA), Inc. (United States)

Laser micromachining, drilling and marking is extensively used within the aerospace, automotive and firearms industries. The unique properties of lasers make them ideal tools for micromachining a wide diversity of materials, including steel alloys [1]. We describe the results of micromachining of low carbon steel and stainless steel alloys, using a high powered diode pumped solid state (DPSS) laser operating at a wavelength of 355nm. The laser was configured with beam conditioning optics to produce either a flat top beam or a Gaussian output which was then sent through a galvanometer scanner and telecentric lens beam delivery system. This paper outlines the interrelationship of process variables of both a flat top beam shape and Gaussian beam shape. Process variables measured included the optimum laser focus plane, energy density, pulse frequency, galvanometer scan rate, and number of pulses, pulse overlap and focal spot diameter. Optimum process performance was evaluated based on a statistical dimensional comparison of the micromachined features from each test coupon, including uniformity and surface roughness of the micromachined surface, the minimization of surface irregularities (stalagmite type slag / debris / corn row patterns) and taper angle of the micromachined feature side walls.

8130-17, Session 4

Laser beam shaping for studying thermally induced damage in diamond

B. N. Masina, Council for Scientific and Industrial Research (South Africa); A. Forbes, Council for Scientific and Industrial Research (South Africa) and Univ. of KwaZulu-Natal (South Africa)

We outline the generation of shaped laser beams for the laser heating of industrial diamond. By shaping the pump light, we may customise the source term of the heat equation, and thereby generate custom thermal gradients across the diamond. In this paper we will present theoretical and experimental results on this subject, with the aim of controlled study of the thermal properties of diamond.

8130-18, Session 4

Reducing beam shaper alignment complexity: diagnostic techniques for alignment and tuning

T. E. Lizotte, Hitachi Via Mechanics (USA), Inc. (United States)

Safe and efficient optical alignment is a critical requirement for industrial laser systems used in a high volume manufacturing environment. Of specific interest is the development of techniques to align beam shaping optics within a beam line; having the ability to instantly verify by a qualitative means that each element is in its proper position as the beam shaper module is being aligned. There is a need to reduce these types of alignment techniques down to a level where even a newbie to optical alignment will be able to complete the task. Couple this alignment need with the fact that most laser system manufacturers ship their products worldwide and the introduction of a new set of variables including cultural and language barriers, makes this a top priority for manufacturers. Tools and methodologies for alignment of complex optical systems need to be able to cross these barriers to ensure the highest degree of up time and reduce the cost of maintenance on the production floor. Customers worldwide, who purchase production laser equipment, understand that the majority of costs to a manufacturing facility is spent on system maintenance and is typically the largest single controllable expenditure in a production plant. This desire to reduce costs is driving the trend these days towards predictive and proactive, not reactive maintenance of laser based optical delivery systems [1]. With proper diagnostic tools, laser system developers can develop proactive approaches to reduce system down time, safe guard operational performance and reduce premature or catastrophic optics failures. Obviously analytical data will provide quantifiable performance standards which are more precise than qualitative standards, but each have a role in determining overall optical system performance [1]. This paper will discuss the use of film and fluorescent mirror devices as diagnostic tools for beam shaper module alignment off line or in-situ. The paper will also provide an overview methodology showing how it is possible to reduce complex alignment directions into a simplified set of instructions. Two examples will be used including a UV DPSS laser and UV Excimer laser beam shaper alignment process.

8130-19, Session 4

Efficient laser ablation using beam shaping and beam splitting

R. S. Patel, J. Bovatsek, A. Tamhankar, Spectra-Physics®, a Newport Corp. Brand (United States)

Efficient use of the available energy from a laser source is important to achieve maximum material removal for the laser material processing applications. Especially, with availability of short pulse width high energy per pulse pulsed lasers it is necessary to deposit optimal amount of energy to achieve most efficient ablation and removal of material with minimal heat affected zone. While there are various ways one can deliver optimal amount of energy to the target material we have chosen beam shaping and beam splitting technique. We have shown that using beam shaping and beam splitting material removal efficiency can be improved. Experimental data for scribing Silicon and Sapphire in most efficient way is presented.
8130-21, Session 5

**Diamond turning considerations for the manufacture of beam shaping optics**

G. E. Davis, G. L. Herrit, A. R. Hedges, II-VI Infrared (United States)

Advances in diamond turning technology have offered optical engineers new degrees of freedom in the design of beam shaping optics. While designers have these new manufacturing methods at their disposal, they may not be aware of special process limitations that impact the cost and quality of components. The purpose of this paper is to present some of these critical manufacturing issues in the context of various beam shaping applications. We will discuss four key diamond turning technologies and the types of beam shaping optics that they are best-suited to produce. These technologies include the standard 2-axis diamond turning lathe, slow tool servo (STS) which introduces a programmable spindle position to the lathe, fast tool servo (FTS) which is a separate fast-acting limited-stroke axis, and diamond micromilling which incorporates an additional spindle that rotates a diamond end mill at very high speed. Within the discussion we will present various beam shaping applications, the associated optical surface shapes, and the process limitations involved with their production. In summary we will present this data in a matrix that will help the optical engineer design solutions that balance performance with manufacturability.

8130-22, Session 5

**Diffractive beam shapers used for optical testing**

K. J. Kanzler, JENOPTIK Optical Systems, Inc. (United States)

Diffractive beam shapers can be used to gather information about input laser beams. This paper will describe some techniques for using DOE beam shapers to characterize important parameters for TEM00 mode laser beams. Parameters like beam diameter, ellipticity and M-squared will be reviewed. These beam shapers along with other DOEs can be used in real time to adjust input beam parameters for precision laser applications. Optical modeling simulations and real test data will be presented to demonstrate these techniques.

8130-37, Session 5

**Spatial beam shaping for lowering the threshold energy for femtosecond laser pulse photodisruption**

A. Hansen, T. Ripken, A. Heisterkamp, Laser Zentrum Hannover e.V. (Germany)

High precision femtosecond laser surgery is achieved by focusing femtosecond (fs) laser pulses in transparent tissues to create an optical breakdown and therefore a tissue dissection through photodisruption. For moving applications in ophthalmology from corneal or lental applications in the anterior eye to vitreal or retinal surgery in the posterior eye the applied pulse energy needs to be minimized in order to not harm the retina. However, the aberrations of the anterior eye elements cause a distortion of the wave front and consequently an increase in size of the irradiated area and a decrease in photon density in the focal volume. Therefore, higher pulse energy is required to still surpass the threshold irradiance. In this work, aberrations in an eye model consisting of a planoconvex lens for focusing and HEMA (2-hydroxyethyl-methacrylate) in a water cuvette as eye tissue were corrected with a deformable mirror in combination with a Hartmann-Shack-sensor. The influence of an adaptive optics aberration correction on the pulse energy required for photodisruption was investigated. A reduction of the threshold energy was shown in the aberration-corrected case and the spatial confinement raises the irradiance at constant pulse energy. As less energy is required for photodisruption when correcting for wave front aberrations the potential risk of peripheral damage is reduced, especially for the retina during laser surgery in the posterior eye segment. This offers new possibilities for high precision fs-laser surgery in the treatment of several vitreal and retinal pathologies.

8130-20, Session 6

**Imaging micro lens array beam integrator system design for fiber injection**

T. E. Lizotte, Hitachi Via Mechanics (USA), Inc. (United States); F. M. Dickey, FMD Consulting LLC (United States)

This paper documents the design, analysis and testing of beam integrator systems for the investigation of the injection of a single mode laser into square and round fibers (two sizes each), and a rectangular fiber. This research focused on methods that could enhance the development of a uniform speckle pattern at the output end of the fiber, the injection systems are designed to fill the modes of the fiber (as much as practicable) and match the NA of the fiber. The designs for the square and rectangular fibers are based on lenslet array components available from off-the-shelf fabricators. It can be argued that the number of modes injected into the fiber is proportional to the number of lenslets in the input beam. Evaluation at the design phase leaned towards lenslet arrays with small lenslet sizes. However, diffraction limits how small the lenslet arrays can be. For this reason the final designs were configured using a micro lens array based imaging integrator approach. An overview and tests results will be presented to evaluate the benefits and limitations of such fiber injection techniques.

8130-23, Session 6

**Combination of a micro lens multi-spot generator with a galvanometer scanner for flexible parallel micromachining of silicon**

M. Zimmermann, BLZ Bayerisches Laserzentrum GmbH (Germany) and Erlangen Graduate School in Advanced Optical Technologies (Germany); M. Schmidt, Friedrich-Alexander- Univ. Erlangen-Nürnberg (Germany) and BLZ Bayerisches Laserzentrum GmbH (Germany) and Erlangen Graduate School in Advanced Optical Technologies (Germany)

Multi focus optics are used for parallelizing production and for large-scale material processing. These elements split the beam into a periodic spot pattern with a defined grid and spot size. The challenge lies in the generation of a homogeneous envelope. Additionally the demand for flexible systems for an in-process changing of optical properties increases. Different components for multi spot generation like diffractive optical elements or micro lens arrays were investigated. Diffractive optical elements offer a lot of freedom in the generation of arbitrary intensity distributions. The disadvantage is the complex design of these elements, the limits regarding flexibility and the relatively cost-intensive production. Within the paper we present the investigation of a micro lens array in a fly’s eye condenser setup for the generation of homogeneous spot patterns. The multi spot generator is combined with a galvanometer scanner for forming an arbitrary shaped laser beam into a spot-, ring or arbitrary array pattern. We show the principal functionality of the multi-spot generator by using wave optical simulation and principles of fourier optics. Furthermore constrains of this setup are demonstrated. The multi spot scanner is used for micro structuring of silicon an polyimide with a nanosecond diode pumped solid state laser. The ablation rate and structure quality are compared to single spot processing.
Applying of refractive beam shapers in combination with laser scanning optics

A. V. Laskin, MoTech GmbH (Germany); V. V. Laskin, AdiOptica Optical Systems GmbH (Germany)

Combining the refractive beam shapers with laser scanning optics is often considered to realize various industrial laser technologies as well as techniques used in scientific and medical applications. Today the 2- and 3-axis galvo mirror scanners with F-theta, telecentric or other lenses as well as gantry systems are widely used in different applications like micromachining, solar cell manufacturing, welding, drilling holes and others which performance can be improved by applying of beam shaping optics. And due to their unique features, such as low output divergence, high transmittance as well as extended depth of field, the refractive field mappers provide a freedom in building an optimum optical system. There will be considered several optical layouts based on various refractive beam shapers piShaper to generate laser spots of uniform intensity which sizes span from several tens of microns to millimetres. Examples of real implementations will be presented as well.

Strong reducing of the laser focal volume

T. Godin, Ecole Nationale Supérieure d’Ingenieurs de Caen et Ctr. de Recherche (France); S. S. Ngocobo, Council for Scientific and Industrial Research (South Africa); E. Cagniot, M. Fromager, Ecole Nationale Supérieure d’Ingenieurs de Caen et Ctr. de Recherche (France); A. Forbes, Council for Scientific and Industrial Research (South Africa)

Many applications of lasers seek nowadays for focal spots whose corresponding volume is getting smaller and smaller in order to ensure high spatial resolution. The latter is usually limited by the Rayleigh criterion. To go beyond the diffraction limit, is nowadays a subject under strong investigations, and this property is called as super-resolution which usually relates to the focusing of light into a spot having dimensions smaller than the diffraction limit. Our objective has been to develop a new method for obtaining super-resolution that we believe to be more efficient than existing methods. Indeed, we are able to decrease the focal volume by a factor of several hundred, when existing methods do not exceed few tenths. Another interesting feature of our method is the decoupling between transversal and longitudinal resolutions within the focal volume, contrary to Gaussian beams where both the size of field is proportional to the square of its beam-waist. The method that has been developed theoretically and experimentally is based on two steps: First, the laser is forced to oscillate on a high-order but single transversal mode TEM0p, which is secondly spatially beam-shaped thanks to a proper Diffraction Optical Element (DOE) that allocates the super-resolution feature. These results will provide a technological leap in the improvement of spatial resolution of many laser applications such as: 3-D laser prototyping, non-linear microscopy, micro and nano-processing of materials, optical tweezers, etc.

Laser beam shaping and mode conversion using vortex phase structures

R. Soskind, West Windsor - Plainsboro High School South (United States); Y. G. Soskind, DHPC Technologies (United States)

In this paper, we present a novel technique for beam shaping and mode conversion of elliptical laser beams employing vortex phase elements. We show that a vortex phase element with topological charge m = 1 can effectively transfer an elliptically shaped fundamental TEM00 mode into a TEM01 mode. When used with a spatial light modulator, the proposed technique allows beam shape adjustments by applying electrical control signals. Compared to existing static mode conversion techniques, the presented technique may perform dynamic switching between the different laser modes. The developed technique may have several practical applications in the fields of photonics and laser optics, including beam splitters and interferometers, fiber lasers, high speed optical modulators, and optical tweezers.

Properties of propagation-independent laser beams in the presence of obstructions

M. Soskind, West Windsor - Plainsboro High School South (United States); Y. G. Soskind, DHPC Technologies (United States)

In this paper, we discuss the properties of propagation-independent structured laser beams. We show the influence of different beam obstructions on the resulting structure of the beams. We present a reconstruction technique that, in spite of the remarkable self-healing properties of propagation-independent beams, allows us to define the size and shape of the obstructions encountered by the structured beam during propagation. The presented technique may have several practical applications in the fields of photonics and laser optics, including high resolution microscopy, optical information processing, and optical cryoproduction.

Pulse stretcher based on multilayer volume holographic gratings

L. Guo, Shandong Univ. of Technology (China); A. Yan, Shanghai Institute of Optics and Fine Mechanics (China); S. Fu, Shandong Univ. of Technology (China); X. Liu, Shanghai Institute of Optics and Fine Mechanics (China); X. Ge, Shandong Univ. of Technology (China)

A system of multilayer volume holographic gratings (MVHGs) is composed of multiple layers of volume holographic gratings separated by intermediate layers. As a novel diffraction elements, because of more free parameters, multilayer volume holographic gratings have become an ideal candidate for various promising technological applications such as optical interconnects, pulse shaping and optical filters. In this paper, a pulse stretcher system based on MVHGs is shown. The diffraction properties of the pulse stretcher under ultrashort pulse are investigated using the modified multilayer coupled wave theory. The spectral intensity distributions of the diffracted beam are calculated. The diffraction bandwidth, diffraction pulse duration and the total diffraction efficiency of the pulse stretcher are also analyzed. The pulse broadening is accomplished by adjusting the width of the intermediate layer of a system of MVHGs. The calculation results show that using this new pulse stretcher system to broaden pulse has many advantages: the efficiency of diffraction is high, the structure of stretcher is adjustable to vary the amount of temporal broadening of the light pulse, and the structure is also more compact than alternative approaches.

Improvement of combining efficiency of coherent beam combination from phase-locked laser array by optimizing design of Dammann grating

B. Li, A. Yan, X. Lv, J. Sun, L. Liu, Shanghai Institute of Optics
The output power from a single laser is typically limited by effects such as gain saturation, nonlinearities and optical facet damage. In recent years, much attention has been paid to coherent beam combination of laser arrays that can produce a laser with higher output power and brightness than that of individual lasers. With recent advances in beam combining technology, laser arrays are becoming a viable alternative for high power, high beam quality laser systems. Many researchers have studied beam combination in laser arrays using various techniques such as the Talbot cavity, structured mirrors, self-imaging resonator, active phase correction and phase gratings. However, there still exists the limitation that a significant percentage of energy resides in undesired sidelobes of the far field of phase-locked laser arrays. This unavoidably leads to a reduction of beam quality. Recently, Yan propose an efficient beam combining technique for coherent laser arrays that uses a phase plate and a conjugate Dammann grating (CDG) in the front and back focal plane of a Fourier lens, respectively. But the combining efficiency and the beam quality are not high in their experiment because of the design and fabricated errors of the phase grating.

In this paper, we demonstrated an efficient technique for optimizing design of Dammann gratings and highly improved combining efficiency of a coherent beam combination system from phase-locked laser array. The system uses a conjugate Dammann grating and a phase plate in the back and front focal plane of a Fourier lens. Using genetic algorithm, we optimized the Dammann grating and the corresponding phase plate. The combining efficiency and beam quality of the combined beam can be improved evidently. This will be valuable for obtaining high power and high beam quality laser beams.

8130-32, Poster Session

**Comparison of the diffraction characteristics of continuous wave, ultrashort laser pulse and chirped ultrashort pulse diffracted by multi-layer reflection volume holographic gratings**

A. Yan, J. Sun, Y. Zhou, Y. Zhi, L. Liu, Shanghai Institute of Optics and Fine Mechanics (China)

Volume holographic gratings (VHG) are of wide interest in many applications because of their properties of high diffraction efficiency, excellent wavelength selectivity and angular selectivity. Recently, because of more free parameters, multi-layer volume holographic gratings (MVHG) have become an ideal candidate for various promising technological applications such as optical interconnects, pulse shaping and optical filters. Therefore, a knowledge of the diffraction behaviors of such system would be very valuable for characterizing and optimizing such volume diffractive optical elements.

In this paper, we extend the coupled wave theory of multi-layer gratings to study the Bragg diffraction properties of continuous wave, ultrashort laser pulse and chirped ultrashort pulse, and present a systematically theoretical analysis on the spectrum distribution of the diffracted intensities, the diffraction bandwidth, and the total diffraction efficiency of a system of MRVHG. The system of MRVHG is composed of multiple layers of reflection VHG separated by intermediate layers. The comparisons of the diffraction characteristics for these beams are investigated. The analysis and observations of this paper will be valuable for the accurate analysis of the interaction of ultrashort optical pulses and a variety of periodic structures, facilitating the design and the investigation of novel optical devices based on multiple layers of MVHG.

8130-34, Poster Session

**Optical design and modern optical device applied to laser beam shaping lens module**

C. Tsai, Kun Shan Univ. (Taiwan); Y. Fang, Z. Chen, G. Huang, J. Huang, C. Lin, W. Li, National Kaohsiung First Univ. of Science and Technology (Taiwan)

The aim of this research is to analyze the difference size of laser spot diameter when the GRIN lens and the aspheric lens are employed in laser reshaping system, respectively. Two kinds of lens designs based on genetic algorithm (GA) optimization are presented in this research. One is composed of one spherical lens and one Grin lens, the other is composed of one spherical lens and one aspheric lens. Two proposal designs are analyzed to find out one the best result in laser shaping system. Traditionally optical optimization softwares which employ least damping square (LDS) method have their difficulties in dealing with flat top beam shaping process because it is neither well-defined as image optics nor non-image optics. The GA will help us find the fit coefficients of aspheric lens and the well GRIN profile to achieve the laser shaping requirement. In this research, two kinds of designs with the GA which has been comprehensively employed in many applications before, for symmetry system, are demonstrated to get the optimum laser shaping in the uniformity of flat top. The GA program will be written in macro language of Light Tool. The simulation results show that the GA is very useful for laser shaping optimization.

8130-35, Poster Session

**The investigation of optical vortices and hexagonal patterns in three plane wave interference**

L. Kreminska, C. L. Corder, J. Teten, The Univ. of Nebraska at Kearney (United States)

We demonstrated that optical vortices can be created by means of interference of three waves from a common laser source. Different intensity patterns can be generated starting from common two wave interference fringes up to regular hexagonal structures. The created vortices exist throughout the transition from two wave to complete three wave interference and have been shown to move along predictable lines in space under contrast perturbations. The law of conservation of topological charge was fulfilled for the interference of three waves.

8130-36, Poster Session

**Dynamic parabolic optical lattice**

A. Ruelas, S. López-Aguayo, J. C. Gutiérrez-Vega, Instituto Tecnológico y de Estudios Superiores de Monterrey (Mexico)

We introduce and discuss the shaping properties of a novel optical lattice that we call dynamic parabolic optical lattice (DPOL). While the transverse structure of the DPOL is characterized by a suitable superposition of parabolic nondiffracting beams with different transverse wave numbers, its longitudinal structure exhibits a controlled periodic modulation. We address the existence and the controlled stability of two-dimensional solitons in DPOLs and characterize its propagation. An efficient numerical method for constructing nondiffracting parabolic beams and DPOLs is presented as well.
Reducing asymmetric imaging errors through selective assembly and tolerance desensitization

M. C. Funck, RWTH Aachen (Germany); P. Loosen, RWTH Aachen (Germany) and Fraunhofer-Institut für Lasertechnik (Germany)

Asymmetric imaging errors are frequently the main cause for tight tolerances and high demands on manufacture and assembly of optical systems. In order to increase robustness and reduce manufacturing cost a designer can include tolerance sensitivities in the optimization function in order to find insensitive designs. This procedure is commonly referred to as desensitization and a number of means to achieve this have been developed in the past using both global and local optimization methods. It can be frequently observed that desensitization redistributes sensitivities thereby reducing the sensitivity of very sensitive parameters but slightly increasing the sensitivity of formerly insensitive parameters. While using compensation to reduce some of the most sensitive parameters can have a positive impact on tolerance desensitization lateral compensation is often expensive to realize. Some of the complexity of alignment procedures and mechanical mounts can be alleviated by using selective assembly during series production. Selective assembly is based on measurements of components and subassemblies aiming at finding best matches prior to the assembly.

We investigate the potential of using tolerance desensitization in conjunction with selective assembly to reduce asymmetric errors in imaging optical systems. The investigations concentrate on strategies to find tolerance insensitive design forms under the presence of selective assembly compensators and the selection of suitable parameters for desensitization and measurement. Tolerancing for selective assembly and effects of production volume will be discussed.

Impact of tolerance accuracy to design desensitization

R. M. Bates, A. D. Greengard, FiveFocal LLC (United States)

Several methods have been demonstrated for desensitization of a lens design to manufacturing errors with the result of increased as-built performance at the expense of a slightly reduced nominal performance. A recent study demonstrated a targeted desensitization method tuned for the most sensitive lens parameters can greatly increase yield for a known set of manufacturing tolerances. The effectiveness of such a targeted desensitization relies on two key pieces of information; lens sensitivities - easily obtained through modeling software - and manufacturing tolerance distributions gleaned from accurate metrology over many samples. Targeted desensitization to known and unknown manufacturing tolerances is examined with case studies for a typical camera objective, LWIR imager, and miniature camera lens demonstrating the yield impact of using known tolerance distributions in design.

Tolerancing molded plastic optics

M. P. Schaub, Raytheon Missile Systems (United States)

Compared to glass optics, differences in the materials, configurations and manufacturing processes of molded plastic optics lead to differences in the approach to their design and analysis. This paper discusses differences in tolerance analysis between molded plastic optic and conventional glass optic systems.

The sine condition as an alignment tool

M. B. Dubin, J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

The sine condition is typically thought of as a design tool. It can, however, be used to test the alignment of a system or used as a tool during alignment. The primary method for doing this is to look for linearly field dependant astigmatism. This aberration is a key indicator of the state of alignment. This test can be used as a final acceptance test, or in some cases, it can be used to determine the misalignment in the system. This paper presents the basic concept, an alternate way to think about how it works and some experimental results that demonstrate how it functions.

Laser system tolerancing and alignment techniques at the National Ignition Facility

S. C. Burkhart, Lawrence Livermore National Lab. (United States)

The National Ignition Facility (NIF) is the world's largest optical system, with over 14,000 large and small optics, positioned and aligned during commissioning, with a substantial fraction actively aligned each laser shot. The laser system was completed, with the first 192 beam participation shot on March 10, 2009. Designed for stockpile stewardship, inertial confinement fusion research, and basic high energy density science, the NIF is in full operation and conducting laser shots using 1.3MJ, 351nm, 20ns pulses to <1cm targets. A brief overview of the facility and it's status will be presented.

The beam-to-target alignment requirement is 50µm RMS for the 192 beam ensemble. In addition there are internal pointing and centering requirements in the laser to ensure beams stay within their allowed apertures. These top level requirements were distributed to design teams in a tolerance stack-up for installation, active alignment, vibration, and drift. To first order, these teams and their respective project phases comprise the mechanical design staff, precision survey and component placement, optical systems alignment commissioning, and active alignment systems. We will describe these phases, the tolerancing tools used, and the alignment methods employed to achieve the operational success achieved by NIF to date.

Target Diagnostic positioning and pointing has received intense attention by the NIF project in the past 2 years of operation. We will review the methods used to position and point X-ray and neutron imaging diagnostic fields of view to within 100µm of target laser, and plans for improved diagnostic alignment systems based upon precision survey and photogrammetry.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.
A novel fiber-optic probe measures the velocity distribution of an impinging surface along many lines of sight. Reflected light from each spot on the surface is Doppler shifted with a small portion of this light propagating backwards through the launching fiber. The reflected light is mixed with a reference laser in a technique called Photon Doppler Velocimetry, providing continuous time records.

A matrix array of 56 single-mode fibers sends their light through a relay system consisting of three types of lenses. Seven sets of these relay lenses are grouped into a close-packed array allowing the interrogation of seven regions of interest. A six-faceted prism with a hole drilled into its center was used to direct the light beams into different regions. Several types of relay lens systems have been evaluated, including doublet and molded aspheric singlets. The optical design minimizes beam diameters and also provides excellent imaging capabilities. One of the fiber matrix arrays can be replaced by a coherent bundle. To minimize back reflections, this special bundle will have alternating rows of fibers to transmit or receive light.

The close-packed array of seven relay systems provides 392 beam trajectories. The pyramid prism has its six facets polished at two different angles varying the density of surface point coverage. The fiber matrix arrays are angle polished at 8° to minimize back reflections. This causes the minimum beam waist to vary along different trajectories. Precision metrology on the direction cosines trajectories is measured to satisfy environmental requirements for vibration and temperature.

8131-07, Session 2

Using point source microscope (PSM) to find conjugates and assist in alignment of elliptical and parabolic off-axis mirrors

M. B. Borden, R. E. Parks, College of Optical Sciences, The Univ. of Arizona (United States)

Though the Point Source Microscope (PSM) is primarily an alignment instrument, it can also be used to determine the conjugates of elliptical and parabolic off-axis mirrors. With the PSM mounted to an XYZ stage and the mirror placed approximately at either the sagittal or tangential focus, the PSM can be adjusted to the exact focus of the mirror. To minimize spot size as well as coma, the aperture of the mirror is reduced by using a mirror covering with a hole in it. Determining the appropriate hole sizing is discussed in further detail in this publication. With the PSM position at optimal focus, a laser range finder is then used to determine the exact conjugate distance of the mirror. This is accomplished by positioning the back surface of the range finder at the cat’s eye location (focus of the PSM’s objective lens) of the PSM. As the range finder measures distances from its back surface, the distance acquired is the conjugate of the mirror. The same procedure is then repeated for the other conjugate. Using the foci of these two conjugates, the sagittal and tangential radii of curvature (Rs and Rt) can be calculated. These values can then be used to find the distance from the mirror vertex to the optical axis (h) as well as the vertex radius (Rv). This information is to be used to aid in the positioning of the mirror in an optical system.

8131-08, Session 3

Achieving tolerances in an intolerant world: telephoto contact lenses and other unconventional imaging systems

J. Ford, E. J. Tremblay, Univ. of California, San Diego (United States)

Optical system design is always constrained by achievable fabrication tolerances, and there is a constant balance between design performance and the cost or yield of the fabrication process. However, many of the best designs are achieved by starting from the manufacturing platform, and modifying the basic structure of the system to take maximum advantage of symmetries in the system. We will describe several optical systems whose symmetries have allowed us to bypass some of the more problematic tolerances. The first is a multi-reflection imaging system using concentric aspheric mirrors, diamond turned into a single optical element, which allowed us to create a 3x magnification Galilean telescope just 1 mm thick, designed to be incorporated into a contact lens as a vision aid. The second system is a multi-scale lens design which explores a different type of symmetry: a bilateral monocentric primary lens, followed by over 200 identical secondary optics, which together form an aggregate 2000 megapixel imager. And the third system is a non-imaging solar concentrator using micro-optic lenslets and micro-reflectors which couple incident sunlight into a slab waveguide, where the problem of aligning the lenslets to the micro-reflectors has been bypassed by using the focal spot from each lenslet to form (or reveal) it’s corresponding injection feature.

8131-09, Session 3

Tolerancing considerations for visual systems

J. Schwiegerling, The Univ. of Arizona (United States)

The eye is often the final detector in imaging systems. Here we examine some of the aspects of the eye and the human visual system and see how they relate to the overall performance of the optical system. Tolerances on MTF and chromatic aberration are explored.

8131-10, Session 3

Orthogonal polynomials and tolerancing

J. R. Rogers, Synopsys, Inc. (United States)

Previous papers have established the inadvisability of applying tolerances directly to power-series aspheric coefficients. The problem is a low correlation between any one coefficient and optical quality. The reason is that the individual terms are not orthogonal, so an error in one coefficient can be almost completely balanced by appropriate changes in the other coefficients. If only one coefficient differs from its nominal target, then the difference may be regarded as an error, and one can consider applying a tolerance to it. However, when multiple coefficients depart from their nominal values, then it is no longer known that the departures of the coefficients from nominal are actually “errors”; in fact, the departures might be what is necessary to optimally balance the departures of other coefficients. In such a case it is not appropriate to restrict the departure of each individual term from its nominal value.

Zernike surfaces and the new Forbes surface types have certain orthogonality properties over the circle described by the “normalization radius.” This suggests that one could apply tolerances directly to the coefficients of such surface types, at least for surfaces close to the aperture stop. However, at surfaces away from the stop, the optical beam is smaller than the surface, and the aspheric terms are not orthogonal over the area sampled by the beam. It is unclear what problems this causes.

In this paper, we investigate the breakdown of orthogonality as the surface moves away from the aperture stop, and the implications of this for tolerancing.
8131-11, Session 3

Systems modeling and optical verification of a proposed infrared telescope

R. S. Upton, M. W. Noble, National Solar Observatory (United States)

A multi-level optical systems modeling and verification strategy for a space-based infra-red telescope is presented. The level of optical systems modeling is directly related to the number and complexity of the model inputs, and the type of wavefront sensing and focus control simulated during telescope testing and operations. The modeling inputs include residual surface polishing error, thermal print through, mirror rigid body misalignments, and secondary mirror actuator step error. The outputs of the model include coherent PSF effects such as those arising from manufacturing errors, and incoherent effects, such as those arising from the jitter errors of the telescope and space-craft pointing. The optical modeling strategy is encapsulated in MATLAB and ZEMAX as stand-alone applications at the National Optical Astronomy Observatory, and as an integrated model for the most complex model. The optical modeling is used at the Applied Physics Laboratory to directly support optical systems development, engineering information quality, and system validation guidance.

8131-12, Session 4

Maintaining hexapod range while co-pointing the Large Binocular Telescope

A. Rakich, Large Binocular Telescope Observatory (United States)

The Large Binocular Telescope on Mt Graham in Arizona consists of two 8.4 m telescopes mounted on a common gimbal. Each independent telescope has hexapods controlling the position of individual optical elements. These can be used to drive each telescope to point to a common target (or known offsets to these) as is required for many of the observational modes of the telescope. The hexapods have a limited range of travel, particularly the primary mirror hexapods. This paper discusses the approach that has been taken to achieve optical co-pointing while maintaining the maximum possible range of travel in the hexapods.

The approach described here is, starting with collimated but not co-pointed telescopes, to first calculate a coma-free rotation of the optical elements that will equalize the percentage consumption of range on pairs of hexapod elements that effect (X,Y) pointing: i.e. (X,ry) and (Y,rx) respectively. On a collimated telescope this results in a state in which the hexapod values are equal at the center of the mirror. Next a further calculation step is taken which maximizes the available range of travel of the hexapods for a given set of initial hexapod values. X and Y are the angular azimuth and elevation rotation stages to provide the spherical coordinates of a given point. A best fit to a sphere of the measured points was performed. The resulting RoC was within 20 ppm of the nominal RoC, also showing good agreement with the results of a laser tracking system.

8131-13, Session 4

LIDAR metrology for prescription characterization and alignment of large mirrors

B. H. Eegholm, Sigma Space Corp. (United States); W. L. Eichhorn, NASA Goddard Space Flight Ctr. (United States); R. J. von Handorf, Ball Aerospace & Technologies Corp. (United States); J. E. Hayden, Sigma Space Corp. (United States); R. G. Ohl, NASA Goddard Space Flight Ctr. (United States); G. W. Wenzel, QinetiQ North America (United States)

We describe the use of LIDAR, or “laser radar,” as a fast, accurate, and non-contact tool for the measurement of the radius of curvature (RoC) of large mirrors. We report the results of a demonstration of this concept using a commercial laser radar system. We measured the RoC of a 4.5m x 1m aperture, spherical mirror with a nominal RoC of 4800 mm with a manufacturing tolerance of +/- 6mm. The rectangular aperture of the mirror is related to its role as ground support equipment used in the test of part of the James Webb Space Telescope (JWST). The RoC of such a large mirror is not easily measured without contacting the surface. From a position near the center of curvature of the mirror, the LIDAR scanned the mirror surface, sampling it with 1 point per 3.5 cm2. The measurement consisted of 3983 points and lasted only a few minutes. The laser radar was able to detect the presence of the mirror surface, and encoder information from the mirror was used to provide range, and encoder information from the optical systems modeling and verification strategy for a space-based infra-red telescope is presented. The level of optical systems modeling is directly related to the number and complexity of the model inputs, and the type of wavefront sensing and focus control simulated during telescope testing and operations. The modeling inputs include residual surface polishing error, thermal print through, mirror rigid body misalignments, and secondary mirror actuator step error. The outputs of the model include coherent PSF effects such as those arising from manufacturing errors, and incoherent effects, such as those arising from the jitter errors of the telescope and space-craft pointing. The optical modeling strategy is encapsulated in MATLAB and ZEMAX as stand-alone applications at the National Optical Astronomy Observatory, and as an integrated model for the most complex model. The optical modeling is used at the Applied Physics Laboratory to directly support optical systems development, engineering information quality, and system validation guidance.

8131-14, Session 4

Pupil alignment considerations for large deployable space telescopes

B. J. Bos, R. G. Ohl, NASA Goddard Space Flight Ctr. (United States)

For many optical systems the properties and alignment of the internal apertures and pupils are not critical or controlled with high precision during optical system design, fabrication or assembly. In wide angle imaging systems, for instance, the entrance pupil position and orientation is typically unconstrained and varies over the system’s field of view in order to optimize image quality. Aperture and pupil tolerances typically do not receive the same amount of scrutiny as optical surface aberrations or throughput characteristics because they are typically graceful with misalignment, generally only causing a slight reduction in system sensitivity near the edges of an instrument’s field of view due to vignetting. But for a large deployable space-based observatory like the James Webb Space Telescope (JWST), we have found that pupil alignment is a key parameter. For in addition to vignetting, JWST pupil errors cause unertainty in the wavefront sensing process that is used to construct the observatory on-orbit. Furthermore they also open stray light paths that degrade the science return from some of the telescope’s instrument channels. In response to these consequences, we have developed several pupil alignment techniques for the cryogenic vacuum test where JWST science instrument pupil alignment is verified. These approaches use pupil alignment references within the JWST science instruments; pupil imaging lenses in three science instrument channels; and a unique pupil characterization mechanism in the optical test equipment. This allows us to verify the lateral pupil alignment of the JWST science instruments to approximately 1-2% of their pupil diameters.

8131-15, Session 4

Stray light in PICARD SODISM instrument: design, check, flight results, and alignment issues

P. Etcheto, Ctr. National d’Études Spatiales (France); M. Mireille, M. M. Meftah, G. Thuillier, Lab. Atmosphères, Milieux, Observations Spatiales (France); P. Assus, Observatoire de la Côte d’Azur (France)
The PICARD satellite, dedicated to the monitoring of solar activity, includes several imaging and radiometric instruments. One of them, SODISM, is a high resolution radio-imaging telescope measuring the Sun diameter and total flux in near UV and visible wavelengths. Besides its mirrors, it includes highly reflective components which generate ghost images, disturbing both the Sun image area and the aiming channel. The Sun aiming sensor is also disturbed by stray light. These effects are compounded by tilt tolerances, which shift the ghosts from the nominal image. The stray light study was performed through ASAP modelling, based on measured components, broad source incoherent ray tracing and multiple splints, since some high order ghosts were significant while the primary ghosts were blocked. Each path was studied separately, checking its effect on instrument performance and the possible effect of tilts. The most critical ones could be reduced by design improvements, while some relatively intense ghosts proved tolerable due to their location and shape. These improvements were implemented on the flight model. Ground tests and flight results show some residual ghosts, which could not be fully suppressed due to mechanical tolerances. They shall be taken into account by image processing.

8131-25, Session 4
Alignment and testing of the NIRSpec filter and grating wheel assembly
T. Leikert, Carl Zeiss Optronics GmbH (Germany)
In order to perform spectrometric measurements, the Near Infrared Spectrometer (NIRSpec) aboard the James Webb Space Telescope (JWST) needs the ability to select various spectral band widths and split these up into its comprised wavelengths. These functions are achieved by the Filter Wheel Assembly (FWA) and the Grating Wheel Assembly (GWA). The filters of the FWA select a different bandwidth of the spectrum each while the gratings on the GWA yield specific diffractive characteristic for spectral segmentation. A high spectral sensitivity as well as the ability to detect the spectra of various objects at the same time result in high requirements regarding the positioning accuracy of the optics of both mechanisms in order to link the detected spectra to the 2-dimensional images of the observed objects.
The NIRSpec mechanism including FWA and GWA will operate at temperature levels below 42K which are established during testing inside of a cryostat. However the alignment and testing of these mechanisms requires a lot of thought since there is very limited access to the item under test within such a device. Alignment needs to be preloaded based on simulations and testing is reduced to optical methods and evaluation of electrical signals.
This paper describes the methods used for the various alignment steps, the corresponding tests and their precision of measurement as well as the achieved accuracies in the mechanism performance.

8131-16, Poster Session
Alignment estimation performances of merit function regression with differential wavefront sampling in multiple design configuration optimization
E. Oh, Yonsei Univ. (Korea, Republic of) and Korea Ocean Research & Development Institute (Korea, Republic of); S. Kim, Yonsei Univ. (Korea, Republic of)
In our earlier study, we suggested a new method called Multiple Design Configuration Optimization (‘MDCO’ hereafter) method that combines the merit function regression (MFR) computation with the differential wavefront sampling method. In this study, we report alignment state estimation performances of the method while applying it to three target optical systems. They are i) a two-mirror Cassegrain telescope of 58mm in diameter for deep space earth observation, ii) a three-mirror anastigmat of 210mm in aperture for ocean monitoring from the geostationary orbit, and iii) on-axis/off-axis pairs of a extremely large telescope of 27.4m in aperture. First we introduced known amounts of alignment state disturbances to the target optical system elements. Example alignment parameter ranges may include, but not limited to, from 800microns to 10mm in decenter, and from 0.1 to 1.0 degree in tilt. We then ran alignment state estimation simulation using MDCO, MFR and DWS. The simulation results show that MDCO yields much better estimation performance than MFR and DWS over the alignment disturbance level of up to 150 times larger than the required tolerances. In particular, with its requirement of single field measurement, MDCO exhibits greater practicality and application potentials in shop floor optical testing environment.

8131-17, Poster Session
A multi-objective approach in the optimization of optical systems taking into account tolerancing
B. Fonseca Carneiro de Albuquerque, Instituto Nacional de Pesquisas Espaciais (Brazil); L. Liao, J. Sasián, College of Optical Sciences, The Univ. of Arizona (United States)
In this paper we propose the use of a Multi-Objective approach for the lens design optimization problem. In this novel way of treating the problem, we will look and optimize at the same time the image quality and the system tolerancing, but different from the published methods we don’t combine both criteria in a single merit function. As a result we get a set of non-dominated solutions that generates the Pareto Front. This method gives better insights about the available trade off solutions for the problem. The Multi-objective optimization can be easily implemented with evolutionary methods of optimization, which has been applied in the problem of lens design with good results.

8131-18, Poster Session
A case study for cost-effective lens barrel design
M. Saayman, Denel Dynamics (South Africa); J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)
A case study is presented to illustrate some of the cost-driving trade-offs involved in optomechanical systems design, where simple lens barrels are concerned. We examine two different lens barrel designs for a double Gauss lens, and compare them in terms of cost, manufacturability, and performance. We show that the cost and turnaround time can differ significantly between the two approaches. We also show how the optomechanical tolerances (axial spacing, element decenter, and element tilt) are realized in each design, in order to satisfy the optical performance requirements.

8131-19, Poster Session
Statistical truths of tolerance assignment in optical design
R. N. Youngworth, Light Capture, Inc. (United States)
The process of assigning tolerances to optical designs is intrinsically statistical, regardless of volume. Papers covering the statistics of tolerancing, however, have been infrequent. This paper will discuss a number of probabilistic nature of tolerancing that all optical designers and engineers should understand.
8131-20, Poster Session

Use of geometric dimensioning and tolerancing for precision optical assemblies

C. L. Hopkins, J. H. Burge, College of Optical Sciences, The Univ. of Arizona (United States)

Design metrics such as wavefront error and RMS spot size can be of great importance in evaluating an optical system. However, they don’t mean much at the component level especially in the fabrication of a hard戴着 for mounting optics. Machinists and inspectors rely on the proper application of Geometric Dimensioning & Tolerancing (GD&T) to evaluate the quality of their work. This paper will examine techniques for selecting component level tolerances and geometric controls which can be communicated to the parts fabricator by analyzing their impact on system performance.

The process presented is based on a generic optical system with a given set of image quality metrics. First, raytrace software is used to determine position and orientation requirements for each optical component. Next, solid models of several approaches are generated for mounting the optics and various methods of geometric control are applied to each approach. Tolerances are chosen based on a statistical 3-D tolerance analysis of the solid model configuration such that position or orientation requirements are met. Each mounting approach and GD&T scheme is then evaluated based on manufacturability. Using this technique, the optomechanical design engineer will be able to associate individual part manufacturing tolerances to over-all system performance. Geometric Dimensioning & Tolerancing will be in accordance with ASME Y14.5M.

8131-21, Poster Session

Low uncertainty alignment using computer generated holograms

M. B. Dubin, L. Coyle, College of Optical Sciences, The Univ. of Arizona (United States)

The Wide Field Corrector for the Hobby Eberly Telescope is a four mirror corrector that is designed to work with a spherical primary. Because of the required performance, the alignment tolerances on the mirrors are tight. In addition, the amount of aberration in the corrector makes it very difficult to align the mirrors optically. To accomplish this alignment task, a new approach has been developed to sense the misalignment of the mirrors. Computer generated holograms are aligned to the axis of the mirrors and then these holograms are aligned to each other. This paper presents the basic concept, how it will be implemented in the Wide Field Corrector and experimental results showing what the level of uncertainty is.

8131-22, Poster Session

Thin profile solar concentrators with high angular tolerance using wedge prism and diffractive gratings

T. Waritanant, National Central Univ. (Taiwan); S. Boonruang, National Science and Technology Development Agency (Thailand); T. Chung, National Central Univ. (Taiwan)

A novel design of thin profile solar concentrators with large angular tolerance is proposed comprising of a wedge prism and diffractive gratings which concentrate a broad solar spectrum up to 500 nm (from 400 to 900 nm). The design utilizes two different diffractive gratings. Transmission grating fabricated on top of the wedge prism operates on shorter wavelengths of the solar spectrum while reflection grating fabricated under the wedge prism operates on longer wavelengths. The diffracted light rays from each grating that satisfy total internal reflection (TIR) condition within the wedge prism are then guided through to the collection surface of the wedge prism. Both gratings are blazed with different angles to ensure that the power of the diffracted light is concentrated in one direction. The simulation model of this design is constructed using Coupled Wave Analysis (RCWA) for the calculation of each grating’s diffraction efficiency and geometrical optics calculation for the tracing of each ray produced by grating diffractions and surface refractions. The results from simulation model show maximum collection efficiency of more than 53% and maximum concentration ratio of 3.7. Large angular tolerance is achieved with full width at half maximum of collection efficiency for different incident angles being 106 degrees and 19 degrees on each plane of incident. This characteristic of the design reduces the need of precise alignment and tracking system requires by most commercially available solar concentrators.

8131-23, Poster Session

Mercury Imaging X-ray Spectrometer (MIXS) in BepiColombo mission: environmental tests

M. Pajas, Instituto Nacional de Técnica Aeroespacial (Spain)

The Mercury Imaging X-ray Spectrometer (MIXS) onboard ESA's mission BepiColombo to Mercury will measure X-rays emitted from the surface and the magnetosphere. BepiColombo will journey to Mercury during a 6 years long cruise. It will enter in orbit around Mercury in 2020, starting an observational programme planned for at least 2 years, with 2 dedicated spacecraft: Mercury Planetary Orbiter (MPO), built by ESA, Mercury Magnetospheric Orbiter (MMO), provided by JAXA in collaboration with ESA.

One of the main instruments of the BepiColombo mission will be the “Mercury Imaging X-ray Spectrometer” (MIXS), with its complementary instrument “Solar Intensity X-ray and particle Spectrometer” (SIXS). MIXS+SIXS will allow to map the chemical composition of the Mercury surface with a large spatial resolution (few tens of km). MIXS is being developed by a European Consortium led by University of Leicester (UL).

INTA-CAB is responsible for the Spanish contribution to MIXS.

The INTA facilities are being used to perform the complete qualification of MIXS at instrument level. The qualification will be very critical, due to the harsh environment around Mercury, the lack of redundancy and the long cruise phase (6 years) required to arrive to the final orbit around Mercury.

The testing activities at INTA are performed following the requirements indicated in the ESA EID-A, and include:
- Mechanical vibration.
- Thermal vacuum cycling.
- Electromagnetic Compatibility.

Functional tests of the FM and FS models will be performed before, during and after each of the tests, by using a radioactive source illuminating the detectors.

8131-24, Poster Session

The alignment of the Cassegrain telescope primary mirror and iso-static mount by using CMM

W. C. Lin, S. Chang, Instrument Technology Research Ctr. (Taiwan)

In order to meet both optical performance and structural stiffness requirements of the Cassegrain telescope, the primary mirror shall be mounted with the main plate by iso-static mount and the secondary mirror shall be hold and fixed by the truss structure. This article describes of the alignment of the Cassegrain telescope primary mirror and iso-
static mount by using coordinate-measuring machine (CMM), and the
design and assembly of mechanical ground support equipment (MGSE).
The primary mirror adjusting MGSE consists of three X, Y, Z linear stages
and point contact platforms, which hold the mirror while avoid the
rotated movement when adjusting the stage. This MGSE provide the
adjustment of tilt and height for the mirror. After the CMM measurement,
the coordinates of measured point on the mirror will be analyzed by the
software based on least square fitting to find the radius of curvature,
conic constant, decenter and tilt, etc. According to these results, the
mirror posture will be adjusted to reduce the decenter and tilt by the
designed MGSE. The tilt in X and Y direction are reduced within 0.02
degrees and the distance deviation from the best fitted profile of the
mirror to the main plate shall be less than 0.015mm.
8132-01, Session 1

**Precision spectroscopy on atomic hydrogen and its influence on fundamental constants**

C. G. Parthey, A. N. Matveev, J. Alnis, A. Beyer, R. Pohl, K. Predehl, N. N. Kolachevsky, T. Udem, T. W. Hänsch, Max-Planck-Institut für Quantenoptik (Germany)

For the last five decades, precision spectroscopy on atomic hydrogen along with hydrogen’s calculable atomic structure have been fueling the development and testing of quantum electrodynamics (QED) and have lead to the precise determination of the Rydberg constant and the proton charge radius. Furthermore, the outstanding precision in measuring the 1S-2S transition has been used to set limits on a possible variation of fundamental constants and violation of Lorentz boost invariance. It promises a stringent test of the charge conjugation/particle/antiparticle (CPT) theorem by comparison with the same transition in antihydrogen.

Two recent measurements of the 1S-2S transition in atomic hydrogen have pushed the accuracy below the 1e-14 level for the first time. For one of these measurements, we have used the world’s longest dedicated optical fiber link (900 km) to phase-coherently connect the hydrogen frequency to a remote cesium fountain clock. The results can be used to set new limits on a possible Lorentz boost invariance violation. A recent measurement of the Lamb shift in muonic hydrogen by R. Pohl et al. has allowed to determine the proton charge radius with ten times higher accuracy as before. However, the obtained value differs by five standard deviations from the proton charge radius obtained from ordinary hydrogen. The discrepancy hints to a problem in either theory or experiment. We hope to contribute to the resolution by providing additional experimental input to the adjustment calculations which are used to determine the proton charge radius and the Rydberg constant.

8132-02, Session 1

**Fiber-based frequency combs with relative frequency stability of 10^-20-level**

H. Inaba, Y. Nakajima, K. Iwakuni, K. Hosaka, A. Onae, M. Yasuda, D. Akamatsu, F. Hong, National Institute of Advanced Industrial Science and Technology (Japan)

Fiber-based frequency comb (fiber-comb) is an indispensable tool in the field of optical frequency standard and metrology. Broad control bandwidth of the carrier-envelope offset frequency (ICEO) and the repetition rate (fre) are required if we are to reduce the comb mode linewidth. High-speed control of the ICEO can be achieved by varying the pump power in the mode-locked fiber laser. High-speed control of the cavity length (fre) control has also been achieved by varying the effective optical length of the laser cavity using an intra-cavity electro-optic modulator (EOM). We have reported fiber-combs with relative frequency stability of 10^-19 level and relative linewidth of 10 MHz level. Although the relative stability and linewidth of the fiber comb exceed the uncertainty of present optical clocks, the margin of the stability and the linewidth is not sufficiently large. Therefore, in this study, we have tried to improve the relative frequency stability of the combs. Especially, we employ a mode-locked erbium-doped fiber laser with an intra-cavity wave-guide EOM as a comb source in order to improve the robustness. We also reduce the number of the optical amplifier branches in the comb system to diminish the fiber noise. We were able to obtain the servo bandwidth of approximately 1.4 MHz (for cavity length control) and 400 kHz (for ICEO control). Beat frequencies between two independent combs locked to a common 1064 nm reference laser (out-of-loop beat) were measured at several wavelengths. Consequently, relative frequency stability of 10^-20-level has been observed at 10 000-s averaging time.

8132-03, Session 1

**High harmonic generation in VUV via passive enhancement of near infrared femto-second pulses**

K. Wakui, K. Hayasaka, T. Ido, National Institute of Information and Communications Technology (Japan)

VUV with a high repetition rate is obtained via the high harmonic generation method using a passive enhancement cavity for NIR femto-second pulses. An interesting application of such quasi-cw VUV would be directly probing VUV transitions for optical clocks. Our Ti:S oscillator generates NIR pulses whose repetition rate, bandwidth, and averaging intensity are 112 MHz, 20 nm, and 850 mW, respectively. The passive enhancement cavity is made of six mirrors and a high NIR reflector with gratings structure for VUV. Xenon gas was used as the nonlinear medium. The average intensity of the out-coupled 5th harmonic (159 nm) was measured to be 1.5 uW.

8132-04, Session 1

**VUV frequency combs and limitations of intracavity high-harmonic generation due to plasma dynamics**

R. J. Jones, D. R. Carlson, J. Mongelli, E. M. Wright, College of Optical Sciences, The Univ. of Arizona (United States)

The dynamic intracavity ionization of a dilute gas target can substantially alter the pulse formation inside resonant fs enhancement cavities. We numerically and experimentally study these effects and how they affect intracavity high harmonic generation.

8132-05, Session 2

**Precision measurements and advanced laser systems for applications on Earth and in space**

A. Peters, Humboldt-Univ. zu Berlin (Germany) and Ferdinand-Braun-Institut (Germany)

This talk will present an overview of the activities of the Optical Metrology group at the Humboldt University Berlin. These include optical tests of the foundations of special relativity and matter wave experiments in gravitational physics, which are performed in terrestrial laboratories as well as in microgravity environments (drop tower, upcoming space missions). A special focus will be on novel, hybrid integrated laser systems which have been developed at the Ferdinand-Braun-Institut specifically for such precision measurement applications.

8132-07, Session 2

**Overcoming the quantum projection noise (QPN) limit without preparation of the spin-squeezed state**

N. Shiga, National Institute of Information and Communications Technology (Japan); M. Takeuchi, The Univ. of Tokyo (Japan)

Atomic clocks have reached the Quantum Projection Noise (QPN) limit of stability and it has been proposed to use the entangled atomic ensemble in order to overcome the QPN limit. Here, we propose a noble method
that could possibly overcome the QPN limit without need of preparing the entangled atomic ensemble, and we call it “Coherence-Maintained (CM) Ramsey method.”

Traditional Ramsey method measures a phase difference between atom and the Local Oscillator (LO), so in principle it is capable of suppressing the LO noise down to white phase noise level. However, destruction of the coherence of the atomic spin accompanied with projection measurement introduces the additional noise and therefore limited to white frequency noise, which is called QPN limit.

The proposed CM Ramsey method employs dispersion measurements, i.e. Faraday rotation, in order to measure the phase difference without destroying the atomic phase. By repeating the CM Ramsey method with sufficiently small dead time, one could suppress the LO noise down to white phase noise level, achieving the 1/\tau dependence of the Allan variance that can overcome the QPN limit. For the best stability, we need a proper feedback mechanism, and that is still under progress.

We are preparing a proof-of-principle experiment using the ensemble of trapped Yb ions with hyperfine splitting (12.6 GHz) as a clock transition and report the current status of the experiment as well.

8132-08, Session 3
Frequency of the 40Ca+ Optical Clock transition and evaluation of systematic shifts
Y. Huang, Q. Liu, J. Cao, B. Ou, P. Liu, H. Guan, X. Huang, K. Gao, Wuhan Institute of Physics and Mathematics (China)

The trapping and laser cooling 40Ca+ ion on the way towards optical frequency standards has been developed on our group.

A single 40Ca+ ion is trapped in a miniature Paul trap. A commercial Ti:Sapphire laser and one home-build diode laser at 729 nm are locked to two high-finesse ULE cavities separately by the PDH method.

The single ion fluorescence line shape signal is optimized by minimizing the excess micromotion.

The three magnet coil pairs aligned along three perpendicular directions are set to generate an arbitrary magnetic field. The full Zeeman profile components of the clock transition are achieved by counting the number of the quantum jumps observed in a fixed time period at different frequency.

The systematic frequency shifts are evaluated with a “clock” transition at 729 nm. The total systematic uncertainty of the clock resonance has been characterized to about 10-15. The center frequency of 40Ca+ 4s2S1/2 − 3d2D5/2 optical clock transition were measured by an fs comb system referenced to a standard hydrogen maser. We lock the 729 nm laser system to atomic transition is made by the four points locking method. A standard Allan deviation of less than 10−14 at 2000 s is obtained for the comparison between the 40Ca+ optical frequency standard and a H-Maser using a femtosecond laser frequency comb.

8132-11, Session 4
Optical direct comparison of 87Sr optical lattice clocks using a >50 km telecommunication fiber link
H. Hachisu, A. Yamaguchi, M. Fujieda, M. Kumagai, S. Nagano, T. Ido, National Institute of Information and Communications Technology (Japan); T. Takano, The Univ. of Tokyo (Japan); M. Takamoto, H. Katori, The Univ. of Tokyo (Japan) and Japan Science and Technology Agency (Japan)

The stability of state-of-the-art optical clocks has recently reached 10−18 level. The remarkable development requires an improvement in frequency comparison technique in order to certify the same level of identical frequencies. Frequency transfer using optical fiber network is one of the most promising scheme. In this aspect, an 87Sr-based-optical lattice clock in NICT is compared to that of the University of Tokyo using a >50 km fiber link. The comparison has resulted in the 10−15 level of fractional frequency difference. Further improvement is on the way to attain the 10−16 level, which has not been demonstrated by using the conventional satellite link.

8132-12, Session 4
Frequency comparison of optical lattice clocks
M. Takamoto, T. Takano, H. Katori, The Univ. of Tokyo (Japan)

Optical lattice clocks are expected to be highly stable by taking advantage of a large number N>>1 of atoms, which improves the quantum projection noise (QPN) limit as 1/√N. However, their actual stability is severely limited by the instability of probe laser. We demonstrated the frequency comparison of two optical lattice clocks synchronously interrogated by a common probe laser to cancel out the probe laser’s frequency noise. The Allan standard deviation of 1×10^{-17} was achieved for an averaging time of 2,000 s, which is close to the QPN limit for about 1,000 atoms.
Progress toward an optical lattice clock with 1e-17 fractional inaccuracy

M. Swallows, M. Bishop, Y. Lin, S. Blatt, M. Martin, C. Benko, A. M. Rey, J. Ye, JILA (United States)

Optical atomic clocks based on ensembles of neutral alkaline earth atoms trapped in a magic wavelength optical lattice are promising candidates for the next generation of frequency standards. These clocks can in principle equal the impressive accuracy achieved by single-ion clocks, while surpassing them in terms of stability. One obstacle that must first be overcome is an atomic density-dependent collisional shift of the clock transition, which can occur even if the clock is based on an ensemble of spin-polarized ultracold fermions. We have greatly reduced this shift in the JILA Sr optical lattice clock by trapping atoms in a two-dimensional optical lattice. By doing so, we exploit a novel quantum many-body effect to suppress collisional shifts in lattice sites containing N > 1 atoms. We have made a high precision measurement of these effects, and find that the collisional shift in our 2D lattice clock is 0.5 ± 1.7 × 1e−17 at normal operating densities. Shifts of the clock transition due to room-temperature blackbody radiation are another limiting source of systematic inaccuracy for the JILA Sr standard. We are currently upgrading our apparatus to allow interrogation of the clock transition inside a cryogenically shielded region. Finally, we are constructing a new ultrastable laser system which will exhibit a fractional frequency stability at the 1e-16 level for short time scales. With this new laser system, the JILA Sr standard should exhibit quantum projection noise-limited stability.

Atomic frequency standards at NICT

T. Ido, National Institute of Information and Communications Technology (Japan)

Three atomic frequency standards including a strontium lattice clock, a single calcium ion clock, and cesium fountain clock are in operation in National Institute of Information and Communications Technology (NICT), Japan. The relative stability between two optical clocks, Sr and Ca+, has been recently measured to be in 10^-16 level. Evaluation of systematic inaccuracy for the JILA Sr standard. We are currently upgrading our apparatus to allow interrogation of the clock transition inside a cryogenically shielded region. Finally, we are constructing a new ultrastable laser system which will exhibit a fractional frequency stability at the 1e-16 level for short time scales. With this new laser system, the JILA Sr standard should exhibit quantum projection noise-limited stability.

Recent progress of time and frequency research in NIM

Z. Fang, T. Li, X. Gao, Y. Lin, National Institute of Metrology (China)

Recent progresses in the field of time and frequency metrology in NIM mainly include: the accomplishment of NIM5 cesium fountain clock with an uncertainty of 2.5E-15; progress of a strontium optical lattice clock; progress of self-developed erbium fiber optical frequency comb and its intended application for ultra-low phase noise microwave generation, etc.

Current status of the 171Yb optical lattice clock at NMIJ, AIST

M. Yasuda, T. Kohno, K. Hosaka, H. Inaba, Y. Nakajima, D. Akamatsu, F. Hong, National Institute of Advanced Industrial Science and Technology (Japan)
stabilization of two clock lasers to transitions in the same atomic system. The two transitions show different sensitivities to external perturbations, which can be used to control frequency shifts, and to search for temporal variations of the fine structure constant.

Frequency measurements of the 87Sr optical lattice clock were performed against the caesium fountain CSF1. They are in agreement with the values reported by other groups. Investigations of the blackbody radiation shift are in progress.
8133-01, Session 1
Measurement technology based on laser internal/external cavity tuning
S. Zhang, Tsinghua Univ. (China)
For an ordinary cavity laser with two cavity mirrors, if the length of lasers cavity changes half wavelength the laser frequency changes one longitudinal mode separation. For a three cavity laser, in which a feedback mirror is used to feed the laser output beam back into the laser cavity, the external cavity changes half wavelength the laser intensity changes one time. This presentation gives some research results in measurement based on changing (tuning) the length of laser internal/external cavity. HeNe laser cavity tuning nanometer displacement measurement instruments (laser nanometer rulers), HeNe laser feedback effect displacement measurement, Nd:YAG laser feedback effect nanometer displacement measurement, benchmark of phase retardation measurement instruments of a wave-plate based on laser frequency splitting, in-site phase retardation measurement instruments of a wave-plate based on laser feedback and polarization hopping. Quasi-common-path Micro-chip Nd:YAG laser feedback interferometers, non-contact surface profile measurement. Some of these instruments are in applications and behave some advantages without replacers.

8133-02, Session 1
Micron-feature surface mapping interferometer for hard-to-access locations
G. Abramovich, K. G. Harding, GE Global Research (United States)
This paper describes a compact imaging Twyman-Green interferometer to measure small features such as corrosion pits, scratches and digs on hard to access objects such as mounted turbine blades. The shoebox size interferometer was designed to guarantee proper orientation and working distance relative to the inspected section. The system also provides an extended acceptance angle to permit the collection at selected view points on a subject. We will also describe the various image shifting techniques investigated as part of the prototype. In operation, a reference flat is driven by a piezoelectric actuator and the interference image is relayed to the camera using a 10X objective. All the components including the camera and the laser source were integrated into the compact enclosure with the exception of power supplies. The interferometer has shown to provide sub-micron depth resolution and diffraction limited spatial resolution (a few microns). This paper will present the final performance achieved with the system and provide examples of applications.

8133-03, Session 1
Study on three-dimensional shape measurement of partially diffuse and specular reflective surfaces with fringe projection technique and fringe reflection technique
L. Huang, A. K. Asundi, Nanyang Technological Univ. (Singapore)
Three-dimensional shape metrology using fringe projection technique and fringe reflection technique are effective ways to reconstruct three-dimensional shape with different reflectance properties. Fringe projection technique is used for measuring objects with diffuse surfaces and relies on the principle of triangulation, while fringe reflectometry is used for specular reflective specimens based on principle of reflection. While fringe projection technique directly provides the profile, fringe reflectometry measures the slope of the surface from which the profile is integrated. Actually, certain surfaces with reflectance, which is partially diffuse and partially specular, can be measured with both techniques mentioned above. For both methods, projected patterns are computer generated and phase shifting methods are applied. For fringe projection profilometry the sensitivity of three-dimensional measurement directly depends on system calibration and geometric configuration. Furthermore, the precision of dimensional measurement directly relies on the system sensitivity and the precision of phase measurement. For the fringe reflection technique, the sensitivity of dimensional measurement does not directly depend on geometry, which actually only directly determines the slope measuring sensitivity. Hence, phase measuring precision only directly yields the precision of slope measurement, which will influence the accuracy and precision of three-dimensional dataset through the following integration process. In this paper, the performance of these two fringe based techniques when measuring partially diffuse and specular reflective targets are analyzed with respect to their sensitivity and accuracy. The measuring sensitivity and precision of both techniques are compared and discussed theoretically in mathematical models and experimentally with actual measurement of some partially diffuse and specular surfaces.

8133-04, Session 1
Auto-exposure for 3D shape measurement using a DLP projector
S. Zhang, L. Ekstrand, Iowa State Univ. (United States)
Automatically adapting the camera exposure time based on the optical property of the measured object is crucial for industrial applications where a minimum human intervention is usually desirable, and 3D shape measurement with digital fringe projection techniques is not an exception. However, it is very challenging to realize such a capability for a conventional fringe projection system where only a finite increment of camera exposure time is allowed due to the digital fringe generation nature. We recently proposed a new technique for 3D shape measurement that only requires binary structured patterns to realize conventional phase-shifting algorithms. Specifically, the sinusoidal fringe patterns are realized by properly defocusing the projector. Because this technique coincides with the operation mechanism of the digital-light-processing (DLP) projector, it permits the use of an arbitrary exposure time for 3D shape measurement. And because an arbitrary exposure can be used, this new technique provides the opportunity to develop a strategy camera exposure time control automatically. This paper will present a 3D shape measurement system that could change its exposure time automatically according to the optical property of the measured object. This technique optimize the exposure time analyzing the percentage of saturated pixels when a uniform pure white is shining onto the object. We have found that by controlling the exposure time automatically, the high-quality 3D shape measurement can always be achieved for any type of diffuse objects. This paper will present the principle of the technique and show some experimental results.

8133-05, Session 1
A novel phase reconstruction method using frequency shifting
C. Zhang, X. Liu, H. Chen, X. Peng, Shenzhen Univ. (China)
Phase reconstruction is the key technology of PMP (Phase Measuring Profilometry) widely used in three dimensional (3-D) shape measurements for scientific and industrial purposes. Phase reconstruction is a two-step process: phase evaluation and phase unwrapping. Mostly, there
8133-06, Session 2

**Profilometry based on wavelength-spacing tunable multi-wavelength fiber laser source**

S. Park, M. Jeong, C. Kim, Pusan National Univ. (Korea, Republic of)

Various interferometer technologies have been developed for profilometry and tomography. Recently, the optical frequency comb has been developed, which is tunable in wavelength-spacing. The tunable wavelength-spacing is implemented by using the motorized polarization differential delay line in the Sagnac loop interferometer. The polarization differential delay line is an optical device that splits the light into orthogonal polarization and varies the time that one polarization travel compared to the other before combining them together. It is possible to change easily the comb interval with simple control electronics. By using of this novel interferometric scheme, we can achieve the interferometric signal depending on the optical path difference between the sample and reference. As combining the peak positions from the signal information, the surface profile can be obtained successfully.

8133-07, Session 2

**Surface profile measurement using broadband dual SOA wavelength-swept laser**

H. S. Lee, M. Jeong, C. Kim, Pusan National Univ. (Korea, Republic of)

We demonstrate a broadband wavelength-swept laser using two gain medium for the surface profile imaging with higher resolution. The configuration of wavelength-swept fiber ring laser consists of two semiconductor optical amplifiers (SOA’s) around 800 nm, two isolators, two 3 dB fiber couplers, two polarization controllers, a fiber Fabry-Perot tunable filter and an output fiber coupler. Since two laser cavities are built with two SOA’s of the center wavelength of 800 nm and 830 nm, respectively, the wavelength swept laser has a capability of a broadband sweeping range of more than 60 nm. The measured axial resolution is less than 5 um and the average output power of this laser is measured to 5 mW. We also demonstrate a 3 dimensional surface profile using a Fourier-domain optical coherence tomography image technique based on the proposed wavelength-swept laser.

8133-08, Session 2

**Non-phosphor white LED light source for interferometry**

V. Heikkinen, B. Wälchi, J. Aaltonen, H. Rääkkönen, I. Kassamakov, E. Häggeström, Univ. of Helsinki (Finland)

Solid state light sources are replacing a tungsten filament based bulbs in Scanning White Light Interferometric (SWLI) measurement systems. Sources such as white LEDs generate less heat, have shorter switching times, allow stable spectrum and have longer lifetimes than traditional lamps. Phosphor based white LEDs produce a wide spectrum but have two separate peaks which causes interferogram ringing. This makes measuring multi layered structures difficult and may degrade measurement precision also when measuring a single reflecting surface. The LEDs spectral stability and switching time are also degraded due to the phosphor. Most non phosphor white LEDs have non gaussian spectra, but multi LED based white LEDs can achieve switching times and stability similar to single color LEDs. By combining several LEDs and by controlling their input current independently it is possible to create almost an arbitrary spectrum. We designed a new light source based on non phosphor white LED (American Opto Plus LED, L-513NPWC-15D) combined with single color LEDs to fill the spectral gap between the blue and yellow peaks of the non phosphor white LED. By controlling the LEDs individually a wide nearly gaussian shaped spectrum was achieved. This wide continuous spectrum creates short interferograms (FWHM ~1 µm) with low side peaks. To demonstrate the properties of this source we measured through a 5 µm thick polymer film. The measured interferograms show how the well localized interference created by the source allows measurement of both surfaces of thin films simultaneously.

8133-09, Session 2

**Color pattern projection method for three-dimensional measurement**

T. Wakayama, T. Yoshizawa, Saitama Medical Univ. (Japan)

There is a special requirement for measuring and evaluating various parts inside a car in the fields of automobile industry. In regards to a strong requirement from car manufacturers, there were no appropriate measuring instruments available inside a car. To meet this requirement, we have proposed to incorporate a recent digital device such as a single MEMS mirror into projection optics. These key devices in our projection technique brought the mechanism of the projection from time domain to spatial domain. Due to this revision, first of all, such a small size system like a palm-top camera became attainable, and low cost measurement system has been potentially realized. Moreover, we adopted phase-shifting technique which is most popular technique applicable to industrial dimensional measurement and inspection in automobile industry and others. The camera will be potentially as small as a photographic digital camera in dimensional size. In this system, we control a single MEMS mirror and a laser diode to produce the projection pattern with appropriate period and arbitrarily structured intensity distributions like a sinusoidal and a binary pattern. In this paper, we propose recent improvement of the principle and its applications. We have developed three-dimensional measurement method based on a single MEMS mirror using three- color laser diodes and 3-CCD camera. The measurement method has combined the merits of pattern projection method using two colors with the merits of optical sectioning method, simultaneously.

8133-10, Session 2

**High-speed triangulation-based point sensing using phase detection**

K. G. Harding, GE Global Research (United States)
Triangulation sensors have been in wide use for many years. Most point sensors use a laser spot, which is detected using either a lateral effect photodiode or a linear detector array. The centroid of the spot is used to determine the range using triangulation. On many engineered surfaces, this spot image may suffer from speckle, surface texture, or other issues that limit the ability to repeatedly measure the centroid. Many analysis means, such as fitting of the spot, zero crossing, and averaging methods have been tried to make the sensor more robust to surface influenced noise. This paper will present a system using a split image and phase detection to obtain the range. The speed of the sensor is gained by using simple point photodiodes and a more effect to obtain the phase measurement. The paper will discuss the pros and cons of this approach, and show results on untreated metal parts.

8133-11, Session 2
Improving the resolution and accuracy of a compact 3-D shape measurement system
K. Deng, P. S. Huang, Univ. of Michigan-Shanghai Jiao Tong Univ. Joint Institute (China)
We have recently developed a compact 3-D shape measurement system based on the combined stereovision and phase shifting method. This system consists of a miniature projector (Pico Projector from Texas Instruments) and two small cameras arranged as a stereo pair. The projector projects phase shifted fringe patterns, which are captured by both cameras simultaneously. The two phase maps calculated are used for stereo matching. The 3-D shape of the object is then reconstructed by the triangulation method. This research focuses on improving the resolution and accuracy of the measurement system. First, we use a 2-D Hermite interpolation method to achieve accurate stereo matching at the sub-pixel level. Then we use the averaging of multiple fringe images to reduce random noise of the system. Finally, we use an error compensation method to reduce the measurement error within the measurement volume, which is mainly caused by lens distortion. Experimental results show that after the above measures, a resolution of better than 10 µm and an accuracy of better than 100 µm within a measurement range of 100 x 67 mm can be achieved. This paper will describe the methods used and presents the experimental results obtained.

8133-12, Session 3
Development of a probe for inner profile measurement and flaw detection
T. Yoshizawa, T. Wakayama, Saitama Medical Univ. (Japan); Y. Kamakura, NPO 3D Associates (Japan)
There are various requirements for measuring the inner diameter and/or inner profile of pipes, tubes and other objects similar in shape. Especially in mechanical engineering field, serious problems come from automobile industry because the inner surface of engine blocks or other die casts are strongly requested to be inspected and measured by non-contact methods (not by the naked eyes inspection using a borescope). If the inner diameter is large enough like water pipes or drain pipes, complicated and large equipment may be applicable. However, small pipes with a diameter ranging from 10mm to 100mm are difficult to be inspected by such a large instrument as is used for sewers inspection. And we propose an instrument which has no moving elements such as a rotating mirror for scanning a beam. This optically sectioned profile of an inner wall of pipe-like objects is analyzed to produce numerical data of inner diameter or profile. Here, we report recent development of the principle and applications of the optical instrument with a simple and compact configuration. In addition to profile measurement, we found flaws and defects on the inner wall were also detected by using the same probe. Up to now, we have developed probes with the diameter of 8mm to 25mm for small size objects (12mm to 100mm in diameter) and the 80mm probe for larger samples such as 600mm size container.

8133-13, Session 3
Surface profile measurement using a modified stereomicroscope
P. S. Huang, J. Gao, D. Wu, Univ. of Michigan-Shanghai Jiao Tong Univ. Joint Institute (China)
Stereomicroscopes are widely used in scientific research as well as medical and industrial applications. Traditional stereomicroscopes provide visual depth perception but not quantitative measurement. In this research, we propose to modify a traditional stereomicroscope so that it can be used to provide quantitative 3-D surface profile measurement. The method we use is the combined stereovision and phase shifting method, which was proposed recently for high-accuracy 3-D surface shape measurement. A miniature projector (Pico Projector from Texas Instruments) is used to project phase-shifted fringe patterns to the object surface through one of the two optical channels. Two identical black-and-white cameras are used to capture the images of the object surface, one for each channel of the stereomicroscope. The calculated phase maps are used for stereo matching at the sub-pixel level. The 3-D surface profile is reconstructed using the triangulation method. With a zoom ratio of 1–6.3x, we can achieve a field of view of 2–12.6 mm with a resolution of 0.2–1.26 µm respectively (0.01% of the field of view). Experimental results will be presented to demonstrate the performance of the developed instrument.

8133-14, Session 3
Automated 3D imaging system for CZT wafer inspection and characterization
Y. Liao, E. Heidari, G. Abramovich, C. Nafis, GE Global Research (United States); A. Butt, GE Global Research (United States); J. Czechowski, K. Andreini, K. G. Harding, J. E. Tkaczyk, GE Global Research (United States)
We describe the design and evaluation of the 3D stereo, near infrared, imaging system for CZT inspection system. The system provides rapid acquisition and data analysis that results in detailed mapping of crystal defects across the area of wafers up to 100mm diameter and through thicknesses of up to 15mm. In addition, through 3D cluster analysis, it identifies the classes of the global defects. In order to determine the actual detection limit, we used a Scanning Electron Microscope (for surface impurities) and a micron resolution confocal microscope (for embedded impurities) and compared the data to corresponding small impurities detected by our system. Finally, we analyzed the functional relationship between the electrical characteristics of the CZT wafers to their physical impurities.

8133-15, Session 3
Low noise surface mapping of transparent plane-parallel parts with a low coherence interferometer
L. L. Deck, P. J. de Groot, Zygo Corporation (United States)
Highly polished plane parallel optics are found in many industries, but are particularly important in the data storage and photo-lithography industries. In those applications, the glass surface characteristics have become especially demanding, requiring extremely low noise measurements of the surface profile to control the fabrication process and minimize the adverse affects of surface irregularities on performance associated with these glass components. We describe the capabilities of a low-noise phase-shifting equal-path interferometer especially designed for high-precision surface mapping of transparent plane-parallel parts. The interferometer applies spatially and temporally incoherent illumination to minimize noise and isolate the surface of interest. With a 100mm aperture, less than 0.1% distortion, 50pm surface height precision...
and 50um lateral sampling, the interferometer is designed to capture the spatial frequencies with the fidelity required for current and next generation disks and other thin glass structures.

8133-16, Session 4
**Challenges faced in applying 3D non-contact metrology to turbine engine blade inspection**

J. Ross, GE Aviation (United States); K. G. Harding, GE Global Research (United States); E. Hogarth, GE Aviation (United States)

Turbine airfoils are key components used in several important industries: jet engines for commercial and military aircraft propulsion, steam turbine generators, and automatic transmissions. Of these applications, aircraft engines have the most critical requirements for control of airfoil geometry. Today, aircraft airfoil shapes are typically measured by three methods: dedicated hard gauges, coordinate measurement machines (CMMs), and in a small, but growing number of shops, 3D non-contact inspection systems. Optical 3D systems offer the potential to collect many more points than have been practical in the past at speeds usable in production. But there are many challenges to be addressed, such as surface reflectivity, data alignment, and the wide range of shapes to be inspected without taking a long time to do so. This paper will discuss the lessons learned from the application of 3D non-contact metrology systems as applied to the measurement of critical aircraft engine parts.

8133-17, Session 4
**Evaluating a hybrid 3-dimensional metrology system: merging data from optical and touch probe devices**

J. R. Gerde, U.S. Customs and Border Protection (United States); W. A. Christens-Barry, Equipoise Imaging, LLC (United States)

In a project to meet requirements for CBP Laboratory analysis of footware under the Harmonized Tariff Schedule of the United States (HTSUS), a hybrid metrology system comprising both optical and touch probe devices has been assembled. A unique requirement must be met: To identify the interface—typically obscured in samples of concern—of the “external surface area upper” (ESAU) and the sole without physically destroying the sample. The sample outer surface is determined by discrete pointcloud coordinates obtained using laser scanner optical measurements. Measurements from the optically inaccessible insole region are obtained using a coordinate measuring machine (CMM). That surface similarly is defined by pointcloud data. Mathematically, individual command scanner data sets are transformed into a single, common reference frame. Custom software then fits a polynomial surface to the insole data and extends it to intersect the mesh fitted to the outer surface pointcloud. This line of intersection defines the required ESAU boundary, thus permitting further fractional area calculations to determine the percentage of materials present. With a draft method in place, and first-level method validation underway, we examine the transformation of the two dissimilar data sets into the single, common reference frame. We also will consider the six previously-identified potential error factors versus the method process. This paper reports our on-going work and discusses our findings to date.

8133-18, Session 4
**In vitro interferometric characterization of dynamic fluid layers on contact lenses**

B. C. Primeau, The Univ. of Arizona (United States); J. E. Greivenkamp, College of Optical Sciences, The Univ. of Arizona (United States); J. J. Sullivan, 3M Co. (United States)

The anterior refracting surface of the eye when wearing a contact lens is actually the thin fluid layer that forms on the surface of the contact lens. Under normal conditions, this fluid layer is less than 10 microns thick. The fluid layer thickness and topography change over time and are affected by the material properties of the contact lens, and may affect vision quality and comfort. An in vitro method of characterizing dynamic fluid layers applied to contact lenses mounted on mechanical substrates has been developed using a phase-shifting Twyman-Green interferometer. This interferometer continuously measures light reflected from the surface of the fluid layer, allowing precision analysis of the dynamic fluid layer. Movies showing this fluid layer behavior can be generated. The fluid behavior on the contact lens surface is measured, allowing analysis beyond what typical contact angle or visual inspection methods provide.

The interferometer system has measured the formation and break up of fluid layers. Different fluid and contact lens material combinations have been used, and significant fluid layer properties have been observed in some cases. The interferometer is capable of identifying features in the fluid layer less than a micron in depth with a spatial resolution of about ten microns. An area on the contact lens approximately 6 mm wide can be measured with the system. This paper will discuss the interferometer design and analysis methods used. Measurement results of different material and fluid combinations are presented.

8133-19, Session 4
**Profile measurement of thin films by linear wavenumber-scanning interferometry**

O. Sasaki, S. Hirakubo, S. Choi, T. Suzuki, Niigata Univ. (Japan)

A halogen lamp and an acousto-optic tunable filter are used to create a light source whose wavenumber is scanned exactly and linearly with time through detection of a phase change of an interference signal produced by the wavenumber scanning. When the linearly wavenumber-scanned light is incident into a film and there is no reference light, the interference signal becomes a sinusoidal wave whose frequency is an integral multiple p of a fundamental frequency. First the length of the detected interference signal is determined to be one period of the fundamental frequency and the wavenumber-scanning width for one period of the fundamental frequency is also determined. Next when a reference light is used, the interference signal consists of three sinusoidal waves with different frequencies. The optical path difference of the front surface of the film is adjusted so that three sinusoidal frequencies are integral multiples of the fundamental frequency. The positions of the front and rear surfaces of the film can be obtained from the wavenumber-scanning width and phases of the two sinusoidal waves related to the two surfaces. The film thickness was about 4 microns and p=4, and the wavenumber-scanning width was about 0.00033 1/1nm. The measurement error was less than 10 nm.

8133-29, Poster Session
**A novel laser tracking testbed for robot trajectory errors**

A. Li, X. Jiang, Z. Li, Y. Bian, Tongji Univ. (China)

A novel measurement of laser coarse-fine coupling tracking is proposed for robot trajectory errors, which can not only meet the requirements of the large range, rapid response and dynamic tracking, but also achieve the high accuracy of submicroradian magnitude due to the ingenious system setup. As the key components of the laser testbed, the tracking range of coarse tracking mechanism is no less than ±15° in pitch angle and ±180° in azimuth angle with the tracking accuracy better than 50 µrad. While the fine tracking range is no less than 1400 µrad both in level and vertical field angle with the tracking accuracy better than 0.5 µrad. The mating relations among the prism deviation angle, step motor stepping angle.
and encoder resolution are studied to meet the test requirements of robot trajectory.

The mathematic model of robot errors is studied according to the motion definition of circular and linear trajectory. The optimization algorithm to remove system error and improve the position accuracy of robot motion is deduced. After building a robot experiment platform together with the laser tracking test system, the optical alignment is performed before the robot test. The relations between the laser tracking test system and the robot pose, especially the harmonious motion parameters, are studied. The calibration method of robot errors, as well as some error factors affecting the test uncertainty, is given to be considered according to the test experiment results.

8133-30, Poster Session

Three-dimensional optical microscopy based on angle deviation method for submicron structure measurements

M. Chiu, C. A. Chen, C. Ten, National Formosa Univ. (Taiwan)

An optical microscope with high magnification can measure the three-dimensional profile of a submicron structure by use of the angle-deviation method in one shot. The expanded laser beam with a wavelength of 632.8nm reflected from the test surface and then passing through an optical microscope involves the surface profile information. From geometrical principle, the ray reflected and deflected a small angle from the surface normal causes by the slope of the surface. This angle can be transformed to the intensity or reflectance by use of an angular sensor. The angle-to-reflectance transform is done by a parallelogram prism near at the critical angle. Thus, the contrast of one point on the image pattern after the angular sensor is proportional to its surface height. The image recorded by CCD displays the two-dimensional image and its contrast pattern represents its surface height profile. In addition, the two- and three-dimensional surface profiles are obtained in real-time. The lateral and axial resolutions are within 1µm and several nanometers, respectively.

8133-31, Poster Session

Multi-probe system comprising three laser interferometers and one autocollimator for measuring flat bar mirror profile with nanometer accuracy on a high-precision micro-coordinate measuring machine

P. Yang, The Univ. of Tokyo (Japan)

With the development of super-precision machining technology, it has also become increasingly important to evaluate surface geometry (straightness, flatness) with nanometer accuracy. Therefore, we described a multi-probe system comprising three laser interferometers and one autocollimator to measure a flat bar mirror profile with nanometer accuracy. The laser interferometers probe the surface of the flat bar mirror that is fixed on top of a scanning stage, while the autocollimator simultaneously measures the yaw error of the scanning stage. The flat bar mirror profile and horizontal straightness motion error are reconstructed by an application of simultaneous linear equation and least-squares methods. The average measurement uncertainty of the flat bar mirror profile was simulated to be only 10 nm with installation distances of 10 and 21 mm between the first and second, and first and third interferometers, respectively. To validate the simulation results, a pre-experiment was built using an X-Y linear stage driven by a stepper motor with steps of 1 mm along the X direction. Experiments were conducted with fixed interferometers distances as the same in the simulation on a flat bar mirror. The two standard deviation of the flat bar mirror profile is mainly fitting the range of simulation results. Comparison of our measured data with the results measured by Zygo's interferometer system showed agreement to within approximately 10 nm. The results from the pre-experiment verify the performance of multi-probe method. Moreover, we have designed and built the multi-probe system on a high-precision micro-coordinate measuring machine to eliminate the systematic error of the moving stage.

8133-32, Poster Session

Bending measurement technique based on single-mode optical fiber with low-normalized frequency

S. O. Gurbatov, O. B. Vitrik, Y. N. Kulchin, Institute for Automation and Control Processes (Russian Federation)

One of the urgent tasks of natural and man-made objects monitoring is the registration of bending deformations, including distributed bends with large radius of curvature appearing at the construction stage or during the operation of the facilities. This problem arises, for example, in monitoring construction and hydraulic engineering objects, pipelines, as well as, aircraft, rocket and shipbuilding objects.

In this paper, the task of the registration of bending deformation in large-scale objects is proposed to solve on the basis of guided radiation losses measurement arising from the bending of single-mode optical fiber. However, significant losses occur in standard optical fibers used in fiber-optic communications systems at the radii of curvature less than a centimeter, which does not allow them to measure the bending deformation with small curvature. Another problem arises when registering the bending deformation by the proposed method is the oscillatory dependence of optical power attenuation coefficient on bending radius in the single-mode fiber waveguide.

As a result, a fiber optic method for measuring bending deformation using optical fiber waveguide with low normalized frequency has developed. It was shown that an optical fiber waveguide working in a single mode regime with low normalized frequency is appropriate to use for registration of bending deformation with large curvature radiiuses. Experimentally demonstrated is a 140-fold increase in sensitivity of optical fiber to bending. Zero refraction index contrast on the optical cladding/air boundary is shown to be necessary for suppression of oscillations in the dependence of fundamental mode attenuation coefficient on bending radius.

8133-33, Poster Session

An improved arterial pulsation measurement system based on optical triangulation and its application in the traditional Chinese medicine

J. Wu, W. Lee, Y. Lee, Ming Chuan Univ. (Taiwan); C. Lin, National Yunlin Univ. of Science and Technology (Taiwan); J. Chiu, Ming Chuan Univ. (Taiwan); C. Tai, National Yunlin Univ. of Science and Technology (Taiwan); J. Jiang, National Taiwan Univ. (Taiwan)

An improved arterial pulsation measurement (APM) system that uses three LED light sources and a CCD image sensor to measure pulse oscillations in the dependence of fundamental mode attenuation coefficient on bending radius.

Experimentally demonstrated is a 140-fold increase in sensitivity of optical fiber to bending. Zero refraction index contrast on the optical cladding/air boundary is shown to be necessary for suppression of oscillations in the dependence of fundamental mode attenuation coefficient on bending radius.
The application of laser triangulation method on the blind guidance

J. Wu, Ming Chuan Univ. (Taiwan); J. Wang, St. John's Univ. (Taiwan); W. Fang, Y. Shan, National Taiwan Univ. (Taiwan); S. Ma, Feng Chia Univ. (Taiwan); H. Kao, St. John’s Univ. (Taiwan); J. Jiang, National Taiwan Univ. (Taiwan); Y. Lee, Ming Chuan Univ. (Taiwan)

A new apparatus for blind-guidance is proposed in this paper. The optical triangulation method is used to realize the system we proposed. The main components comprise a laptop, a camera and two laser modules. One laser module emits a light line beam vertically. Another laser module emits a light line beam horizontally. The track of the light line beam on the ground or on the object is captured by the camera, and the image is sent to the laptop for computation. The system can calculate the object width and the distance between the object and the blind in terms of the light line positions on the image. Based on the experiment, the distance could be measured with an accuracy of better than 3% within the range of 60 to 150 cm. And the object width could be estimated with an accuracy of better than 3% within the range of 60 to 150 cm.

Multichannel adaptive interferometer based on dynamic photorefractive holograms for nanometrology

M. N. Bezruk, R. V. Romashko, Institute for Automation and Control Processes (Russian Federation)

Multichannel adaptive measuring interferometry system is developed. Key element of the system is dynamic hologram written in photorefractive crystal (PRC). Due to ability of dynamic hologram to be rewritten, an adaptive interferometer is capable to work in unstable environment. Multichannel system operated at single wavelength. Interchannel cross-talk free operation of the system is achieved by holograms spatial multiplexing in PRC without application external electric fields to crystal. It is shown that increase of channels number does not lead to sensitivity diminishing. We used CdTe:V as a photorefractive crystal.

It was found that sensitivity of single channel when all other channels are turned off is 16.2. Turning on all channels does not affect on RDL in channel. Average value of RDL for all channel was amounted (17.1±1.1). Consequently, if number of multiplexing channels is increased, sensitivity of interferometer does not decrease in case if an optical beams from different channels does not overlapped in crystal. Therefore using of orthogonal geometry of wave mixing makes possible to create adaptive measuring system with very great number of channels. Thus if we have PRC of 6*6 mm2 and object beams with lateral diameter 0.7 mm it is possible to create 70 channel interferometer.

It was experimentally founded that using fast semiconductor CdTe:V recording time of holograms was 3ms at light intensity 140 mW/mm2. It allows to provide cut frequency of adaptive interferometer of 700 Hz. It make possible to provide steady work of multichannel interferometer in unstable conditions which characterized by noise impact with typical frequency of 50÷100 Hz.

Measuring hairiness in carpets by using surface metrology

R. A. Quinones, Sr., B. Ortiz-Jaramillo, S. A. Orjuela Vargas, S. De Meulemeester, L. Van Langenhove, W. Philips, Univ. Gent (Belgium)

Recently a new carpet scanner using structured light triangulation was designed. The scanning consists in capturing with a camera the reflection of a laser line progressively projected along the carpet surface. The performance of classical scanners was improved by placing the carpets in a drum, to better capture the structure given by the piles. Range images were built by detecting per frame the dominant edges at different scales using wavelet space representation. This method excludes information given by hairs, which is a relevant characteristic in the evaluation. We recently present an automatic grading system already generic for carpets with low pile construction and without color patterns. The grades are computed using linear models with texture features extracted from the range images. Appearance changes in carpets with high pile construction were still not well detected, because those changes are also related to other characteristics such as thickness and hairiness. Therefore, algorithms measuring such characteristics in the carpet structure were still required. We present in this paper an approach based on surface metrology that directly measures the hairiness of the carpet from the frames. We measure the distances between the maximum intensity of the laser line reflection and the reflection given by the hairs. We found that these features are complementary to the previous texture features explored. The use of the automatic grading has been expanded including some carpets types with high pile construction by combining features based on both features. The full method can be used to evaluate other material surfaces.

Phase shifting interferometry for measurement of transparent samples


A Michelson interferometer was implemented to analyze a phase object by using polarization phase-shifting interferometry. The Michelson interferometer produces two beams with circular polarization of opposite rotations one respect to the other obtained by a combination of a quarter-wave plate Q and a linear polarizer filter P0 that generates linearly polarized light at an appropriate azimuth angle entering the Michelson interferometer. Using two retardation plates (QL and QR) with mutually orthogonal fast axes placed in front of the two beams (A, B) to generate left and right nearly-circular polarized light.

The system is coupled to a 4-f system with bi-Ronchi gratings in the Fourier plane. Diffraction orders appear in the image plane, forming a rectangular array were around each order, an interference pattern appears due to the optical fields associated to each beam when proper matching conditions are met. The interference of the fields associated with replicated beams centered on the diffraction orders is achieved by a proper choice of the beams spacing with respect to the gratings period.

In this paper we propose an optical system using single-shot phase shifting interferometry modulated by polarization, presenting insensitivity against external vibration allowing measuring dynamics events with high accuracy because the optical configuration allows obtaining n-interferograms in one shot.

Experimental results are presented to the study of a thin phase object.

Remote ultra sensible microphone laser

G. E. Sanchez Guerrero, C. Guajardo Gonzáles, P. M. Viera González, R. Selvas Aguilar, L. G. Ramos Traslosheros, Univ. Autónoma de Nuevo León (Mexico)

This paper presents an optical fiber Mach-Zehnder interferometer which is arranged in a configuration of an ultra-sensitive sound detector. This consists in a U-bench mount, a 3dB beam splitter, a few meters of telecom fiber, a 633nm He-Ne laser, a sound acquisition system, and a remote reflective detach surface. The optomechatronic device also enables to capture sound vibration in free air at remote reflective
vibrate surface at a distance as longer as 5 meters. In our case, light is launched into the fiber interferometer and one path arm is broken by a U-bench mount. The other arm is the reference arm which path is remains unchanged. A beam-splitter in the U-bench extracts the beam out of the fiber components and deviates the beam somewhere. This beam bounced off this vibration surface and is catch back through a beam splitter located in between the U-bench mount. Then, the fiber interferometer processes this signal back and a photo-detector acquire this modulate optical signal and by help of a system is demodulated and pre-amplifier the incoming signal into a digital sound signal. The high sensibility of the device is enough to catch sound vibration at a distance as longer as 5 meters and process in a sound recorded file. The system is compact, robust, reliable and cost effective and is suggested as an instrument that can find application where is required a surveillance no-detectable device or a perimeter building protection.

8133-39, Poster Session
Design and characterization of image acquisition system and its optomechanical module for chip defects inspection on chip sorter
M. Chen, P. Huang, Y. Chen, Y. Cheng, Instrument Technology Research Ctr. (Taiwan)

Chip sorter is one of packaging facilities in chip manufactory. The defects will occur for a few of chips during manufacturing processes. If the size of chip defects is larger than a criterion of impacting chip product quality, these flawed chips have to be detected and removed. Defects inspection system is then developed with frame CCD imagers. There’re some drawbacks for this system, such as image acquisition of pause type, complicated acquisition control, easy damage for moving components, etc. And acquired images per chip have to be processed in radicomy and geometry and then pieced together before inspection. They impact the accuracy and efficiency of inspection. So the approaches of image acquisition system and its opto-mechanical module will be critical for system improvement.

In this article, design and characterization of a new image acquisition system and its opto-mechanical module are presented. Defects with size of greater than 15µm have to be inspected. Inspection performance shall be greater than 0.6 m/sec. Thus image acquisition system shall have line rate of greater than 120 kHz for CCD output. The design of system improvement.

Proposed system has advantages of such as transporting chips in constant speed to acquire images, using one image only per chip for inspection, no image-mosaic process, simplifying the control of image acquisition. And the inspection efficiency and accuracy will be substantially improved.

8133-40, Poster Session
Experimental exploration on the correlation coefficient of static speckles in Fresnel configuration
D. Li, Univ. College Dublin (Ireland); D. Kelly, Technische Univ. Ilmenau (Germany); J. T. Sheridan, Univ. College Dublin (Ireland)

The correlation coefficients of static speckles in three dimensions are derived and the results verified using computer simulations and experimental measurements. The investigation shows that longitudinal correlation coefficients of speckle patterns decrease monotonically along the radial direction, based on which an alignment algorithm to align the optical axis with the centre of the detector is proposed. Position shift of the peak coefficient appears when off-axis speckle pattern correlated with its longitudinally displaced counterpart, from which the out-of-plane displacement of the diffruser can be measured at the recording plane. Two applications indicated by the results are explored.

8133-41, Poster Session
High-resolution diameter estimation of micro-thin wires by a novel 3-D diffraction model
K. K. Vyas, Indian Institute of Science (India)

Micro-thin wires are of significant importance to academia, research laboratories as well as industries engaged in micro-fabrication of products related to diverse fields like micromechanics, bio-instrumentation, optoelectronics etc. Critical dimension metrology of such wires often demands diameter estimation with tight tolerances. Amongst other measurement techniques, Optical Diffraclometry under Fraunhofer approximation has emerged over years as a non-destructive, robust and precise technique for on-line diameter estimation of thin wires. However, it is observed that existing Fraunhofer models invariably result in experimental overestimation of wire diameter, leading to unacceptable error performance below 10 µm. In particular for diameters below 50 µm, a novel diffraction model based on Geometric theory is proposed and demonstrated to theoretically quantify this diameter overestimation. The proposed model utilizes hitherto unused paths-ways for the two lateral rays that contribute to the first diffraction minimum. Based the 3-D geometry of the suggested model, a new ‘correction function’ is defined. The theoretical analysis reveals that the actual diameter of the diffracting wire is a product of two factors: overestimated diameter by the existing models and the newly proposed correction function. The analysis reveals further that the said correction function varies non-linearly with diameter and presents a dependence only on the experimentally measured diffraction angle. Based on the proposed model, the communication reports for the first time, a novel diameter-inversion procedure which not only corrects for the overestimated diameter by existing models but also facilitates wire diameter-inversion with high resolution. Micro-thin metallic wires having diameters spanning the range 1-50 µm are examined. Simulations and experimental results are obtained that corroborate the theoretical approach.

8133-42, Poster Session
Absolute thickness measurement of silicon wafer using wavelength scanning interferometer
Y. Ghim, Korea Research Institute of Standards and Science (Korea, Republic of); A. Suratkar, Intel Corp. (United States); A. Davies, The Univ. of North Carolina at Charlotte (United States); Y. Lee, Korea Research Institute of Standards and Science (Korea, Republic of)

Silicon wafers are widely used in various applications of semiconductor and solar cell. One of interesting issues for mass production for silicon wafers is quality control, especially for thickness uniformity. In this paper, we describe wavelength scanning interferometry based on spectroscopic reflectometry using infrared light (4 nm tuning range at 1550 nm) for three-dimensional thickness measurements of thin wafers less than 100 µm with fine lateral and depth resolution. Other optical methods that are based on Fourier techniques are limited to thicker wafers when using such a short tuning range source. For example, the minimum thickness measurable with the conventional Fourier-based technique using a 4 nm-tunable (500 GHz) 1550 nm laser is approximately 170 um. Thus our proposed method enables a significant extension of thickness measurements and represents a significant advance. It is also interesting that the so-called ‘ripple-error’ or ‘fringe-bled through’ is much reduced with a reflectometry-based analysis compared to a Fourier-based analysis. Our proposed method was verified by measuring and testing several wafers with various thicknesses.
Error analysis and compensation in phase-shifting surface profiler
Q. Hu, QUEST Integrated, Inc. (United States)
This paper analyzes the error sources in phase-shifting surface profiler, including phase-shifting generation, color imbalance, phase-shifting algorithms, surface contour extraction, and data analysis, etc. Some methods to improve the measurement accuracy and resolution are also proposed including transfer functions and look-up tables for various error sources. The limitations in accuracy are also discussed. Some initial test results will be given to verify the feasibility.

Uniaxial 3D shape measurement with a binary phase-shifting technique using projector defocusing
S. Zhang, L. Ekstrand, Y. Xu, Iowa State Univ. (United States)
In an attempt to compensating the phase errors induced by improperly defocused binary structured patterns, we found that: (1) the phase error can be described as a function of depth z; and (2) the error function is monotonic on either side (positive or negative) of the perfectly focal plane (0). These findings provide not only the opportunity to compensate for this type of phase errors though software, but also the potential to retrieve the depth z by analyzing phase errors. The former has been proven successful previously. Moreover, our further analysis indicates that the phase error is intrinsic to the depth z and is independent of viewing perspective. In other words, the phase error is theoretically invariant to the viewing direction of a camera. This indicates that (1) the 3D information can be retrieved by analyzing the phase errors, and (2) the 3D information can be obtained even if the camera captures images from the same angle as the projector projection. In other words, it does not require triangulation for depth retrieval, which is fundamentally different from most 3D shape measurement techniques where triangulation is mandatory. This paper will present this uniaxial 3D shape measurement technique based on the analysis of defocused binary structured patterns. Comparing with a conventional triangulation-based method, this technique has the advantage of measuring deep holes, and has the merit of developing more compact 3D systems. This paper will present the principle of the proposed technique and will show some preliminary experimental results.

Method for the evaluation 3D non-contact inspection systems
K. G. Harding, GE Global Research (United States)
Three dimensional, optical measurement systems are becoming more widely used in applications ranging from aerospace to automotive. These systems offer the potential for high speed, good accuracy, and more complete information than older contact based technology. However, the primary standards employed by many to evaluate these systems were specifically designed around touch probe based coordinate measurement machines (CMMs). These standards were designed to work with the limitations of touch probes, and in many cases can not measure the types of features and errors associated with non-contact systems. This paper will discuss the deficiencies of employing contact based characterization tests to non-contact systems, and suggest a new set of tests specifically to cover the many aspects pertinent to non-contact, optical 3D measurement systems. Some of the performance aspects addressed in this characterization method includes: sensitivity to surface reflectivity and roughness, the effect of angle of incidence of measurements, means to characterize volumetric variations that may fit complex functions, and considerations of both spatial and depth resolutions. Specific application areas will be discussed as well as the
use of artifacts to provide practical functional data that can predict system performance on real world parts.

8133-25, Session 6

Surface resistivity/conductivity of different organic-thin films by shearography

K. J. Habib, Kuwait Institute for Scientific Research (Kuwait)

Optical shearography techniques were used for the first time to measure the surface resistivity/conductivity of different organic-thin films, without any physical contact. Different organic coatings, ACE Premium-grey Enamel, a yellow Acrylic Lacquer, and a gold Nail Polish, on a metallic alloy, i.e., a carbon steel, was investigated at a temperature stage simulating the severe weather temperatures in Kuwait, especially between the daylight and the night time temperatures, 20-60 oC. The investigation focused on determining the in-plane displacement of the coatings, which amounts to the thermal deformation (strain) with respect to the applied temperature range. Then, the alternating current (AC) impedance (resistance) of the coated samples was determined by the technique of electrochemical impedance spectroscopy (EIS) in 3.5 % NaCl solution at room temperature. In addition, a mathematical model was derived in order to correlate between the AC impedance (resistance) and to the surface (in-plane) displacement of the samples in solutions. In other words, a proportionality constant (surface resistivity or conductivity=1/ surface resistivity) between the determined AC impedance (by EIS technique) and the in-plane displacement (by the optical interferometry techniques) was obtained. Consequently the surface resistivity () and conductivity () of the coated samples in solutions were obtained. Also, electrical resistivity values () from other source were used for comparison with the calculated values of this investigation. This study revealed that the measured value of the resistivity for the anodized coated samples were in a good agreement with the one found in literature for the same coatings.

8133-26, Session 6

High-resolution electric speckle pattern interferometry by using only two speckle patterns

Y. Arai, Kansai Univ. (Japan)

Electric speckle pattern interferometry (ESPI) with using fringe scanning methods is a useful method for the out of plane and in-plane deformation displacement measurement of an object with some rough-surfaces. Now, the temporal carrier technology by using a high speed camera is also employed for a large deformation measurement. However, in the measurement which should treat with a much faster deformation phenomenon, the higher speed camera than an ordinary camera is required in order to grab images smoothly. As the results, it is getting to be difficult to set up the optical system physically and financially. In order to solve the problems, the development of new analyzing methods that can measure the deformation distribution of the object by the limited information without using a much higher speed camera has been required. In this paper, a new measurement method is developed by using basic characteristics of speckle phenomena. In the new method, the special optical system that can record some spatial information in each speckle is constructed. The high resolution deformation analysis by using only two speckle patterns before and after deformation process can be realized by using the new optical system. In experimental results, it can be confirmed that the resolution-power of the new method is more precise than 1/100 wavelength of the light source in optical system, and is also equivalent to the resolution-power of ordinary method which is required to at least 3 sheets of speckle patterns in the deformation analysis.
8134-01, Session 1

Optical hybrid analog-digital signal processing based on spike processing in neurons

M. P. Fok, P. R. Prucnal, Princeton Univ. (United States)

Technologies for real-time signal processing have received considerable attention due to their processing power for numerous applications. Neuromorphic engineering provides the capability of performing practical computing and signal processing based on the biophysical model of neuronal computation. Spike processing in neurons is of particular interest due to its efficiency and cascaddability that benefits from hybrid analog-digital processing. We propose and demonstrate an optical hybrid analog-digital signal processing primitive that implements the functionality of an integrate-and-fire neuron. This optical primitive has a processing speed that is nine-orders of magnitude faster than a biological neuron and is capable of performing high-capacity signal processing. It employs a Ge-doped nonlinear optical fiber and off-the-shelf semiconductor devices. Utilizing this hybrid analog-digital processing primitive, we can implement processing algorithms that are too complex for existing optical technologies and have a much higher bandwidth compared with existing electronic technologies. The spiking neuron comprises a small set of basic operations (delay, weighting, spatial summation, temporal integration, and thresholding), and is capable of performing a variety of processing functions, depending on how it is configured. It opens up a range of optical processing applications for which electronic processing is too slow. In this paper, an overview of optical hybrid analog-digital signal processing will be presented. Several simple photonic neuromorphic circuits, including the auditory localization algorithm of the barn owl and the crayfish tail-flip escape response will also be introduced.

8134-02, Session 1

Autonomous wireless radar sensor mote for target material classification

K. M. Iftekharuddin, M. Khan, E. McCracken, L. Wang, R. Kozma, The Univ. of Memphis (United States)

An autonomous wireless sensor network consisting of different types of sensor modalities is a topic of intense research due to its versatility and portability. These types of autonomous sensor networks commonly include passive sensor nodes such as infrared, acoustic, seismic, and magnetic. However, fusion of another active sensor such as Doppler radar in the integrated sensor network may offer powerful capabilities for many different sensing and classification tasks. In this work, we demonstrate the design and implementation of an autonomous wireless sensor network integrating a Doppler sensor into wireless sensor node with commercial off the shelf components. We also investigate the effect of different types of target materials on the return radar signal as one of the applications of the newly designed radar-mote network. Different types of materials can usually affect the amount of energy reflected back to the source of an electromagnetic wave. We obtain mathematical and simulation models for the reflectivity of different homogeneous non-conducting materials and study the effect of such reflectivity on different types of targets. We validate our simulation results on effect of reflectivity on different types of targets using real experimental data collected through our autonomous radar-mote sensor network.

8134-03, Session 1

Multi-objective adaptive composite filters for object recognition

J. L. Armenta, V. H. Diaz-Ramirez, J. J. Tapia-Armenta, Ctr. de Investigación y Desarrollo de Tecnología Digital (Mexico)

A new algorithm to design optimal trade-off correlation filters for pattern recognition is presented. The algorithm is based on a heuristic optimization of several conflicting quality metrics simultaneously. By the use of the heuristic algorithm the impulse response of a conventional composite filter is iteratively synthesized until an optimal trade-off of the considered quality metrics is obtained. Computer simulation results obtained with the proposed filters are provided and compared with those of existing trade-off correlation filters in terms of recognition quality measures in cluttered, noisy, and geometrically distorted input scenes.

8134-04, Session 1

Distortion-invariant face recognition using multiple phase-shifted reference-based joint transform correlation technique

M. N. Islam, Farmingdale State College (United States); V. K. Asari, Univ. of Dayton (United States); M. A. Karim, Old Dominion Univ. (United States)

We have developed a novel face recognition technique utilizing optical joint transform correlation (JTC) technique which provides with a number of salient features as compared to similar other digital techniques, including fast operation, simple architecture and capability of updating the reference image in real time. The proposed technique incorporates a synthetic discriminant function (SDF) of the target face estimated from a set of different training faces to make the face recognition performance invariant to noise and distortion. The technique then involves four different phase-shifted versions of the same SDF reference face, which are individually joint transform correlated with the given input scene with unknown faces and other objects. Appropriate combination of correlation signals yields a single cross-correlation peak corresponding to each potential face image. The technique also involves a fringe-adjusted filter to generate a delta-like correlation peak with high discrimination between the target face and the non-target face and background objects. Performance of the proposed face recognition technique is investigated through computer simulation where it is observed to be efficient and successful in different complex environments.

8134-05, Session 1

Acceleration of radial basis functions for visual robot calibration using GPGPUs

T. M. Taha, Univ. of Dayton (United States)

In this paper we present the acceleration of Radial Basis Functions on GPGPUs for visual calibration of industrial robots.

8134-06, Session 1

Margin setting: the early years

H. J. Caulfield, Alabama A&M Univ. (United States)

Pattern recognition in terms of algorithms (there are many of them) and
and reduces the influence of chromatic dispersion in optical-OFDM system if RIN is adjusted to -155 dB/Hz. We investigated the optimal values for linewidth and RIN for a coded optical-OFDM system for its better performance. The limiting value of linewidth should be 6.5MHz up to which optical power remains almost constant and RIN value corresponding to this linewidth is measured to be -155 dB/Hz, and the average value of RIN is measured to be -125 dB/Hz. The results of our simulations for Optical-OFDM and thermal noise-dominated scenario are observed for different DGDs and the worst-case scenario (k = 1/2), assuming that the channel state information is known on a receiver side. The OFDM signal bandwidth is set to BW = 0.25 B (where B is the aggregate bit rate set to 10 Gb/s), the number of subchannels is set to NOAM = 64, FFT/IFFT is calculated in NFFT = 128 points, the RF carrier frequency is set to 0.75 B, the bandwidth of optical filter for SSB transmission is set to 2 B, and the total averaged launched power is set to 0 dBm. The guard interval is obtained by cyclic extension of NG= 2*16 samples. The Blackman-Harris windowing function is applied. The 16-QAM OFDM with and without channel estimation is observed in simulations. The effect of PMD is reduced by (1) using a sufficient number of subcarriers so that the OFDM symbol rate is significantly lower than the aggregate bit rate and (2) using the training sequence to estimate the PMD distortion. For DGD of 1/BW, the RZ-OOK threshold receiver is not able to operate properly because it enters the BER error floor. Note that 16-QAM OFDM without channel estimation enters the BER floor, and even advanced FEC cannot help much in reducing the BER.

8134-07, Session 2

Analyzing the OFDMA capacity in SISO and MIMO for wireless communication systems

S. Mohseni, M. A. Matin, Univ. of Denver (United States)

Orthogonal Frequency Division Multiple Access (OFDMA) is a technique that it uses several narrow bands for transmitting the large amounts of digital data over a radio wave simultaneously. The Multiple Access (MA) is part of the abbreviation which refers to this fact that the data which are sent in downlink can be received and used by many users at the same time. In OFDM, the OFDM symbols in time are sequentially allocated to the different users, but in the OFDMA the system directly allocates them to the different users.

In another word, The OFDMA is a multi-user version of Orthogonal Frequency Division Multiplexing(OFDM). OFDMA by spacing the channels much closer to each other can use the spectrum more efficiently. Even though there are different ways for partitioning the radio resource for multilayer communication system, because of the advantages that OFDMA has, it has always been considered as the first choice for broadband wireless networks.

In this paper, the structure of the OFDMA, the channel capacity for Single Input single output (SISO) and Multi Input Multi Output (MIMO) for OFDMA discuss and study, and then the conditions that make OFDMA optimal or suboptimal discuss. When the OFDMA is not optimal we show what the performance gap is; then finally we propose an algorithm for computing the OFDM and OFDMA capacity. All the simulations have been done in MATLAB.

8134-08, Session 2

Performance analysis of coded OFDM fiber-optics communications

K. J. Bhatia, R. S. Kaler, Thapar Univ. (India); T. S. kamal, Sant Longowal Institute of Engineering and Technology (India); R. Kaler, Thapar Univ. (India)

A novel high spectral efficiency all-optical sampling orthogonal frequency-division multiplexing scheme is proposed using space frequency Block coding (SFBC) techniques and nonlinear behavior of vertical-cavity surface-emitting laser diodes is exploited by relative intensity to noise (RIN). We show that in long-haul fiber optics communications, SFBC-coded OFDM increases spectral efficiency and reduces the influence of chromatic dispersion in optical-OFDM system if RIN is adjusted to -155 dB/Hz. We investigated the optimal values for linewidth and RIN for a coded optical-OFDM system for its better performance. The limiting value of linewidth should be 6.5MHz up to which optical power remains almost constant and RIN value corresponding to this linewidth is measured to be -155 dB/Hz, and the average value of RIN is measured to be -125 dB/Hz. The results of our simulations for Optical-OFDM and thermal noise-dominated scenario are observed for different DGDs and the worst-case scenario (k = 1/2), assuming that the channel state information is known on a receiver side. The OFDM signal bandwidth is set to BW = 0.25 B (where B is the aggregate bit rate set to 10 Gb/s), the number of subchannels is set to NOAM = 64, FFT/IFFT is calculated in NFFT = 128 points, the RF carrier frequency is set to 0.75 B, the bandwidth of optical filter for SSB transmission is set to 2 B, and the total averaged launched power is set to 0 dBm. The guard interval is obtained by cyclic extension of NG= 2*16 samples. The Blackman-Harris windowing function is applied. The 16-QAM OFDM with and without channel estimation is observed in simulations. The effect of PMD is reduced by (1) using a sufficient number of subcarriers so that the OFDM symbol rate is significantly lower than the aggregate bit rate and (2) using the training sequence to estimate the PMD distortion. For DGD of 1/BW, the RZ-OOK threshold receiver is not able to operate properly because it enters the BER error floor. Note that 16-QAM OFDM without channel estimation enters the BER floor, and even advanced FEC cannot help much in reducing the BER.

8134-09, Session 2

A new technique for compensating the effects of carrier frequency offset (CFO) for orthogonal frequency division multiplexing

S. Mohseni, M. A. Matin, Univ. of Denver (United States)

Orthogonal frequency division multiplexing (OFDM) has been selected for broadband wireless communication system. OFDM can provide large data rates with sufficient robustness to radio channel impairments. One of the major drawbacks for OFDM system is Carrier frequency offset (CFO). Frequency offset has been recognized as a major disadvantage of OFDM. The OFDM systems are sensitive to the frequency synchronization errors in form of Carrier Frequency Offset (CFO), because it can cause the Inter Carrier Interference (ICI) which can lead to the frequency mismatched in transmitter and receiver oscillator. Lack of the synchronization of the local oscillator signal (LOS); for down conversion in the receiver with the carrier signal contained in the received signal can cause to degrade the performance of OFDM. On the other hand the orthogonality of the OFDM relies on the condition that transmitter and receiver operate with exactly the same frequency reference. To compensate the effect of CFO the researchers have proposed various CFO estimation and compensation techniques and algorithms by now. In this paper, the reason of creating CFO and the effects of the CFO on the performance of the OFDM system will study. The major CFO estimation algorithm and techniques will be reviewed and discussed in literature briefly and then our proposed algorithm and technique for estimating and compensation of the effect of CFO will be offered.

8134-10, Session 2

Computational reacquisition of a real three-dimensional object for integral imaging without matching of pickup and display lens array

J. Jung, J. Hong, G. Park, K. Hong, B. Lee, Seoul National Univ. (Korea, Republic of)

The research field of three-dimensional (3D) technologies is considerably widened from 3D display to various applications. Among them, integral imaging and its applications are remarkable methods to acquire and
display a volumetric 3D object with full parallax. However, integral imaging has fundamental issues between acquisition and display phase, which are the pseudoscopic problem and matching of lens specification in pickup and display phase. The depth information of real object is reversed between pickup and display phase because of the direction of rays in acquisition and display phase. It is called the pseudoscopic problem. In addition, the lens array used in display phase has to be matched with pickup lens array for reconstructing 3D object without flipping.

In this paper, we propose the computational reacquisition method to overcome the pseudoscopic and matching problem between acquisition and display phase. First, the depth information of real object is extracted with high precision using optical flows of sub-images. To reconstruct the volumetric 3D object with reversal of depth information, we adopt the triangular mesh reconstruction between point clouds in virtual space. After reconstruction, the real 3D object can be captured in orthoscopic geometry using OpenGL, which can be rotated and translated in reacquisition process. Furthermore, the reacquisition process can generate the elemental image without matching of pickup lens array.

In this paper, we present the experimental results of pickup, reconstruction, reacquisition, and display with various specification of lens array. The proposed method can help to broadcast 3D contents using integral imaging.

8134-11, Session 2

Spectrum analysis of optical signals is based on the resonance phenomenon
M. A. Vaganov, O. D. Moskaletz, St. Petersburg State Univ. of Aerospace Instrumentation (Russian Federation)

Receiving of spectroscopic information by the known modern spectral devices is based on the spatial processing of analyzed optical radiation. This method of receiving spectroscopic information requires a precise alignment and a rigid construction that considerably increases mass and sizes of device.

The spectral device considered in this paper carries out spectral decomposition based on the resonance phenomenon, i.e. the spectral decomposition is implemented by the principle of the narrow-band optical filtration in n parallel channels. Each channel contains the narrow-band optical filter (resonator) which has been set on the certain wave length.

In contrast to the traditional spectral devices, this device can make parallel analysis of optical radiation spectrum, excepting a direct contact with the field of radiation sources. The group of optical fibers realizes the function of transmitting analyzed optical radiation on the given distance.

The results of experimental research are given. These results prove functionality of this spectrum analyzer of optical signals. Furthermore the results of experimental research of white light radiation source are given. The metal halogen lamp was used as a source of white light radiation. This lamp is a part of the spectrum analyzer and is used as the standard source for adjustment of spectral device.

This device realizes ideas of patent 86734 of the Russian Federation.

8134-12, Session 3

High-resolution imaging of retinal neural function
X. Yao, The Univ. of Alabama at Birmingham (United States)

Stimulus-evoked fast intrinsic optical signals (IOSs) in the retina may provide a new method to evaluate the functional connectivity of photoreceptors and inner neurons. In this experiment, we demonstrate the feasibility of IOS imaging of a frog retina slice preparation that allows simultaneous observation of stimulus-evoked responses from the photoreceptors to inner neurons. Robust IOSs were consistently detected from stimulus activated photoreceptor outer segments, inner plexiform layer (IPL), and ganglion cells; and weak IOSs could be occasionally identified in the outer nuclear layer, outer plexiform layer, and inner nuclear layer between the PR and IPL. At the photoreceptor layer, high magnitude IOSs were mainly confined to the area covered by the visible light stimulus. In comparison, IOSs of the IPL and ganglion layer could spread beyond the image area. High resolution IOS images showed complex spatial distributions of positive and negative IOSs at different retinal layers. At the photoreceptor and ganglion layers, positive and negative optical responses were mixed at a sub-cellular scale.

We speculate that the positive and negative signal complexity might result from different types of localized light scattering and transmission changes associated with single activated photoreceptor or ganglion cells. We consistently observed that the IPL was dominated by positive-going optical responses. We hypothesize that the positive signal that dominated the IOS response in the IPL might be related to light scattering changes due to light-regulated release of synaptic vesicles at nerve terminals.

8134-13, Session 3

Development of strain visualization system for microstructures using single fluorescent molecule tracking on three dimensional orientation microscope
S. Yoshida, K. Yoshiki, Univ. of Hyogo (Japan); M. Hashimoto, Osaka Univ. (Japan); T. Namazu, S. Inoue, Univ. of Hyogo (Japan)

We developed a high-spatial-resolution observation system for stress-strain distribution. In micro/nanostructures, heterogeneous mechanical properties due to preexisting defects cause unpredictable deformations. Non-contact assessment without damage of this heterogeneity is important for industrial and scientific applications such as MEMS (microelectromechanical system)/NEMS (nanoelectromechanical system), polymers, and biological tissue. We suggest a scheme to visualize the heterogeneous distribution of strain in micro/nanostructures by tracing the geometric arrangement of fluorescent single-molecule markers (tracers) sprayed onto the surface of the structures. Deformation between the two tracers is calculated from variations in their physical relationship. Because the density of the distributed tracers limits the spatial resolution of visualization, we traced both the 3D position and 3D molecular orientation of each tracer, which indicate the displacement and surface normal direction of local points on the surface, respectively, to suppress the reduction of spatial resolution due to aliasing.

We sprayed single molecules on a MEMS scanning mirror by ultrasonic atomization to trace the 3D position and 3D orientation-simultaneously. We determined the 3D position by SMD (single-molecule detection), widely used in bioscience research, and 3D orientation by 3D-orientation microscopy, developed previously by us. The 3D orientation microscope detected the molecular orientation from the angular polarization distribution of fluorescence emitted by the tracers. We estimated the spatial resolution as <500 nm in the observation plane and <5000 nm in the depth direction, and the angular resolution was <3.95°.

We visualized the strain distribution at the joining area between a supporting beam and the frame of the MEMS mirror.

8134-14, Session 3

Accurate colour control by means of liquid crystal spatial light modulators
I. Moreno, J. L. Martinez, Univ. Miguel Hernández de Elche (Spain); P. García-Martínez, Univ. de València (Spain); M. Sánchez-López, Univ. Miguel Hernández de Elche (Spain)

We present the application of a simple physical model to accurately predict the broadband spectral transmittance and colorimetric properties of a twisted-nematic liquid crystal display (TNLCD). We spectroscopically calibrated the retardance parameters to evaluate the spectrum of the
light transmitted by a TNLCD sandwiched between two linear polarizers. When the TNLCD is illuminated with a broadband light source, the full spectrum can be predicted as a function of the addressed grey level for any arbitrary orientation of the polarizers. When the TNLCD is illuminated with spectrally separated components onto different pixels, and then recombined, a full colour and luminance control is achieved. Experimental results confirming the validity of the proposed systems are presented, both on the measured spectral responses as well as on the trajectories at different chromatic diagrams. The presented results can be useful for optoelectronic systems requiring an accurate control of the spectral characteristics of the light.

8134-15, Session 3

Two-dimensional phase imaging based on closed-loop feedback control
E. Watanabe, The Univ. of Electro-Communications (Japan); M. Toshima, Japan Women's Univ. (Japan); C. Fujikawa, Tokai Univ. (Japan)

Recently, in the biomedical measurement field, to advance the clarification of cell's function, the quantitative measurement with non-invasive diagnosis for a transparent object has become needed. To observe the shape of transparent biological cell, in the present day, the fluorescence microscopy has been very useful. However, since the fluorescence microscopy is largely affected by the fluorescent substance, the phase contrast microscope is used to convert relative phase information into intensity information. If absolute phase information can be acquired noninvasively, it becomes possible to obtain the quantitative three-dimensional shape on the biological cell. In addition, the refractive index modulation type optical elements with microstructure, including the optical waveguide devices and the high dispersion Volume Phase Holographic (VPH) grating, are developed with the advancement of optical communications technology. Since optical devices are often manufactured using optical sensitization resin, they do not have mechanical structure. So, stylus method and a scanning electron microscope (SEM) cannot be used for evaluation. The structure is estimated by comparing the characteristic with simulation results. Therefore, a simple method to directly measure the refractive index distribution is desired. We are developing the scanning Mach-Zehnder type interferometer that detects refractive index distribution as phase change, assuming transparent object with a constant thickness and smooth change in refractive index. We have been able to measure and confirm phase variations less than a wavelength from a small fraction of a wavelength to several wavelengths in linear scale by introducing the feedback control technique. In this paper, we describe the high accuracy vertical phase measurement system we have constructed, and the two-dimensional scanner for the biological cell in the fluid medium, followed by the report of fundamental evaluation result as applications in tissue engineering.

8134-16, Session 3

Converting a 3D surface into a set of points with directional scattering properties for high-resolution radar response simulation
H. Perälä, M. Väilä, J. Jylhä, I. Venäläinen, A. J. E. Visa, Tampere Univ. of Technology (Finland)

It is practical and efficient to simplify targets to point scatterers in radar simulations. With low-resolution radars, the radar cross section (RCS) is a sufficient feature to characterize a target. However, RCS is dependent only on the aspect angle and totals the target scattering properties to a scalar value for each angle. Thus, a more detailed representation of the target is required with high-resolution radar techniques, such as Inverse Synthetic-Aperture Radar (ISAR). Traditionally, high-resolution targets have been modeled placing identical point scatterers in the shape of the target, or with a few dominant point scatterers. As extremely simple arrangements, these do not take the self-shadowing into account and are not realistic enough for high demands. Our radar response simulation studies required a target characterization akin to RCS, which would also function in high-resolution cases and take the self-shadowing and multiple reflections into account. Thus, we propose an approach to converting a 3-dimensional surface into a set of scatterers with locations, orientations, and directional scattering properties. The method is intended for far field operation, but could be used in the near field with alterations. It is based on ray tracing which provides the self-shadowing and reflections naturally. In this paper, we present ISAR simulation results employing the proposed method. Being invariant to the used radar wavelength, the extracted scatterer set enables the fast production of realistic simulations including authentic RCS scattering center formation. This paper contributes to enhancing the reality of the simulations, yet keeping them manageable and computationally reasonable.

8134-17, Session 3

Improving spatial coherence in high power lasers
A. D. McAulay, Lehigh Univ. (United States)

Two ways to improve spatial coherence in high power lasers are considered and compared, spatial filter and adaptive optics. High-power lasers are usually produced by using a succession of optical amplifiers. As intensity increases in optical amplifiers or lasers, spatial coherence decreases because of uneven heating and other nonlinearities. It is common to use a spatial filter in the form of a pinhole after each stage that will block the parts of the beam that are spatially incoherent and would scatter sideways out of the beam. The loss of light blocked by the pinhole lowers amplification so that more amplifiers are required. An alternative approach to improving spatial coherence uses adaptive optics. In this case the wavefront is measured using a wavefront sensor such as a Hartman wavefront sensor or with a photonic crystal. (A. D. McAulay and H. Tong, SPIE 5435-13 April 2004). The measurements are used to compute settings for a deformable mirror (A. D. McAulay, Optical computer architectures, Wiley 1991). (A. D. McAulay, Optical Engineering, 25(18), Jan.1986). This involves a complicated feedback loop and discretization of the wavefront sensor and deformable mirror that limits the accuracy depending on the application. We discuss the pros and cons for each approach to determine which approach is more suitable for what application. For example adaptive optics is used for improving spatial coherence in the Airborne laser program (ABL). On the other hand spatial filters are used in some inertial confinement experiments for nuclear fusion.

8134-22, Poster Session

High-quality edge-enhancement imaging in optical microscopy
S. Wei, Nankai Univ. (China); S. Zhu, Nankai Univ. Affiliated Hospital (China); X. Yuan, Nankai Univ. (China)

Since biological cells are weak-phase objects, their images formed in bright-field optical microscopes are usually displayed with small contrast. A famous technology to solve this problem is coherent spatial image filtering with a spiral phase structure which has been used as a spatial filter to implement a radial Hilbert transform for optical filtering in image processing, leading to a strong and isotropic edge contrast enhancement of both amplitude and phase objects. We report a Bessel-like amplitude modulated spiral phase filtering system for real-time spatial image edge enhancement in optical microscopy. The method is based on a Fourier 4-f spatial filtering system. And this method can transform phase gradient to intensity distribution. We compare the PSF of Bessel-like amplitude modulated spiral phase filter, conventional spiral phase filter, dark field spiral phase filter and the Laguerre-Gaussian modulated spiral phase filter. And the proposed technique further reduces the imaging diffraction
noise with the new filter. Experimental verifications in edge enhancement are implemented by a phase-only spatial light modulator for realizing the amplitude modulated spiral phase. It is shown that the proposed technique is able to achieve high contrast cells edge enhancement with high resolution.

8134-23, Poster Session

Characteristic values of Mueller-matrix images of biological tissues during the diagnostics of physiological changes

A. V. Dubolazov, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine)

In this work, we have theoretically grounded conceptions of characteristic points observed in coordinate distributions of Mueller matrix elements for a network of human tissue biological crystals. The interrelation between polarization singularities of laser images inherent to these biological crystals and characteristic values of above matrix elements is found. We have determined the criteria for statistical diagnostics of pathological changes in the birefringent structure of biological crystal network by using myometrium tissue as an example. The paper deals with investigating the processes of laser radiation transformation by biological crystals networks using the singular optics techniques. The results obtained showed a distinct correlation between the points of “characteristic” values of coordinate distributions of Mueller matrix (M=0; +1) elements and polarization singularities (L- and C-points) of laser scattering field.

8134-24, Poster Session

Complex degree of mutual anisotropy in diagnostics of biological tissues physiological changes

A. V. Dubolazov, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine)

To characterize the degree of consistency of parameters of the optically uniaxial birefringent liquid crystals (protein fibrils) nets of biological tissues (BT) a new parameter - complex degree of mutual anisotropy is suggested. The technique of polarization measuring the coordinate distributions of the complex degree of mutual anisotropy of biological tissues is developed. It is shown that statistic approach to the analysis of complex degree of mutual anisotropy distributions of biological tissues of various morphological and physiological states and optical thicknesses appears to be more sensitive and efficient in differentiation of physiological state in comparison with investigations of complex degree of mutual polarization of the corresponding laser images.

8134-25, Poster Session

A fractal and statistic analysis of Mueller-matrix images of phase inhomogeneous layers

A. V. Dubolazov, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine)

The features of polarization tomography of optically anisotropic architectonic nets of biological tissues of different morphological structure have been investigated. The criteria of early diagnostics of the appearance of degenerative-dystrophic and pathological changes of the structure of biological tissues optically anisotropic architectonics have been determined. Specific features of the formation of local and statistical polarization structures of laser radiation scattered in phase- inhomogeneous layers of biological tissue were studied. The distribution of azimuth and ellipticity of boundary field polarization was found to correlate with the orientation-phase structure of multifractal phase-inhomogeneous layers. A method of polarization phase reconstruction of BT architectonics was suggested. Polarization fractalometry of two-dimensional parameters of Mueller matrixes of biological tissue images is effective in diagnostics of changes of coordinate distributions of orientations and optical anisotropy of their architectonic nets, formed by the collagen bundles. The set of diagnostically urgent properties, determining the interconnection between statistic, correlation and fractal characteristics of 2D Mueller matrixes parameters of biological tissue images and their physiological state has been determined.

8134-26, Poster Session

Study the effect of the symbol time offset (STO) for OFDM in wireless communication systems

S. Mohseni, M. A. Matin, Univ. of Denver (United States)

Orthogonal Frequency Division Multiplexing (OFDM) which is a digital multi-carrier modulation scheme has been accepted by most of the wireless communication systems and has a wide range of applications, i.e. WLAN IEEE 802.11a, Ultra-wideband (UWB), Digital Video Broadcasting (DV) and so on. In OFDM systems three significant synchronization errors can occur, Symbol Time Offset (STO), Sampling Clock Frequency Offset (SCFO), and Carrier Frequency Offset (CFO).

STO can create two problems; phase shift (phase distortion), and Inter Symbol Interference (ISI) which can reduce the performance of OFDM system. By using the STO estimation techniques with using of the synchronizing technique in receiver, the effect of phase shift can be compensated and we can overcome the effect of STO.

In this paper we discuss and investigate the cause of creating STO and its effect for OFDM communication systems. We also talk about a few proposed algorithms for STO estimation technique in literature, and then we propose our STO Estimation algorithm for removing and canceling this phenomenon with showing the simulation result. All the simulations have been done in MATLAB.

8134-27, Poster Session

Extended focal depth and lateral super resolution in optical coherent tomography system

W. Liang, Univ. of Jinan (China); M. Yun, M. Liu, F. Xia, Qingdao Univ. (China)

The resolution of the Optical Coherence Tomography (OCT) system is defined the depth resolution and the lateral resolution of the system. The depth resolution is dependent on the coherence length and the lateral resolution depends on the beam waist on the sample. In OCT, the depth (axial) and the lateral resolutions are independent of one another. Optical axial resolution can thus be increased by selecting a broad band source since the coherence length of the light source is inversely proportional to the bandwidth. The numerical aperture (NA) of the lens that focuses the beam on the sample determines the lateral resolution. Large NA results in a high lateral resolution. However, the depth of focus which is defined by two times of Raleigh range of the focused beam will be decreased. This is a trade-off between lateral resolution and depth of focus.

In this paper, a new kind of polarization pupil mask, which consists of a three-portion half-wave plate between two parallel quarter-wave plates, is introduced into the OCT systems. has the ability to realize the focal shift and extend the focal depth in a small range when used as an apodizer in the optical imaging system. The results show that high focal depth which is two times of the original optical system and the lateral superresolution can be realized at the same time. Furthermore, it is shown that the focal shift strongly depends on the phase of the half-wave plate, and there is a linear relation between of them.
8134-28, Poster Session

A new method for acquiring the complex hologram in optical scanning holography

M. Zhu, E. Dai, L. Liu, A. Yan, J. Sun, Y. Wu, Y. Zhou, Y. Zhi, Shanghai Institute of Optics and Fine Mechanics (China)

In this paper, we propose a new method that can acquire the complex hologram of a 3D object for optical scanning holography (OSH) by using polarized optical elements and a 90 degree 2×4 optical hybrid. The 3D object is scanned by two coaxial beams with orthogonal polarization and the transmitted/ or reflected signal light is divided into two beams by a polarized beamsplitter (PBS). Then these two separated beams pass through a quarter and a half wave plates, respectively, and heterodyne detected by a 90 degree 2×4 optical hybrid with two balanced detectors. The complex hologram, which contains the 3D information of the object, can be constructed from the outputs of the balanced detectors of the optical hybrid. Compared with the conventional OSH, the acousto-optic modulator and complex electronic system are not needed in this method. Another advantage of this method lies in its high efficiency since there is no energy loss in the generation of the scanning beam by using the polarized optical elements. This method should be used for 3D holographic microscopy and 3D holographic television.

8134-29, Poster Session

Study on resampling interpolation algorithms for Fresnel telescope imaging system

X. Lv, L. Liu, A. Yan, J. Sun, B. Li, Shanghai Institute of Optics and Fine Mechanics (China)

Fresnel telecope full-aperture synthesized imaging ladar is a new high resolution active laser imaging technique. It is based on the optoelectronic data collection from the relative scanning between target and two co-centric coaxial beams of orthogonal polarization quadratic wavefronts. Optical receiving system of low quality is allowed to be used to increase optical receiving aperture and decrease laser transmitting power due to the use of an optical hybrid. In the operational mode with moving target by beam scanning, because of the movement of the target, space distribution of the complex data is not regular or uniform. What’s more, if the target is a mesh target or moves in oblique line, the space distribution and the numerical value of sampling data will be more complex.

In order to use FFT in signal processing, the sampling data should be uniform in quadrature space distribution. As a result, algorithms for fresnel telecope imaging system should include resampling interpolation process. We test several resampling interpolation algorithms for Fresnel telecope. Mathematical analysis and computer simulation are also given. The work is found to have substantial practical value and offers significant practical benefit for high resolution imaging of Fresnel telecope laser imaging ladar.

8134-30, Poster Session

The location of laser beam cutting based on the computer vision

Y. Wu, Shanghai Institute of Optics and Fine Mechanics (China); S. Zhu, Shanghai Kasu Intelligent Technology Co., Ltd. (China); Y. Zhi, W. Lu, J. Sun, E. Dai, A. Yan, L. Liu, Shanghai Institute of Optics and Fine Mechanics (China)

Based on the computer vision theory, this article researched the algorithm for the location of laser beam cutting. This article combines Canny operator and thresholding image. It overcomes the inaccuracy of edge detection and clutter jamming problem which are caused by the poor quality of acquired images. Collecting the key points of target edge, making B-spline curves fitting, it solved the problem that target edge is jagged. And it uses interpolation algorithm to locate the point for laser beam cutting. At last, we developed corresponding and professional software system which is based on Visual Studio2003 C#.

8134-31, Poster Session

Sample spectra of optical signals

A. Zhadanov, O. D. Moskaletz, St. Petersburg State Univ. of Aerospace Instrumentation (Russian Federation)

New kind of optical signals spectral processing is considered. This processing is performed as optical radiation sample spectrum analysis. The sample spectrum means analysis on discrete sequence of finite time intervals. These spectra are variable in time and introduced into optical spectral measurements theory for the first time. Presently optical spectral devices operate with the power spectrum. At the same time a detailed examination of optical spectrum analyzing procedures requires the non-traditional theory introduction for optical spectral measurements of complex time-variable spectra. Complex instantaneous and moving optical spectra are known.

Optical range spectral devices that can measure sample spectra are considered as linear systems. That totally corresponds to Fourier integral theory. Comprehensive description of any linear system is its response to a delta effect. Complex spectrum spread function of an optical spectral device that performs sample spectrum analysis is introduced as a response to the delta function. This spectrum spread function allows determining the most important in spectrum measurement theory spectral device input-output ratio and in measurement of complex sample spectra. This ratio is a linear integral operator. The complex spectrum spread function is integral operator kernel.

Complex sample spectrum in optical range can be obtained by using a dispersive system. Examination the single optical pulse distribution in a dispersive medium is the theoretical basis of measurement the complex sample spectrum. Dispersive system is considered to be an optical four-pole network. Transfer function is its comprehensive description. The dispersive system parameters are defined to allow the optical signals complex spectrum measurement. The transition to traditional optical spectroscopy power spectra is considered. These spectra are the time quadratic averaging complex sample spectra result. Transition to the power spectrum includes quadratic photodetection and partial quadratic effects summation.

8134-32, Poster Session

Development of the visual encryption device using higher-order birefringence

H. Kowa, T. Murana, K. Iwami, N. Umeda, Tokyo Univ. of Agriculture and Technology (Japan); M. Tsukiji, Uniopt Co. Ltd. (Japan); A. Takayanagi, Tokyo Univ. of Agriculture and Technology (Japan)

We propose and demonstrate a novel visual encryption device composed of higher-order birefringence elements. When a material which has higher-order birefringence is placed between a pair of polarizers and illuminated with white light to observe it, it appears just white. In contrast, when it is illuminated with monochromatic light, the transmitted intensity varies depending cosinusoidally on the wavelength. Array of such material can express information (e.g. letters and/or images) by controlling birefringence of each pixel. If the birefringence phase difference is adjusted for a certain wavelength, the information will be clearly displayed with a certain wavelength. We call this wavelength a key wavelength. The encryption device was fabricated by controlling the amount of higher-order birefringence so as to give a high contrast only at the key wavelength under polarized illumination. Thus, the information stored in the device can be decoded only by illuminating it with the key wavelength.

To confirm the validity of the encryption principle, we constructed a 3 ×
8134-20, Session 4

Automated segmentation of the dynamic heart tube in OCT images with Snake based on noise model

S. Sun, Clemson Univ. (United States)

To segment the dynamic heart tube in optical coherence tomography (OCT) images is essential for studying heart development. However, it is a great challenge to process the very large 2D, 3D and 4D (3D volumes + time) OCT slices manually. So, segmentation with computer automatically is critical. Due to its noisy feature, as well as the deformable aspect of the object, the heart tube, it is difficult to carry out the segmentation with conventional approach. An active contour model (Snake), in which objects are detected in a given image using techniques of curve evolution, is thought as a good solution to this issue. In this paper, a segmentation algorithm of the dynamic heart tube in OCT images with Snake is explored. Firstly, the noise of the OCT image is analyzed in detail and the mathematic model of the noise is established and tested. Secondly, the image is denoised, the coarse contour of the image is detected and a new convolution kernel for the Snake is proposed, considering the noise characteristic of the OCT image. The performance of the proposed system is compared with the existing ones and the pros and cons are discussed. Finally, a fast algorithm is discussed.

8134-33, Poster Session

A common-path white-light shearing interferometer with adjustable spatial carrier

G. Chen, China Academy of Engineering Physics (China)

No abstract available
8135-01, Session 1

Statistical segmentation and porosity quantification of 3D x-ray micro-tomography
D. M. Ushizima, J. B. Ajo-Franklin, P. Nico, A. A. MacDowell, E. W. Bethel, Lawrence Berkeley National Lab. (United States)

Synchrotron particle accelerators enable the acquisition of high-resolution micro-tomography, allowing imaging of solid materials at micrometer level. Consequently, there is generation of large data files, which undermines the performance of several image processing and segmentation algorithms. We propose a methodology to filter, segment and extract features from stacks of image slices of porous media, using efficient algorithms. A first step is responsible for reducing the image noise through signal-to-noise ratio analysis, so that one can tune scale parameters to the filtering algorithm. Next, a fast anisotropic filter removes ring artifacts from each slice, smoothing homogeneous regions while preserving borders. Later, the image is partitioned using statistical region merging, exploiting the intensity similarities of each segment. At last, we calculate the porosity of the material based on the solid-void ratio. Our contribution is to design a pipeline tailored to deal with large data-files, to use free libraries and to run on high performance computers. We illustrate our methodology using more than 2,000 micro-tomography images from 4 different porous materials imaged using high-resolution x-ray. Also, we compare our results with common, yet fast algorithms often used for image segmentation, which includes median filtering and thresholding. This paper is part of an effort to implement nondestructive techniques to quantify properties in the interior of solid objects, including information on their 3D geometries, which supports modeling of the fluid dynamics into the pore space of the host object.

8135-02, Session 1

Evaluation of the paper surface roughness on real-time using image processing
A. O. Pino, Univ. Politécnica de Catalunya (Spain)

Surface roughness measurement is one of the central measurement problems in paper industry. Measurements require laboratory conditions, but there is a need for measuring the roughness during the production process. At the moment, air leak methods (Bendtsen, Bekk, Sheffield and Parker Print Sun) are standardized and employed as roughness rating methods. We present an experimental approach to measure of the roughness of the paper online based in the analysis of speckle pattern on the surface. The image formed by speckle in the paper surface is considered as a texture, and therefore texture analysis methods are suitable for the characterization of paper surface. The properties of this speckle pattern are used for estimation and quantification of roughness parameter. We applied digital image processing using statistics of second order, specifically the gray level co-occurrence matrix (GLCM), so this method can be considered as non-contact surface profiling method. The results are contrasted to air leak methods (Bendtsen and Bekk).

8135-03, Session 1

Methodology for approximating and implementing fixed-point approximations of cosines for order-16 DCT
A. T. Hinds, InfoPrint Solutions Co. (United States)

No abstract available

8135-04, Session 1

Contactless cardiac pulse measurements during exercise using imaging PPG with motion-artifacts reduction
Y. Sun, S. Hu, V. Azorin-Peris, Loughborough Univ. (United Kingdom); S. E. Greenwald, Barts and The London School of Medicine and Dentistry (United Kingdom); J. Chambers, Loughborough Univ. (United Kingdom); Y. Zhu, Shanghai Jiao Tong Univ. (China)

Compared to the contact photoplethysmographic (PPG) senor, imaging PPG (iPPG) could provide comfortable physiological assessment over a wide range of anatomical locations. However, the characteristic of susceptible to motion artifacts limits the application range of iPPG systems. In this paper, continuous monitoring of the respiratory and pulsatile variation during cycling exercise was taken via an experimental iPPG system with motion artifacts reduction techniques. To evaluate the reliability and sensitivity of the iPPG system and also motion cancellation techniques, two levels of the physical exercise were introduced. A 12 minutes continuous recording was taken from each of 10 volunteers. The time-frequency-representation (TFR) method was used to visualize the time-dependent behavior of the signal frequency. The results show that heart and respiration rates could be successfully traced even under a high-intensity physical exercise. This feasibility study therefore lead to a new insight in accurate clinical assessment and remote sensing of vital signs for sports purpose.

8135-05, Session 1

Page layout analysis and classification in complex scanned documents
M. S. Erkilinc, M. Jaber, E. Saber, Rochester Institute of Technology (United States); P. Bauer, Hewlett-Packard Co. (United States)

In this paper, a classification algorithm is proposed to locate and extract text, image, line and strong-edge regions in color-scanned documents. The algorithm is developed to handle simple to complex page layout structure and content (text only vs. book cover that includes text, lines, graphics and/or photos). Text and image recognition in scanned document is an essential application for document retrieval from digital archives and web sites. The proposed algorithm can also be used for object-oriented rendering in a printing pipeline.

The methodology consists of four modules. The first module employs wavelet analysis to generate a text-region candidate map which is enhanced by applying a Run Length Encoding technique for verification purposes. The image extraction module is based on block-wise segmentation where basis vector projections are used. The basis vectors give an initial map for image/pictorial regions. Moreover, Hough transform is utilized to locate lines in the scanned document. Techniques for edge detection, edge linkages, and line-segment fitting are utilized to detect strong-edges in the last module. After those four region maps are obtained, using a Markov Random Field model in an Iterative Computational Mode framework is employed to generate a final page layout map.
8135-06, Session 1

Gas plume detection algorithms for thermal hyperspectral imagery

E. M. Burdette, L. L. West, S. E. Lane, J. M. Cathcart, Georgia Tech Research Institute (United States)

Remote detection and identification of gaseous plumes is of interest in many areas, including pollution detection, geothermal emissions monitoring, and military target analysis. Spectral gas plume analysis has been enabled by hyperspectral imaging radiometers, leading to the development of numerous plume detection algorithms and data processing techniques. To date such processes have largely been applied to datasets collected during controlled gas releases, where the gas temperature, concentration, and background radiance are known. Using a novel dataset showing gaseous plumes emitted continuously by underground thermal features at Yellowstone National Park, we apply known material identification algorithms to detect the presence of individual gas species in a mixed gas cloud. Prior to applying detection algorithms, we explore data pre-processing variations on image irregularity and off-angle correction. Because the sensor transforms the spectral features of the materials it observes depending on material geometry and location within the scene, among other factors, developing an accurate spectral radiance signature of the gas or gases of interest is a challenging aspect of gas plume identification. We therefore present results from different target modeling and discrimination efforts preceding the intra-scene search for target matches. We demonstrate the successful detection and identification of carbon dioxide gas from a mixture of water vapor, hydrogen sulfide, and carbon dioxide. Thoughts on generalizing our detection methods for application to other uncontrolled gas release scenarios are also presented.

8135-07, Session 1

Estimation of camera matrix in lunar surface using N-views

P. Duraisamy, Univ. of North Texas (United States)

This paper focusses 2D-3D camera pose estimation in lunar surface using craters as features by N-views. The estimation of 2D-3D camera pose in lunar surface is challenging problem due to lack of conventional features like points, lines and corners. We used craters as our feature using generalized hough transform. The pose estimation is implemented by determining extrinsic camera parameters using crater matching between images. We also shown the validity of the approach by experimenting on N-views using crater as features.

8135-08, Session 1

A method of improving structured light scanning point cloud using stereo image processing

R. Shi, L. Zhu, Y. Yu, Beijing Univ. of Civil Engineering and Architecture (China)

Main defect of the structured light scanning is that the edge part is lost in the point clouds of scanned object. This study is to present a method that can remedy the flaw. Many scholars try to combine laser scanning data with digital images. Because there are more detailed textures in the images, and many kinds of algorithms can be used to extract the image edge to improve the laser scanning point cloud. Thereby, the structured light scanning should be more feasible since its images are the original data accessed. This research tried to combine the image processing method to a structured light system in order to improve the quality of the point cloud and the TIN derived. The approach is followed as below: Firstly, a high-precision edge extraction algorithm is used to extract the edge from each image of a pair of stereo image respectively. Exactly, a Positioning Operator is adopted to position the point and edge of the image feature by sub-pixel accuracy. Secondly, based on an Epipolar Constraint, the corresponding image features (point and edge) are determined only from the results of the feature extraction. The 3D coordinates of every pair of points are calculated with the functions of photogrammetry and then, the 3D edge model is built. Thirdly, the 3D edge model is transformed to the unified structured light coordinate system by a coordinate transformation algorithm. After overlying the edge part of the 3D model to the original point cloud from structured light system, their hiatus can be restored and the resolution of the original point cloud can be improved.

8135-09, Session 1

Pattern recognition with composite correlation filters designed from noisy training images

P. M. Aguilar-Gonzalez, V. I. Kober, Ctr. de Investigación Científica y de Educación Superior de Ensenada (Mexico)

Correlation filters for target detection are usually designed under the assumption that the appearance of a target is explicitly known. Because the shape and intensity values of a target are used, correlation filters are highly sensitive to changes in the target appearance in the input scene, such as those of due to rotation or scaling. Composite filter design was introduced to address this problem by accounting for different possibilities for the appearance of the target within the input scene. However, explicit knowledge for each possible appearance is still required. In this work, we propose composite filter design when an object to be recognized is given in noisy training images and its exact shape and intensity values are not explicitly known. Optimal filters with respect to the peak-to-output energy criterion are derived and used to synthesize a single composite filter that can be used for distortion invariant target detection. Parameters required for filter design are estimated with suggested techniques. Computer simulation results obtained with the proposed filters are presented and compared with those of common composite filters.

8135-10, Session 1

Multi-classification of objects in cloudy environments

O. G. Campos Trujillo, V. H. Diaz-Ramirez, F. J. Ramirez Arias, Ctr. de Investigación y Desarrollo de Tecnología Digital (Mexico)

A two-step procedure for the reliable recognition and multiclassification of objects in cloudy environments is presented. The input scene is preprocessed with the help of an iterative algorithm to remove the effects of the cloudy environment followed by a complex correlation filtering for the multiclassification of target objects. The iterative algorithm is based on a local heuristic search inside a moving window using a nonlinear signal model for the input scene that relates the scene-depth and the intrinsic parameters of the environment such as the scattering coefficient, ambient light, and objects reflectance. A main objective of the local search is to estimate the scene-depth inside the moving window that maximizes the local contrast of the restored image inside the window. The preprocessed scene is therefore correlated with a multiclass correlation filter based in complex synthetic discriminant functions. The correlation filter is constrained to yield prespecified magnitude and phase values at the central locations of the training images. The magnitude information in the output complex correlation plane is used for recognition of objects whereas the phase information is employed for the classification of the recognized targets. Computer simulation results obtained with the proposed approach in synthetic and real cloudy images are presented, discussed, and compared with existing similar methods in terms of different performance metrics.
8135-11, Session 1

3D object recognition with integral imaging using neural networks
C. M. Do, Univ. of Connecticut (United States)

An overview of three-dimensional (3D) object recognition using neural networks is presented. Three dimensional sensing and imaging of 3D objects is performed using an integral imaging optical set up. Neural network technique is applied to recognize 3D objects. Experimental results are presented together with computational results for performance assessment.

8135-12, Session 1

LADAR range image interpolation exploiting pulse width expansion
J. W. Motes, R. K. Martin, K. Mathews, Air Force Institute of Technology (United States)

Laser radar (LADAR) systems produce both a range image and an intensity image. When the transmitted LADAR pulse strikes a curved surface, the returned pulse is expanded temporally. This makes it possible to estimate the gradient of a surface, pixel by pixel. This paper seeks to find the gradient of the surface of an object from a realistic LADAR return pulse that includes probabilistic noise models and atmospheric effects. Interpolation techniques applied to the embedded information in the gradient will allow the sampling density to be taken below the Nyquist criterion while still facilitating an effective 3D reconstruction of an image.

8135-73, Session 1

Fast computing of discrete cosine and sine transforms of types VI and VII
R. Chivukula, Y. A. Reznik, Qualcomm Inc. (United States)

Discrete Sine Transform (DST) of type VII has recently been shown to be useful for image and video coding. At the same time, type VII as well as type VI transforms seem escaped attention of researchers working on fast algorithms, and to the best of our knowledge no such algorithms have been published yet. In this paper we derive a family of fast algorithms for discrete cosine and sine transforms (DCT and DST) of types VI and VII by establishing a mapping between these transforms and Discrete Fourier Transform of length 2N+1, where N is the length of the original DCT/DST transforms. We use this mapping to derive complete designs of DST and DCT transforms of lengths N=4, 8, and 16.

8135-13, Session 2

Seam carving for semantic video coding
M. Décobas, Thales Communications S.A. (France) and Telecom ParisTech (France); F. Capman, E. Renan, Thales Communications S.A. (France); F. Dufaux, B. Pesquet-Popescu, Telecom ParisTech (France)

No abstract available

8135-14, Session 2

Mosaic-guided video retargeting for video adaptation
C. Tsai, T. Yen, C. Lin, National Tsing Hua Univ. (Taiwan)

Video retargeting from a full-resolution video to a lower-resolution display will inevitably cause information loss. Content-aware video retargeting techniques have been studied to avoid critical visual information loss while resizing a video. Maintaining the spatio-temporal coherence of a retargeted video is very critical on visual quality. In this paper, we propose the use of a panoramic mosaic to guide the scaling of corresponding regions of video frames in a video shot to ensure good spatio-temporal coherence. In the proposed method, after aligning video frames in a shot to a panoramic mosaic constructed for the shot, a global scaling map for these frames is derived from the panoramic mosaic based on a rate-distortion optimization framework. Subsequently, the local scaling maps of individual frames are derived from the global map and is further refined according to spatial coherence constraints. Our experimental results show that the proposed method can minimize the information loss due to retargeting while maintaining spatio-temporal coherence.

8135-15, Session 2

Dependent video coding using a tree representation of pixel dependencies
G. Valenzise, L. Amati, Politecnico di Milano (Italy); A. Ortega, The Univ. of Southern California (United States); S. Tubaro, Politecnico di Milano (Italy)

Motion-compensated prediction induces a chain of coding dependencies between pixels in video. In principle, an optimal selection of encoding parameters (motion vectors, quantization parameters, coding modes) should take into account the whole temporal horizon of a GOP. However, in practical coding schemes, these choices are made on a frame-by-frame basis, thus with a possible loss of performance. In this paper we describe a tree-based model for pixelwise coding dependencies: each pixel in a frame is the child of a pixel in a previous reference frame. We show that some tree structures are more favorable than others from a rate-distortion perspective, e.g., because they entail a large descendence of pixels which are well predicted from a common ancestor. We favor such structures by adding a special “discount” term to the conventional Lagrangian cost adopted at the encoder. The proposed method has a global impact on the encoder performance, since it affects the choice of: motion vectors; quantization parameters; and coding modes. We modified a state-of-the-art H.264/AVC codec to embed our tree model. Our experiments demonstrate that taking into account the temporal dependencies between pixels can lead to substantial coding gains for sequences with little motion, whereas there is still large room for improvement in sequences with medium-to-high motion.

8135-16, Session 2

Perceived quality of DIBR-based synthesized views
E. Bosc, Institut National des Sciences Appliquées de Rennes (France); R. Pepion, P. Le Callet, Univ. de Nantes (France); M. Koppel, P. Ndjiki-Nya, Fraunhofer-Institut für Nachrichtentechnik Heinrich-Hertz-Institut (Germany); L. Morin, M. Pressigout, Institut National des Sciences Appliquées de Rennes (France)

This paper considers the reliability of usual assessment methods when evaluating virtual view synthesized images in the multi-view video context. Virtual views are generated from Depth Image Based Rendering (DIBR) algorithms. Because DIBR algorithms involve geometric transformations, new types of artifacts come up. The question regards the ability of commonly used methods to deal with such artifacts. This
paper investigates how correlated usual metrics are to human judgment, and in which way they can be used to assess perceived quality of synthesized views. The experiments consist in assessing seven different view synthesis algorithms by subjective and objective methods. Three different 3D video sequences are used in the tests. Resulting virtual synthesized sequences are assessed through objective metrics and subjective protocols. Results show that usual objective metrics can fail assessing synthesized views, in the sense of human judgment.

8135-17, Session 2

Centralized and interactive compression of multiview images

A. Gelman, P. L. Dragotti, Imperial College London (United Kingdom); V. Velisavljevic, Deutsche Telekom AG (Germany)

In this paper, we propose two multiview image compression methods. The basic concept of both schemes is the layer-based representation, in which the captured three-dimensional (3D) scene is approximated by planar depth layers characterized by a constant depth value. The first algorithm is centralized scheme where each layer is de-correlated using a separable multidimensional wavelet transform applied across the viewpoint and spatial dimensions. The transform is modified to efficiently deal with occlusions and disparity variations for different depths. Although the method achieves a high compression rate, the joint encoding approach infers transmission of all data to the users. By contrast, in an interactive setting, the users request only a subset of the captured images, but in an unknown order a priori. We address this scenario in the second algorithm by substituting the viewpoint transform with Distributed Source Coding (DSC) principles so that we exploit the redundant structure of multiview data and still maintain random access capabilities at the image level. We also demonstrate that both proposed compression schemes outperform H.264/MVC and JPEG 2000.

8135-18, Session 2

Intra prediction based on image inpainting methods and perceptual encoder control

P. Ndjiki-Nya, D. Doshkov, H. Kaprykowsky, T. Wiegand, Fraunhofer-Institut für Nachrichtentechnik Heinrich-Hertz-Institut (Germany)

Recent investigations have shown that one of the most beneficial elements for higher compression performance, especially in high-resolution video, is the incorporation of larger block partitioning of slices. In this work, we will address the question of how to integrate perceptual aspects into new video coding schemes based on large block structures. This is rooted in the fact that high frequency texture regions yield high coding costs when using classical prediction modes as well as encoder control based on the mean squared error criterion. To handle this problem, we will investigate the incorporation of novel intra predictors based on image completion methods. Furthermore, the integration of a perceptual-based encoder control using the well-known structural similarity index will be analyzed. A major aspect of this work is the evaluation of the coding results in a quantitative (i.e. statistical analysis of changes in mode decisions) as well as qualitative (i.e. coding efficiency) manner.

8135-19, Session 2

On the use of directional transforms for still image coding

T. Bruylants, A. Munteanu, J. Cornelis, P. Schelkens, Vrije Univ. Brussel (Belgium)

In the recent years, a lot of research was performed on the use of directional transforms for the compression of still imagery, with the main focus on the application of block-based directional adaptive discrete wavelet transforms (B-DA-DWT). Although similar to that of the classic discrete wavelet transforms, this class of transforms provides the extra ability to adapt to the geometric features in an image. Other work proposes a segmentation driven (SD-DA-DWT) approach in order to minimize various artifacts caused by the B-DA-DWT and to improve the overall coding performance. However, as a significant drawback, all of the proposed methodologies suffer from the fact that extra side-information needs to be coded, depending on the type of applied transform. The generated overhead is not negligible and often seems to compensate the original targeted performance gains, while at the same time significantly increasing the complexity of the transform algorithm. Moreover, in combination with rate-distortion driven entropy coding, several types of artifacts appear at lower bit-rates, causing severe degradation of visual performance. This paper describes various considerations and trade-offs that were made during the search towards a practical solution that improves compression performance and visual quality when using directional adaptive transforms in still image coding. Next to a general introduction and overview of technology on directional transforms, it also presents various objective and subjective performance results and comparisons of the respective methodologies.

8135-20, Session 2

Performance analysis of WebP and VP8 based on objective evaluations

F. De Simone, J. Lee, L. Goldmann, T. Ebrahimi, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

Today, several alternatives for compression of digital pictures and video sequences exist to choose from. Beside standard solutions, like JPEG, JPEG 2000, JPEG XR, H.264/AVC-MPEG 4, to mention some examples, open access options like the WebP image compression and the VP8 video compression are currently gaining popularity. In this paper, we present the methodology and the results of the rate-distortion performance analysis of WebP and VP8. The analysis is based on the results of subjective quality assessment experiments, which have been carried out to compare the two algorithms to a set of state of the art image and video compression standards.

8135-21, Session 2

Advances in region-based texture modeling for video compression

F. Zhang, D. R. Bull, Univ. of Bristol (United Kingdom)

This paper will present a region-based video compression algorithm which uses texture segmentation and classification as a basis for efficient coding. Within the framework of a conventional block based codec, our approach exploits both texture warping and dynamic texture synthesis. A perspective motion model is employed to warp static textures and a texture model based approach is used to synthesise dynamic textures. Spatial and temporal artefacts are prevented by a new in-loop video quality metric. The proposed method has been integrated into an H.264 video coding framework with results offering significant bitrate savings (up to 50%) for similar visual quality, across a range of formats and content.

8135-22, Session 3

Predictive video decoding using GME and motion reliability

Y. M. Chen, I. V. Bajic, Simon Fraser Univ. (Canada)

In this paper, we present an improved approach to predictive video decoding based on global and local motion reliability. Global motion
estimation and region segmentation are the fundamentals in our method to
to extract global and local reliability information from received motion
vector (MV) field. This reliability analysis is then utilized to refine MV
field and determine the ordinal depth of all moving regions. A temporal
interpolator is finally applied to compose a future frame. Our results
indicate that the proposed method achieves better visual quality compare
to other state-of-the-art frame prediction approaches, particularly in the
sequences involving moving camera and objects.

8135-23, Session 3

**Effective packetization algorithm of LT codes for stable video streaming over wireless network**

D. Lee, W. Kim, H. Song, Pohang Univ. of Science and Technology (Korea, Republic of)

In this work, we propose an effective And-Or tree based packetization algorithm of Luby Transform (LT) codes to provide stable video streaming services by minimizing the deterioration of video streaming service quality caused by lost packets over error-prone wireless network. To accomplish our goal, the proposed packetization algorithm considers the relationships among encoded symbols of LT codes based on an And-Or tree analysis tool, and then puts these encoded symbols into packets to minimize the packet loss effect during packet transmission and improve the decoding success rate of LT codes by reducing the correlations among packets. We conduct a mathematical analysis to prove performance of our packetization algorithm of LT codes compared with conventional packetization algorithm. Finally, the proposed system is fully implemented in Java and C/C++, and widely tested to show that the proposed packetization algorithm works reasonably well. The experimental results are provided to demonstrate that the proposed packetization algorithm supports more stable video streaming services with higher peak signal-to-noise ratio (PSNR) than the conventional packetization algorithm with various packet loss patterns, including random and burst packet loss patterns.

8135-24, Session 3

**An improved approximate decoding with correlated sources**

M. Kwon, H. Park, Ewha Womans Univ. (Korea, Republic of)

We consider ad hoc sensor network topologies that aim for distributed delivery of correlated multimedia data. In order for efficient data delivery, we deploy network coding technique in conjunction with approximate decoding algorithm. The algorithm can utilize the additional information of correlated source data in the decoding process, thereby leading to significantly improved decoding performance and enhanced robustness for delay-sensitive applications. One of main advantages of the algorithm is to enable receivers to decode the original source data even when the number of received data packets is not sufficient for perfect decoding. Hence, this is the key for delay-sensitive applications such as multimedia delivery. We further enhance the approximate decoding algorithm, such that it can consider the case where the source data have a linearly changing correlation over time. We study the several properties of the proposed algorithm and show what impacts of the source correlation are on the decoding performance. This study is fundamental research with straightforward idea, but essential step to extend the former study and extract properties which enable the theory to have wide application. Our experimental results confirm that the proposed algorithm improves the performance of the approximate decoding.

8135-26, Session 3

**Reinventing multimedia delivery with MPEG’s DASH**

I. Sodagar, H. Pyle, Microsoft Corp. (United States)

A technical overview of MPEG’s DASH standard and examples of how to use standard in applications.

8135-70, Session 3

**The need for an Internet video compression standard**

L. M. Bivolarski, Skype, Inc. (United States); M. Raad, RAADTECH Consulting (Australia)

This paper presents the argument for the development of an Internet video compression standard. The history and science of video compression is reviewed with a focus on identifying how network technology has influenced video compression technology. It is argued that the use of the Internet to deliver video content, an application it was not designed for, and the fact that the Internet is here to stay, calls for a critical look at existing video compression standards. An analysis of the performance of these standards in delivering content over the Internet is provided with an explanation of why these standards have shortcomings in this application domain. Because of this, it is argued, video compression technology for the Internet will need to be different to what is used in other application domains. The paper further presents a discussion on what the technical characteristics of video compression technology would need to be for it to deliver high quality video over the Internet in an interoperable manner, thereby concluding that a new video compression standard is needed.

8135-27, Session 4

**Optimized adaptive HTTP streaming for mobile devices**

H. Kalva, B. Furht, V. Adzic, Florida Atlantic Univ. (United States)

No abstract available

8135-28, Session 4

**Dynamically configurable software architecture for multi-media streaming**

M. Biswas, R. Pinnamaraju, Marvell Semiconductor, Inc. (United States)

No abstract available

8135-29, Session 4

**Color enhancement for portable LCD displays in low-power mode**

H. H. Chen, K. Shih, National Taiwan Univ. (Taiwan)

No abstract available
A novel autostereoscopic display system to provide seamless stereoscopic view changes

C. Kim, Korea Advanced Institute of Science and Technology (Korea, Republic of); H. Lee, W. Cheong, N. Hur, Electronics and Telecommunications Research Institute (Korea, Republic of)

No abstract available

A distributed multi-channel demand-adaptive p2p VoD system with optimized caching and neighbor-selection

H. Zhang, Univ. of California, Berkeley (United States); M. Chen, The Chinese Univ. of Hong Kong (Hong Kong, China); A. Parekh, K. Ramchandran, Univ. of California, Berkeley (United States)

We design an optimized distributed P2P Video-on-Demand (VoD) caching system. The caching nodes are heterogeneous “micro-servers”, e.g., idle PC users, set-top boxes and infrastructure nodes. Given limited storage, bandwidth and number of users they can connect to and serve simultaneously, we aim to optimize video caching on these distributed nodes. Our caching scheme has the following salient features: (1) it optimizes network topology; (2) it achieves provably optimal throughput, and is adaptable to varying supply and demand patterns across multiple video channels irrespective of video popularity; and (3) it is fully distributed and requires little or no maintenance overhead. The combinatorial nature of the network topology building and the system demand for distributed algorithms makes the problem uniquely challenging. By utilizing Lagrangian decomposition and Markov chain approximation based arguments, we address this challenge by designing two distributed algorithms running in tandem: a primal-dual storage and bandwidth allocation algorithm and a “soft-worst-neighbor-checking” topology-building algorithm. Our scheme provably converges to a near-optimal solution, and is easy to implement in practice. Packet-level simulation results show that the proposed scheme achieves minimum server load under highly heterogeneous combinations of supply and demand patterns, and is robust to system dynamics of nodes churn, nodes asynchrony, and random delays in the network.

Perceptual compressive sensing scalability in mobile video

L. M. Bivolarski, Skype, Inc. (United States)

Scalability features embedded within the video sequences allows for streaming over heterogeneous networks to a variety of end devices. Compressive sensing techniques that will allow for lowering the complexity increase the robustness of the video scalability are reviewed. Human visual system models are often used in establishing perceptual metrics that would evaluate quality of video. Combining of perceptual and compressive sensing approach outlined from recent investigations. The performance and the complexity of different scalability techniques are evaluated. Application of perceptual models to evaluation of the quality of compressive sensing scalability is considered in near perceptual lossless coding scheme.

On the visual quality enhancement of super-resolution images

A. H. Yousef, Old Dominion Univ. (United States); Z. Rahman, NASA Langley Research Ctr. (United States); M. A. Karim, Old Dominion Univ. (United States)

Super-resolution (SR) is the process of obtaining a higher resolution image from a set of lower resolution (LR) blurred and noisy images. One may then, envision a scenario where a set of LR images is acquired with a sensor on a moving platform. In such a case, an SR image can be reconstructed in an area of sufficient overlap between the LR images which generally have a relative shift with respect to each other by subpixel amounts. The visual quality of the SR image is affected by many factors such as the optics blur, the inherent signal-to-noise ratio of the system, quantization artifacts, etc. In addition to these factors, for the system described above, the number of scensals (scene elements) i.e., the number of overlapped images used for SR reconstruction within the SR grid and their relative arrangement is a key factor in determining the quality of the SR image. In most cases of microscanning techniques, the subpixel shifts between the LR images are pre-determined; hence the number of the scensals within the SR grid and their relative positions with respect to each other are known and, as a result, can be used in obtaining the reconstructed SR image with high quality. However, in the scenario described in this research, the LR images have relative shifts that are unknown. Even when the correct shifts have been obtained, the arrangement of the LR scene elements does not form a pre-determined grid as required by most micro-scanning algorithms. This random pattern of subpixel shifts can lead to unpleasant visual quality, especially at the edges of the reconstructed SR image. Also, depending on the available number of the LR images and their relative positions, it may be only be possible to produce SR along a single dimension—diagonal, horizontal or vertical, and use interpolation in the orthogonal dimension because there isn’t sufficient information to produce a full 2D image. Thus, in this paper we investigate the impact of the number of overlapped regions and their relative arrangement on the quality of the SR images, and propose a technique that optimally allocates the available LR scensals to the SR grid in order to minimize the expected unpleasant visual artifacts.

An image-set for identifying multiple regions/levels of interest in digital images

M. Jaber, M. S. Bailly, Y. Wang, E. Saber, Rochester Institute of Technology (United States)

In the field of identifying regions of interest (ROI) in digital images, several image-sets are referenced in the literature; the open-source ones mostly present a single main object (usually located at or near the image center as a pop-out). In this paper, we present a comprehensive image-set (with its ground-truth) which will be eventually made publically available. The database includes images that signify multiple-regions-of-interest or multiple-levels-of-interest. The former terminology signifies that the scene has a group of subjects/objects (not necessarily spatially-connected regions) that share the same level of perceptual priority to the human observer while the latter indicates that the scene is complex enough to have primary, secondary, and background objects. Our methodology for developing and conducting a psychophysical experiment employed to generate the proposed image-set is described. The image-set is developed to be used in training and evaluation of ROI detection algorithms. Applications include image compression, thumbnailing, summarization, and mobile phone imagery.
8135-35, Session 5

A channel-based color fusion technique using multispectral images for night vision enhancement

Y. Zheng, Alcorn State Univ. (United States)

A fused image using multispectral images can increase the reliability of interpretation because it combines the complimentary information apparent in multispectral images. While a color image can be easily interpreted by human users (for visual analysis), and thus improves observer performance and reaction times. We propose a fast color fusion method, termed as channel-based color fusion, which is efficient for real time applications. Notice that the term of “color fusion” means combing multispectral images into a color-version image with the purpose of resembling natural scenes. On the other hand, false coloring technique usually has no intention of resembling natural scenery. The framework of channel-based color fusion is as follows, (1) prepare for color fusion, preprocessing (denoising, normalization and enhancement) and image registration; (2) form a color fusion image by properly assigning multispectral images to red, green, and blue channels; (3) fuse multispectral images (gray fusion) using a wavelet-based fusion algorithm; and (4) replace the value component of color fusion in HSV color space with the gray-fusion image, and finally transform back to RGB space. In night vision imaging, there may be two or several bands of images available, for example, visible (RGB), image intensified (II), near infrared (NIR), medium wave infrared (MWIR), long wave infrared (LWIR). In the full paper, we will present the channel-wise color fusions with two-band (e.g., NIR + LWIR, II + LWIR, RGB + LWIR) or three-band (e.g., RGB + NIR + LWIR) multispectral images.

8135-36, Session 5

From index to metric: using differential geometry to define a global visual quality metric

T. Richter, Univ. Stuttgart (Germany)

While traditional image quality metrics like MSE are mathematically well understood and tractable, they are known to correlate weakly to image distortion as observed by human observers. To address this situation, many full reference quality indices have been suggested over the years that correlate better to human perception, one of them being the well-known Structural Similarity Index by Wang and Bovik. However, while these expressions show higher correlations, they are often not very tractable mathematically, and in specific are rarely metrics in the strict mathematical sense. Specifically, the triangle inequality is often not satisfied, which could either be seen as an effect of the human visual system being unable to compare images that are visually too different, or as a defect of the index capturing the global situation correctly. In this article, the latter position is taken, and it is shown how the SSIM can be understood as a local approximation of a global metric, namely the geodesic distance on a manifold. While the metric cannot be computed explicitly in most cases, it is nevertheless shown that in specific cases its expression is identical to Weber's Law of luminance sensitivity of the human eye.

8135-37, Session 5

EEM quantization revisited: asymptotic optimality for variable rate coding

T. Richter, Univ. Stuttgart (Germany)

Equal-Expectation Magnitude Quantization (EEM) aims at minimizing the distortion of a quantizer with defined reconstruction points by shifting the deadzone parameter such that the expectation value of the signal equals the reconstructed value. While intuitively clear, this argument is not sufficient to prove rate-distortion optimality.

In this work, it is show that the EEM quantizer is rate-distortion optimal up to third order in an expansion in powers of the quantization bucket size in the high-bitrate approximation, and the approximating series for the optimal quantizer is computed.

This result is compared to an even simpler quantization strategy based on the Lloyd-Max quantizer which selectively sets coefficients to zero. It is shown that both strategies lead to the same asymptotic expansion for the threshold parameter, but zeroing coefficients provides optimality in one additional order in the quantization bucket size.

8135-38, Session 5

Wavefront aberration function from hard contact lenses obtained with two different techniques

A. S. Cruz Felix, E. Lopez-Olazagasti, J. D. Sánchez-de-la-Llave, G. Ramirez-Zavaleta, E. Tepichín, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico)

The analysis and measurement of the wavefront aberration function are very important tools in the field of visual optics; they are used to understand the performance of the human eye in terms of its optical aberrations. In recent years, we have compared, through two different methods, the wavefront aberration function of a reference refractive surface of 5 mm in diameter and we have demonstrated its equivalence[1]. Now, we want to extend these results to hard contact lenses. These hard contact lenses have been subjected to different laser ablation techniques which are typically used in refractive surgery. Our goal is to characterize the resultant ablation profile. We show our preliminary results obtained for both, a non-ablated hard contact lens and the corresponding ablated samples.


8135-39, Session 5

Improve the image discontinuous problem by using color temperature mapping method

W. Jeng, O. Mang, C. Lai, National Chiao Tung Univ. (Taiwan)

This article mainly focuses on image processing of ring field capsule endoscopy. First, it used the ring field capsule endoscopy (RFCE) to take the images, the sample is a parametric geometric picture, but the images captured by RFCE were blurred due to the RFCE has aberration problems in the image center and lower light uniformity affect the image quality. To solve the problems, image processing can use to improve it. Therefore, the images captured by different time can use Person correlation coefficient algorithm to connect all the images, and using the color temperature mapping way to improve the discontinuous problem in the connection region. After the image processing the Person correlation coefficient is 0.72 higher than the original 0.69 which is without using color temperature mapping.

8135-40, Session 6

On MPEG work towards a standard for visual search

Y. A. Reznik, Qualcomm Inc. (United States)

This paper reviews recent work by MPEG standards committee (ISO/IEC JTC1 SC29 WG11) towards a standard enabling efficient and interoperable design of Visual Search applications. We will explain the scope and requirements for the standard, details of the evaluation framework, and timeline envisioned by the Call for Proposals.
8135-43, Session 6
Compressing a set of CHoG features
V. R. Chandrasekhar, Stanford Univ. (United States); Y. A. Reznik, Qualcomm Inc. (United States); G. Takacs, D. M. Chen, S. S. Tsai, B. Girod, Stanford Univ. (United States)

This paper offers a novel compression scheme based on Digital Search Trees (DST) for compressing an unordered set of CHoG features. The order in which a set of features is transmitted does not matter for computer vision applications as they are typically based on "bag-of-words" matching. Hence, by ordering features, one can potentially gain an additional \( \log_2(m!) \) bits compared to when features are transmitted in the original order. The proposed scheme first builds a DST from a set of features and uses the structure of the DST to define a canonical ordering on the feature set. The subsequent coding scheme results in close to \( -\log_2(m!) \) bits savings as predicted by theory.

8135-44, Session 6
3D face reconstruction from limited images based on differential evolution
Q. Wang, J. Li, Old Dominion Univ. (United States); V. K. Asari, Univ. of Dayton (United States); M. A. Karim, Old Dominion Univ. (United States)

3D face modeling has been one of the greatest challenges for researchers in computer graphics for many years. Various methods have been used to model the shape and texture of faces under desired illumination and pose conditions from a given image. In this paper, we propose a novel method for the 3D face synthesis and reconstruction by using a simple and efficient global optimizer. A 3D-2D matching algorithm which employs the integration of 3D Morphable model (3DMM) and Differential Evolution (DE) is addressed. In 3DMM, the estimation process of fitting shape and texture to 2D images is considered as the problem of approximating global minima in a high dimensional feature space, in which optimization is apt to local convergence. Unlike the traditional scheme used in 3DMM, DE appears to be robust against stagnation in local minimum and sensitiveness to initial value in face reconstruction. Benefiting from DE's successful performance, 3D face models are created based on single 2D image with respect to various illumination and pose context. The preliminary experiment results demonstrate that we are able to automatically create virtual 3D faces from single 2D images with high performance. The validation process showed that there is a small difference between the input images and 2D faces generated by synthesized 3D model.

8135-45, Session 6
Automated crystal detection from microscopic protein crystal images
J. Gubbi, S. Marusic, The Univ. of Melbourne (Australia); M. Parker, St. Vincent's Institute of Medical Research (Australia); M. Palaniswami, The Univ. of Melbourne (Australia)

Synthesis of protein crystals is a critical step in rational drug discovery. Due to advancement in application of robotics in crystal development, there is an urgent need to build systems which can identify protein crystals as they crystalize. Presently, this procedure is performed manually where the user has to go through large number of images in identifying protein crystals. The proposed method is aimed at detecting crystal formation and classifying them to known crystal types from a large dataset of microscopic images. Conventional spatial domain techniques, such as edge detection or morphological operators fail due the significant high spatial frequency noise or texture information, which although largely imperceptible when viewing the original images, poses significant challenges in segmenting only the crystals. The other issue is the presence of non-crystal artifacts and other features (such as water drop edges) which render a number of techniques reported in the literature inconclusive in the correct classification of crystals. A combination of Dual Tree - Complex Wavelet Transform, Hough transform and Support Vector Machines is used in the proposed method. The edge detection is performed within this framework is the Laplacian of Gaussian method. It achieves far better results than edge detection on raw images alone. This method has been applied to individual regions to eliminate non-interesting areas. The most promising results are obtained from low resolution subbands. The results are shown to out-perform the most promising systems reported in literature in terms of detecting crystal formation and in accurate classification of crystals.

8135-46, Session 6
Early forest fire detection using principal component analysis of infrared video
J. A. Saghri, R. F. Radjabi, California Polytechnic State Univ., San Luis Obispo (United States); J. T. Jacobs, Raytheon Co. (United States)

Early detection and mitigation of forest fires can reduce state/national budget deficits, property damage, pollution, and save lives. A novel and promising land-based early forest fire detection scheme is proposed which relies on exploitation of fire plume temporal signature (temporal reflectance variation, or thermal scintillation/frequency). The presence of fire plume signature is detected via application of principal component analysis continuously to stream of IR video images of a fire prone region. Unlike common techniques which rely on measurement and discrimination of fire plume directly from its infrared and/or visible reflectance imagery, this scheme is based on exploitation of fire plume temporal signature, i.e., its reflectance variation/temporal frequency. The method is simple and relatively inexpensive to implement. Land-based infrared (IR) cameras are strategically located in potential fire-prone areas. The sequence of IR video feed from each camera is digitally processed via principal component analysis (PCA) to detect the presence of fire plume temporal signature. Since plume temporal and spatial reflectance values are random and uncorrelated, PCA conveniently captures the plume footprint in the resulting lower-order principal component (PC) images. Preliminary results are promising.

8135-47, Session 6
Semi-automatic ground truth generation for license plate recognition
S. Wang, Industrial Technology Research Institute (Taiwan); H. Lee, Tzu Chi Univ. (Taiwan)

The purpose of ground truth data is to provide an absolute reference to be compared with algorithms' results. However, collecting ground truth data for real-life applications is an important but very disturbing task. This is particularly true for license plate recognition applications because of time-consuming manual. In this paper, we present a method of semi-automatic ground truth generation for license plate recognition in video sequences. The method started from detection of repeated character-line regions to eliminate non-interesting regions followed by a general license plate recognition system to recognize the numbers. Then, we proposed a vehicle leaving detection mechanism to predict vehicle leaving by a license-plate-centric tracking method. The leaving event would be used to reset the voting numbers of the tracked vehicle and to restrict the searching areas of the next input frame. Once the vehicle is out of the camera field of view, the license-plate-centric tracking mechanism is used to detect the timestamps of the vehicle entering. Finally, the ground truth data of the passing vehicle is collected with the three attributes, i.e., the timestamps of entering and leaving and the identity numbers of the vehicle. In our experiments, all frames with the license plate heights ranging from 12 to 40 pixels were captured from an entrance at the North gateway of National Chiao-Tung University, Taiwan. The result shows that the proposed method can achieve low false alarms rate and miss rate.
8135-40, Poster Session

**A study on portable fluorescence imaging system**

H. C. Chang, National Applied Research Labs. (Taiwan)

The fluorescent reaction is that an organism or dye, excited by UV light (200-405 nm), emits a specific frequency of light; the light is usually a visible or near infrared light (405-900 nm). During the UV light irradiation, the photosensitive agent will be induced to start the photochemical reaction. In addition, the fluorescence image can be used for fluorescence diagnosis and photodynamic therapy of skin diseases, which has become a useful tool to provide scientific evidence in many biomedical researches. However, most of the methods on acquiring fluorescence biology traces are still stay in primitive stage, catching by naked eyes and researcher’s subjective judgment. This article presents a portable camera to obtain the fluorescence image and to make up a deficit from observer competence and subjective judgment. Furthermore, the portable camera offers the different exciting light sources (375nm and 395 nm) for user to record fluorescence image and makes the recorded image become persuasive scientific evidence. In addition, when the raising the rate between signal and noise, the signal processing module will not only amplify the fluorescence signal up to 70 %, but also decrease the noise to 50% from environmental light.

8135-41, Poster Session

**Full-field white-light optical coherence tomography of red blood cells**

I. V. Smirnov, E. V. Bogolyubova, A. L. Kalyanov, V. V. Lychagov, V. P. Ryabukho, N.G. Chernyshevsky Saratov State Univ. (Russian Federation); L. I. Malinova, Saratov State Medical Univ. (Russian Federation)

Full-field scanning white light OCT used to human red blood cells investigation. A software package was developed to data visualization and interpretation. An algorithms of computer vision was used. The Full-field white light OCT is based on optical scheme of Linnik interferometer, Stepper motor was used to object movements along the optical axis. We used an incandescent lamp as a light source and a CCD camera without IR filter for interferograms registration. This combination of a source and a detector allowed us to obtain a spatial resolution of about 1 micron.

Developed algorithm of signal processing combines the principles of low-coherence interferometry and full-field tomography, providing a high speed scanning and great accuracy. It is also possible to visualize a profile of the sample surface in three-dimensional mode, as the most intuitive way of presenting the data. The investigation of blood slides from patients with various pathologies was conducted using the developed software. The blood glucose concentration effect on a shape of red blood cells was ascertained. In the paper the radius and shape of the surface of red blood cells of patients with various pathologies were compared. Findings are in good agreement with the results obtained by other methods including cytometry.

8135-48, Poster Session

**Simulations of optical autofocus algorithms based on PGA in SAIL**

N. Xu, L. Liu, Q. Xu, Y. Zhou, J. Sun, Shanghai Institute of Optics and Fine Mechanics (China)

The phase perturbations due to propagation effects can destroy the high resolution imagery of Synthetic Aperture Imaging Ladar (SAIL). Some autofocus algorithms for Synthetic Aperture Radar (SAR) were developed and implemented. Phase Gradient Algorithm (PGA) is a well-known one for its robustness and wide application, and Phase Curvature Algorithm (PCA) as a similar algorithm expands its applied field to strip map mode. In this paper the autofocus algorithms utilized in optical frequency domain are proposed, including optical PGA and PCA respectively implemented in spotlight and strip map mode. Firstly, the mathematical flows of optical PGA and PCA in SAIL are derived. The simulations model of the airborne SAIL is established, and the compensation simulations of the synthetic aperture laser images corrupted by the random errors, linear phase errors and quadratic phase errors are executed. The compensation effect and the cycle index of the simulation are discussed. The simulation results show that both the two optical autofocus algorithms are effective while the optical PGA outperforms the optical PCA, which keeps consistency with the theory.

8135-49, Poster Session

**A hardware implementation of nonlinear correlation filters**

S. Martinez-Díaz, H. Castañeda Giron, Instituto Tecnológico de La Paz (Mexico)

Correlation methods have been used extensively the last few decades for pattern recognition, in images. With the purpose of design robust correlation filters several approaches have been proposed. Recently, nonlinear correlation filters for distortion-invariant pattern recognition were introduced. The filters are designed as a logical combination of binary objects. In this case, pattern recognition is carried out with a space-variant nonlinear operation, called morphological correlation, which is applied among images. In order to obtain invariance to geometrical distortions, the filters are designed including distorted versions of a reference object. These kinds of filters are robust to non Gaussian noise and non-homogeneous illumination. A drawback of nonlinear filters is the high computational cost of the correlation process. On the other hand, the calculation of nonlinear correlation can be parallelized by using specialized hardware. With the intention of reduce processing time, in this paper we propose a parallel coprocessor, implemented on a Field Programmable Gate Array (FPGA). FGPA’s have been used in several applications as an auxiliary processor, which executes the more time consuming tasks. Simulation results of proposed system are provided and discussed.

8135-50, Poster Session

**An image processing method for reducing the impact of external vibration on MEMS IR imaging system**

C. Gong, L. Dong, M. Hui, Y. Zhao, Beijing Institute of Technology (China)

Nowadays, the research of IR imaging system based on a micro-electro-mechanical-system (MEMS) micro-cantilever is becoming a hot field of infrared imaging. However, it is generally acknowledged that the MEMS IR imaging system cannot resist various external vibrations. The paper describes a real-time digital image processing method for reducing the impact of the vibrations and improving the quality of IR images. The method includes two steps which are motion detection and morphological denoising. We have applied it to the MEMS IR imaging system successfully. The method and its processing results are presented in the paper.

8135-51, Poster Session

**Accuracy of image restoration using microscanning image system**

J. L. Lopez-Martinez, V. I. Kober, Ctr. de Investigación Científica y
Various techniques for image recovery from degraded observed images using microscanning image system were proposed. The methods deal with additive, multiplicative interferences, and sensor's noise. Basically, they use several observed images captured with small spatial shifts. In this paper, we analyze the tolerance of restoration methods to small shift errors (subpixel spatial errors) during camera microscanning. Computer simulation results of obtained with the restoration methods using degraded images from an imperfect microscanning system are compared with those of ideal microscanning system in terms of signal restoration criteria.

8135-52, Poster Session
Dense and accurate motion and strain estimation in high-resolution speckle images using an image-adaptive approach
C. Cofaru, W. Philips, W. Van Paepegem, Univ. Gent (Belgium)

Digital image processing methods represent a viable and well acknowledged alternative to strain gauges and interferometric techniques for determining full-field displacements and strains in materials under stress. This paper presents an image adaptive technique for dense motion and strain estimation using high-resolution speckle images that show the analyzed material in its original and deformed states. The algorithm starts by dividing the speckle image showing the original state into irregular cells taking into consideration both spatial and gradient image information present. Subsequently the Newton-Raphson digital image correlation technique is applied to calculate the corresponding motion for each cell. Adaptive spatial regularization in the form of the Geman-McClure robust spatial estimator is employed to increase the spatial consistency of the motion components of a cell with respect to the components of neighbouring cells. To obtain the final strain information, local least-squares fitting using a linear displacement vector field model is performed on the horizontal and vertical displacement fields. To evaluate and validate the presented image partitioning and motion estimation techniques two numerical and two real experiments are employed. The numerical experiments simulate the deformation of a specimen with constant strain across the surface as well as small rigid-body rotations present while real experiments consist specimens that are subjected to uniaxial load. The results indicate very good accuracy of the recovered strains as well as better rotation insensitivity compared to classical techniques.

8135-53, Poster Session
A new planar pattern for camera calibration
X. Liu, D. He, Shenzhen Univ. (China); Y. Yin, Tianjin Univ. (China); C. Zhang, X. Peng, Shenzhen Univ. (China)

In this paper, we proposed a new planar pattern as the calibration target for camera calibration. The pattern consists of ninety-nine circular markers with almost uniform distance but not. In order to calibrate the camera by this planar pattern, we have to know the accurate coordinates of these ninety-nine markers, for which the image process and close-range photogrammetry techniques were employed. Firstly, we took multiple photos of the inaccurate planar pattern from different multi-poses. Then all circular markers in the photos could be detected automatically and the image-coordinates of markers would also be located using image process techniques. Secondly, we detected the homonymous markers from different photos due to the markers’ special topology relation in the pattern. Thirdly, the 3D coordinate of markers with a scale-constraint would be constructed accurately based on close-range photogrammetry technique. And the scale could be achieved from an accurate actual distance between two markers. Finally we multiplied the 3D coordinates of markers computed by photogrammetry by this scale, and obtained the actual 3D coordinates of these markers. With these markers, whose coordinates were corrected, we calibrated a CCD camera and achieved valid results with low re-projection error. The experimental results validated the advantage of this pattern as calibration target, high-precision, low-cost and easy-implementation, which can be widely applied in vision measurement and camera calibration.

8135-54, Poster Session
In vivo full depth of eye-imaging spectral-domain optical coherence tomography
C. Dai, Shanghai Institute of Technology (China)

It is necessary to apply the spectral-domain optical coherence tomography (OCT) to image the whole eye segment for practically iatrical use, but the imaging depth of spectral-domain OCT technique is limited by CCD resolving power. By now, no result about this research has been reported. In our study, a new dual channel dual focus OCT system is adopted to detect the whole eye. The cornea and the crystalline lens are simultaneously imaged by using full range complex spectral-domain OCT in one channel, the retina is detected by the other. The new system was successfully tested in imaging of the volunteer’s eye. The preliminary results presented in this paper demonstrated the feasibility of this approach.

8135-55, Poster Session
An efficient lane marker detection algorithm using Log-polar transform and RANSAC
J. Kim, H. Lim, LED-IT Fusion Technology Research Ctr. (Korea, Republic of); C. Lee, J. Jang, Yeungnam Univ. (Korea, Republic of)

Recently lane detection algorithm is an essential part of the intelligent vehicle systems and has many applications such as driver assistance system (DAS), lane departure warning system (LDWS), lane keeping system (LKS) and so on. This lane detection algorithm has received considerable attention since the 1990’s. However, the lane detection algorithm has especially the hard problems, for examples, parked and moving vehicles, bad quality lines, shadows cast from trees, buildings and irregular/strange lane shape, emerging and merging lanes, sun glare, writings and other markings on the road (e.g. pedestrian crosswalks).

We develop an efficient lane markers detection algorithm based on the log-polar transform and the random sample consensus (RANSAC) algorithm. To extract the optimal lane marker points, we set firstly the regions of interest (ROIs) with variable block size and perform the preprocessing steps which are smoothing filtering and the adaptive thresholding within ROIs. Then the lane markers are extracted by using a Canny edge operator. From the extracted lane markers, the end points of lane marker are selected to fit a segment of straight or curve lane for each ROI. To fit the lane model, we adopt the general road model which is the parabola model, these points are transformed to the log-polar space. The straight lane and curve lane can be classified at the log-polar space easily. Finally, we use the RANSAC to detect the exact lane markers of road. The experiments are performed on our database that has many different conditions including various weather and road.

8135-56, Poster Session
Segmentation and classifying of synapses in microscopic images
S. Yona, A. Katsman, D. Gitler, Y. Yitzhaky, Ben-Gurion Univ. of the Negev (Israel)

One of the parameters which determine the characteristics of synapses is the number of vesicles and their spatial spread. These vesicles can be marked fluorescently and be identified through optical instruments.
The purpose of this work is to classify and quantify synapses and their properties in the cultures of a mouse’s hippocampus, from images acquired by a microscope. Quantification features include the number of synapses, their intensity and their size characteristics.

The images obtained by the microscope contain hundreds to several thousands of synapses with various elliptic-like shape features and intensities. These images also include other features such as glia cells and other biological objects beyond the focus plane. Those features reduce the visibility of the synapses and interrupt the segmentation process.

The proposed method performs first a background subtraction. Then, suspected centers of synapses are identified as local maxima points, and the tendency of identified bell-like objects to be synapses is evaluated according to their intensity properties. Next bulks of synapses are distinguished from single synapses and finally, the borders of each identified synapse and bulk are detected.

Delimiting the borders of the synapses is important in order to determine the amount of vesicles in the whole synapse and not just in its center. As for the detection of the centers of the synapses, results indicate a better performance of the proposed algorithm over previous iterative methods, when measuring rates of true positive (centers of synapse that were identified) and false positive (objects that were falsely identified as centers).

A method for improved localization of edges in multi/hyperspectral imagery

S. R. Vantaram, E. Saber, Rochester Institute of Technology (United States)

Detection of edges has been a long standing low-level visual processing problem especially in the image understanding and analysis realm. Gradient (scalar or vector) computation finds an important place in various image processing and computer vision tasks such as object detection, recognition and feature extraction, to name a few. Acquisition of functional/useful gradient maps from remotely sensed data for applications such as segmentation, classification, anomaly and change detection etc., to name a few, has often proven to be an extremely challenging task. In this paper, we propose an enhanced vector field gradient estimation approach for remote sensing imagery. Our work is based on the principle that adjusting the partial derivatives of individual channels of a multi-band image to only comprise of contributions towards their associated local scalar gradient maxima using a non-maximal suppression scheme, before being employed in a vector field approach for gradient computation, can yield highly localized responses in the eventual gradient map. More specifically, the novelty of the proposed algorithm lies in the fact that it leverages the advantages of non-maximal suppression to enhance the results arising from a vector field gradient approach, as opposed to its conventional use for enhancing the outcomes obtained from a gradient calculation of a scalar field (single band image). The proposed algorithm was tested on several multispectral and hyperspectral image datasets with favorable results.

Enhancement of the accuracy of the astronomical measurements carried on the wide-field astronomical image data

M. Rerábek, P. Páta, Czech Technical Univ. in Prague (Czech Republic)

Accuracy of the astronomical measurements is more than important with respect to astronomical image data evaluation. This measurement precision decreases due to optical aberrations which are present in each real optical system. Especially the wide-field systems contain a lot of different kinds of high order optical aberrations which have negative impact to the image quality and imaging system transfer characteristics. Therefore, for precise astronomical measurement (astrometry, photometry) over the entire field of view, it is very important to comprehend how the optical aberrations affect the transfer characteristics of optical system. There are the relations between amount of high order optical aberrations and astrometry measurement precision discussed in this paper. This contribution also describes two experiments used to improve the accuracy of the astrometry. First one focuses on the using of point spread function (PSF) model in known deconvolution algorithms. The principal difficulty is that these systems are space variant and it means that Fourier approaches can no longer be used for restorations of original image. Deconvolution algorithm and partially invariant model of optical system, which allows us to use Fourier appliance will be presented. The second approach how to improve the astronomical measurements is to use novel detection algorithm using PSF model which is based on the aberrations modelling.

A novel dimming algorithm using local boosting algorithm for LED backlight system in LCD TVs

J. Lee, J. Kim, H. Lim, LED-IT Fusion Technology Research Ctr. (Korea, Republic of); K. Seong, J. Jang, Yeungnam Univ. (Korea, Republic of)

Since the conventional LCD TVs have the high light leakage of liquid crystals, it is difficult to realize the real black color. And it brings about a low contrast ratio. To reduce the light leakage and increase the contrast ratio, the backlight dimming technology has been developed.

We decide the brightness of input image using classification method which uses the max level and the average level. And then we apply the proposed local dimming boost algorithm for the optimal local dimming method. We make use of different pixel intensity bands and the original image has to classify whether a dark image or a bright image. The proposed dimming algorithm divided into two methods that the max level and the average level. And then we increased contrast ratio of gray image by 30% for classify gray level of image correct. In an experiment increases about 30% of the contrast ratio makes optimal image of dimming data generation. After aforementioned process, we make use of average level data or max level data and generated first dimming data. Since the aforementioned backlight-dimming algorithm totally reduces image brightness, the following local dimming boosting algorithm is proposed to improve image contrast ratio and reduce power consumption. To solve the drawbacks of above-mentioned conventional dimming methods, we propose the boosting algorithm for the optimal local dimming method.

The experimental results show that the proposed algorithm has higher contrast ratio and lower power consumption than the conventional methods.

Photoacoustic laser Doppler velocimetry using the self-mixing effect of RF-excited CO2 laser

J. Choi, Honam Univ. (Korea, Republic of)

A LDV with simple structure, in which the feedback of scattered light was used, was constituted and evaluated in order to measure the rotation speed of a body of revolution by using the CO2 laser. Some part of the scattered light occurring when laser light was projected on a moving object was projected into a laser resonator, so that it may create a self-mixing with eigen optical frequency. The self-mixing of the light was altered into the doppler-shifted frequency due to the subtle pressure change in the resonator caused by the photoacoustic effect. The altered frequency is in proportion to the rotation speed of the rotating body,
it was possible to measure the speed of the object by observing the frequency caused by the pressure occurring inside the laser resonator. And it was found out that the measured value of doppler-shifted frequency, which was carried out changing the speed of the object and the incident angle of laser light to the object, was in accordance with the established theory. There was 5% of error between the established theoretical values and the actually measured values when the wavelength of the laser was 10.59

8135-61, Poster Session

Uniformly spaced 3D modeling of human face from two images using parallel particle swarm optimization

Y. Chang, Y. Tsao, Chang Gung Univ. (Taiwan); S. Lee, Chang Gung Memorial Hospital (Taiwan)

Three dimensional numerical modeling of human face has many potential applications, such as virtual reality, animation, visual surveillance, and face recognition. While many commercial optical systems are available for 3D human face surface data reconstruction, the systems normally use more than two cameras. This requirement is due to the difficulty of searching corresponding locations on images captured from different viewpoints especially when the cameras are located far apart from each other. This work proposes a scheme for finding the correspondence between uniformly spaced locations on one of the images using only two cameras. The approach utilizes structured light to enhance patterns on the images and is initialized with the scale-invariant feature transform (SIFT). Successive locations are found in order by searching for the best match of transformed patches using a parallel version of the particle swarm optimization (PSO) algorithm. The algorithm is modified such that consistent results are obtained in a restricted period of time. In the algorithm, each swarm is assigned with different parameters realizing diverse search behaviors. Parallelism is achieved by sharing a pre-determined number of particles with higher cost values between the swarms through a buffer, called the common pool. Furthermore, false locations of the resultant 3D data are singled out for correction by searching for outliers from fitted curves. Case studies show that the scheme is able to correctly generate 456 evenly spaced 3D coordinate points in 23 seconds from a single shot of projected human face using a PC with 2.66GHz Intel Q9400 CPU and 4GB RAM.

8135-62, Poster Session

Face recognition using spectral and spatial information

S. A. Robila, M. Chang-Reyna, Montclair State Univ. (United States); N. D’Amico, Univ. of Maryland, College Park (United States)

Accurate individual identification is an essential part of any authentication protocol. Often, such identification is done using biometrics. Among biometrics, face recognition provides an unobtrusive and if needed discrete method of classifying individuals, a task that has become increasingly important in many fields swamped by deluge of data available (but lack of human analysts) such as surveillance, law enforcement, and access control. Spectral imaging, i.e. images collected over hundreds of narrow contiguous light spectrum intervals constitute a natural choice for expanding face recognition image fusion, especially since it may provide information beyond the normal visible range, thus exceeding the normal human sensing. While face recognition from grayscale or color images has seen a considerable research effort, little work is being done to investigate the use of spectral imaging for this problem. Our work is geared at designing an efficient method for facial recognition by using hyperspectral imaging. In previous work we have separately investigated the use of spectra matching and image based matching. In spectra matching, individual face spectra are being classified based on spectral similarities. In image based matching, we investigated various approaches based on orthogonal subspaces (such as PCA and OSP). In the current work we provide an automated unsupervised method for face recognition that starts by detecting the face in the image and then proceeds to perform both spectral and image based matching. The results are then fused in a single classification decision. The algorithm is tested on an experimental hyperspectral image database of 17 subjects each with four different facial expressions and viewing angles. Our results show that the decision fusion leads to improvement of recognition accuracy when compared to the individual approaches as well as to recognition based on regular imaging. The work expands on previous band extraction results and has the distinct advantage of being one of the first that combines spatial information (i.e. face characteristics) with spectral information. In addition, the techniques are general enough to accommodate differences in skin spectra.

8135-63, Poster Session

Optimized retinal nerve fiber layer segmentation based on optical reflectivity and phase retardation for polarization-sensitive optical coherence tomography

B. Wang, A. S. Paranjape, T. E. Milner, H. G. Rylander III, The Univ. of Texas at Austin (United States)

Segmentation of retinal nerve fiber layer (RNFL) from swept source polarization-sensitive optical coherence tomography (SS-PSOCT) images is fundamental to determine RNFL thickness and calculate birefringence. Traditional RNFL segmentation methods based on image processing and boundary detection algorithms utilize only optical reflectivity contrast information, which is strongly affected by speckle noise. We propose a fully automated RNFL segmentation method based on both optical reflectivity and phase retardation in RNFL to achieve optimized RNFL segmentation. The upper boundary of the RNFL is relatively easy to detect since the transition from the vitreous to the inner limiting membrane is abrupt and is characterized by high contrast due to the difference in refractive index. The lower boundary of the RNFL is a transition zone from the birefringent axons of the retinal ganglion cells to the cell bodies themselves. This transition is best detected anatomically by the change in birefringence at the lower boundary of the RNFL. Simple filtering followed by edge detection techniques is applied to SS-PSOCT clustered scan images to estimate preliminary RNFL segmentation. Three incident polarization states and Levenberg-Marquardt nonlinear fitting of normalized Stokes vectors on Poincaré sphere allow determination of phase retardation from the preliminary segmentation based solely on optical reflectivity contrast. Optimized RNFL segmentation is then achieved by moving the lower boundary of preliminary RNFL segmentation and searching for the local minimum of Levenberg-Marquardt fitting uncertainty. This method finds optimized RNFL segmentation with lowest achievable fitting uncertainty and optimizes the phase retardation measurement. Clinical results from a healthy volunteer illustrate that the proposed segmentation method estimates phase retardation in RNFL with lower uncertainty than traditional approaches.

8135-64, Poster Session

Meteor automatic imager and analyzer: current status and preprocessing of image data

K. Fliegel, P. Páta, S. Vítek, Czech Technical Univ. in Prague (Czech Republic); P. Koten, Astronomical Institute of the ASCR, v.v.i. (Czech Republic)

In this paper we present current progress in development of new observational instruments for the double station video experiment called MAIA (Meteor Automatic Imager and Analyzer). The main goal of the MAIA project is to monitor activity of the meteor showers and sporadic
Conference 8135:
Applications of Digital Image Processing XXXIV

meteor each night for the period of at least 3 years. The system is based on the two stations with the gigabyte Ethernet cameras, sensitive image intensifiers and automatic processing of the recorded data. Electro-optical characteristics of the system were previously measured in the laboratory and the result confirmed our expectations according to image quality and resolution. Recently first night sky observation was carried. This paper presents further analysis of imaging parameters based on acquisition of testing video sequences in real environment at different light conditions. Among the most important characteristics belong the noise model, PSF, conversion function, flat-field and dark frame. Based on these results, preprocessing algorithms are developed and tested to get the best possible image data for astronomical analysis from the double station system.

8135-65, Poster Session

Open source database of images DEIMOS: stereoscopic images
K. Fliegel, S. Vitěk, M. Klima, P. Páta, Czech Technical Univ. in Prague (Czech Republic)

In this paper we present current progress in the project DEIMOS (Database of Images: Open Source). The DEIMOS database is created as an open-source database of images and videos for testing, verification and comparing of various image and/or video processing techniques. This paper is focused on description of new stereoscopic content available in the database. This database of stereoscopic images with various parameters in acquisition and image processing is intended for testing and optimization of metrics for objective image quality assessment. There are many similar databases for 2D content but the number of available databases is still very limited in the case of stereoscopy. Our database is annotated with mean opinion scores of perceived image quality from human observers for each testing condition and also contains eye tracking data captured in subjective experiment. Dependence of perceived image quality on particular testing condition is quantified and discussed.

8135-66, Poster Session

Roadmap for biometric facial recognition with correlation filters
S. Pinto-Fernandez, V. H. Díaz-Ramirez, Ctr. de Investigación y Desarrollo de Tecnología Digital (Mexico)

Facial recognition has become a very important tool for authentication of individuals in many critical applications such as security surveillance in airports and border crossing. Pattern recognition with correlation filter has been very popular in last decades because it has a good mathematical basis, and can be implemented in digital programmable systems and in hybrid opto-digital processors at high rate. In this paper we present a comparison performance between different facial recognition algorithms considering principally correlation based methods. We present several computer simulations results obtained with the considered algorithms and we compare their performance in terms of recognition and classification ability, tolerance to input scene distortions, and computational complexity.

8135-67, Poster Session

A mathematical morphology-based approach for vehicle detection in road tunnels
A. Friaas-Velázquez, J. O. Niño-Castaneda, V. Jela#269;a, A. P?urica, W. Philips, Univ. Gent (Belgium)

A novel approach to automatically detect vehicles in road tunnels is presented in this paper. Non-uniform and poor illumination conditions prevail in road tunnels making difficult to achieve robust vehicle detection with either standard object or motion detectors. Apart of the tunnel lighting, other important sources of illumination are the head and rear lights of the vehicles, which may drastically change the scene conditions, and thus the appearance of the vehicles. Also, shadows and reflections are an issue, since they cause a considerable number of false detections.

The proposed vehicle identification approach consists of the following steps: image pre-processing, morphological background subtraction, clustering, and object validation. In order to cope with the illumination issues, we propose a local higher-order statistic filter to make the detection invariant to illumination changes and pass the image into a high-pass domain. A background model of the tunnel is generated in this new domain, and a morphological-based background subtraction is then applied. The outcome of this last step are parts of vehicles detected, which are clustered by using information like centroid coordinates, area, and lane position. The vehicle’s boundaries are approximated by getting the convex hull of the clustered segments. Finally, a vehicle validation test is run to discard false detections.

An evaluation test comparing our approach with a benchmark object detector has been conducted. The results show that our approach outperforms the benchmark object detector in terms of false detection rate and the overlapping area between convex hull and the ground truth segmentation of the vehicles.

8135-68, Poster Session

Swimming behavior detection for nitocra spinipes in water quality evaluation
Z. Jia, Henan Polytechnic Univ. (China)

The Environmental Protection Agency has over the years suggested a number of biological tests for characterization of industrial waste water, among which a test with the brackish water crustacean Nitocra spinipes can be found. It is of substantial interest to design a low-cost early warning test apparatus for brackish water. The principle of a test is to monitor the swimming behaviour of Nitocra spinipes by the use of digitized video films in daylight or indoor illumination. In our study, grown animals are of a size between 0.6 to 0.8 mm, and it is empirically known that their swimming behaviour is affected by the amount of toxic substances in the water. The first processing step is to manually mark the position of each animal on a starting image, then find out the image difference between starting image and the image in the sequence, finally find out locations of animals on the new image. The processing result is satisfactory.

8135-69, Poster Session

Combining C_Mean clustering and LBP for outdoor face images
Z. Jia, W. Wang, Henan Polytechnic Univ. (China)

For facial recognition, a number of algorithms have been tested on standard databases in internet (e.g. ORL and YALE: indoor images), the facial recognition accuracy (rate) is over 90%. In the same way, the algorithms are tested on OculusAI database or Celebrity database (outdoor images), the recognition rate drastically decreases. Comparing Celebrity database with standard database such as ORL and YALE, it is distinctly manifest that the Celebrity database is more variable in facial rotating angle as well as ornaments such as hat, ring, and earrings etc., which make the images more complicated. To increase the accuracy of facial recognition, a new algorithm is studied by combining C_Mean clustering algorithm and LBP algorithm, the developed new algorithm can increase facial recognition accuracy greatly in OculusAI database, and the testing results are satisfactory.
Tree structure matching pursuit based on Gaussian scale mixtures model

P. Liu, D. Liu, Z. Liu, J. Wei, Ctr. for Earth Observation and Digital Earth (China)

Compressed Sensing (CS) theory has gained so much attention recently in the areas of signal processing. In Compressed Sensing (CS) theory, the most important prior is the sparsity of the transform coefficients. The sparsity and the sample measurements decide how well the signal can be accurately reconstructed. However, except for the sparsity, there are other important priors about transform coefficients such as the tree structure and the statistical dependencies that could be employed in CS reconstruction. The tree structure of the coefficients has been employed in such method as model based CS and the statistical dependency of the coefficients is employed in such method as Bayesian based CS. In fact, the two priors about the transform coefficients can be combined into Matching Pursuit method to acquire better result in CS image construction.

In this paper, we propose to introduce the Gaussian Scale Mixtures (GSM) model into the tree structure based Orthogonal Matching Pursuit (TSOMP) reconstruction algorithm. The tree structure based Orthogonal Matching Pursuit method selects a group of tree nodes in the greedy algorithm based reconstruction. But the tree structure is often badly influence by the noise in the iteration and the errors produced by the greedy search algorithm. Then the statistical dependencies of the coefficients are used to increase the stability in searching the tree structure subspace. This enhances the clustering feature of the transform coefficients. In every iteration, firstly, the tree structure is searched by greedy algorithm and the intra-scale dependences of the coefficients is made use of; secondly, the GSM smoothing is employed to regularize the tree structure of the transform coefficients, this GSM model is the priors of the inter-scale dependences of the coefficients, and it will reduce the noise corrupting to image details; then thirdly, a image reconstruction is preformed by solving of a linear equation; at last, instead of directly using the magnitudes of the wavelet coefficients obtained in the previous searching, the estimated wavelet coefficients by the GSM model are used to construct the new tree structure subspace for the next iteration. In the proposed method, the statistical feature priors form the inter-scale dependences of the coefficients and the tree structure priors from intra-scale dependences of the coefficients are combined to improve the accuracy of the Orthogonal Matching Pursuit algorithm, and then the noise and instability in compressed sensing reconstruction are well reduced.

Experiments were performed to compare the proposed method with some existing state-of-the-art CS recovery algorithms such as Orthogonal Matching Pursuit, Bayesian Compressive Sensing and the Tree-Structured Wavelet Compressive Sensing. We also compare these methods under the different level of noise situation. Experimental results show that the proposed method improves reconstruction accuracy for a given number of measurements and more image details are recovered.
Noise tolerant dendritic lattice associative memories
G. X. Ritter, M. S. Schmalz, E. T. Hayden, Univ. of Florida (United States)

Linear classifiers based on the real numbers with addition and multiplication feature prominently in the literature pattern recognition. Another approach to the construction of pattern classification operators involves the use of the extended real numbers (the reals with positive and negative infinity) together with addition, maximum, and minimum operations. These lattice-algebra based pattern classifiers have been shown to exhibit superior information storage capacity, fast training and convergence, high pattern classification accuracy, and low computational cost. Such attributes are not generally found, for example, in classical neural nets based on the linear inner product. In a special type of lattice associative memory (LAM), called a dendritic LAM or DLAM, by varying the design of noise or error acceptance bounds, it is possible to achieve noise-tolerant pattern classification.

This paper presents theory and algorithmic approaches for the computation of noise-tolerant lattice associative memories (LAMs) under a variety of input constraints. Of particular interest are the classification of nonergodic data in noise regimes with time-varying statistics. DLAMs have successfully been applied to pattern classification from hyperspectral remote sensing data, as well as spatial object recognition from digital imagery. The authors’ recent research in the development of DLAMs is overviewed, with experimental results that show utility for a wide variety of pattern classification applications. Performance results are presented in terms of measured computational cost, noise tolerance, classification accuracy, and throughput for a variety of input data statistics and noise levels.

Algorithms for adaptive nonlinear pattern recognition
M. S. Schmalz, G. X. Ritter, E. T. Hayden, Univ. of Florida (United States); G. Key, Frontier Technology, Inc. (United States)

In Bayesian pattern recognition research, static classifiers have featured prominently in the literature. A static classifier is essentially based on a static model of input statistics, thereby assuming input ergodicity that is not realistic in practice. Classical Bayesian approaches attempt to circumvent the limitations of static classifiers, which can include brittleness and narrow coverage, by training extensively on a data set that is assumed to cover more than the subtext of expected input. Such assumptions are not realistic for more complex pattern classification tasks, for example, object detection using pattern classification applied to the output of computer vision filters. In contrast, with a two-step process, it is possible to render the majority of static classifiers adaptive such that the tracking of input nonergodicities is supported. Firstly, one develops operations that dynamically insert (or resp. delete) training patterns into (resp. from) the classifier’s pattern database, without requiring that the classifier’s internal representation of its training database be recomputed. Secondly, one develops and applies a pattern replacement algorithm designed to optimize the pattern database for a given set of performance measures.

This paper presents theory and algorithmic approaches for the efficient computation of adaptive linear and nonlinear pattern recognition operators, in particular, tabular nearest-neighbor encoding (TNE), classical neural nets and lattice associative memories (LAMs). Of particular interest are the classification of highly nonergodic data in noise regimes with time-varying statistics. The TNE paradigm, as well as lattice neural networks (LNNs) and dendritic LAMs discussed herein, have been successfully applied to the computation of object classification in hyperspectral remote sensing and target recognition applications. The authors’ recent research in the development of adaptive LAMs, LNNs, and DLAMs is overviewed, with experimental results that show utility for a wide variety of pattern classification applications. Performance results are presented in terms of measured computational cost, noise tolerance, classification accuracy, and throughput for a variety of input data statistics and noise levels.

Massively parallel computation of lattice associative memory classifiers
M. S. Schmalz, G. X. Ritter, E. T. Hayden, W. H. Chapman, Univ. of Florida (United States)

Over the past 25 years, concepts and theory derived from neural networks (NNs) have featured prominently in the literature of pattern recognition. Classical NNs based on the linear inner product offer challenges based on the use of multiplication and addition operations. In contrast, NNs having nonlinear kernels based on Lattice Associative Memories (LAM) theory tend to concentrate their work primarily in addition and maximum/minimum operations. The emergence of LAM-based NNs, with their superior information storage capacity, fast convergence and training due to relatively lower computational cost, are well as noise-tolerant classification has extended the capabilities of neural networks far beyond the limited applications potential of classical NNs.

This paper explores theory and algorithmic approaches for the efficient computation of LAM-based neural networks, in particular lattice neural nets and dendritic lattice associative memories. Of particular interest are massively parallel architectures such as graphics processing units (GPUs). Originally developed for video gaming applications, GPUs hold the promise of very high computational throughput (e.g., over a teraflop peak throughput for an Nvidia Fermi processor) without compromising numerical accuracy (e.g., the Fermi GPU supports double precision arithmetic). Unfortunately, currently-available GPU architectures feature a limited memory hierarchy that can produce unacceptably high data movement latencies for relatively simple operations, unless careful design of theory and algorithms is employed. Advantageously, the Fermi GPU is optimized for efficient computation of joint multiply and add operations. As a result, the linear or nonlinear inner product structures of NNs are inherently suitable to the Fermi’s (and other GPU’s) computational capabilities. The authors’ recent research in quantification of GPU performance for inner-product operations is overviewed, with experimental results that show utility for a wide variety of pattern classification applications using classical NNs or lattice-based NNs. Performance results are presented in terms of measured throughput for a variety of data burdens and partitioning approaches.

Fractal based watermarking of color images
L. McLaughlin, Texas A&M Univ.-Kingsville (United States); M. Mehruhooglu, Texas A&M Univ. Corpus Christi (United States)

Digital watermarking continues to be an open area of research. In this work, fractals are employed to spatially embed the watermark(s) in the RGB domain. The watermarks are tested separately in each of the three
planes R, G, and B. A blind detection scheme is utilized in which the only information required for detection are the fractal(s) used for embedding. Next, combinations of embedding in the RG, RB, GB, and RGB planes are used. The efficacy of the embedding combinations in the various planes are studied to determine the best combinations for the tested fractals, images and attacks. The results are compared with previously published methods by the authors.

8136-05, Session 2

The optimum discrete scan-type approximation of low-pass type signals bounded by a measure like Kullback-Leibler divergence

Y. Kida, Ohu Univ. (Japan); T. Kida, Tokyo Institute of Technology (Japan)

We present a running approximation of discrete signals by a FIR filter bank that minimizes various worst-case measures of error, simultaneously.

We assume that the discrete signal is a sampled version of unknown original band-limited signal that has a main lobe and small side-lobes. The output signal of the filter bank is a final approximation signal.

The output signal is generated from its discrete sample values based on the Shannon sampling theorem. But, it uses an infinite number of sample values.

Hence, we use a finite number of sample values, we cannot avoid error of approximation.

On the other hand, the running approximation by a multi-dimensional FIR filter bank using shift-invariant interpolation filters is increasing its importance in modern multi-dimensional signal processing.

The original multi-dimensional band-limited signal can be reconstructed from its discrete sample values based on the Shannon sampling theorem. But, it uses an infinite number of sample values.

Hence, we use a finite number of sample values, we cannot avoid error of approximation.

In this discussion, we explain briefly a new concept of multi-legged-type signals made by scan-type approximation.

Firstly, we show interpolation functions that have an extended bandwidth and satisfy condition called discrete orthogonality.

Secondly, we present a set of signals and a running approximation satisfying all of these conditions of the optimum approximation.

8136-06, Session 2

Extension of the concept of multi-legged-type signals to the optimum multi-dimensional running approximation of multi-dimensional band-limited signals

Y. Kida, Ohu Univ. (Japan); T. Kida, Tokyo Institute of Technology (Japan)

The original multi-dimensional band-limited signal can be reconstructed from its discrete sample values based on the Shannon sampling theorem. But, it uses an infinite number of sample values.

Hence, we use a finite number of sample values, we cannot avoid error of approximation.

On the other hand, the running approximation by a multi-dimensional FIR filter bank using shift-invariant interpolation filters is increasing its importance in modern multi-dimensional signal processing.

Hence, the minimization of running approximation errors in a FIR multi-dimensional filter bank for multi-dimensional band-limited signals is the important problem of multi-dimensional signal processing.

In this discussion, we explain briefly a new concept of multi-legged-type signals that are combined signals of many one-dimensional band-limited signals, each body segment of which constitutes a set of small separable domains made by scan-type approximation.

Then, we extend this concept to multi-dimensional hyper signal space and, based on this concept, we propose an approximation method of the extended multi-dimensional multi-legged-type signals and we prove that the presented approximation is the optimum.

Then, introducing a measure of error that becomes quite large for errors caused by the running approximation and becomes small otherwise, we present extended optimum approximation that minimizes various worst-case measures of approximation error at the same time.

Application of multiple-input multiple-output space division multiplexing system is discussed. Some examples are given.

8136-11, Session 2

Limited-photon 3D image recognition using photon-counting integral imaging

C. M. Do, Univ. of Connecticut (United States)

An overview of three-dimensional (3D) image recognition using photon-counting integral imaging is presented. A Poisson distribution model is used to generate photon-counting elemental images and reconstruct 3D images. Slices of 3D reconstructed images are the image source for recognition purpose. Experimental and computational results are shown to evaluate the performance of the method.

8136-08, Session 3

Aligning images with CAD models via quaternion optimization

P. F. Stiller, Texas A&M Univ (United States)

This paper introduces an algorithm for “mapping” information in a 2D image onto a 3D CAD model of an object. For example, imagine an image of an object taken at a remote location. The object has some surface damage requiring the fabrication of a patch. The photo of the damaged area is transmitted back to the facility that will design and fabricate the patch. The goal is to align the image with a CAD model of the original object, so that the exact location of the damage can be determined and precisely the correct patch manufactured. We assume that the user is able to identify a minimum of 4 feature points in the image and the corresponding feature points on the CAD model. Beyond that, we assume no information other than knowledge of the size of the camera’s CCD and the location of the center of projection in the image. Our algorithm, known as the quaternion optimization algorithm, optimally positions the camera in CAD space so as to align the matched features appropriately, and permits the mapping of other image pixels (the damaged area) to the CAD model. Surprisingly the solution for the camera position comes down to minimizing the value of a homogeneous quartic polynomial over the unit 3-sphere in 4 space (unit quaternions). The algorithm has been tested in conjunction with researchers and engineers at Etegent Technologies, Ltd. in Cincinnati, Ohio using photos of a damaged surface on an aircraft and a CAD model of the airplane.

8136-09, Session 3

The optimum approximation of multi-dimensional vector signals by multi-input multi-output matrix filter banks

Y. Kida, Ohu Univ. (Japan); T. Kida, Tokyo Institute of Technology (Japan)

We consider multi-dimensional multi-input multi-output systems composed of multi-dimensional analysis-filter matrices, multi-dimensional interpolation-filter matrices and middle sampler matrices of multi-dimensional signals.

Under the condition that the multi-dimensional analysis-filter matrices and the middle sampler matrices are given, we consider a problem of approximating the multi-dimensional input-signal vector by the multi-dimensional output-signal vector of the above system.

We assume that the set of input-signal vectors of this system is contained in a certain given set of input-signal vectors.
The output vector of the system is equal to the sum of products between impulse responses of the interpolation-filter matrices and the discrete sample values that are identical to the output of the middle sampler matrices.

We prove that the proposed approximation minimizes any upper-limit measure of approximation error compared to any other approximation using the same set of sample values. If the ordinary Fourier transform is adopted in the formulation, we show a fast calculation method of the optimum interpolation-filter matrices. An example is given that clarify the effectiveness of the proposed method.

8136-10, Session 3

The optimum running approximation of band-limited signals based on new concept of multi-legged-type signals in a hyper domain

Y. Kida, Ohu Univ. (Japan); T. Kida, Tokyo Institute of Technology (Japan)

Sampling theorem of one-dimensional band-limited signals proved that the original signal can be reconstructed from its discrete sample values. But, it uses an infinite number of sample values. Hence, if we use a finite number of sample values, we cannot avoid error of approximation.

On the other hand, an approximation by a filter bank using shift-invariant interpolation filters is increasing its importance in modern signal processing.

Hence, the minimization of approximation errors in a filter bank for band-limited signals is the important problem of signal processing. Specially, the minimization of the error associated with running approximation by the FIR filter bank is one of the most difficult problems of the signal processing.

In this discussion, we introduce a new concept of multi-legged-type signals in a hyper-space, each body segment of which constitutes a set of small separable domains made by scan-type approximation.

Based on this concept, we propose an approximation method of the multi-legged-type signals and we prove that the presented approximation is the optimum.

Then, introducing a measure of error that becomes quite large for errors caused by the running approximation and becomes small otherwise, we present extended optimum approximation that minimizes various worst-case measures of the running approximation error at the same time.

Moreover, an application of multiple-input multiple-output/space division multiplexing system is discussed. Some examples are given.

8136-12, Session 4

Theory and experiments of remote tracking and measurements of moving objects

C. J. Hu, Southern Illinois Univ. at Carbondale (United States) and Sunnyfuture, Boulder (United States)

As the author published and will publish in several SPIE conferences (4 papers in the period of January 2009 to April 2011), we can use a novel image processing Edge Detection Method, developed by the author in the last 2 years, to recognize and to track remotely any moving object on the ground by an IR camera used in conjunction with a signal processing chip installed on-board in a communication satellite. Live experiments using simulated satellite IR snapshots of a moving ground vehicle, sampled at periodical times, showed that the VB6 software designed by the author can automatically track this moving vehicle in consecutive snapshots and automatically measure its distance of movement, speed of movement, and angular change of object orientation between any two adjacent snap-shots. It can also numerically predict the vehicle’s immediate future movement at the latest snap-shot. All these can be done in real-time. The automatic, real-time print-outs of numerical measurements are seen to be quite accurate compared to the ones we can measure manually by using protractor and ruler on the snapshots. Single vehicle tracking and measurements are to be presented in live in this coming April, D&S Conference, Orlando.

Design and experiments to generalize this single-vehicle measurements to multiple-vehicle automatic tracking and measurements are 90% completed at the present time. Both theory and experiments of the multiple vehicle measurements will be explained and demonstrated in live in this conference.

8136-13, Session 4

Optimizing feature extraction in image analysis using experimented designs, a case study evaluating texture algorithms for describing appearance retention in carpets

S. A. Orjuela Vargas, R. A. Quinones, Sr., B. Ortiz-Jaramillo, F. Rooms, R. De Keyser, W. Philips, Univ. Gent (Belgium)

The variety of techniques available for extracting characteristics from images may result in a high amount of data to be analyzed. In many image processing investigations the relevant features of interest are visually chosen, implying human subjectivity. With this method dependences between the processes involved in image analysis are not evaluated, decreasing reliability of the results.

Conducting a planning phase in advance using the experimental design theory ensures reliability of the results. The main advantage is the identification of dependences between processes, optimally detecting process combinations while both the development time and overall costs are reduced. Only few investigations applying Experimental design theory in image analysis exist, most of them focusing in applications rather than in the method.

We present a case study, evaluating texture algorithms for describing appearance retention in carpets, which is evaluated by assigning numbers to different degrees of changes in appearance. Recently, we found that Local Binary Pattern (LBP) techniques are appropriate for quantifying such changes. Therefore, we consider in this experiment, texture analysis algorithm based on the latest extensions of the LBP technique.

We first quantify monotonicity and discriminance from the description of texture features vs the numbers. Then, we evaluate the performance of the techniques using probability values obtained from statistical tests.

We evaluate dependences between techniques, types of carpets and different image resolutions. Finally, inferences and results are clearly stated and communicated by interpreting the probability results. The main concepts of the theory are presented in detail for using it in other image applications.
8136-14, Session 4

**Edge pattern analysis for edge detection and localization**

B. Jiang, National Institute of Aerospace (United States)

Edge detection processing plays an important role in image processing, and at its most basic level classifies image pixels into edges and non-edge pixels. The accuracy of edge detection methods determines the eventual success or failure of computerized analysis procedures which follow the initial edge detection determinations. In view of this downstream impact, considerable care should be taken to improve the accuracy of the front-end edge detection. In general, edges would be considered as abrupt changes or discontinuity in intensity of an image. Therefore, most of edge detection algorithms are designed to capture signal discontinuities but the spatial character of especially complex edge patterns has not received enough attention. The edge detection operation generally has two main steps: filtering, and localization. I temporarily neglect the effect of filtering process, and assume the selective filter is ideal in the first step. The focus of this paper is on the second step whose aim is accurately detecting and localizing sharp, local intensity changes. Edges can be divided into basic patterns such as pulse, step and ramp: different types have different shapes and consequent mathematical properties. In this paper, the behavior of various edge patterns, under first, second, even higher, derivatives are examined and analyzed to determine how to accurately detect and localize these edge types, especially reducing “double edge” effect that is one important drawback to the derivative method. General rules about the depiction of edge patterns are proposed to reduce localization error in the discrete domain of the digital image. Asides from the ideal patterns, other patterns representing basic edge categories, such as stair, are examined to broaden the initial analysis. Experiments conducted to test my propositions support the idea that edge patterns are instructive in enhancing the accuracy of edge localization.

8136-21, Session 4

**Multi-dimensional feature extraction from 3D hyperspectral images**

M. Mehrübeoglu, Texas A&M Univ. Corpus Christi (United States)

A hyperspectral imaging system has been set up and used to capture hyperspectral image cubes from various samples in the 400-1000 nm spectral region. The system consists of an imaging spectrometer attached to a CCD camera with fiber optics light source as the illuminator. The significance of this system is its capability to capture 3D spectral and spatial data that can then be analyzed to extract information about the underlying samples, monitor the variations in their response to perturbation or changing environmental conditions, and compare optical properties. In this paper preliminary results are presented that analyze the 3D spatial and spectral data in reflection mode to extract features to differentiate among different classes of interest using biological and metallic samples. Studied biological samples possess homogenous as well as non-homogenous properties. Metals are analyzed for their response to different surface treatments, including polishing. Similarities and differences in the feature extraction process and results are presented. The mathematical approach taken is discussed. The hyperspectral imaging system offers a unique imaging modality that captures both spatial and spectral information that can then be correlated for future sample predictions.

8136-22, Session 4

**Interactive region-based retrieval**

A. Bursuc, T. B. Zaharia, TELECOM & Management SudParis (France); F. Prêteux, Mines ParisTech (France)

This paper presents a novel method for retrieving different instances of a region or object of interest in a video database. We propose a dynamic region construction and matching algorithm aiming at obtaining the most similar instance of the query model from each candidate image. An interactive selection mechanism allows the user to select an object directly from the video and to start a query using as input this information in order to access visually similar content.

8136-07, Poster Session

**A novel calibration method of CCD camera for LAMOST**

Y. Gu, Y. Jin, Z. Chao, Univ. of Science and Technology of China (China)

Large Sky Area Multi-object Fiber Spectroscopic Telescope - LAMOST, with a 1.75m-diameter focal plane on which 4000 optical fibers are arranged, is one of major scientific projects in China. During the surveying process of LAMOST, the optical imaging system makes the astrometric objects be imaged in the focal plane, and the optical fiber positioning system controls the 4000 fibers to be aligned with these objects and obtain their spectrum. In order to correct the positioning error of these optical fibers, the CCD camera is used to detect these fibers’ position in the way of close-range photogrammetry.

As we all know, the calibration quality of the CCD camera is one of the most important factors for detection precision. However, the camera calibration has two following problems in the field work of LAMOST. First, the camera parameters are not stable due to the changes of on-site work environment and the vibration during movement. So, the CCD camera must be on-line calibrated. Second, a large-size high-precision calibration target is needed to calibrate the camera, for the focal plane is very big. Making such a calibration target, it is very difficult and costly. Meanwhile, the large calibration target is hard to be fixed on LAMOST because of the space constraint.

In this paper, an improved bundle adjustment self-calibration method is proposed to solve the two problems above. The results of experiment indicate that this novel calibration method needs only a few control points while the traditional calibration methods need much more control points to get the same precision. So the method could realize the on-line high-precision calibration of CCD camera for LAMOST.

8136-15, Poster Session

**Experimental test of turbulence prediction algorithms**

D. Del Moro, M. Stangalini, R. Piazzesi, F. Berrilli, Univ. degli Studi di Roma Tor Vergata (Italy)

Short time-scale prediction of the evolution of turbulent processes is of interest in many applications, among these Adaptive Optics (AO). Three possible approaches to this problem are the attempts to predict its evolution through Auto Regressive Moving Average (ARMA) modelling, Neural Networks or linear approximations. Each of these approaches involves an algorithm which forecasts a future turbulence state using as input the knowledge of past measured states.

An experimental test to compare these different approaches has been set up at the Tor Vergata University Solar Physics Laboratory: a Kolmogorov spectrum turbulence introduces aberrations in the optical path of an AO system and the data from a Shack-Hartmann sensor is used to predict the successive state of the wavefront.

The results, advantages and drawbacks of the three different methods are compared.
8136-16, Poster Session

A comparative test of different compression methods applied to solar high resolution images

D. Del Moro, Univ. degli Studi di Roma Tor Vergata (Italy); E. Pietropaolo, Univ. degli Studi dell’Aquila (Italy); F. Giannattasio, F. Berrilli, Univ. degli Studi di Roma Tor Vergata (Italy)

In this work we conduct a comparative study on different data compression methods applied to high resolution images of the solar surface acquired at the Solar Dunn Telescope in Sacramento Peak with the IBIS (Interferometric Bidimensional Spectrometer) instrument.

Our aim is to perform an estimation of the quality, efficiency and workload of the considered computing techniques both in the so-called lossless modality, where in the reconstruction phase there is no loss of information, and in lossy mode, where it should be possible to reach a high compression ratio at the expense of image information. In the latter case we quantify the quality with image analysis conventional methods and more specifically with the reconstruction of physical parameters through standard procedures used in this kind of observations. The considered methods constitute the most frequently adopted image compression procedures in a variety of fields of application; they exploit in different ways the properties of the Discrete Wavelet Transforms often coupled with standard entropy coders or similar coding procedures applied to the different bit planes in order to allow a progressive handling of the original image.

In the lossless approach we found that all methods give a compression ratio around 2. For a lossy compression we reached a compression ratio of 16 (equivalent to a 1 bit per pixel) without any perceptual difference between original and reconstructed images.

8136-18, Poster Session

The research on pattern recognition in distributed fiber sensor system

H. Wu, D. Zhao, Fudan Univ. (China)

Distributed Fiber Sensor System is a new type of system, which could be used in long-distance condition for monitoring and inspection. Position determination analysis toward this system is popular in previous papers, but pattern recognition of the output signals of the sensor has been missed for a long time. This function turns to critical especially when it is used for real security project in which quick response to intrusion is a must. This paper provides a MFCC-based approach to extract features of the sensing signals and does the recognition experiments using neural network, which could be used for pattern recognition in real project, and the approach is proved by large practical experiments and projects.

8136-19, Poster Session

Image analysis and pattern recognition for the localisation of medical devices in the operational field

P. L. Chirco, M. Zanarini, SOFTEC Technology & Research (Italy)

Localisation of devices can be of paramount importance during surgery, in particular when probes are used.

A simple but effective system has been developed based on the geometric matching analysis of the image of the operational field as acquired by an overviewing visual camera. Indeed, a target object containing known patterns is placed around the head of the probe; an accurate system for imaging identifies and locates the patterns.

The instrumentation needed for the localisation is simple and work in the visual light environment.

8136-20, Poster Session

N-order phase unwrapping system tolerant to noise

M. A. Navarro Rodriguez, J. C. Estrada, M. Servin, Ctr. de Investigaciones en Optica, A.C. (Mexico)

The present work shows preliminary results of a phase unwrapping technique used in interferometry. Wrapped phase maps are the result of the modulus 2\pi ambiguities caused for the phase recovery function arctan. Here we present a recursive n-order phase unwrapping system that removes the ambiguities, it’s robust to noise and fast.

The system is able to recover the unwrapping phase in presence of high noise, according to stability of the system that can be controlled. This high noise causes line sequential integrations of phase differences to fail. The system is not numerically-heavy in comparison with other methods that tolerate the noise. The application areas of the system can be: optical metrology, magnetic resonance, and those imaging systems where information is obtained as a demodulated wrapped phase map.
8137-01, Session 1
2D-3D image registration using Lidar and aerial image in lunar surface
P. Duraisamy, Univ. of North Texas (United States)

In this paper we discuss about registration between 2D image -3D data in lunar surface. It is challenging problem to register between two different modalities in lunar surface due to lack of conventional futures. We used craters as features to register between two different modalities. We also used extrinsic camera parameters for estimating camera pose estimation without any apriori knowledge. We validated our approach on two different views of data sets using craters as feature.

8137-02, Session 1
Algorithm development for outlier detection and background noise reduction during NIR spectroscopic data processing
D. Abookasis, Ariel Univ. Ctr. of Samaria (Israel); J. J. Workman, Biotechnology Business Associates (United States) and Liberty Univ. (United States)

This study describes a hybrid processing algorithm for use during calibration/validation of near-infrared spectroscopic signals based on spectra cross-correlation and pre-processing filtering combined with a partial-least square regression (PLS) analysis. In the first step of the algorithm, exceptional signals (outliers) are detected and removed based on spectra correlation criteria we have developed. Then, signal filtering based on orthogonal signal correction (OSC) was applied, before being used in the PLS model, to filter out background variations. After outlier screening and OSC treatment, a PLS calibration model matrix is formed. Common statistics such as standard error of cross-validation mean relative error, coefficient of determination, etc. were computed to assess the fitting ability of the algorithm. Once a model has been built, it used to predict the concentration of the unknown (blind) samples. Algorithm performance was tested on several hundred blood samples prepared at different hematocrit and glucose levels using blood materials from thirteen healthy human volunteers. During measurements samples were subjected to extreme variations in temperature, flow rate, and sample pathlength. Experimental results which show a significant decrease in standard error of prediction in comparison to the factorial approach highlight the potential, applicability, and effectiveness of the proposed method.

8137-03, Session 1
A data-driven approach for processing heterogeneous categorical sensor signals
C. P. Calderon, A. Jones, S. Lundberg, R. C. Paffenroth, Numerica Corp. (United States)

False alarms generated by sensors pose a substantial problem to a variety of fusion applications.
We focus on situations where the frequency of a genuine alarm is "rare" but the false alarm rate is high.
The goal is to mitigate the false alarms while retaining power to detect true events.
We propose to utilize data streams contaminated by false alarms (generated in the field) to compute statistics on a single sensor’s misclassification rate.

The nominal misclassification rate of a deployed sensor is often suspect because it is unlikely that these estimates were tuned to the specific environmental conditions in which the sensor was deployed.
Recent categorical measurement error methods will be applied to the collection of data streams to "train" the sensors and provide point estimates along with confidence intervals for the misclassification and estimated prevalence. By pooling a relatively small collection of misclassified random variables arising from a single sensor and using data-driven misclassification rate estimates along with estimated confidence bands, we show how one can transform the stream of categorical random variables into a test statistic with a known distribution. The procedure shows promise for normalizing sequences of misclassified random variables coming from different sensors (with a priori unknown population parameters) to comparable test statistics; this facilitates "fusion" through various downstream processing mechanisms.
We envision using such output to feed false discovery methods that exploit the comparable test statistics in a chemical sensor fusion context where reducing false alarms and maintaining substantial power is important.

8137-04, Session 1
Backscatter behaviour and tracking of ogive shaped objects in optical range
C. F. Hahlweg, Helmut-Schmidt Univ. (Germany)

In recent years session we presented devices and methods for laser based trajectory measurement of hand gun bullets, which also included the estimation of light scatter from such bodies in free flight. While our first approach for gathering the scatter qualities of arbitrary projectiles using metrological image processing resulted in a polar fourier series of the outer contour of the projectile, which could be used to calculate the scatter behavior, the question of determining the contour as an parameterized ogive came up, which then could also be used to determine the type of projectile literally on the fly - assumed high enough image resolution. The present paper is understood as a continuation of last years papers with focus on the scatter characteristics of ogive shaped bodies and the metrological identification of the ogives of projectiles.

8137-05, Session 1
A combined target spectral-spatial dense descriptor feature for improved tracking performance
J. J. Weinheimer, S. G. Beaven, P. V. Villeneuve, Space Computer Corp. (United States)

In EO tracking, target features can be used to improve performance since they help distinguish the targets from each other when confusion occurs during normal kinematic tracking. In this paper we introduce a method to encode target spatial information into a signature, allowing us to convert the problem of spatial template matching into one of signature matching. This allows us to apply multivariate algorithms commonly used to process Hyperspectral data to panchromatic imagery. In addition, we also show how the spatial signature can be naturally extended with spectral information to produce a signature that contains both spectral and spatial information to provide a more unique target feature.
To this end, we introduce a new descriptor called Spectral DAISY for encoding spatial information into a signature, based on the concept of the DAISY1 dense descriptor. We demonstrate the process on real data and show how the combined spatial/spectral feature can be used to improve target/track association over spectral or spatial features alone.
Design and analysis of an FMCW radar system for vehicle tracking
N. Gale, A. Roy, L. Hong, Wright State Univ. (United States)
The ability to accurately detect and track ground vehicles is an essential component in many applications from traffic monitoring and enforcement to automatic cruise control and automated collision avoidance. Over the last few decades, frequency modulated continuous wave (FMCW) radar have become the industry standard for these applications due to their compact size, low power, and high data rate. There are several companies that provide these sensors at low cost, but the sensors can require expensive test equipment to calibrate. The ability to use these sensors right out of the box without expensive calibration practices is a key to deploying these sensors rapidly and at low cost. An uncalibrated commercial-off-the-shelf (COTS) FMCW radar system was used to collect data along the roadside with vehicles moving within the sensor’s field of view. A moving target indication (MTI) technique is used to suppress stationary background clutter, while magnitude thresholding and CFAR approaches are applied for signal detection. These detections are fed into an extended Kalman filter framework using both nearest neighbor and probabilistic approaches for data association. Results from the tracking scenarios are compared to ground truth in the form of GPS data that was collected from onboard the moving vehicles.

Game theoretic approach to similarity based image segmentation
D. Shen, G. Chen, Consultant Professional (United States); Y. Zheng, Alcorn State Univ. (United States)
Image segmentation problem is to decompose a given image into segments, i.e., regions containing “similar” pixels. This problem can be straightforwardly cast into a clustering problem, where pixels represent the objects to cluster. In this way a cluster corresponds to a segment of the image. There exist different more or less complicated ways of defining a similarity measure between two pixels. In particular, standard approaches take into account brightness, color, texture or boundary information, or combinations of them in order to build a good similarity measure. In this paper, we offer a similarity-based image segmentation approach based on game theory. The basic idea behind our approach is that the similarity based clustering problem can be considered as a multiplayer non-cooperative “clustering game”. Within this context, the notion of a cluster turns out to be equivalent to a classical equilibrium concept from game theory, as the latter reflects both the internal and external cluster conditions alluded to before. We also show that there exists a correspondence between these equilibria and the local solutions of a polynomial, linearly-constrained, optimization problem, and provide an algorithm for finding them. Experiments on image segmentation problems show the superiority of the proposed approach.

Optimal filters with heuristic 1-norm sparsity constraints
M. Yazdani, R. Hecht-Nielsen, Univ. of California, San Diego (United States)
We present a design method for sparse optimal Finite Impulse Response (FIR) filters that improve the visibility of a desired stochastic signal corrupted with white Gaussian noise. We emphasize that the filters we seek are of high-order but sparse, thus significantly reducing computational complexity. An optimal FIR filter for the estimation of a desired signal corrupted with white noise can be designed by maximizing the signal-to-noise ratio (SNR) of the filter output with the constraint that the magnitude (in 2-norm) of the FIR filter coefficients are set to unity [Makhoul 1981]. This optimization problem is in essence maximizing the Rayleigh quotient and is thus equivalent to finding the eigenvector with the largest eigenvalue. While such filters are optimal, they are rarely sparse. To ensure sparsity, one must introduce a cardinality constraint in the optimization procedure. For high-order filters such constraints are computationally burdensome due to the combinatorial search space. We relax the cardinality constraint by using the 1-norm approximation of the cardinality function. This is a relaxation heuristic similar to the recent sparse filter design work of Baran, Wei, and Oppenheim [Baran et al 2010]. The advantage of this relaxation heuristic is that the solutions tend to be sparse and the optimization procedure reduces to a convex program, thus ensuring global optimality. In addition to our proposed optimization procedure for deriving sparse FIR filters, we show examples where sparse high-order filters significantly perform better than low-order filters, whereas complexity is reduced by a factor of 10.
remarkably successful (e.g., Euler's continuity eq. for fluid flow, Poisson's eq., Fourier's heat equation, Maxwell's equations, Schroedinger equation, Dirac equation, Yang-Mills equations, Einstein's field equation for general relativity, Fokker-Planck eq., Boltzmann transport eq., Navier-Stokes eq., Euler-Lagrange eqs., Hamilton-Jacobi eq., Klein-Gordon eq., Seiberg-Witten eqs., etc.). More specifically, our theory benefits from many notions developed in physics and especially fluid dynamics (irrotational flow, incompressible flow, Hamiltonian dynamics, Poisson's eq., etc.). That is, we have used a physics based approach to nonlinear filters.

8137-11, Session 2

A survey of maneuvering target tracking Part VId: sampling-based nonlinear filtering

X. Li, V. P. Jilkov, The Univ. of New Orleans (United States)

This paper is Part VId of a comprehensive survey of maneuvering target tracking without addressing the so-called measurement-origin uncertainty. It provides an in-depth coverage of sampling-based nonlinear filters, commonly referred to as particle filters, developed particularly for handling the uncertainties induced by potential target maneuvers as well as nonlinearities in the dynamical systems commonly encountered in target tracking. Various implementations and tracking applications are reviewed. Also addressed are computational issues, such as different schemes for resampling and parallel processing.

8137-12, Session 2

Tracking with biased measurements

S. V. Bordonaro, Naval Undersea Warfare Ctr. (United States); P. Willett, Y. Bar-Shalom, Univ. of Connecticut (United States)

In many target tracking applications, estimation of target position and velocity is performed in Cartesian coordinates. Use of Cartesian coordinates for estimation stands in contrast to the measurements, which are traditionally the range, azimuth and elevation measurements of the spherical coordinate system. It has been shown in previous works that the classical nonlinear transformation from spherical to Cartesian coordinates introduces a bias in the position measurement. Various means to negate this bias have been proposed. In many active SONAR and RADAR applications, the sensor also provides a Doppler, or range rate, measurement. Use of Doppler in the estimation process has also been proposed by various authors. The goals of this paper are two-fold. The first goal is to show that a bias, similar to the bias shown by previous authors for conversion of position measurements, exists when measuring Doppler from a moving platform. The second is to examine the effects of biased measurements on estimation performance and the effectiveness of proposed compensation approaches.

8137-13, Session 2

Breaking the Bayesian bottleneck

F. E. Daum, J. Huang, Raytheon Co. (United States)

We show numerical results for many examples of nonlinear filtering problems, including: diverse nonlinearities, various levels of stability of the plant (as gauged by the eigenvalues of the Jacobian of the plant) including both stable and unstable plants, process noise, measurement noise, initial uncertainty in the state vector, dimension of the plant, number of particles, multimodal densities, etc. It turns out that the accuracy of the filter varies by many orders of magnitude depending on the values of these parameters.

We have solved the well known and important problem of “particle degeneracy” using a new theory, called particle flow. Our filter is four orders of magnitude faster than standard particle filters for any given number of particles, and we required many orders of magnitude fewer particles to achieve the same filter accuracy. Our filter beats the EKF accuracy by several orders of magnitude for difficult nonlinear problems. Our theory uses exact particle flow to compute Bayes' rule, rather than a pointwise multiply. We do not use resampling or proposal densities or importance sampling or any other MCMC method. But rather, we design the particle flow with the solution of a linear first order highly underdetermined PDE, like the Gauss divergence law in electromagnetics.

8137-14, Session 2

Improving multi-sensor tracking with the addition of lesser quality radar data

C. A. Rea, M. E. Silbert, Naval Air Systems Command (United States)

The ability to track multiple maneuvering targets, such as boats or even people, in using multiple sensors is a difficult and important problem. However, often the sensors used are different, with different accuracies and different detection capabilities. It becomes problematic to determine how best to combine the data from these sensors. Since each sensor provides information, and information is additive, then theoretically the best estimate should be obtained by combining the information from all sensors. In previous work it was shown that multiple disparate sensors do not improve the state estimations of a tracker when compared to using only the single best sensor. This paper will look at how to best use all data available to a data fusion engine, regardless of source, and aims to answer the questions “Does the best tracking performance truly result from throwing away data? Can the performance of the single high quality sensor be surpassed utilizing all data?” Current fielded systems use a “best of breed” approach when selecting which data to integrate into a track. We will investigate using a modified IMM and compare it to existing algorithms to find if “best of breed” is really the best of breed.

8137-15, Session 3

Multiple-hypothesis tracking for the cyber domain

S. Schwengler, S. S. Blackman, Raytheon Space & Airborne Systems (United States); J. Holisopple, CUBRC (United States); M. Hirsch, Raytheon Co. (United States)

This paper discusses how methods used for conventional multiple hypothesis tracking (MHT) can be extended to domain-agnostic tracking of entities from non-kinematic constraints such as those imposed by cyber attacks in a potentially dense false alarm background. MHT is widely recognized as the premier method to avoid corrupting tracks with spurious data in the kinematic domain but it has not been extensively applied to other problem domains. The traditional approach is to tightly couple track maintenance (prediction, gating, filtering, probabilistic pruning, and target confirmation) with hypothesis management (clustering, incompatibility maintenance, hypothesis formation, and N-association pruning). However, by separating the domain specific track maintenance portion from the domain agnostic hypothesis management piece, we can begin to apply the wealth of knowledge gained from ground and air tracking solutions to the cyber (and other) domains. These realizations led to the creation of Raytheon’s Multiple Hypothesis Extensible Tracking Architecture (MHETA).

In this research, we showcase MHETA for the cyber domain, plugging in a well established method, CUBRC’s INFormation Engine for Real-time Decision making, (INFERD), for the association portion of the MHT. The result is a CyberMHT. We demonstrate the power of MHETA-INFERD using both simulated and real-world data. Using metrics from both the tracking and cyber domains, we show that while no tracker is perfect, by applying MHETA-INFERD, advanced non-kinematic tracks can be captured in an automated way, perform better than non-MHT approaches, and decrease analyst response time to cyber threats.
Discrimination and tracking of dismounts using low-resolution aerial video sequences

R. Narayanaswami, A. Tyurina, D. Diehl, R. K. Mehra, Scientific Systems Co., Inc. (United States); J. M. Chinn, Air Force Research Lab. (United States)

In this paper we investigate the detection and tracking of dismounts using low resolution aerial video sequences (IR and EO). This process consists of (1) alignment, (2) detection of moving objects and (3) extraction of features of moving objects and (4) tracking. The resolution of the data in our algorithm testing and implementation was in the range of 10-50 pixels on target. We start with frame to frame registration of the video signal to identify background versus moving foreground for identification of potential dismounts with the further aim of classification. Moving objects are defined as areas of significantly different pixels in a current frame and an average of several previous frames. The identified moving objects are classified by size to obtain sub images containing potential dismounts. Tracking starts with chip construction and feature extraction and consists of the following steps (1) Track the object of interest through the video stream, discard if spurious, (2) Construct a chip of sub images and (3) Compute features: static from frames and kinematics from the chip. Kinematic features include frequency of intensity variation of pixels relative to the center of area of the dismount. The tracking mechanism should be robust to changes of viewing angle, lighting and partial occlusions. The method we have presently implemented is based on known inter-frame alignment parameters, estimated speed of tracked objects, and their static features, such as size, color etc. The temporal frequencies of pixel intensities can distinguish moving objects such as cars from dismounts.

Application of a joint tracking and identification method to dismount targets

S. S. Blackman, R. A. Rosen, K. V. Krikorian, C. G. Durand, S. Schwoegler, Raytheon Space & Airborne Systems (United States)

This paper presents a method for tracking dismounts/humans in a potentially dense clutter background. The proposed approach uses Multiple Hypothesis Tracking (MHT) for data association and Interacting Multiple Model (IMM) filtering. The problem is made difficult by the presence of random and persistent clutter, such as produced by moving tree branches. There may also be moving targets, such as vehicles and animals, that are not of interest to the user of the tracking system but must be tracked in order to separate these targets from the targets of interest. Thus, a joint tracking and identification method has been developed to utilize the features that are associated with dismount targets. The filter uses a Dempster-Shafer approach to combine feature data to determine the target type (dismount versus other) and feature matching is also used in the track score used for MHT data association.

The paper begins by giving an overview of the features that have been proposed in the literature for distinguishing humans from other types of targets. These features include radar cross section, target dynamics, and spectral and gait characteristics. For example, the spread of the Doppler/velocity spectrum is a feature that is sent to the tracker and a large width will be an indication that the observation is from an animal, rather than a vehicle. Then, a distinct periodic pattern, such as a peak at about 2 Hz, can be used to identify the target as a human and, along with the target speed, may even be used as a target signature. The manner in which these features are estimated during signal processing and how these data are included in the track score is described.

A test program that was conducted in order to produce data for analysis and development is described. Typical results derived from real data, collected during this test program, are presented to show how feature data are used to enhance the tracking solution. These results show that the proposed methods are very effective in separating the tracks on dismounts from those formed on clutter and other objects.

Comparison of a grid-based filter to a Kalman filter for the state estimation of a maneuvering target

M. E. Silbert, The George Washington Univ. (United States) and NAVAIR (United States); T. Mazzuchi, S. Sarkani, The George Washington Univ. (United States)

Providing accurate state estimates of a maneuvering target is an important, but difficult problem. This problem occurs when needing to track maneuvering boats or even people wandering around. In an earlier paper, a specialized grid-based filter was introduced as an effective method to produce accurate state estimates of a target moving in two dimensions, while requiring only a two-dimensional grid. As was shown, this grid-based filter produces accurate state estimates because the filter can capture the kinematic constraints of the target directly, and thus account for them in the estimation process. In this paper, the relative performance between a grid-based filter and a Kalman filter is investigated. In particular, the state estimates (position and velocity) from a grid-based filter are compared to those from a Kalman filter, against a maneuvering target. This comparison will incrementally increase the maneuverability of the target to determine how maneuverable the target must be to gain the benefit from a grid-based filter. The paper will discuss the target motion model, the corresponding implementation of the grid-based filter, and the tailoring of the Kalman filter used for the study. The results will show that the grid-based filter typically performs at least as good as the Kalman filter, but often performs better. A key disadvantage of the grid-based filter is that it is much more computational than a Kalman filter. The paper will discuss the straightforward parallelization of the computations, making the processing time for the grid-based filter closer to those needed for a Kalman filter.

A Gaussian sum filter framework for space surveillance

J. T. Horwood, N. D. Aragon, A. B. Poore, Numerica Corp. (United States)

While standard Kalman-based filters, Gaussian assumptions, and covariance-weighted metrics work remarkably well in data-rich tracking environments such as air and ground, their use in the data-sparse environment of space surveillance is more limited. In order to properly characterize non-Gaussian density functions arising in the problem of long term propagation of state uncertainties, a framework for a Gaussian sum filter is described which achieves uncertainty (covariance) consistency and an accurate approximation to the Fokker-Planck equation up to a prescribed accuracy. The filter is made efficient and practical by (i) using coordinate systems adapted to the physics (i.e., orbital elements), (ii) only requiring a Gaussian sum to be defined along one of the six state space dimensions, and (iii) the ability to initially select the component means, covariances, and weights by way of a lookup table generated by solving an offline nonlinear optimization problem. The efficacy of the Gaussian sum filter and the improvements over the traditional unscented Kalman filter are demonstrated within the problems of data association and maneuver detection.

Multiple model cardinalized probability hypothesis density filter

R. Georgescu, P. Willett, Univ. of Connecticut (United States)

Mahler introduced a new approach to tracking in which target states and measurements are modeled as random finite sets. The resulting
Probability Hypothesis Density (PHD) filter propagates the first-moment approximation to the multi-target Bayesian posterior distribution. The follow up Cardinalized PHD (CPHD) filter is a recursive filter that propagates both the posterior likelihood of (an unlabeled) target state and the posterior cardinality density (probability mass function of the number of targets).

Extensions of the PHD filter to the multiple model (MM) framework have been published and were implemented either as a particle filter or a Gaussian Mixture (GM), for the case of linear and later nonlinear target dynamics and/or measurement models.

In this work, we introduce the multiple model version of the more elaborate CPHD filter. We present a detailed derivation of the prediction and update steps of the MMCPHD in the case of two nearly constant velocity models and proceed to a GM implementation. The new filter is accompanied by a track management scheme dealing with events such as track initiation, update, merging, spawning and deletion.

We tested the new tracker on the challenging Metron multitarget sonar dataset. Metrics of performance are reported, such as track probability of detection, track fragmentation, number of false tracks and RMSE, and the improvements made possible by the multiple model version of the CPHD over the single filter are highlighted.

8137-21, Session 3

Group targets tracking using hypergraph matching for data association

S. Wu, SRI International Sarnoff (United States)

Group moving targets are number of targets independently moving in a physical space but keeping their relative order or pattern invariant. The up to date state-of-art multi-target tracking (MTT) data association methods (GNN,JPPDA,MHT) are easily fail on group targets tracking problems, since the tracker-to-observation ambiguity cannot be resolved if only using the track to observation information.

A hypergraph G is represented by G = {V;E}, where V is a set of elements called nodes or vertices, E is a set of non-empty subsets containing d-tuple of vertices called hyperedges. It can be used as a new mathematic tool to represent a group of moving targets if we let each target be a vertex and a d-target subset be an hyperedge. Under this representation, this paper reformulates the traditional MTT data association problem as an hypergraph matching one between the hypergraphs formed from tracks and observations, and shows that the traditional approach (only uses the vertex-to-vertex information) which is a special case under the proposed framework. In addition to the vertex-to-vertex information, since the hyperedge-to-hyperedge information is also used in building the assignment matrix, the hypergraph matching based algorithms give better performance than that from the traditional methods in group target tracking problems. We demonstrate the declaration from simulations as well as video based geotracking examples.

8137-39, Poster Session

A cost-effective and open mobile sensor platform for networked surveillance

W. Sheng, G. Li, J. Du, C. Zhu, Oklahoma State Univ. (United States)

In this paper, a compact, low-cost and open multi-agent mobile sensor platform for networked surveillance is presented. A compact sensor design is realized by off-the-shelf components: an iRobot Create, an Atom processor-based computer, a Hokuyo laser range finder, and a Q24 fisheye camera. The software system consists of three main modules: a control module for iRobot movement, a data acquiring module for sensor reading, and a data processing module for navigation and target tracking. All modules are built on the open source Robot Operation System (ROS). This platform is used to form a mobile sensor network for military surveillance research. Compared to traditional stationary surveillance systems, our platform is capable of higher mobility and therefore, achieving better surveillance performance in terms of confidence of target tracking and adaptability. We develop novel algorithms for target tracking, which is realized by fusing the data from the omnidirectional camera and the laser range finder. Due to the distributed computing nature of the platform, we also conduct cooperative target-tracking through the fusion of multiple mobile sensors.

The performance of the proposed mobile surveillance system is evaluated through experiments. The results from the experiments prove that the proposed platform is a promising tool for networked surveillance research and practice. Future research problems that could be investigated using this platform are also discussed in this paper. This work results from a project supported by a DURIP program through the DoD Army Research Office.

8137-38, Poster Session

A survey of maneuvering target tracking Part Vlc: approximate nonlinear density filtering in discrete time

X. Li, V. P. Jilkov, The Univ. of New Orleans (United States)

This paper is Part Vlc of a comprehensive survey of maneuvering target tracking without addressing the so-called measurement-orient uncertainty. It provides an in-depth coverage of various approximate density-based nonlinear filters in discrete time developed particularly for handling the uncertainties induced by potential target maneuvers as well as nonlinearities in the dynamical systems commonly encountered in target tracking. An emphasis is given to more recent results, especially those with good potential for tracking applications. Approximate techniques for density-based nonlinear filtering in mixed time have been covered in a previous part. Sampling-based nonlinear filtering will be surveyed in a forthcoming part.

8137-40, Poster Session

Performance evaluations of multipath, multitarget tracking using PCRLB

M. Subramaniam, McMaster Univ. (Canada); K. Punithakumaran, GE Healthcare (Canada); M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, R. Tharmarasa, McMaster Univ. (Canada)

In this paper, we study the performance of the multipath-assisted multitarget tracking using multiframe assignment for initiating and tracking multiple targets by employing one or more transmitters and receivers. The basis of the technique is to use the posterior Cramer-Rao lower bound (PCRLB) to quantify the optimal achievable accuracy of target state estimation. In real scenarios, it is more appropriate to assume that the locations of the reflection points/surfaces are not accurately known to the receiver. This leads to a challenging problem of fusing the direct and multipath measurements from the same target where the multipath-reflection mode is unknown. The problem becomes more complex due to missed target detections and when non-target originated measurement returns are present due to false alarms and clutter. We used different topological configurations in our evaluations and showed that incorporating multipath information improves the performance of the algorithm significantly in terms of estimation error. This work is motivated by tracking ground targets using bearing and time difference of arrival (TDOA) measurements. Simulation results are presented to show the effectiveness of the proposed method.
8137-41, Poster Session

**Bayesian approach to joint super-resolution and trajectory estimation for closely spaced objects via infrared focal plane data**

L. Lin, H. Xu, W. An, National Univ. of Defense Technology (China)

This paper addresses the problem of super-resolution for midcourse closely spaced objects (CSO) using infrared focal plane data. Within a short time window, the mid-course CSO trajectories on the focal plane can be modeled as following a straight line with a constant velocity. Thus, the object’s initial state(initial projection positions and velocities on the focal plane)exclusively corresponds to its trajectory on the infrared focal plane. The objects initial state and radiant intensities, as well as the object numbers and the sensor noise variance, are considered random variables, and a Bayesian model is proposed which is utilized to define a posterior distribution on the parameter space. To maximize this posterior distribution, we use a reversible jump Markov chain Monte Carlo (RJMC) method to perform the Bayesian computation. The proposed approach uses the multiple time-consecutive frames to estimate the model parameters directly, thus not only avoiding data association in multi-target tracking but also gaining a higher performance of super-resolution. Simulation results show that the proposed approach is effective and feasible.

8137-42, Poster Session

**Evaluation of automated algorithms for small target detection and non-natural terrain characterization using remote multi-band imagery**

E. Hallenborg, Space and Naval Warfare Systems Ctr. Pacific (United States)

Experimental remote sensing data from the 8 to 12 micron wavelength NASA Thermal Infrared Multispectral Scanner (TIMS) have been a valuable resource for multispectral algorithm proof-of-concept, a prime example being a spectral small target detector founded on maximum likelihood theory, termed the Generalized Linear Feature Detector (GLFD) (Yu et al., 1993; Yu et al., 1997); GLFD tests on low signal-to-clutter ratio rural Australian TIMS imagery yielded a detection rate of 5 out of 7 (71%) for small extended targets, e.g. buildings up to 10 meters in extent, at a 1 part per million false alarm rate. Separately, techniques such as Independent Component Analysis (ICA) have since shown good promise for small target detection as well as terrain feature extraction (e.g., Kuan & Healey, 2004; Winter, 2008). In this study, we first provide higher-confidence GLFD performance estimates by incorporating a larger set of TIMS imagery and ground truth. Secondly, alongside GLFD we perform ICA, which effectively separates many non-natural features from the highly cluttered natural terrain background; in particular, our TIMS results show that a surprisingly small subset of ICA components contain the majority of non-natural “signal” such as paved roads amid the clutter of soil, rock, and vegetation.

8137-43, Poster Session

**Tracking a large number of CSO using the particle PHD filter via optical sensor**

L. Lin, H. Xu, W. An, Sheng, D. Xu, National Univ. of Defense Technology (China)

We propose a filtering framework for tracking a large number of closely spaced objects (CSO) that is based on the particle probability density (PHD) filter and multiassignment data association. The original particle PHD filter suffers from drawbacks of slow track initiation and unstable multi-target state estimation performance when being applied to tracking large numbers of CSO. In order to cope with these drawbacks, a novel birth particle sampling scheme is present first to quicken track initiation, which samples birth particles around measurements, and carry out this sampling process after the particle PHD filter update process not only avoiding invalid birth particles update but also holding uninformative weights for birth particles, and then a non-iterative multi-target estimation technique is proposed, which partitions each particle to the specific measurement using maximum likelihood test and selects the resulting particle clusters with highest cluster-weights for estimating multi-target state. Furthermore, the unresolved measurements from CSO make it necessary to relax traditional one-to-one association restricition, thus a multiassignment track-to-estimation approach is present here to allow for the multiple-to-one track-to-estimation association. Meanwhile, an M/N rule for track initiation and multiple consecutive misses for track deletion are used to account for the sensitivity of the PHD filter to missed detections and false alarms. Simulation of tracking target complex on the infrared focal plane, and experiment of tracking flying bird swarm with real video data, are performed, and the results show that the proposed filtering framework is effective and efficient.

8137-44, Poster Session

**Nonlinear dynamic stochastic filtering of signal phase in interferometric systems**

M. A. Volynsky, I. P. Gurov, A. E. Veisei, Saint-Petersburg State Univ. of Information Technologies, Mechanics and Optics (Russian Federation)

Interferometric methods are widely used in measurement of geometric quantities, optical metrology and non-contact testing. High accuracy, noise-immunity and fringe processing speed play an important role in practical use of interferometric systems.

In last decade, the new approach to interference fringe processing was proposed based on fringe recurrence dynamic evaluating interference fringe parameters like fringe amplitude, frequency and phase [1,2]. This approach is based on using recurrence algorithms, in which fringe signal value is predicted to a following discretization step using full information available before this step, and fringe signal prediction error is used for step-by-step dynamic correcting the fringe parameters. A few versions of the recurrence fringe processing algorithm, in particular, in the form of extended Kalman filtering were successfully applied to interference fringe parameters evaluating in rough surface profilometry, multilayer tissue evaluating, and optical coherence tomography, in analyzing 2-D fringe patterns.

New results were recently obtained using Markov model of interference fringes with random initial conditions and stochastic filtering that confirmed advantage in accuracy and possibility to recover unwrapped fringe phase with respect to well-known extended Kalman filtering method. Comparison in accuracy and stability of the both approaches was conducted and discussed in detail.

REFERENCES


8137-45, Poster Session

**Noise-induced outpulsing technique for energy efficiency improvement of laser radar systems**

M. G. Serikova, E. G. Lebedko, Saint-Petersburg State Univ. of Information Technologies, Mechanics and Optics (Russian Federation)
Laser radar systems are widely used as space orientation systems by military, geodetic surveying, and in space applications. There are stringent requirements for a false alarm probability (of the order of 0.0001) for the systems. The complex target environment and a receiver noises cause the attenuation of the signal-to-noise ratio (down to 15 or lower).

New signal processing technique for laser radar systems is suggested. The technique provides the signal detection during an interval between a receiver noise bursts. As a result of the given technique the system is more energy efficient. The principle is that a pulse shoot is matched with a trailing edge of a noise burst and the signal presence decision is made according to a leading edge of the next burst. There is a contradiction between requirements for the impulse frequency (some MHz) and false alarm probability, that’s why double-threshold processing is offered. The lower level induces outpulsing while the higher one determines target detection performance.

Since duration of such time intervals is random, statistic analysis was made via modulation testbed. The latter is based on a low-lighted electron-multiplier phototube as a noise source. Eventually distribution laws of two-level crossing interval were defined. As a result the optimal threshold configuration, filter parameters and mean outpulsing frequency were found. Mentioned results provide low false alarm probability (about 0.0001 or less) with improvement of the system energy efficiency (~30%) at the same time.

8137-22, Session 4

3D ISAR image reconstruction of targets through 2D rotations

Z. Qiao, J. Lopez, G. Garza, The Univ. of Texas-Pan American (United States)

In our paper, we study three dimensional Inverse Synthetic Aperture Radar (ISAR) imaging of objects through two dimensional rotations. We consider a second axis of rotation so that the target is undergoing rotational motion in two dimensions. Two algorithms for forming a 3D image of such a target scene are presented in detail. Our imaging algorithms are derived from a scalar wave equation model. The first of which is based on a far-field Fourier Transform inversion scheme, whereas the second algorithm is based on a filtered back projection inversion scheme, which does not require the use of a far-field approximation. Finally, we will show the 3D simulations for the two algorithms.

8137-23, Session 4

Improved multiframe data association using smoothing for multiple maneuvering target tracking

R. Tharmarasa, McMaster Univ. (Canada); N. Nandakumaran, Curtin Univ. of Technology (Australia); M. McDonald, Defence Research and Development Canada (Canada); T. Kirubarajan, McMaster Univ. (Canada)

Data association is the crucial part of any multitarget tracking algorithm in a scenario with multiple closely spaced targets, low probability of detection and high false alarm rate. Multiframe assignment, which solves the data association problem as a constrained optimization, is one of the well-known methods to handle the measurement origin uncertainty. If the targets do not maneuver, then multiframe assignment with one or two frames will be enough to find the correct data association. However, more frames must be used to decide the data association for maneuvering targets. Smoothing, which uses measurements beyond the estimation time, provides better estimates of the target states. The cost of assigning a target to a measurement can be calculated more accurately if better estimates of the targets states are available. In this paper, we propose an improved multiframe data association with better cost calculation using multiple model smoothing. The effectiveness of the proposed algorithm is demonstrated on simulated data.

8137-25, Session 4

Automatic track initialization and maintenance in heavy clutter using integrated JPDA and ML-PDA algorithms

K. Harishan, R. Thamarasa, T. Kirubarajan, McMaster Univ. (Canada); T. Thayaparan, Defence Research and Development Canada (Canada)

Target tracking in high clutter or low signal-to-noise environments presents many challenges to tracking systems. Joint Maximum Likelihood estimator combined with Probabilistic Data Association (JMLPDA) is a well known parameter estimation solution for the initialization of tracks of very low observable, low signal-to-noise-ratio targets in higher clutter environments. On the other hand, the Joint Probabilistic Data Association (JPDA) algorithm, which is commonly used for track maintenance, lacks automatic track initialization capability. This paper presents an algorithm to automatically initialize and maintain tracks using an integrated JPDA and JMLPDA approach that seamlessly shares information on existing tracks between the JMLPDA (used for initialization) and JPDA (used for maintenance) components. The motivation is to share information between the maintenance and initialization stages of the tracker, that are always on-going, so as to enable the tracking of an unknown number of targets using the JPDA approach in heavy clutter. The effectiveness of the new algorithm is demonstrated on a heavy clutter scenario and its performance it compared against that of the standard JPDA tracker.

8137-27, Session 4

Labeled labelless multitarget tracking with features

D. Crouse, P. Willett, Univ. of Connecticut (United States)

Past work has shown the benefits of using Minimum Mean Optimal Sub-Pattern Assignment (MMOSPA) estimates for multitarget tracking. Namely, that one can get the “smoothness” of the estimates associated with Minimum Mean Squared Error (MMSE) estimation coupled with the resistance to track coalescence associated with Maximum Likelihood (ML) estimation. Though MMOSPA estimates are typically “labelless”, that is, one does not know which estimate corresponds to which target, recent work has established a probabilistic framework for maintaining track identity probabilities.

In this paper, we extend such work to allow for the use of classification information derived from features or attributes to improve the performance of the tracker. We also note the difference between a target’s “identity” and the nature of the target as determined by classification information.

8137-28, Session 4

Adaptive multi-target-tracker

C. Sung, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

On successive images, objects are either imaged in small size or in large size. Thus, in a long sequence, such as a highway scene or an airspace scene, images of cars or planes may range from small blob-like image structures to extended-dimensional image structures (and vice versa). In this case, the development of a process chain for automatic object tracking is a great challenge, since it requires the use of different approaches in combination, regarding both the extraction of image features and the grouping of characteristics.

An adaptive multi-target tracker combines various methods for object detection and tracking such as feature-based methods and trajectories-based tracking, thus providing meaningful results with variable shape, brightness and size of the target images.
An adaptive multi-target tracker is generic, since it offers a choice of alternative methods for the individual tasks, depending on the tasks, the used image sensors and the type of motion of the target objects. In the case of a high dynamic scene, dynamically varying parameter values must be used for the detection of object images and object tracking. This requires an automatic generation of parameter values by adaptive adjustment.

In this paper, the selected process chains for the automatic and seamless tracking of multiple object images and for the interpretation of target objects in image sequences are presented. Detailed descriptions of objects are extracted from the images for the interpretation of target objects. The comparison with existing object descriptions in the search system permits to decide what the object represents.

8137-36, Session 4

Parallel processing for particle filters: or what could I do with a billion particles?
F. E. Daum, J. Huang, A. Noushin, Raytheon Co. (United States)

Modern computer technology allows us to use hundreds or thousands of processors for particle filtering. For example, GPUs are now very inexpensive and easy to use, and in many applications they yield several orders of magnitude speedup, but not for particle filters, which suffer from the bottleneck due to resampling. In particular, one thousand processors applied to standard particle filters typically results in only a factor of ten speedup, and the root cause of this large discrepancy is the resampling of particles that is required by standard particle filters. It would be much better to avoid resampling in particle filters. It turns out that we have invented a new theory of particle filters that never resamples particles, and hence avoids this well known bottleneck to parallelization, and hence our new particle flow filter is embarrassingly parallelizable.

The usual naive expectation is that if we use 1,000 processors then we can speedup an algorithm by roughly a factor of 1,000. Reality has taught us otherwise. Moreover, the theory and practice of parallel processing developed many decades ago teaches us that such an expectation is naive for particle filters. We review the somewhat sparse literature on parallelization of particle filters, and we show (using simple block diagrams) that our new theory does not suffer from such bottlenecks. It is easy to run particle filters with billions of particles today, both on PCs and GPUs, and we have done so for a number of interesting applications.

The best paper on the subject of parallel processing for standard particle filters is: “A GRAPHICS PROCESSING UNIT IMPLEMENTATION OF THE PARTICLE FILTER,” Gustaf Hendeby, Jeroen D. Hol, Rickard Karlsson, Fredrik Gustafsson; 15th European Signal Processing Conference (EUSIPCO 2007), Poznan, Poland, September 3-7, 2007. In particular, figures 5 & 6 in this excellent paper make it crystal clear that resampling is the big problem, and that hundreds or thousands of processors only speeds up the runtime by less than a factor of ten. To understand these issues better, one should scrutinize this most excellent paper by Hendeby et al.

8137-37, Session 4

Analogies between physical particles and particles in filters
F. E. Daum, Raytheon Co. (United States)

Physical particles share many characteristics with particles as currently used in particle filters, as listed in the following table (items 1 to 6):

<table>
<thead>
<tr>
<th>Item</th>
<th>Physical particles</th>
<th>Particles in filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mass</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Probability density</td>
<td>Schrödinger-Born</td>
</tr>
<tr>
<td>3</td>
<td>Gradient dynamics</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Fluid flow</td>
<td>Yes (e.g., irrotational, incompressible)</td>
</tr>
<tr>
<td>5</td>
<td>Birth &amp; death</td>
<td>Yes (resampling)</td>
</tr>
</tbody>
</table>

These analogies, however, do not extend to the last three items in the above table (items 7 to 9).

6. wave-particle duality: Yes (ODEs for particles to solve PDEs)
7. charge, spin, etc.: No
8. quantization of mass, charge, spin, etc.: Yes (regularized LeGland)
9. symmetries (time, space, rotation, CPT, gauge invariance): Yes (not really, but Cramér-Rao bound is roughly analogous)
10. anti-particles: No but adjoint method is analogous (backwards time)
11. principle of least action: Yes (but it has been suggested for log-h by Mahendra Mallick)
12. Heisenberg uncertainty principle: Yes (not really, but Cramér-Rao bound is roughly analogous)
13. super strings: Yes (sort of (regularized LeGland))
14. quantum cohomology: Yes (sort of for log-h (1st order linear underdetermined PDE))

We will elaborate on the analogies listed in this table for both standard particle filters as well as log-homotopy filters. For example, the fundamental equation for log-homotopy is a first order linear underdetermined PDE, and the task is to find a unique solution efficiently using a system of ODEs (i.e., particles). Thus, the wave-particle duality is clearly evident for log-homotopy particle filters. In physics wave-particle duality is manifested in simple optical experiments and theories going back to Newton & Huygens. Second, wave-particle duality is famous in quantum experiments and theory. Third, wave-particle duality is one way to write the solution of the Hamilton-Jacobi equation (a PDE) using particles that obey the Euler-Lagrange equations (ODEs); this duality is evident in both classical physics (optics and mechanics) and quantum mechanics and quantum field theory. Quantum cohomology is a relatively new string theory that attempts to solve a first order linear underdetermined PDE system, to compute Gromov-Witten invariants for quantum gravity, analogous to log-homotopy filters, which must solve a first order linear underdetermined PDE. It is not surprising that we can use the same tricks invented for physics to compute a unique solution of this PDE; for example, assume that the velocity field is the gradient of a potential (see Daum & Huang, “Exact particle flow” April 2010). In fact, essentially all of the ten methods that we have used so far for our exact particle flow were borrowed from physics.

Moreover, there are other properties of physical particles that could be used in more advanced particle filters using log-homotopy (items 10 to 14). But perhaps the most interesting and useful question is why the particles in filters do not have charge & spin and other quantum numbers, and furthermore, why mass is not quantized in particle filters (items 7 to 9). One way to explain this difference is that physical particles are quantized owing to symmetries, whereas there are no such symmetries for particle filters. In particular, the usual story in physics is that symmetry forces the fundamental equation for log-homotopy is a first order linear underdetermined PDE. It is not surprising that we can use the same tricks invented for physics to compute a unique solution of this PDE; for example, assume that the velocity field is the gradient of a potential (see Daum & Huang, “Exact particle flow” April 2010). In fact, essentially all of the ten methods that we have used so far for our exact particle flow were borrowed from physics.

Hence, in search of a more fundamental explanation, one can speculate that this is because the technology used by filters is floating point arithmetic in general purpose computers, whereas physical particles at the Planck scale actually are roughly analogous to bits in our modern computers. This line of speculation reminds us of John Wheeler’s famous essay, “It from bit,” which speculates that physics could be explained using something like Shannon information (i.e., bits and entropy) and limits of propagation of information as the fundamental stuff. For example, Erik Verlinde recently derived Newton’s & Einstein’s gravity equations using Shannon information theory (“On the origin of gravity and the laws of Newton” January 2010). Similarly, this reminds us of Norbert Wiener’s analysis that shows that bits are essentially optimal to encode Shannon information when cost is linear in quantization scale; all modern computers use bits, and hence engineers and the market in the 20th and early 21st centuries seems to concur with Wiener’s analysis. We can further speculate that God awarded the contract for making and maintaining particles to the lowest bidder, who naturally followed Wiener’s optimal design for quantizing mass, charge, spin, etc. If we limit our perspective to electrons vs. protons and neutrons,
Wiener's analysis holds very accurately (i.e., two levels of mass to a very good approximation). Actually, Wiener showed that the optimal number of levels of quantization was slightly greater than 2, and this matches physical particles very well. In physics, it is remarkable how often Wiener's magic number 2 appears in this context; for example: future vs. past in time, fermions vs. bosons, particles vs. forces, matter vs. anti-matter, positive vs. negative unit charge on electrons & protons, left vs. right, up vs. down, quadratic Lagrangians, strong vs. weak fields, stable vs. unstable particles & theories, E vs. M in Maxwell’s theory, even vs. odd parity, etc. etc.

It would be extremely presumptuous to think that we could know why God made the World that we see; however, it is somewhat less presumptuous to speculate on why humans in the 21st century on Earth see the World as the assortment of quantized particles evident in our experiments. This is a subtle but crucial distinction. The latter focuses on the limitations of human perception with 21st century technology, whereas the former attempts to understand God’s intentions.

There are three reasons for such speculations: (1) invent better particle filters using ideas from physics; (2) understand fundamental issues in physics better using ideas from particle filters; and (3) it is fun. In particular, we will explore the benefits of exploiting symmetries for particle filters, analogous to Sanjoy Mitter’s use of gauge invariance to understand exact finite dimensional filters thirty years ago.

8137-29, Session 5
Dynamic sector processing using 2D assignment for rotating radars
B. K. Habtemariam, R. Thamarasa, T. Kirubarajan, McMaster Univ. (Canada); M. Pelletier, ICx Radar Systems (Canada)

Electronically scanned array radars as well as mechanically steered rotating antennas return measurements with different time stamps during the same scan while sweeping form one region to another. Typically, data association algorithms wait till the end of a whole scan to process the returns in that scan in order to satisfy the common “one measurement per track” assumption. For example, multitarget tracking algorithms like the Multiple Hypothesis Tracker (MHT) and the Multiframe Assignment Tracker (MFA) wait to receive the full scan of measurements before data association, which is a crucial step before updating tracks. Data processing at the end of a full scan results in delayed state updates. This issue is more apparent while tracking fast moving targets with low scan rate sensors.

In this paper we present new dynamic sector processing algorithm using 2-D assignment for continuously scanning radars. A complete scan can be divided into sectors, which could be as small as a single detection, depending on the scanning rate and scarcity of targets. Data association followed by filtering and target state update can be done dynamically while sweeping from one end to another. Along with the benefit of immediate track updates, continuous tracking results in challenges such as multiple targets spanning multiple sectors and targets crossing consecutive sectors. Also, associations after receiving a sector may require changes in association in previous sectors. Such difficulties are resolved by the proposed recursive generalized 2-D assignment algorithm that uses a dynamic Hungarian assignment technique. The algorithm offers flexibility with respect to changing cost and size for fusion of measurements received in consecutive sectors. Furthermore the proposed technique can be extended to multiframe assignment for jointly processing data from multiple scanning radars. Experimental results based on rotating radars are presented.

8137-30, Session 5
Benchmarks for target tracking
D. T. Dunham, Vectrinx, Inc. (United States); P. D. West, Georgia Tech Research Institute (United States)

The term benchmark originates from the chiseled horizontal marks that surveyors made, into which an angle-iron could be placed to bracket (“bench”) a leveling rod, thus ensuring that the leveling rod can be repositioned in exactly the same place in the future. A benchmark in computer terms is the result of running a computer program, or a set of programs, in order to assess the relative performance of an object by running a number of standard tests and trials against it. This paper will discuss the history of simulation benchmarks that are being used by multiple branches of the military and agencies of the US government. These benchmarks range from missile defense applications to chemical biological situations. Typically, a benchmark is used with Monte Carlo runs in order to tease out how algorithms deal with variability and the range of possible inputs. We will also describe problems that can be solved by a benchmark.

8137-31, Session 5
Information exchanged between fusion tracker and other fusion functions
O. E. Drummond, CyberRnD, Inc. (United States)

Multiple-sensor data fusion offers the opportunity for substantial improvement in functional performance compared to single sensor processing. Data fusion processing, however, could be substantially more complex than processing with data from a single sensor. Consequently, data fusion processing typically involves more processing functions than processing with data from a single sensor. Accordingly, the fusion tracker function may be required to provide more and better information to the other fusion-level/network-level functions. The fusion track function may also be required to receive and act on more information from the other fusion functions than the information typically received by a single sensor tracker. The types of information that might be required by the fusion tracker function to be provided to the other fusion functions plus the types of information provided by the other fusion functions that the fusion tracking function might have to utilize are the subject of this presentation.

A data-fusion processing system could be fairly simple or sophisticated and complex or anywhere in between these two extremes depending on the specifics of application. The fusion processing design depends on the requirements; the characteristics, limitations, and locations of the sensors, processors, threat, communications, and operating conditions; the location of the users; and the state of the art of fusion processing. Thus the type and functional decomposition of a data fusion processing system for one application could be very different from another application and thus, the exchange of information between the fusion tracker function and other fusion functions could be different. These issues are summarized as background for the discussion of the specifics of the type of information provided by the fusion tracker function to the other fusion functions. The introduction also provides background for the discussion of the specifics of the type of information provided by the other fusion functions to the fusion tracker function and the type of special processing needed to act on that information. Note also that the fusion tracker function could be simply a single tracker if the fusion processing is centralized and would involve multiple trackers if fusion processing is distributed.

8137-32, Session 5
Regression data classification with data reduction techniques and support vector machines
D. Zhao, Univ. of Connecticut (United States)

The recent advances in data collection and storage capacities have led to information overload in many applications, e.g., on-line monitoring of spacecraft operations with time series data. It is therefore desirable to perform data reduction before storage or transmission of the data. For the Turbofan engine degradation simulation data sets, the failure of the system is determined by the combination of five key components. The datasets consist of three input parameters and twenty one sensor
outputs. The dimensionality of the acquired data is lower than the space that is measured in. Therefore, data reduction techniques are expected to help reduce run time while maintaining an acceptable level of performance.

We apply several data reduction techniques to the data sets with the goal of determining the remaining useful life (RUL) of each engine component using Support Vector Machines and PSVM classifiers. We investigated 2-class and 4-class situations. The correct rate of the classifiers was in the range of 70%.

Based on our tests, data reduction techniques coupled with SVM-type classifiers provided a significant reduction in processing load with an acceptable loss in performance.

8137-33, Session 5

Cooperative sensing in mobile sensor networks based on distributed consensus

W. Sheng, H. M. La, Oklahoma State Univ. (United States)

Mobile sensor networks (MSNs) have wide applications such as military target detection and tracking, detection of toxic chemicals in contaminated environments, and search and rescues in disasters, etc. In many applications, a core problem is to conduct cooperative scalar field mapping (or searching) over a large area of interest.

Centralized solutions to the scalar field mapping may not fit for large mobile sensor network due to the single-point-of-failure problem and the limited scalability. In this paper, autonomous mobile sensor networks are deployed to map scalar fields in a cooperative and distributed fashion. We develop a cooperative sensor fusion algorithm based on distributed consensus filters. In this algorithm, each agent receives measurements from its neighboring agents within its communication range, and iteratively updates the estimate of the unknown scalar field and an associated confidence map. A motion planning algorithm is used to obtain a path for complete coverage of the field of interest. A distributed flocking control algorithm is adopted to drive the center of the mobile sensor network to track the desired paths. Computer simulations are conducted to validate the proposed algorithms. We evaluate the mapping performance by comparing it with a centralized mapping algorithm. Such a cooperative sensing approach can be used in many military surveillance applications where targets may be small and elusive.

This work results from a project supported by a DURIP program through the DoD Army Research Office.

8137-34, Session 5

Spectrally assisted target tracking

L. E. Hoff, Hoff Engineering (United States); E. M. Winter, Technical Research Associates, Inc. (United States)

Tracking of multiple vehicles can be accomplished with a single band high-resolution sensor as long as the vehicles are continuously in view. However, in many cases the vehicles pass through or behind blackouts, such as through tunnels or behind tall buildings. In these cases, the vehicles of interest must be re-acquired and recognized from the collection of vehicles present after the blackout. The approach considered here is to add an additional sensor to assist a single band high-resolution tracking sensor, where the adjunct sensor measures the vehicle signatures for recognition and re-acquisition. The subject of this paper is the recognition of targets of interest amongst the observed objects and the re-acquisition after a blackout. A GLRT algorithm is compared with the Spectral Angle Mapper (SAM) and Euclidian distance algorithms. All three algorithms were evaluated on a simulated database of signatures created by measuring samples from old automobile gas doors. The GLRT was the most successful in recognizing the target after a blackout and could achieve a 95% correct reacquisition rate. The results show the feasibility of using a hyper spectral sensor to assist a multi target tracking sensor by providing target recognition for reacquisition.
8138-01, Session 1

SAR moving target imaging in a sparsity-driven framework
O. Onhon, M. Cetin, Sabanci Univ. (Turkey)

In synthetic aperture radar (SAR) imaging, sparsity-driven imaging techniques have been shown to provide high resolution images with reduced sidelobes and reduced speckle, by allowing the incorporation of prior information about the scene into the problem. Just like many common SAR imaging methods, these techniques also assume the targets in the scene are stationary over the data collection interval. Here, we consider the problem of imaging in the presence of targets with unknown motion in the scene. Moving targets impose phase errors in the SAR data and these errors cause defocusing in the corresponding spatial region in the reconstructed image. We view phase errors resulting from target motion as errors on the observation model of a static scene. Based on these observations we propose a method which not only benefits from the advantages of regularization-based imaging but also compensates the errors arising due to the moving targets. Considering that in SAR imaging the underlying scene usually admits a sparse representation, a nonquadratic regularization based framework is used. The proposed method is based on minimization of a cost function which involves regularization terms imposing sparsity on the reflectivity field to be imaged, as well as on the spatial structure of the motion-related phase errors, reflecting the assumption that only a small percentage of the entire scene contains moving targets. Experimental results demonstrate the effectiveness of the proposed approach in reconstructing focused images of scenes containing multiple targets with unknown motion.

8138-03, Session 1

Refractive index map reconstruction in optical deflectometry using total-variation regularization
L. Jacques, A. Gonzalez Gonzalez, E. Fournou, P. Antoine, Univ. Catholique de Louvain (Belgium)

We study the resolution of an inverse problem arising in Optical Deflectometry: the reconstruction of refractive index map of transparent materials from laser deflection measurements under multiple orientations. This problem is solved from a standard convex optimization procedure aiming at minimizing the Total Variation of the map (as a prior information) while matching the observed data (fidelity constraint). In this process, the forward measurement operator, mapping any index map to its deflectometric observation, is simplified in the Fourier domain according to a modified Projection-Slice theorem. Our method is also applicable to other imaging techniques such as differential phase-contrast X-ray tomography.

8138-04, Session 1

Compressively sampling the plenacoustic function
R. Mignot, G. Chardon, L. Daudet, Ecole Supérieure de Physique et de Chimie Industrielles (France) and Univ. Pierre et Marie Curie (France)

This study deals with the sampling of the sound field in a room, more precisely the evolution of the “Room Impulse Response” (RIR) as a function of the spatial positions of the source and the receiver, the so-called plenacoustic function.

With standard Shannon sampling, the measurement of a time-varying 3-D image requires a number of measurement points / microphones that is unreasonably large for practical use. However, informed by the physical nature of the signal, the “Compressed Sensing” (CS) principle can reduce the number of sensors if the signal is approximately sparse in some dictionaries. Here, we apply CS to the acquisition and interpolation of the plenacoustic function in a spatial domain, based on the sparsity of the soundfield on a dictionary of plane waves. Unfortunately, because of space dimensionality and size of atoms, even the simplest standard sparse decomposition algorithms are too expensive in terms of CPU and memory requirements.

Two new algorithms are presented. The first one exploits the structured sparsity of the sound field, with orthogonal projections of the estimated modal deformations onto a basis of plane waves sharing the same wavenumber. The second algorithm computes a sparse decomposition on a dictionary of independent plane waves, with a time / space variable separation to reduce the memory usage.

Both methods are compared to the regular sampling on synthetic signals. Their performance is evaluated according to the size and configuration of the sensor array, the size of the reconstruction domain and the time / frequency limit.

8138-05, Session 2

An iterative weighted one-norm minimization algorithm for sparse signal recovery
O. Yilmaz, H. M. Mansour, M. P. Friedlander, The Univ. of British Columbia (Canada)

We propose an iterative algorithm that solves a sequence of weighted one-norm minimization problems to recover sparse signals from incomplete linear measurements. The algorithm utilizes the ability to extract partial support information from the solutions to standard and weighted one-norm minimization. The weights are adjusted to promote non-zero coefficients in subsets of the support estimates that remain invariant between iterations. We provide extensive experiments to show that our algorithm outperforms state of the art sparse recovery techniques.

8138-06, Session 2

Deterministic matrices with the restricted isometry property
D. G. Mixon, Princeton Univ. (United States)

The state of the art in compressed sensing uses sensing matrices which satisfy the Restricted Isometry Property (RIP). Unfortunately, the known deterministic RIP constructions fail short of the random constructions, which are only valid with high probability. In this paper, we propose different constructions and compare with the literature.

8138-07, Session 2

Application of frames in digital fingerprinting
N. Kiyavash, Univ. of Illinois at Urbana-Champaign (United States); D. G. Mixon, Princeton Univ. (United States); C. Quinn, Univ. of Illinois at Urbana-Champaign (United States); M. Fickus, Air Force Institute of Technology (United States)

We show case a novel application for frames in digital rights management. Specifically, we consider the problem of digital fingerprinting as a game between the fingerprint embedder aiming to protect the digital content and a coalition of attackers working to defeat the scheme. We demonstrate that frames are particularly well suited as additive fingerprint designs against Gaussian averaging collusion attacks from the fingerprint embedder’s viewpoint. On the other hand, we
characterize the coalition’s best strategies in terms of having the highest chance of evading detection.

8138-08, Session 2
Non-orthogonal fusion frames
P. G. Casazza, Univ. of Missouri-Columbia (United States)

Fusion frames have found broad application to problems in sensor networks, distributed processing and much more. We will show that by using non-orthogonal projections, we can find significantly larger classes of tight and sparse fusion frames.

8138-09, Session 2
Grassmannians in frame theory
J. Cahill, Univ. of Missouri-Columbia (United States)

The Grassmannian is the set of k dimensional subspace of an n dimensional vector space. This set naturally parametrizes isomorphism classes of frames. We will present several results which exploit this fact.

8138-10, Session 3
Higher degree total variation (HDTV) algorithms for biomedical inverse problems
M. Jacob, Y. Hu, Univ. of Rochester (United States)

We introduce generalized regularization functionals to overcome the practical problems associated with current total variation (TV) schemes such as poor approximation properties, poor contour regularity, and staircase artifacts. Based on a reinterpretation of the classical TV penalty, we derive a novel isotropic TV scheme involving higher order derivatives. This approach considerably minimizes the staircase artifacts and patchy reconstructions that are commonly observed in TV reconstructions. In addition, we introduce a novel rotation invariant anisotropic HDTV penalty to improve the regularity of the edge contours. We apply the algorithm to several biomedical inverse problems, which demonstrates the improved performance.

8138-11, Session 3
Smooth sampling trajectories for sparse recovery in MRI
R. M. Willett, Duke Univ. (United States)

Recent attempts to apply compressed sensing to MRI have resulted in pseudo-random k-space sampling trajectories which, if applied naively, may do little to decrease data acquisition time. This paper shows how an important indicator of CS performance guarantees, the Restricted Isometry Property, holds for deterministic sampling trajectories corresponding to radial and spiral sampling patterns in common use. These theoretical results support several empirical studies in the literature on compressed sensing in MRI. A combination of Gersgorin’s Disc Theory and Weyl’s sums lead to performance bounds on sparse recovery algorithms applied to MRI data collected along short and smooth sampling trajectories.

8138-12, Session 3
Non-iterative and exact inverse scattering solution using compressive MUSIC
J. Ye, O. Lee, K. Jin, KAIST (Korea, Republic of)

Inverse scattering problem is to recover the unknown targets from the measurements of scattered fields, and has various bioimaging applications such as microwave imaging, ultrasound imaging, T-ray tomography and etc. Recently, we showed that the problem can be exactly solved non-iteratively using compressive sensing approach by exploiting the joint sparsity. The main contribution of this paper is to extend the idea and demonstrate that near optimal solution can be obtained for any number of snapshots using so-called compressive MUSIC algorithm, where parts of unknown support is found by compressive sensing and the remaining support can be found deterministically using a generalized MUSIC criterion. Numerical results verify that this method outperforms the conventional algorithms.

8138-13, Session 3
Numerical evaluation of subsampling effects on image reconstruction in compressed sensing microscopy
Y. Le Montagner, Institut Pasteur (France) and Telecom ParisTech (France); M. de Moraes Marim, Institut Pasteur (France); E. Angelini, Telecom ParisTech (France); J. Olivo-Marin, Institut Pasteur (France)

When undergoing a reconstruction through a compressed sensing scheme, real microscopic images are affected by various artifacts that lead to detail loss. Here, we discuss how the sampling strategy and the sub-sampling rate affect the CS reconstruction, and how they should be determined according to a targeted accuracy level of the reconstruction. We investigate the relevance and limits of theoretical results through several numerical reconstructions of test images. We discuss the quantitative and qualitative artifacts that affect the reconstructed signal when reducing the number of measurements in the Fourier domain. We conclude by extending our results to real microscopic images.

8138-14, Session 3
Fresnelab: sparse representations of digital holograms
M. Liebling, Univ. of California, Santa Barbara (United States)

Digital holography plays an increasingly important role for biomedical imaging; it has particularly low invasiveness and allows quantitatively characterizing both amplitude and phase of propagating wave fronts. Fresnelets have been introduced as both a conceptual and practical tool to reconstruct digital holograms, simulate the propagation of monochromatic waves, or compress digital holograms. Propagating wave fronts that have, in their originating plane, a sparse representation in a traditional wavelet basis have a similarly sparse representation in propagation-distance-dependent Fresnelet bases. Although several Fresnelet applications have been reported in the past, no implementation has been made widely available. Here we describe a Matlab-based Fresnelet toolbox that provides a set of user-friendly functions to implement several, previously described algorithms, including a multi-scale Fresnel transform and a sparsity-based autofocusing tool for digital holography.

8138-15, Session 4
Phase retrieval via matrix completion
T. Strohmer, Univ. of California, Davis (United States)

The problem of reconstructing a signal from the magnitude of its Fourier transform plays a key role in numerous applications. This problem, also known as phase retrieval, has challenged engineers, physicists, and mathematicians for decades. We present a theoretical and numerical framework to phase retrieval via matrix recovery. Among others, our
8138-16, Session 4

Block sparsity models for broadband array processing
P. T. Boufounos, Mitsubishi Electric Research Labs. (United States); B. Raj, Carnegie Mellon Univ. (United States); P. Smaragdis, Univ. of Illinois at Urbana-Champaign (United States) and Adobe Systems Inc. (United States)

Recent work has demonstrated the power of sparse models and representations in signal processing applications and has provided the community with computational tools to use it. In this paper we explore the use of sparsity in localization and beamforming when capturing multiple broadband sources using a sensor array. Specifically, we reformulate the wideband signal acquisition as a block sparsity problem, in a combined frequency-space domain. In this domain the signal is sparse in the spatial domain but has support in all frequencies. Using techniques from the model-based compressive sensing literature we demonstrate that it is possible to robustly capture, reconstruct and localize multiple signals present in the scene.

8138-17, Session 4

Deterministic compressed sensing
S. Jafarpour, Princeton Univ. (United States)

The central goal of compressed sensing is to capture attributes of a signal using very few measurements. The limitations of the random sensing framework include performance guarantees, storage requirements, and computational cost. This talk will describe two deterministic alternatives. The first is based on expander graphs. We show that by reformulating signal reconstruction as a zero-sum game we can efficiently recover any sparse vector. We also demonstrate resilience to Poisson noise. The second is based on error correcting codes. We show that order Reed Muller codes optimize average case performance. We also describe a very simple algorithm, one-step thresholding, that succeeds when more sophisticated algorithms, developed in the context of random sensing, fail completely.

8138-18, Session 4

Compressed sensing with coherent and redundant dictionaries
D. Needell, E. J. Candes, Stanford Univ. (United States); Y. C. Eldar, Technion-Israel Institute of Technology (Israel); P. Randall, Princeton Univ. (United States)

This talk will present new results on signal recovery from undersampled data for which the signal is not sparse in an orthonormal basis, but rather in some arbitrary dictionary. The dictionary need not even be incoherent, and thus this work bridges a gap in the literature by showing that signal recovery is feasible for truly redundant dictionaries. We show that the recovery can be accomplished by solving an L1-analysis optimization problem. The condition on the measurement matrix required for recovery is a natural generalization of the well-known restricted isometry property (RIP), and we show that many classes of matrices satisfy this property. This condition does not impose any incoherence requirement on the dictionary, so our results hold for dictionaries which may be highly overcomplete and coherent. We will also show numerical results which highlight the potential of the L1-analysis problem.

8138-19, Session 5

Sparse signal recovery using a hybrid L0-L1 minimization algorithm
D. Liang, L. Ying, Univ. of Wisconsin-Milwaukee (United States)

In compressed sensing, the commonly used L1 minimization is known to shrink the magnitude of recovered signal when the number of measurements is not sufficient. Homotopic L0 minimization requires fewer measurements, but may not be as robust to noisy measurements or compressible signals that are not strictly sparse. The objective of this work is to develop a compressed sensing algorithm that has the benefit of both L1 and homotopic L0 minimizations and requires fewer measurements than either of them. We propose a hybrid L0-L1 quasi-norm minimization algorithm. The hybrid L0-L1 quasi-norm is defined to be a piecewise function which is the L0 quasi-norm if the element of the signal is greater than a threshold, and the L1 norm if the element is below the threshold. The threshold to discriminate large and small elements is updated iteratively, where the value is initialized using the “first jump role” with the signal recovered by L1 minimization. In order to guarantee convergence, a cost function that is strictly concave, continuous and differentiable is designed to approach the desired hybrid L0-L1 quasi-norm as a sequence limit. The proposed algorithm then solves a sequence of minimization problems where the cost function is updated iteratively. Simulations are carried out for both strictly sparse and compressible signals. Recovery from noisy measurements is also tested. We also discuss the choice of threshold r. Results of success-rate curves demonstrate that the proposed algorithm improves the reconstruction accuracy of homotopic L0 or L1 minimization when the same number of measurements is used.

8138-20, Session 5

Diffuse imaging: replacing lenses and mirrors with omnitemporal cameras
A. Kirmani, V. K. Goyal, Massachusetts Institute of Technology (United States)

Conventional imaging is steady-state light sensing using focused optics. The variations of the light field with time are not exploited. We develop a novel signal processing framework for imaging that uses omnidirectional, time-varying illumination and unfocused, time-resolved sensing to replace traditional optical elements such as mirrors and lenses. We demonstrate that with these omnitemporal cameras, it is possible to accomplish tasks that are impossible with traditional cameras. In particular, we generalize the existing work on non-line of sight imaging for looking around corners. We show that using our proposed algorithms and image acquisition architecture, it is possible to image complex occluded scenes at high signal-to-noise ratio and high resolution. We accomplish this without the use of mirrors or specialized ultra-fast optics, by acquiring time-resolved measurement of the light reflected off diffuse surfaces in response to multiplexed spatio-temporal illumination. We also discuss another application of our framework for 3D mapping of large-scale scenes, such as outdoor environments, using a network of omnitemporal cameras. Our proposed imaging applications may be realized with commercially-available, low-bandwidth hardware used in standard optical communication systems. Imaging using single-pixel omnitemporal cameras will allow us to create application-specific, cheap, and robust solutions for acquiring structure and intensity information about natural scenes.

8138-21, Session 5

Analytic sensing for systems governed by the wave equation
8138-25, Session 6
Spectral graph wavelet frames with compact supports
Y. M. Lu, Harvard School of Engineering and Applied Sciences (United States)
In this paper, we construct a new family of wavelet frames for functions defined on graphs. The proposed wavelet frames are near-tight and have compact supports in the graph domain. Furthermore, the analysis and synthesis operators of the frames can be implemented as a sequence of local “averaging” operations. This desirable feature makes it practical to implement the proposed graph wavelet transform in distributed sensor network applications.

8138-26, Session 6
A domain-knowledge-inspired mathematical framework for the description and classification of H&E stained histopathology images
R. Bhagavatula, Carnegie Mellon Univ. (United States); M. L. Massar, Air Force Institute of Technology (United States); J. A. Ozolek, Children’s Hospital of Pittsburgh (United States); C. A. Castro, Magee-Womens Research Institute and Foundation (United States); M. Fickus, Air Force Institute of Technology (United States); J. Kovacevic, Carnegie Mellon Univ. (United States)
We present the current state of our work on a mathematical framework for identification and delineation of histopathology images—local histograms and occlusion models. Local histograms are histograms computed over defined spatial neighborhoods whose purpose is to characterize an image locally. This unit of description is augmented by our occlusion models that describe a methodology for image formation. In the context of this image formation model, the power of local histograms with respect to appropriate families of images will be shown through various proved statements about expected performance. We conclude by presenting a preliminary study to demonstrate the power of the framework in the context of two histopathology image classification tasks that, while differing greatly in application, both originate from what is considered an appropriate class of images for this framework.

8138-27, Session 7
Sparsity-promoting seismic inversion with incoherent wavefields
F. J. Hermann, S. Aravkin, T. van Leeuwen, The Univ. of British Columbia (Canada)
During this presentation, we will give an overview on how dimensionality-reduction approaches from compressive sensing and stochastic optimization can be used to make seismic inversion more efficient. We show that recently popularized source-phase encoding techniques correspond to instances of compressive sensing. When combined with stochastic optimization these techniques lead to a new generation of efficient seismic-data processing, imaging, and inversion techniques designed to work on dimensionality-reduced incoherent wavefields.
Sparse data representation for the reconstruction of N-dimensional seismic wavefields

M. D. Sacchi, Univ. of Alberta (Canada)

Seismic wavefields depend on 4 spatial dimensions and time. The 4 spatial coordinates are defined by the x-y position of sources and receivers. Exploration seisomology utilizes a large areal distribution of sources and receivers to image the earth interior. Logistic and economical constraints often lead to irregularly sampled seismic volumes. This talk concentrates on efforts to reconstruct these multidimensional wavefields prior to imaging. At the core of the problem is the sparse representation assumption in an auxiliary domain which leads to algorithms that permit to estimate unrecorded observations.

Wavelets and wavelet-like transforms on the sphere and their application to geophysical data inversion

F. J. Simons, Princeton Univ. (United States); I. Loris, Univ. Libre de Bruxelles (Belgium); E. Brevdo, Princeton Univ. (United States); I. C. Daubechies, Duke Univ. (United States)

There are now a whole series of flexible parameterizations to represent data on the sphere. Starting with the venerable spherical harmonics, we have the so-called Slepian basis, harmonic splines, wavelets and wavelet-like Slepian frames. In this presentation we focus on the latter two: spherical wavelets developed for geophysical applications on the cubed sphere, and the Slepian "tree", a new construction that shares aspects of Slepian-like concentration and wavelet-like multiresolution. We discuss the basic features of these new mathematical tools, and focus in particular on their usage as model parameterizations for large-scale global geophysical problems that benefit from sparsity-promoting "inversion" algorithms.

Compressive near-field imaging of subwavelength topography

A. Fannjiang, Univ. of California, Davis (United States)

We study the near-field imaging of surface topography (the object) by compressed sensing techniques. The standard approach in the literature typically requires the full measurement of the scattered field along a plane above the object. In our approach we assume that the object has a sparse (or compressible) Fourier or wavelet expansion and reconstruct the object by using comparably sparse measurement. In particular we apply our scheme to image subwavelength topographies. Employing the angular spectrum representation of the scattered field, we decompose the problem into two stages: the first stage being a linear inversion for a modified object and the second a nonlinear fitting of the boundary conditions. The modified object arises as a result of intrinsic nonlinearity of the imaging problem. We apply the compressed sensing techniques to the first stage to identify the significant Fourier/wavelet modes present in the modified object. We also develop a theoretical estimate for these significant modes within a reasonable error bound. For the fitting of the boundary conditions, we consider two different approaches: the first is a local, point-by-point fitting and the second a global, nonlinear least square fitting in the Fourier/wavelet domain. We show that the compressed sensing techniques combined with the Fourier/wavelet fitting provide the best performance especially when the Rayleigh hypothesis becomes invalid.

Compactly supported shearlets: theory and applications

G. Kutyniok, J. Lernzvig, W. Lim, Univ. Osnabrück (Germany)

Many important problem classes in applied sciences are governed by anisotropic features. Shearlet analysis might by now be considered the most versatile and successful methodology to efficiently represent such features, in particular, because it allows a unified treatment of the continuum and digital realm. However, although compact support is often required for applications, most research has so far focussed on band-limited shearlets.

In this talk, we will discuss the construction of compactly supported shearlet frames for 2D and 3D data, which will be also shown to optimal sparsely approximate anisotropic features. Finally, we will present some numerical results.

Sparse image representations using discrete shearlet transform

W. Lim, G. Kutyniok, Univ. Osnabrück (Germany)

In this talk, we will talk about a new multiscale directional representation scheme called the discrete shearlet transform and its various applications in image processing.

We then briefly discuss our ongoing work to construct a compactly supported directional system which is not only a tight frame but also provides optimally sparse approximation of cartoon-like images.

Algebraic pursuits for sparse recovery in redundant frames

V. Cevher, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

We propose and analyze acceleration schemes for hard thresholding methods with applications to sparse approximation in linear inverse systems. Our acceleration schemes fuse combinatorial, sparse projection algorithms with convex optimization algebra to provide computationally efficient and robust sparse recovery methods. We compare and contrast the (dis)advantages of the proposed schemes with the state-of-the-art, not only within hard thresholding methods, but also within convex sparse recovery algorithms.

Sparse modeling with BM3D-frames in inverse imaging

A. Danielyan, V. Katkovnik, K. O. Egiazarian, Tampere Univ. of Technology (Finland)

Following the idea of BM3D filtering, we recently proposed a novel type of frames based on the non-local similarity and collaborative 3-D transform domain representation: the BM3D-frames. In this paper we review the construction and properties of BM3D-frames and demonstrate that they provide a sparse image model, which can be efficiently utilized as regularization in various inverse problems. In particular, we consider image deblurring from Gaussian and Poissonian data and super-resolution. The solution is obtained by iterative procedure which minimizes a variational functional where a maximum likelihood fidelity term is combined with a penalty on complexity of the BM3D-frame.
representation of the estimate. Simulation experiments demonstrate numerical and visual superiority of the proposed algorithms over current state-of-the-art methods confirming the advantage of the BM3D-frames as a sparse image modeling tool.

8138-40, Session 10

Root-exponential accuracy for coarse quantization of finite frame expansions
R. A. Ward, New York Univ. (United States); F. Krahmer, Univ. of Bonn (Germany); R. Saab, Duke Univ. (United States)

Signal quantization is a fundamental problem in the digital age. Viewing a signal as a real-valued vector, quantization involves replacing the vector with coefficients that are each chosen from a finite alphabet. A particularly robust quantization method using redundant finite-frame representation entails approximating a d-dimensional vector, say $x$, with an N-dimensional vector $q$, where $N > d$, taking values in a finite alphabet. The quantity $N/d$ is referred to as the oversampling ratio. In this talk, we show that by quantizing appropriate frame coefficients of signals using sigma-delta quantization schemes, it is possible to achieve root-exponential error accuracy in the oversampling rate. Previously only polynomial accuracy was shown.

8138-41, Session 10

Mask design for high-resolution optical imaging
A. Pezeshki, W. Dang, R. Bartels, Colorado State Univ. (United States)

We study the design of optical masks and the viability of single pixel imaging and compressive sampling for high resolution fluorescence microscopy. This paper is invited to the Frame Theory and Sparse Approximations session.

8138-42, Session 10

Suboptimality of nonlocal means algorithm on images with sharp edges
A. Maleki, Rice Univ. (United States)

This is based on a joint work with Richard Baraniuk and Manjari Naraya. The long history of image denoising testifies to its central importance in image processing. A wide range of denoising have been developed, ranging from simple convolutional smoothing and Wiener filtering to total variation methods and sparsity-exploiting wavelet shrinkage. One of the successful denoising approaches proposed to date is the nonlocal means algorithm. Despite the success of the nonlocal means in applications, the theoretical aspects of this algorithm have been unexplored. In this talk we explain the asymptotic risk analysis of the nonlocal means image denoising algorithm for Horizon class images that are piecewise constant with a sharp edge discontinuity. We prove that the mean-square risk of nonlocal means is suboptimal and in fact is within a $\log$ factor of the mean square risk of wavelet thresholding.

8138-43, Session 10

Spectral tetris fusion frame constructions
A. Heinecke, Univ. of Missouri-Columbia (United States)

Spectral tetris is a flexible and elementary method to derive unit norm frames with a given frame operator. One important application is the construction of fusion frames, a natural framework for performing hierarchical data processing. Fusion frames constructed by spectral tetris are desirable from a computational viewpoint as they are optimally sparse, i.e. have the maximal number of zero entries for their fusion frame operators when represented in the standard orthonormal basis. We talk about the construction of fusion frames by spectral tetris that not only have a prescribed fusion frame operator but moreover have a prescribed sequence of dimensions for their subspaces.

8138-44, Session 10

Signal recovery from notches of the spectrogram
B. G. Bodmann, C. L. Liner, Univ. of Houston (United States)

We review the effect of quasi-periodization on the short-time Fourier transform when the window function is a Gaussian. The notches, also known as zero-crossings, of an appropriately periodized short-time Fourier transform determine a signal up to an overall constant factor if the signal is band-limited and has finitely many non-zero sample values. More generally, at least approximate recovery is possible if the signal is sufficiently concentrated in time and frequency. We investigate a strategy for deconvolution based on zero-crossings, assuming that the signal has an integrable short-time Fourier transform, and additional sparseness properties.

8138-45, Session 10

Separation of data using sparse approximations
G. Kutyniok, Univ. Osnabrück (Germany); D. L. Donoho, Stanford Univ. (United States)

Modern data is customarily of multimodal nature, and analysis tasks typically require separation into the single components. Although a highly ill-posed problem, the morphological difference of these components often allows a precise separation. A novel methodology consists in applying $l_1$ minimization to a composed dictionary consisting of tight frames each sparsifying one of the components. In this talk, we will first discuss a very general approach to derive estimates on the accuracy of separation using cluster coherence and clustered/geometric sparsity. Then we will use these results to analyze performance of this methodology for images consisting of cartoons and texture.

8138-46, Session 11

Sparse methods and deformable models for improved signal and disease diagnosis
J. Huang, The Univ. of Texas at Arlington (United States); D. N. Metaxas, Rutgers, The State Univ. of New Jersey (United States)

No abstract available

8138-47, Session 11

TrackLab: ensemble of online visual trackers
M. Yang, University of California at Merced (United States)

We present an ensemble of online object tracking algorithms that we develop and provide an in-depth critical evaluation against other state-of-the-art methods. We demonstrate that the strength of weakness of these algorithms and propose mechanisms to exploit these methods for different situations.
Sparse representations for facial recognition
I. A. Kakadiaris, M. Papadakis, S. Shah, Univ. of Houston (United States)

In this talk, we review work at the UH Computational Biomedicine Lab in the area of sparse representations for Face Recognition. First, we will focus on the robust detection of facial component-landmarks (e.g., eyes, nose) in the presence of pose-illumination variations and partial occlusions. Our method utilizes a variety of adaptive descriptors combined into a cascade of boosted classifiers. These descriptors come from an ensemble of sparse representations aimed at identifying singularities whose relative joint spatial configuration characterizes each of the sought component-landmarks. Second, we will provide an overview of a method for the selection of compact and robust features for 3D face recognition. This method is based on a Markov Random Field model for the analysis of lattices and provides a measure field that estimates the probability of each vertex being “discriminative” or “non-discriminative” for a given classification task. The resulting biometric signature consists of 360 coefficients, based on which we are able to build a classifier yielding recognition rates that surpass those currently reported in the literature.

Dictionary learning and tomography
V. Etter, I. Jovanovic, M. Vetterli, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

No abstract available

On structured sparsity and selected applications in tomographic imaging
A. Pzurica, F. Bai, J. Aelterman, S. Vanloocke, H. A. Luong, Univ. Gent (Belgium); B. Goossens, Univ. Gent (United States); W. Philips, Univ. Gent (Belgium)

Signal recovery from partial information making use of sparsity priors demonstrated great potentials in signal/image processing. Recent research shows importance of encoding structured sparsity, admitting that in most but purely random signals/images not all the sparse patterns are equally likely. In this paper, we review some formulations of structured sparsity (including block sparsity and graph sparsity) and analyze their application in selected tomographic imaging modalities. In some of these modalities, like magnetic resonance imaging, “standard” compressive sensing is highly popular, but the potentials of more general structured sparsity models are yet to be explored. In others, like microwave tomography, reconstruction from highly incomplete data is typically done using heuristic regularization and we demonstrate potentials of prior models enforcing structured sparsity.

A general framework for transmission and emission tomography based on the XPAD3 hybrid pixels camera
S. Anthoine, J. Aujol, Y. Boursier, M. Clothilde, Aix-Marseille Univ. (France)

Cone Beam Computerized Tomography (CBCT) and Positron Emission Tomography (PET) Scans are medical imaging devices that require solving ill-posed inverse problems.

Accelerated parallel MR imaging with spread spectrum encoding
M. H. Izadi, G. Puy, J. R. F. Marquès, Ecole Polytechnique Fédérale de Lausanne (Switzerland); R. Gruetter, Ecole Polytechnique Fédérale de Lausanne (Switzerland) and Univ. of Geneva (Switzerland) and Univ. de Lausanne (Switzerland); J. Thiran, Ecole Polytechnique Fédérale de Lausanne (Switzerland); D. Van De Ville, Ecole Polytechnique Fédérale de Lausanne (Switzerland) and Univ. of Geneva (Switzerland); P. Vanderghynst, Ecole Polytechnique Fédérale de Lausanne (Switzerland); Y. Wiaux, Ecole Polytechnique Fédérale de Lausanne (Switzerland) and Univ. of Geneva (Switzerland)

Magnetic resonance imaging probes signals in Fourier space. Accelerating the image acquisition while preserving resolution is currently of utmost importance. Firstly, parallel imaging reduces the acquisition time by a multiple coil acquisition. Secondly, other approaches seek to reconstruct the image from incomplete Fourier coverage. In particular, the recent spread spectrum technique underpinned by the theory of compressed sensing resides in encoding the image by pre-modulation with a linear chirp before uniform random Fourier under-sampling. In the present work we advocate the combination of parallel imaging and spread spectrum in order to achieve enhanced accelerations, through simulations and real data reconstructions.

Compressed sensing in k-space: from magnetic resonance imaging and synthetic aperture radar
M. E. Davies, C. Du, S. Kelly, G. Rilling, I. W. Marshall, Y. Tao, The Univ. of Edinburgh (United Kingdom)

We will consider two imaging applications of compressed sensing where the acquired data corresponds to samples in the Fourier domain (aka k-space). The first one is magnetic resonance imaging (MRI), which has been one of the most standard examples in the compressed sensing literature. The second one is synthetic aperture radar (SAR). While the physical processes involved in these two situations are very different, in both cases in idealized conditions the raw data can be viewed as a set of lines in k-space. We will consider the similarities and differences between the two imaging modalities including: dealing with complex valued images, appropriate image models and sampling patterns and the nature and treatment of noise.
8138-55, Session 13

Compressive sensing in MRI with complex sparsification

J. Ji, Y. Dong, Texas A&M Univ. (United States)

MRI signals are inherently complex. Applications of sparsity-constrained imaging methods such as compressive sensing MRI can be enhanced by considering this fact. Specifically, complex transforms such as dual tree complex wavelet transforms can sparsify MR images better than the generic total variation operator or the real wavelet transforms. Therefore, a new method using complex sparsifications can achieve improved image reconstructions. Computer simulations and results from practical MRI applications show and characterize the advantages and limitations of the new method.

8138-56, Session 13

A novel parametric model-driven compressed sensing regularization approach for quantitative MRI from incomplete data

A. A. Samsonov, J. V. Velikina, Univ. of Wisconsin-Madison (United States)

In quantitative MRI, several source images are reconstructed from k-space data and then fit by a modeling equation to yield parametric maps. Several papers have proposed to use model to directly estimate parameters from data, or to design a dictionary for compressed sensing image estimation. Both approaches suffer from long reconstruction times and pitfalls associated with multidimensional nonlinear estimation. We propose a method incorporating model equation into iteratively-reweighted least squares for fast and robust source image estimation from incomplete data. Our method interleaves estimation with updating the sparsifying transform to conform to the physical model. The method was validated for variable flip angle T1 mapping up to 20x acceleration.

8138-57, Session 14

Blind-multichannel image reconstruction for parallel MRI using compressive sensing

H. She, R. Chen, The Univ. of Utah (United States); D. Liang, Univ. of Wisconsin-Milwaukee (United States); E. V. DiBella, H. Wan, The Univ. of Utah (United States); L. Ying, Univ. of Wisconsin-Milwaukee (United States)

In this paper we consider image reconstruction from undersampled multichannel MRI data without the prior knowledge of the coil sensitivity functions. A new technique integrating multichannel blind deconvolution (MBD) and compressive sensing (CS) is developed for joint estimation of the image function and the sensitivity functions. The method is different from the conventional MBD in that the data are undersampled and different from CS in that the sensing matrix is unknown. The method formulates the reconstruction problem as minimizing a cost function, which consists of a data consistent term and two regularization terms exploiting the sparsity of the image and coil sensitivities in the finite-difference domain respectively. Random sampling pattern was used to satisfy the incoherence requirement of CS. The cost function is a nonlinear, nonconvex function of the unknowns. Alternate minimization is used to reduce the computational complexity, where the coil sensitivities are fixed in reconstruction of the image and the image is fixed in reconstruction of the sensitivities. The process is repeated iteratively until the value of the cost function is below a certain constant. The method was evaluated using a number of datasets acquired from 3 Tesla MRI systems. Phantom and in vivo experimental results demonstrate that the proposed method can improve the reconstruction quality over the existing GRAPPA method.

8138-58, Session 14

Morphological paradigm-free mapping: getting most out of fMRI data

C. Caballero Gaudes, Univ. Hospital of Geneva (Switzerland); D. Van De Ville, Univ. Hospital of Geneva (Switzerland) and Ecole Polytechnique Fédérale de Lausanne (Switzerland); N. Petridou, Univ. Medical Ctr. Utrecht (Netherlands); F. Lazeyras, Univ. Hospital of Geneva (Switzerland); P. Gowland, The Univ. of Nottingham (United Kingdom)

Paradigm Free Mapping of the blood oxygenated-level dependent responses observed in functional magnetic resonance imaging (fMRI) studies can provide supplementary information about cortical activations in experimental scenarios where the precise timing of the responses cannot be hypothesized in advance. The presence of non-neuronal physiological and instrumental confounds makes it a challenging task. In this work, we propose a novel approach for fMRI data analysis that decomposes the voxel time series into its morphological components: movement-related signals, low-frequency instrumental drifts, physiological fluctuations, neuronal-related haemodynamic signal and thermal random noise. Our algorithm is based on an overcomplete representation of the time series with an additive linear model. Specifically, each component can be represented with a distinctive morphological dictionary, and the signal’s representation is recovered by means of a least-squares estimator, which is regularized by the L1-norm of the coefficients in the activity-related dictionary. Similar to morphological component analysis, an adapted block coordinate relaxation procedure is used to automatically separate these additive components. We first show results using simulated data as a proof-of-concept, showing promising results in terms of the estimation of the components and robustness against mismatches in the assumed haemodynamic response model, and next we illustrate the feasibility for experimental data acquired on a 7T MR scanner. We envision that this decomposition approach will become more useful with the widespread use of ultra-high-field MR systems and adds an exciting new possibility for exploratory analysis of fMRI data situated between conventional general-linear-model fitting and relatively unconstrained approaches such as independent component analysis.
To accelerate magnetic resonance (MR) imaging, the frequency domain (k-space) is undersampled in the phase encoding directions; however, uniform undersampling in the frequency domain results in aliasing in the spatial (image) domain. To mitigate aliasing, multiple receiver coils measure k-space in parallel, each with different spatial weightings, and the missing k-space data is recovered using GRAPPA, a parallel imaging method that utilizes linear combinations (a convolution kernel) of those different spatial weightings to approximate the necessary frequency shifts. However, the combination of undersampling and parallel imaging produces images with significantly reduced SNR; this SNR loss needs to be mitigated to accommodate further acceleration. Compressed sensing (CS) is one approach to de-noising sparse images. Because MR images are known to be approximately sparse in transform domains like the DWT, and incoherent sampling is easily accomplished in k-space, CS can be applied to the problem of de-noising images produced from undersampled MR data. In this work, the GRAPPA method is modified to choose the linear combination weights to produce sparse full k-space images. The optimization problem regularizes the least-squares fit of ACS lines using a nonconvex simultaneous sparsity penalty function of the coil images resulting from the GRAPPA reconstruction using the kernel. Relative to GRAPPA alone, this approach improves the RMSE of images reconstructed from highly undersampled data.

8138-35, Session 15

**Learned dictionaries for sparse image representation: properties and results**

K. Skretting, K. Engan, Univ. of Stavanger (Norway)

Sparse representation of images using learned dictionaries have been shown to work well for applications like image denoising, inpainting, image compression, etc. In this paper dictionary properties are reviewed from a theoretical approach, and experimental results for learned dictionaries are presented. The main dictionary properties are the upper and lower frame (dictionary) bounds, and (mutual) coherence properties based on the angle between dictionary atoms. Both L0 sparsity and L1 sparsity are considered by using a matching pursuit method, order recursive matching Pursuit (ORMP), and a basis pursuit method, i.e. LARS or Lasso. For dictionary learning the following methods are considered: Iterative least squares (ILS-DLA or MOD), recursive least squares (RLS-DLA), K-SVD and online dictionary learning (ODL). Finally, it is shown how these properties relate to an image compression example.

8138-60, Session 15

**Blind compressed sensing over a union of subspaces**

J. Silva, Duke Univ. (United States)

We address simultaneous signal recovery and dictionary learning based on compressive measurements. Multiple signals are analyzed jointly, with multiple sensing matrices, under a union-of-subspaces assumption. This problem is important, e.g., in image inpainting applications. One of our main contributions is that we consider compressive measurements; previous work on Blind Compressed Sensing is also extended by considering multiple sensing matrices and relaxing restrictions on the dictionary. Conditions are given for recovery of the dictionary and signals with high probability. Additionally, a practical algorithm is presented, and convergence conditions are defined. Experimental results for image inpainting demonstrate the capabilities of the algorithm.

8138-61, Session 15

**Topographic dictionary learning with structured sparsity**

J. Mairal, Univ. of California, Berkeley (United States); R. Jenatton, G. Obozinski, F. Bach, Institut National de Recherche en Informatique et en Automatique (France)

We consider the problem of dictionary learning for data admitting sparse representation, and exploit structured sparsity for modeling dependencies between dictionary elements. To achieve this goal, we regularize the decomposition coefficients of input signals with a group-sparsity penalty where the groups overlap, and present several algorithmic tools to solve the corresponding challenging optimization problems. Our method is flexible enough to efficiently handle any group structure. In particular, when learned on natural image patches and with groups organized on a 2D-grid, the dictionary elements naturally organize themselves on a topographic map, producing similar results as topographic ICA.

8138-62, Session 15

**Design of a tight frame of 2D shearlets-based on a fast non-iterative analysis and synthesis algorithm**

B. Goossens, J. Aelterman, H. A. Luong, A. Pˇzurica, W. Philips, Univ. Gent (Belgium)

The shearlet transform is a recent sibling in the family of geometric image representations that provides a traditional multiresolution analysis combined with a multidirectional analysis. In this paper, we present a fast DFT-based analysis and synthesis scheme for the 2D discrete shearlet transform. Our scheme conforms to the continuous shearlet theory to high extent, provides numerical perfect reconstruction (up to floating point rounding errors) in a non-iterative scheme and is highly suitable for parallel implementation (e.g. FPGA, GPU). We show that our discrete shearlet representation also is a tight frame and the redundancy factor of the transform is around 2.6, independent of the number of analysis directions. Experimental denoising results indicate that the transform performs the same or even better than several related multiresolution transforms, while having a significantly lower redundancy factor.

8138-63, Session 15

**A diagonally-oriented DCT-like 2D block transform**

I. W. Selesnick, Polytechnic Institute of NYU (United States); O. G. Guleryuz, DoCoMo Communications Labs. USA, Inc. (United States)

Due to the prevalence of edge content in images, various directional transforms have been proposed for the efficient representation of images. Such transforms are useful for coding, denoising, and image restoration using sparse signal representation techniques. This paper describes a new non-separable 2D DCT-like orthonormal block transform that is oriented along block diagonals (45 degrees). The approach taken in this paper is to extend to two-dimensions one approach (of several) for constructing the standard 1D DCT. The proposed transform is obtained as the eigenvectors of particular matrices, as is the standard 1D DCT.
RF transient classification using sparse representations over learned dictionaries

D. I. Moody, Los Alamos National Lab. (United States) and Univ. of Maryland (United States); S. P. Brumby, K. L. Myers, N. H. Pawley, Los Alamos National Lab. (United States)

Automatic classification of transient radio frequency (RF) signals is of particular interest in persistent surveillance applications. Because such transients are often acquired in noisy, cluttered environments, and are characterized by complex or unknown analytical models, feature extraction and classification can be difficult. We propose a fast, adaptive classification approach based on non-analytical dictionaries learned from data. Conventional representations using fixed (or analytical) orthogonal dictionaries, e.g., Short Time Fourier and Wavelet Transforms, can be suboptimal for classification of transients, as they provide a rigid tiling of the time-frequency space, and are not specifically designed for a particular signal class. They do not usually lead to sparse decompositions, and require separate feature selection algorithms, creating additional computational overhead. Pursuit-type decompositions over analytical, redundant dictionaries yield sparse representations by design, and work well for target signals in the same function class as the dictionary atoms. The pursuit search however has a high computational cost, and the method can perform poorly in the presence of realistic noise and clutter. Our approach builds on the image analysis work of Mairal et al. (2008) to learn a discriminative dictionary for RF transients directly from data without relying on analytical constraints or additional knowledge about the signal characteristics. We then use a pursuit search over this dictionary to generate sparse classification features. We demonstrate that our learned dictionary is robust to unexpected changes in background content and noise levels. The target classification decision is obtained in almost real-time via a parallel, vectorized implementation.

Tight frame 6-band symmetric wavelets with limited redundancy

F. Abdelnour, Univ. of Pittsburgh Medical Ctr. (United States)

We consider the design of 6-channel tight frame (TF) symmetric wavelet with scaling factor M=4. While orthogonal symmetric filterbanks with M=4 exist, the additional degrees of freedom resulting from relaxing the orthogonality condition lead to smoother limit functions with improved frequency resolution. Moreover, frames have been shown to perform better than the critically sampled counterparts for such applications as noise removal. There has been interest in frame-based wavelets. While a majority of published work on wavelet frames design has focused on the case M = 2, it is possible to design frames with other scaling factors. For example, in earlier work wavelets based on 6-channel tight frame with M = 4 nonsymmetric filterbanks are designed using Groebner basis. In addition to improved frequency resolution, frames with M = 4 offer a reduced redundancy for the same number of filters. Such filterbanks offer design flexibility, allowing additional degrees of freedom and desirable properties such as smoothness of underlying limit functions when compared with their orthogonal counterparts, symmetry, and dense time-frequency plane.

In this paper we design a 6-channel tight-frame symmetric filterbank \{h0, h1, h2, h3, h4, h5\} using Groebner basis methods. The resulting filters have linear phase, limited redundancy, and smooth limit functions. It was possible to obtain filterbanks with KO (zeros at z = -1 and z = j\) for the lowpass filter) up to 5 and Kmin (zeros at z = 1 for bandpass/highpass filters) of 1 or greater. The paper elaborates on the theory of the wavelets based on tight frame with scaling factor of 4, describes the design process, and discusses filterbank design examples.

Sparse signal representations using the tunable Q-factor wavelet transform

I. W. Selesnick, Polytechnic Institute of NYU (United States)

The tunable Q-factor wavelet transform (TQWT) is a fully-discrete wavelet frame for which the Q-factor, Q, of the underlying wavelet and the redundancy, R, of the transform are easily and independently specified. In particular, the specified parameters Q and R can be real-valued. Therefore, by tuning Q, the oscillatory behavior of the wavelet can be chosen to match the oscillatory behavior of the signal of interest, so as to enhance the sparsity of a sparse signal representation. We demonstrate the sparse representation of several oscillatory signals using the TQWT. The TQWT is well suited to fast algorithms for sparsity-based inverse problems because it is a Parseval frame, easily invertible, and can be efficiently implemented using radix-2 FFTs. The TQWT can also be used as an easily-invertible discrete approximation of the continuous wavelet transform.

Parallel magnetic resonance imaging using multichannel sampling theory and beyond

L. Ying, Univ. of Wisconsin-Milwaukee (United States); Z. Liang, Univ. of Illinois at Urbana-Champaign (United States)

Parallel imaging using phased array coils has emerged as a technique to significantly speed up the magnetic resonance imaging process. In this talk, we describe parallel MRI from a signal processing perspective, invoking the multichannel sampling theory (and filter bank theory). We discuss some outstanding practical issues and present our recent development in sampling schemes and reconstruction algorithms to address these issues.
classification. This paper proposes a novel compressed sensing based resting-state fMRI analysis tool called Sparse-SPM. Sparse-SPM is a new spatially adaptive data-driven fMRI analysis method that implements sparse dictionary learning based on sparsity of the signal instead of independence. From individual and group analysis, the proposed approach shows better performance compared to other conventional methods, such as ICA and seed-based approach, in classifying the AD patients from normal using resting-state analysis.

However, many other representations are obtained within this framework, where directionally properties are controlled by different types of orthogonal matrices, such as the newly defined hyperbolets. For this talk, we show how to take advantage of different wavelets with composite dilations to sparsely represent important features in an image, and then use a hybrid thresholding method to obtain improved estimates from noisy observations.

8138-70, Session 18

3D discrete shearlet transform and video denoising
D. Labate, P. Negi, Univ. of Houston (United States)

The shearlet representation, a multiscale pyramid of well-localized waveforms defined at various locations and orientations, was recently proved to provide optimally sparse representations for a large class of 3D data. In this paper, we present the first discrete numerical implementation of the 3D shearlet transform. The algorithm combines a cascade of multiscale decomposition with a stage of directional filtering, based on the use of Pseudopolar FFT. The filters resulting from this decomposition can be implemented as finite-length filters, which ensures that the numerical implementation is highly efficient. To demonstrate the capability of the 3D Discrete Shearlet Transform, we consider a number of problems from video denoising. The performance of the algorithm is successfully compared against other state-of-the-art multiscale denosing techniques, including curvelets and surfacelets.

8138-71, Session 18

Efficient multiscale and multidirectional representation of 3D data using the 3D discrete shearlet transform
B. Goossens, H. A. Luong, J. Aelterman, A. P?urica, W. Philips, Univ. Gent (Belgium)

In recent years, there has been a lot of interest in multiresolution representations that also perform a multidirectional analysis. These representations often yield very sparse representation for multidimensional data. The shearlet representation, which has been derived within the framework of composite wavelets, can be extended quite trivially from 2D to 3D. However, the extension to 3D is not unique and consequently there are different implementations possible for the discrete transform. In this paper, we investigate the properties of two relevant designs having different 3D frequency tilings. We show that the first design has a redundancy factor of around 7, while in the second design the transform can attain a redundancy factor around 3.5. Independent of the number of analysis directions. Due to the low redundancy, the 3D shearlet transform becomes a viable alternative to the 3D curvelet transform. Experimental results are provided to support these findings.

8138-72, Session 18

Multi-composite wavelet estimation
G. R. Easley, System Planning Corp. (United States); D. Labate, Univ. of Houston (United States); V. M. Patel, Univ. of Maryland, College Park (United States)

In this work, we present a new approach to image denoising derived from a general representation known as wavelets with composite dilations. These representations extend the traditional wavelet framework by allowing for waveforms to be defined not only at various scales and locations but also at various orientations. The shearlet representation is, perhaps, the most widely known example of composite wavelets.
8139-01, Session 1

**Micro- and nano-focusing system at Japanese XFEL**

H. Mimura, The Univ. of Tokyo (Japan); M. Yabashi, RIKEN (Japan); H. Ohashi, Japan Synchrotron Radiation Research Institute (Japan) and RIKEN (Japan); H. Yumoto, Japan Synchrotron Radiation Research Institute (Japan); H. Yokoyama, S. Imai, T. Kimura, S. Matsuyama, Osaka Univ. (Japan); Y. Hachisui, H. Ohmori, RIKEN (Japan); K. Yamauchi, Osaka Univ. (Japan); T. Ishikawa, RIKEN (Japan)

Focusing system is very important for various applications at X-ray free electron laser facilities, because extremely intense X-ray laser beam is realized. In Japan, the XFEL facility will be completed at SPring-8 site this year. We are now developing focusing system specialized for Japanese XFEL. In this presentation, we will introduce the overview of the design and performances of the focusing optical system.

This presentation includes optical simulation for design of optical system, fabrication of focusing mirrors and development of focusing units.

8139-02, Session 1

**Nested KB mirror fabrication for synchrotron hard x-ray nano-focusing**

B. Shi, W. Liu, C. Liu, J. Qian, K. Ruben, A. M. Khounsary, P. Zachack, Argonne National Lab. (United States); J. Z. Tischler, G. E. Ice, Oak Ridge National Lab. (United States); L. Assoufid, Argonne National Lab. (United States)

A pair of traditional KB mirrors consists two concave mirrors arrange perpendicular to each other at separate positions. A pair of nested (or Montel [1]) KB mirrors also consists two concave mirrors perpendicular to each other, but standing side by side. Compared to traditional KB mirrors, nested KB mirrors can give more working space, collect larger divergence [2], and give a higher demagnification [3]. Although nested KB mirrors collected less x-ray flux than traditional KB mirrors, nested KB mirrors are capable of deliver a higher x-ray flux by enabling more efficient collecting of x-rays and wide energy range x-ray beam compared with other micro/nano focusing x-ray mirrors.

We report the fabrication method of our nested platinum KB mirrors for synchrotron hard x-ray micro/nano focusing system. The first set of nested KB mirrors includes two 40 mm mirrors fabricated by depositing Pt on the Si substrate using the magnetron sputtering technique. The beamline tests have been performed and an about 150 mm x 150 mm focus spot was achieved [3]. Due to the gap between the nested KB mirrors, which caused the less efficiency, a second pair of KB mirrors was fabricated and one side of the horizontal focusing mirror was cut and polished to reduce the gap. This pair of nested KB mirrors have been tested and results the gap has been narrowed from 10 microns to 3 microns.

References


* This work is supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

8139-03, Session 1

**A dynamically-figured mirror system for high energy nanofocusing at the ESRF**


The design, manufacture and characterisation of a Kirkpatrick-Baez (KB) configuration mirror system for high-throughput nanofocusing down to 50 nm beam sizes are described. To maximize the system aperture whilst retaining energy tunability, multilayer coated optics are used in conjunction with 2 dynamically figured mirror benders. This approach, which has been developed at the ESRF for many years, allows the focusing performance to be optimized when operating the system in the 13-25 keV photon energy range.

Developments in the key technologies necessary for the production of mirror bending systems with dynamic figuring behaviour close to the diffraction limit requirements are discussed. These include system optimisation via finite element analysis (FEA) modelling of the mechanical behaviour of the bender-mirror combination, manufacturing techniques for precisely-shaped multilayer substrates, multilayer deposition with steep lateral gradients and the stitching metrology techniques developed for the characterisation and figure optimisation of the strongly aspherical surfaces. The mirror benders have been integrated into a compact and stable assembly designed for routine beamline operation and results of the initial performance of the system at photon energies up to 29keV at the ESRF ID22NI endstation will be presented.

8139-04, Session 1

**Development of hard x-ray imaging optics with four aspherical mirrors**

S. Matsuyama, N. Kidani, Osaka Univ. (Japan); H. Mimura, The Univ. of Tokyo (Japan); Y. Sano, Osaka Univ. (Japan); K. Tamasaku, Y. Kohmura, M. Yabashi, T. Ishikawa, RIKEN (Japan); K. Yamauchi, Osaka Univ. (Japan)

To realize achromatic full-field X-ray microscopy with a spatial resolution less than 50 nm, we have developed a total reflection mirror system with two pairs of an elliptical mirror and a hyperbolic mirror, which is called “an Advanced Kirkpatrick-Baez system”. A designed optical system has 200x and 300x magnifications in vertical and horizontal directions. The four mirrors with a figure accuracy of 2 nm were fabricated using elastic emission machining (EEM), microstitching interferometry (MSI) and relative-angle-determinable stitching interferometry (RADS). One-dimensional tests for forming a deformed image of a slit were carried out at an X-ray energy of 11.5 keV at BL29XUL (EH2) of SPring-8. As a result, a sharp beam with a FWHM of 43 nm was observed. Also, an obtained width of a field of view was 12 micron in the region of a resolution better than 50 nm. For two-dimensional (2D) imaging, we have developed a mirror manipulator with autocollimators and laser displacement meters. As a preliminary 2D test, an approximately 300-nm resolution in 2D was obtained. The poor result was caused by misalignments. We’ll perform a 2D imaging test, in which we use the improved mirror manipulator, in this April. We’ll present the results of 2D imaging in the meeting.
Automated in-situ optimisation of bimorph mirrors at Diamond Light Source

J. P. Sutter, S. G. Alcock, K. J. S. Sawhney, Diamond Light Source Ltd. (United Kingdom)

Bimorph mirrors are used on synchrotron beamlines throughout the world to focus or collimate light. They minimise wavefront distortion by permitting not only the overall figure, but also the local slope errors, to be corrected using varying voltages on the individual electrodes. However, the optimisation procedure is complex, requiring both accurate in-situ measurement of the slope errors and quick calculation of the voltage corrections. The first has been achieved using a simple custom-built “X-ray eye” to gather data by the pencil beam method already used on ex-situ slope measuring profilers. The second has been achieved using Jython scripts that calculate the voltages by the well-known interaction matrix method. In-situ data are highly repeatable and in good agreement with ex-situ data collected at the Diamond NOM. These procedures may be applied to any type of active mirror and to static optics as well. Diffraction from the incident slits is shown to limit the spatial resolution of the pencil beam method in the hard X-ray case.

At-wavelength metrology and diffraction-limited focusing of bendable soft x-ray KB mirrors


Realizing the full experimental potential of high-brightness, next generation synchrotron and free-electron laser light sources requires the development of reflecting x-ray optics capable of brightness preservation, and high-resolution nano-focusing. At the Advanced Light Source (ALS) beamline 5.3.1, we are developing broadly applicable, high-accuracy, in situ, at-wavelength wavefront measurement techniques to surpass 100-nrad slope measurement accuracy for diffraction-limit Kirkpatrick-Baez (KB) mirrors.

The at-wavelength methodology we are developing relies on a series of wavefront-sensing tests with increasing accuracy and sensitivity, including scanning-slit Hartmann tests, grating-based lateral shearing interferometry, and quantitative knife-edge testing. We will describe the original experimental techniques and alignment methodology that have enabled us to optimally set a bendable KB mirror to achieve a focused, FWHM spot size of less than 150 nm, with 1 nm (1.24 keV) photons at 3.3 mrad numerical aperture. The predictions of wavefront measurement are confirmed by the knife-edge testing.

The side-profiled elliptically bent mirror used in these one-dimensional focusing experiments was originally designed for a much different mrad numerical aperture. The predictions of wavefront-sensing tests with increasing accuracy and sensitivity, including scanning-slit Hartmann tests, grating-based lateral shearing interferometry, and quantitative knife-edge testing. We will describe the original experimental techniques and alignment methodology that have enabled us to optimally set a bendable KB mirror to achieve a focused, FWHM spot size of less than 150 nm, with 1 nm (1.24 keV) photons at 3.3 mrad numerical aperture. The predictions of wavefront measurement are confirmed by the knife-edge testing.

A double multilayer monochromator for the B16 Test beamline at the Diamond Light Source

K. J. S. Sawhney, I. P. Dolbnya, S. M. Scott, Diamond Light Source Ltd. (United Kingdom); M. K. Tiwari, Raja Ramanna Ctr. for Advanced Technology (India); G. M. Preece, S. G. Alcock, A. W. Malandain, Diamond Light Source Ltd. (United Kingdom)

The B16 Test beamline has been built at the 3-GeV Diamond Light Source, and it is in user operation since January 2008. It has been recently upgraded with the addition of a double multilayer monochromator (DMM), which provides further functionality and versatility to the beamline. The multilayer monochromator is equipped with two pairs of multilayer optics (Ni/B4C and Ru/B4C) to cover the wide photon energy range of 2 - 20 keV, with good efficiency. The DMM provides a broad bandpass / high flux operational mode for the beamline and, when used in tandem with the Si 111 double crystal monochromator, it gives a very high higher-order harmonics suppression. The design details of the DMM and the first commissioning results obtained using the DMM will be presented.

Interface diffusion kinetics and lifetime scaling in multilayer Bragg optics

R. W. E. van de Kruijjs, S. Bruijn, A. E. Yakshin, FOM-Institute for Plasma Physics Rijnhuizen (Netherlands); F. Bijkerk, FOM-Institute for Plasma Physics Rijnhuizen (Netherlands) and Univ. Twente (Netherlands)

Multilayer reflective coatings play an enabling role in the development of optics for the EUV wavelength range. This holds in particular for applications in solar telescopes, x-ray free electron lasers, and EUV photolithography. In general, these applications all demand stable optics performance over long lifetimes and therefore allow no changes to occur in the internal multilayer structure. In reality, internal changes in the multilayer structure will occur by means of radiation absorption, or more in general, by thermal load of the optical system.

We show that for Mo/Si multilayers, the internal structure changes under thermal load due to thermal diffusion induced dense interface layer growth, reducing the optical contrast and changing the reflected wavelength. We focus on early-stage diffusion behavior at relatively low temperatures, where MoSi2 silicide interface growth clearly follows a scaling law from which diffusion constants for the system can be obtained. Arrhenius plots show temperature scaling with a single activation energy, with activation energy depending on the exact nature
of the interface being formed. Using Arrhenius analysis, the diffusion constants in a multilayer system can be predicted at specific application temperatures, which allows for accurate optics thermal lifetime prediction.

Using the methods developed, we compared Mo/Si based multilayer coatings with different diffusion barriers, aimed at improving thermal stability, and discuss their relevance to optics performance and optics lifetime. The method described here is of general interest for any multilayer application that is subjected to enhanced thermal loads and represents the enormous technology gain that this type of optics has experienced in the last decade.

8139-10, Session 2
Ultra-dense multilayer-coated diffraction gratings for EUV and soft x-rays
D. L. Voronov, E. H. Anderson, R. Cambie, S. Cabrini, S. D. Dhuey, Lawrence Berkeley National Lab. (United States); L. I. Goray, Russian Academy of Sciences for Research and Education (Russian Federation); E. M. Gullikson, F. Salmassi, T. Warwick, V. V. Yashchuk, H. A. Padmore, Lawrence Berkeley National Lab. (United States)
Diffraction gratings with high efficiency and high groove density are required for EUV and soft x-ray spectroscopy techniques (such as Resonant Inelastic X-ray Scattering, RXS) designed for state-of-the-art spectral resolution and throughput. We report on recent progress achieved at the Advanced Light Source (ALS) in development of ultra-dense multilayer coated blazed (MBG) gratings. In order to fabricate a high quality MBG grating, one should address two main challenges. The first one is to fabricate nano-period saw-tooth substrates with perfect groove profile and atomically smooth surface of the blazed facets. The second challenge relates to uniformed deposition of a multilayer on a highly corrugated surface of the substrates. We show that the required saw-tooth substrates with groove density up to 10,000 lines/mm can be fabricated using high resolution interference and e-beam lithography techniques followed by wet anisotropic etching of silicon. Peculiarities of growth on the saw-tooth substrates of a variety of multilayers, optimized to provide high diffraction efficiency in EUV wavelength range, are also under thorough investigation. With cross-sectional TEM we reveal a transformation of the structure of the multilayer stack, consisting in smoothing of the groove profile of a coated grating. The multilayer profiles measured with the TEM are used for diffraction efficiency simulations and investigation of the impact of the smoothing on grating performance. Thus, we show that a strong smoothing of the grating grooves results in deterioration of the blazing ability of the gratings. This work was supported by the US Department of Energy under contract number DE-AC02-05CH11231.

8139-11, Session 2
Development of super mirrors for high-resolution x-ray LMJ microscopes
P. Troussel, D. Dennetiere, R. Rosch, C. Reverdin, L. Hartmann, Commissariat à l’Energie Atomique (France); F. Bridou, E. Melchakov, F. Delmotte, Lab. Charles Fabry de l’Institut d’Optique (France)
With regards of Laser Mégajoule (LMJ) facility, our laboratory is developing advanced High Resolution X-ray Imaging (HRXI) microscopes. Shrapnel and X-ray loading on this laser imposed to place any HRXI as far away from the source as possible. Grazing incidence X-ray microscopes are the best solution to overpass this limitation. We have designed imaging diagnostics, with a long working distance (> 50 cm) and high resolution. All of them are composed of multi-toroidal mirrors. The microscopes reflect x-rays up to 10 keV using non-periodic multilayer coatings (Super mirrors).

We present these W/SiC Super mirrors, developed in collaboration with the LCFIO. The mirrors were designed and optimized with home made calculation code. Super mirrors are dedicated to work at 0.7° grazing incidence using a reflectivity above 35 %. Metrology for x-ray reflectance in the all range on the synchrotron radiation facility BESSY II is presented. We have also implemented this coating on a Wolter-like microscope working at a different grazing incidence (0.6°) in order to increase the band pass of reflectivity until 20 keV. We display a reflectivity better than 35 %. Potentialities of this HRXI microscope are presented.

8139-12, Session 3
Total-reflection zone plate as a new device for x-ray nanofocusing
H. Takano, Univ. of Hyogo (Japan); T. Tsuji, Univ. of Hyogo (Japan) and Japan Synchrotron Radiation Research Institute (Japan); Y. Kagoshima, Univ. of Hyogo (Japan)
X-ray focusing beam has important potential to give most of conventional x-ray analytical procedures a high spatial resolution with a high flux density. The x-ray focusing techniques have been dramatically improved according to development of synchrotron radiation sources and focusing optics. Focusing mirrors with graded multilayer reflector and multilayer Laue lenses are the typical focusing devices to lead the best performances of focusing in the x-ray region. These devices, however, require ultra-high precision techniques for their fabrication. When x-rays are incident to a zone pattern on a flat substrate with a glancing angle satisfying total reflection condition to zone material, and when the x-rays reflected and diffracted by the zones make focus as well as Fresnel zone plate, the focal size is determined not by the smallest fabricated size of zone on substrate but by that of effective zone size reduced by the glancing view effect. Therefore, high focusing performance can be expected although fabrication of the focusing device is relatively easy to the other x-ray devices. We have developed the focusing device as a total-reflection zone plate (TRZP) for hard x-ray nanofocusing. The TRZP with the finest zone width of 700 nm, fabricated by conventional electron beam lithography, could focus 10 keV x-rays to 14.4-nm size.

In the presentation, theoretical and practical focusing limit of TRZP will be discussed. And advanced types for high efficiency using laminar grating structure and for point focusing using a conical substrate will be suggested as further approaches.

8139-13, Session 3
Characterization of a 20-nm hard x-ray focus by ptychographic coherent diffractive imaging
J. Vila Comamala, A. Díaz, M. Guizar-Sicairos, Paul Scherrer Institut (Switzerland); A. Mantion, Bundesanstalt für Materialforschung und -prüfung (Germany); C. M. Kewish, Synchrotron SOLEIL (France); V. A. Guzenko, O. Bunk, C. David, Paul Scherrer Institut (Switzerland)
Recent advances in the fabrication of diffractive X-ray optics have demonstrated the focusing of hard X-rays to focal spots below 30 nm. However, the characterization of these novel devices is not straightforward using conventional methods such as knife edge scans or by using test objects that are previously known. Here, we have used ptychographic scanning coherent diffractive imaging to characterize a 20 nm-wide X-ray focus produced by Fresnel zone plate at a photon energy of 6.2 keV. An ordinary scanning transmission X-ray microscope was modified to perform the ptychographic scans on a test object. The ptychographic algorithms allowed the reconstruction of the image of the test object as well as the 3D reconstruction of a focused hard X-ray beam waist, with high spatial resolution and dynamic range. The technique was used to characterize state-of-the-art zone-doubled Fresnel zone plates that were expected to concentrate the X-ray beams into focal...
spots below 25 nm in size. The reconstructed wavefields confirm that the zone-doubled diffractive lenses were focusing the incoming radiation into spots as small as 20 nm. This method yields a full description of the focusing field at any propagation distance, including wavefront aberrations at the plane of the lens, and demonstrates its usefulness for metrology and alignment of nanofocusing X-ray optics. It is very robust against the longitudinal position of the sample, and requires no previous knowledge of the test object.

8139-14, Session 3
Coherent high-resolution x-ray microscopy for mesoscopic photonic crystals
I. I. Snigireva, A. A. Snigirev, European Synchrotron Radiation Facility (France)

We developed a high-resolution transmission X-ray microscopy (HRTXM) technique, based on the use of parabolic refractive lenses. The immediate benefit of a lens-based approach is the possibility to retrieve the Fraunhofer diffraction pattern and real-space images in the same experimental setup. This approach is methodologically similar to the traditional method of studying crystalline samples with high-resolution transmission electron microscopy.

The HRTXM experiment was carried out at the micro-optics test bench of beamline ID06. X-rays from 10 to 20 keV were used. The setup consists of condenser - used for sample illumination in imaging mode and as Fourier transformer in diffraction mode, the tunable objective lens and two (large area and high resolution) CCD detectors. At maximum magnification, a resolution of ~100 nm was achieved. We demonstrate the applicability of the HRTXM approach to volume-specific studies of periodic mesoscopic structures, such as natural and artificial opals and inverted photonic crystals.

Short acquisition times with modern area detectors allow the method to be extended to time-resolved studies and combined 3-D real/reciprocal space mapping. Characterization of the real crystal structure during photonic crystal growth is an example of a practical application of this new technique.

8139-15, Session 3
Revisiting the “forgotten” first zoomable refractive x-ray lens
W. H. Jark, Sincrotrone Trieste S.C.p.A. (Italy)

Did anybody ever ask the question: Will I get an x-ray focus, when I operate a Kirkpatrick-Baez mirror pair beyond the critical angle for total reflection?

The first, who could do so, P.Kirkpatrick, already gave an affirmative answer. Infact such a system of two crossed concave lenses can produce an x-ray focus as well. The result was published (P. Kirkpatrick, JOSA 39, 796 (1949)), patented (US 2,559,972) and then it was mostly forgotten. This latter fate is understandable as the system has a rather small effective aperture, limited by significant absorption. This contribution would like to discuss whether the device can today provide more interesting properties in combination with more recent developments in the field of x-ray research. First it will be shown, that the object properties can now be predicted more easily in the framework of the theory for refractive x-ray lenses. Related experimental data will be presented. And finally possible applications will be discussed.

8139-16, Session 4
Commissioning status of XFEL facility at SPring-8
M. Yabashi, K. Tono, RIKEN (Japan); T. Togashi, RIKEN (Japan) and Japan Synchrotron Radiation Research Institute (Japan); T. Sato, Y. Inubushi, RIKEN (Japan); K. Takeshita, S. Takahashi, H. Kimura, H. Ohashi, S. Goto, RIKEN (Japan) and Japan Synchrotron Radiation Research Institute (Japan); T. Hatsui, T. Tanaka, H. Tanaka, T. Ishikawa, RIKEN (Japan)

An XFEL facility in Japan has been constructed from FY2006 to FY2010 at the SPring-8 campus by a joint project team of RIKEN and JASRI. The facility will provide high-quality XFEL radiation above 10 keV with a moderate acceleration energy of 8 GeV. After successful construction of the facility, we have observed the first electron beam in February 21th of 2011. We will start full commissioning towards stable lasing in April. I will introduce the commissioning status and perspective on development of XFEL applications and instrumentation.

8139-17, Session 4
Upgrade status of hard x-ray 100-nm probe beamlines BL37XU and BL39XU at SPring-8
T. Koyama, H. Yumoto, Y. Terada, M. Suzuki, N. Kawamura, M. Mizumaki, N. Nariyama, T. Matsushita, Y. Ishizawa, Y. Furukawa, T. Ohata, H. Yamazaki, T. Takeuchi, Y. Senba, Y. Matsuizaki, M. Tanaka, Y. Shimizu, H. Kishimoto, T. Miura, K. Takeshita, Japan Synchrotron Radiation Research Institute (Japan); H. Ohashi, Japan Synchrotron Radiation Research Institute (Japan) and RIKEN (Japan); M. Yamamoto, RIKEN (Japan); S. Goto, M. Takata, Japan Synchrotron Radiation Research Institute (Japan) and RIKEN (Japan); T. Ishikawa, RIKEN (Japan)

Under the government project aimed at creating a low-carbon society, a trace element analysis beamline BL37XU and a magnetic materials beamline BL39XU at SPring-8 have been upgraded to provide nano-probe analysis to their users and scheduled to start operation in May 2011.

In order to realize nanobeam analysis, we constructed new experimental hutchs which are located about 80 m from the light source, and designed and will install Kirkpatrick-Baez (KB) mirrors and corresponding manipulators. By taking advantage of extended beamline, high demagnification optical design is available. Therefore nanofocusing beam with relatively long working distance and high photon flux density is feasible. Furthermore, liquid-nitrogen cooled Si double crystal monochromators, which were improved to low vibration, were employed in place of existing monochromators.

Designed KB mirror parameters are shown as follows. A targeted focusing beam size and a photon flux density were designed to be 100 nm and over 1 × 10^10 (photons/sec/100×100nm^2). Mirror lengths were designed to be 300 mm (vertical focusing mirror) and 200 mm (horizontal focusing mirror). Focal lengths were designed to be 460 mm (V) and 200 mm (H). A working distance was designed to be 100 mm. Aperture acceptance areas of mirrors were designed to be about 1 mm (V) x 0.7 mm (H). A coating material was adopted to be Rh for a high X-ray reflectivity up to 15 keV. In order to reduce the mechanical vibration and the thermal drift, mirror manipulators are set up onto a granite table with a thickness of 700 mm and a weight of over 2800 kg, and a temperature of new experimental hutchs are planned to control precisely within ±0.05 degree.

In this paper, we report current status of these beamlines.

8139-18, Session 5
Characterization of the FERMI@Elettra's online energy spectrometer
FERMI@Elettra is a the Free Electron Laser (FEL) under commissioning at Synchrotrone Trieste. It will provide a fully coherent and transform limited radiation with a very high brilliance in the VUV/Soft X-ray range. The first part of the photon transport system, aimed to deliver the radiation into the experimental chambers, is dedicated to the beam diagnostic.

This section, called PADReS (Photon Analysis, Delivery and Reduction System) includes the Beam Defining Apertures, Beam Position Monitors, Intensity Monitors, Photon Energy Spectrometer and the transversal coherence measurement system. All the diagnostic will be not invasive and shot to shot with the only exclusion of the transversal coherence measurement. Among these, the photon energy spectrometer is an essential instrument to aid the machine physicist to properly set up the insertion devices as well as to characterize the photon pulses energy distribution during the experiments with sub-meV resolution. In this article we describe the working principles of the Variable Line Spacing (VLS) diffraction gratings applied to the spectrometer as well as the design concept and ray tracing and efficiency simulations. Metrological results of the optics involved and the first characterization results with FEL radiation will be shown. A comparison between the simulated performances and the first data obtained with real radiation will be presented too.

8139-19, Session 5

Heydemann interpolation correction for energy linearisation of soft x-ray monochromators

J. Krempasky, U. Fleischig, P. Oberta, Paul Scherrer Institut (Switzerland); R. Follath, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (Germany)

Material science research in the soft-x-ray regime at the Swiss Light source accommodates five beam lines where the monochromators rely on in-vacuum angular encoders for positioning mirror and gratings. Despite the factory-calibration of the quadrature signals from these rotary encoders, the energy linearization for spectroscopic data requires accurate calibration of the encoder quadrature signals. We discuss the application of the Heydemann correction algorithm for the quadrature signals and compare the linearized angular readout with autocollimator data. Without this calibration the positioning errors go beyond the slope errors of the optical elements which in turn may produce errors up to 100 meV in the soft-X-ray spectroscopy. We show some examples where such errors produce sizeable effects in soft-X-ray spectroscopy

8139-20, Session 5

Johansson crystals for x-ray diffractometry and demanding spectroscopy applications

B. Ehlers, B. Verma, L. Jiang, B. Kim, D. Wilcox, Rigaku Innovative Technologies, Inc. (United States)

Johansson crystals are known for many decades as x-ray optical elements with a high resolving power and small foci. However, in the past their use in applications requiring a small focus and a narrow bandpass were limited due to imperfections that were caused by the applied manufacturing technologies. In particular, while high performing Johansson crystals were manufactured in small quantities in research facilities, they were not available commercially. RIT has developed a technological process of Johansson crystals fabrication that allows the preservation of crystals structure. The angular precision of the bending process of atomic planes and the final crystal surface is better than 4 arcseconds. Results for Silicon and Germanium crystals will be shown. Several technological processes were developed to achieve the high performance of the crystal optic. This includes a crystal topography system to measure the lattice imperfections of the crystal blank. The system uses a 20 mm wide, collimated x-ray beam with a divergence of approximately 7 arcseconds to measure the rocking curve of the crystals over a wide area. Results of the crystal pre-selection process of several different Germanium crystals from different manufacturers are shown. Crystals manufactured with this technology are being coupled with a laboratory x-ray microfocusing source and focus dimensions of less than 10 micrometers are achieved while rejecting K-alpha 2 radiation. Examples of the crystals design and results of the performances of the assembled crystal optic will be presented.

8139-21, Poster Session

Application of focusing X-ray spectrograph with spatial resolution and uniform dispersion in Z-pinch plasmas measurement

Q. Yang, Y. Ye, G. Chen, Z. Li, Q. Peng, China Academy of Engineering Physics (China)

A new focusing X-ray spectrograph with spatial resolution and uniform dispersion (FSSRUD) is described. Uniform dispersion (i.e., the linear dispersion is a constance, or in other words, the X-rays are dispersed on the detector with uniform spacing for every wavelength) is realized by bending the crystal of a spectrograph into a special shape. Since the spatial coordinate of the spectrum obtained by the FSSRUD varies linearly with X-ray wavelength, it is very convenient for identification and processing of the experimental data. In addition, an optimized spectrograph capability can be achieved by customizing the bent shape of the crystal and other spectrograph parameters to satisfy the given requirements of routine measurement. The spectrograph capability is first analyzed using a ray tracing method, the principle to design the shape of the crystal for the FSSRUD is then presented and the spectrograph is constructed for measuring the spectrum of Z-pinch plasmas.

8139-22, Poster Session

The influence of working gas pressure on interlayer mixing in magnetron-deposited Mo/Si multilayers

Y. P. Pershin, E. N. Zubarev, V. V. Kondratenko, V. A. Sevyukova, Kharkov Polytechnical Institute (Ukraine); D. L. Voronov, E. M. Gullikson, Lawrence Berkeley National Lab. (United States); I. A. Artioukov, A. V. Vinogradov, P.N. Lebedev Physical Institute (Russian Federation)

The influence of Ar gas pressure (1-4 mTorr) on the growth of amorphous interfaces in Mo/Si multilayers deposited by magnetron sputtering was investigated by the methods of cross-sectional transmission electron microscopy and small-angle x-ray scattering ( = 0.154 nm). An increase of the Ar pressure was found to result in reduction of the thicknesses of amorphous inter-layers, with composition of the layers being enriched with molybdenum. The indicated interface modification improves the EUV reflectance of Mo/Si multilayer mirrors. This work was supported by the US Department of Energy under contract number DE-AC02-05CH11231.

8139-23, Poster Session

Flush imaging of fine structures of cellular organelles by contact x-ray microscopy with a high intensity laser plasma x-ray source

M. Kado, M. Kishimoto, M. Ishino, Japan Atomic Energy Agency (Japan); S. Tamotsu, K. Yasuda, Nara Women's Univ. (Japan); Y. Kinjo, Tokyo Metropolitan Industrial Technology Research Institute (Japan); K. Shinohara, Waseda Univ. (Japan)
Laser plasma x-ray sources have high intensity and short pulse duration, and are suitable for x-ray microscopy in biology. They make wet live biological specimens possible to be imaged with a single shot x-ray exposure and several works have been done to image them. However there were no reports on the imaging of fine structures of cellular organelles in a live biological cell since higher x-ray intensity is needed for it. We have developed a high intensity laser plasma x-ray source, cooperating it with contact x-ray microscopy, and observed fine structures of cellular organelles in a wet biological cells. It is also important to identify obtained features in the x-ray images since the x-ray microscopy is a novel technology and no references have been provided yet to help identify cell organelles. We have proposed to observe the same biological cells with an optical fluorescence microscope and an x-ray microscope for direct comparison to identify cell organelles in the x-ray images. For this purpose, we have developed PMMA photosresist onto transparent glass plate and cultivated biological cells directly on the PMMA photosresist. X-ray images were obtained right after obtaining fluorescence images of them. Comparing the x-ray images and the fluorescence ones of cellular organelles such as actin filaments and mitochondria we have been clearly able to identify those organelles in the x-ray images and to observe fine structures of them.

8139-24, Poster Session

Scaling of laser produced plasma UTA emission down to 3 nm for next generation lithography and short wavelength imaging

A. Endo, Waseda Univ. (Japan); T. Higashiguchi, T. Otsuka, N. Yugami, Utsunomiya Univ. (Japan); P. Dunne, B. Li, T. Cummins, C. O’Gorman, T. Donnelly, G. D. O’Sullivan, Univ. College Dublin (Ireland)

An engineering prototype high average power 13.5-nm source has been shipped to semiconductor facilities to permit the commencement of high volume production at a 100W power level in 2011. In this source, UTA (unresolved transition array) emission of highly ionized Sn is optimized for high conversion efficiency and full recovery of the injected fuel is realized through ion deflection in a magnetic field. By use of a low density target, satellite emission is suppressed and full ionization attained with short pulse CO2 laser irradiation. The UTA is scalable to shorter wavelengths, and Gd is shown to have similar conversion efficiency to Sn (13.5nm) at a higher plasma temperature, with a narrow spectrum centered at 6.7nm, where a 70% reflectivity mirror is anticipated. Optimization of short pulse CO2 laser irradiation is studied, and further extension of the same method is discussed, to realize 100W power down to a wavelength of 3 nm.

8139-25, Poster Session

Improved resolution for soft-x-ray monochromatization using lamellar multilayer gratings

R. van der Meer, B. Krishnan, Univ. Twente (Netherlands); I. V. Kozhevnikov, A.V. Shubnikov Institute of Crystallography (Russian Federation); M. J. de Boer, Univ. Twente (Netherlands); B. Vratzov, NT&D - Nanotechnology and Devices (Germany) and Univ Twente (Netherlands); B. M. Bastiaens, J. Huskens, W. van der Wiel, K. J. Boller, Univ. Twente (Netherlands); F. Bijkerk, FOM-Institute for Plasma Physics Rijnhuizen (Netherlands)

Lamellar Multilayer Gratings (LMG) offer improved resolution for soft-x-ray (SXR) monochromatization, while maintaining a high reflection efficiency in comparison to conventional multilayer mirrors (MM). A Coupled-Waves Approach (CWA) was used to calculate SXR diffraction by LMGs. From this CWA, a single-order regime was identified in which the incident wave only excites a single diffraction order. It was shown that in this regime the angular width of the zeroth-order diffraction peak, and thus the resolution, simply scales with \( I / (\text{lamel-to-period ratio}) \) without loss of peak reflectivity. To obtain maximal peak reflectivity the number of bi-layers must be increased by a factor of 1/\( \Gamma \). Optimal LMG resolution and reflectivity is obtained in this single-order regime, requiring grating periods of only a few hundred nm, lamel widths 1µm [1].

For the fabrication of LMGs with these dimensions, a novel process based on UV-Nanoimprint Lithography (UV-NIL) and modified Bosch etching is used. Successful fabrication of LMGs with periods down to 200nm, line widths of 60nm and multilayer stack heights of 1µm is demonstrated. SXR reflectivity measurements have been performed on these LMGs at the PTB beamline at the BESSYII synchrotron facility. The resolution is demonstrated to be improved by a factor of 4 compared to conventional MM. Further analysis of these SXR reflectivity measurements is currently being performed.


8139-27, Poster Session

Development of a specimen holder combined with ultra thin film laser plasma x-ray source for compact contact-type soft x-ray microscope to observe hydrated living biological cells

M. Ishino, M. Kado, Japan Atomic Energy Agency (Japan); K. Shinohara, Waseda Univ. (Japan); Y. Yamamoto, I. Hirai, Osaka Univ. (Japan); M. Kishimoto, M. Nishikino, N. Hasegawa, Japan Atomic Energy Agency (Japan); S. Tarnotsu, K. Yasuda, Nara Women’s Univ. (Japan); T. Kawachi, Japan Atomic Energy Agency (Japan)

Ultra thin gold films having a thickness of few ten nano-meter are favorable laser plasma source targets for a soft x-ray microscope, because ultra thin films emit intense soft x-rays of water window region from the rear side with respect to the surface of short pulse laser irradiation. Using rear side emissions, the distance between the x-ray source and the specimens can be reduced and the short distance increases the x-ray flux on specimens. In addition, the microscope system is designed to be compact, when the specimen holder and x-ray source are combined in one piece. The biological specimen holder combined with a gold ultra thin film plasma target has been developed for a contact-type soft x-ray microscope. This x-ray microscope system dose not need any x-ray optics such as a condensed and/or an objective optics causing a degreasing of x-ray photons. Specimen holder equipped with the plasma target keeps biological specimens in wet condition from vacuum. X-ray images of hydrated living macrophages have been obtained successfully by use of the newly developed specimen holder. These experimental results reveal that the soft x-ray image can be taken safely before the debris from plasma target reaching to specimen. Specimen holder combined with plasma x-ray source will be a key component of a compact soft x-ray microscope using in a laboratory.

8139-28, Poster Session

Fabrication of micro accelerator platform for x-ray applications

J. Zhou, J. McNeur, G. Travisch, Univ. of California, Los Angeles (United States); R. Yoder, Manhattanville College (United States)

With recent advances in nanotechnology, traditionally bulky systems such as particle accelerators can be scaled down to portable sizes. Here we present a prototype micro accelerator platform which is a laser powered optical structure made of dielectric materials on a small chip. As the drive
laser comes in and oscillates in the vacuum gap between the dielectrics, the electric field can build up to as high as 1 GV/m and electrons travelling through the gap can get an energy boost.

Fabrication of the device involves advanced lithography, various thin film depositions, as well as fine surface finishing. Details of each of the processes will be discussed, and preliminary beam test results will be presented. The reflection and transmission measurements of the prototype device on the drive laser will be presented, and the resonance frequency and strength will be evaluated. This micro-sized structure can be used for electron acceleration to produce radiations such as X-ray in a compact device.

8139-29, Poster Session

**Shorter wavelength EUV source around 6.0 nm by rare-earth plasma**

T. Otsuka, Utsunomiya Univ. (Japan); D. Kilbane, T. Cummins, C. O’Gorman, T. Donnelly, P. Dunne, G. D. O’Sullivan, Univ. College Dublin (Ireland); W. Jiang, Nagaoka Univ. of Technology (Japan); A. Endo, Waseda Univ. (Japan); T. Higashiguchi, N. Yugami, Utsunomiya Univ. (Japan)

In recent years, dense plasmas have been focused on as high efficiency and high power sources of EUV radiation. The development of sources of EUV emission with a wavelength less than 10 nm is a subject of considerable interest. Wavelengths shorter than 10 nm are especially useful for lithography. We have employed high repetition rate femtosecond laser lithography towards the final stage beyond the 13.5-nm EUV source and for other applications, such as material science and biological imaging near the water window. In particular, in our setup, EUV emission at the relevant wavelength is coupled with a Mo/B4C and/or La/B4C multilayer mirror with a reflective coefficient of 40% at 6.5-6.7 nm.

We have demonstrated a laser-produced plasma extreme ultraviolet source around 6.5-6.7 nm using rare-earth targets of Gd and Tb coupled with a Mo/B4C multilayer mirror attached to hundreds of near-degenerate resonance lines in unresolved transition array resonance lines. We have observed the variation of spectral behavior of resonance line emission in Gd plasmas in the 6.7 nm region when different laser wavelengths are used to change the critical electron densities. As the effects of self-absorption on the resonance lines the Gd plasmas are large, it is important to produce low density plasma using long laser wavelengths and/or low-initial target concentration of Gd. The spectrum based on the low initial density target was narrower and more intense than that of the pure solid target. As a result, the maximum CE was observed to be 1.3% and the spectral purity was also improved.

8139-30, Poster Session

**Characterization of broadband emission around 40 nm from potassium plasma**

H. Terauchi, M. Yamaguchi, T. Otsuka, Utsunomiya Univ. (Japan); T. Higashiguchi, N. Yugami, Utsunomiya Univ. (Japan) and Japan Science and Technology Agency (Japan); T. Yatagai, Utsunomiya Univ. (Japan); R. M. D’Arcy, P. Dunne, G. D. O’Sullivan, Univ. College Dublin (Ireland)

In recent years, the desorption spectrometer employing a compact, efficient discharge-produced microplasma XUV source in 20-100 nm broadband spectral region has been proposed, which has advantage of not damage or melting the surface even after irradiation. Photon energies of XUV source in 20-100 nm are high enough to induce photochemical reactions in most materials including hydrogen, carbon, and oxygen. We have already demonstrated a 40-nm XUV source which based on discharge-produced potassium plasma at a time-averaged electron temperature of about 12 eV and a current of about 200 A. However, the spectrum of the capillary discharge-produced plasma has the contamination due to a capillary material ablation. So, it is difficult to understanding the pure potassium plasma emission behavior. We characterize the emission spectra of a potassium plasma and its temporal behavior at 39 nm. To understanding the potassium spectral behavior without contamination effect, we use a laser-produced plasma to control the plasma parameters by changing the laser intensity and wavelength. Potassium ions produced strong broadband emission around 40 nm ranging from K^2+ to K^4+ ions at a time-averaged electron temperature of about 12 eV. Emission at 39 nm is caused during the recombining phase and it was reproduced by hydrodynamic simulations. As such we would be for atomic processes. As the emission spectral behavior of the laser-produced potassium plasma XUV source is similar to that of the hollow cathode-mode discharge-produced plasma spectrum, it indicates that the emission from the discharge-produced plasma occurs in a region of high electron density close to 10^20 cm^-3.

8139-31, Poster Session

**Diffraction efficiencies of holographic laminar and blazed types gratings for use in a flat-field spectrometer in an energy range of 50-200 eV for transmission electron microscopes**

T. Imazono, T. Kawachi, M. Koike, Japan Atomic Energy Agency (Japan); M. Koeda, T. Nagano, H. Sasai, Y. Oue, Z. Yonezawa, S. Kuramoto, Shimadzu Corp. (Japan); K. Sano, Shimadzu Emit Co., Ltd. (Japan)

We have been developing a compact wavelength-dispersive soft x-ray spectrometer to be attached to transmission electron microscopes. This spectrometer places emphasis on the low energy region for the demanding analysis of the lithium K emission spectrum (~54.3 eV) in the development of lithium-ion batteries. For this purpose, a flat-field holographic spherical grating of a 1200-lines/mm groove density was designed employing aspheric wavefront recording system. Laminar and blazed master (LM and BM) gratings and their respective replica (LR and BR) gratings were fabricated by holographic exposure and ion-beam etching methods. Absolute diffraction efficiencies in an energy range of 50-200 eV at the angle of incidence of 86 degree were measured by the reflectometer installed in the soft x-ray beamline (BL-11) at SR Center of Ritsumeikan University, Japan. The first order diffraction efficiencies of the LM gratings were 5-20% in the measured energy range and 6-9% at 54.3 eV. Those of the BM gratings strongly depended on the blaze angles but they were 5-27% and ~11%, respectively. The replica gratings of both the laminar and blazed types showed the comparable first-order diffraction efficiencies with their respective master gratings.

8139-33, Poster Session

**High spatial resolution with zoomable sawtooth refractive lenses?**

W. H. Jark, Sincrotrone Trieste S.C.p.A. (Italy)

Sawtooth refractive lenses for x-ray focusing can easily be visualised as opened alligators mouths. The mouth closure provides zooming as it changes the amount of prism to traverse for off-axis rays. Optically speaking the material distribution in such a device follows stepwise a parabola. As such it would focus x-rays as long as one can consider it to be a “thin lens”. This approximation is only valid for rather long focal lengths. In fact high spatial resolution will require shorter focal length to be a “thin lens”. This approximation is only valid for rather long focal lengths. In fact high spatial resolution will require shorter focal length. In fact high spatial resolution will require shorter focal length. In fact high spatial resolution will require shorter focal length. In fact high spatial resolution will require shorter focal length. In fact high spatial resolution will require shorter focal length.
The effect of surface residual stress on the performance of high quality x-ray mirrors

J. A. Maj, Argonne National Lab. (United States)

The use of high quality X-ray mirrors on synchrotron beamlines as low-pass, harmonic rejection and even high heat load optical elements has become routine. Nearly perfect optical surfaces generated on substrates held in strain-free fixtures are of paramount importance to their success. Production of these mirrors requires extensive care, yet the effect of residual fabrication stresses has not been closely studied. This paper examines the effect of surface and near-surface residual stress on the performance of hard X-ray mirrors using topography, surface diffraction and X-ray reflectivity techniques. The present approach complements the information provided by standard optical metrology, giving a more comprehensive understanding of polishing induced mirror deformation on X-ray reflectivity. This information is invaluable for the characterization of future, coherence preserving optics where scattering and evanescent sub-surface X-ray penetration may impact beam quality.

Metrology of a Pt-coated nested x-ray focusing KB mirror system

J. Qian, B. Shi, W. Liu, L. Assoufid, Argonne National Lab. (United States)

This poster describes surface metrology of a nested KB mirror system designed to focus polychromatic hard x-rays from the 34-ID beamline at the Advanced Photon Source (APS). The two mirrors were fabricated at the APS using profile coating [1]. One of the mirrors, horizontal mirror, exhibits a height-error-accuracy of 0.76 nm rms and the vertical mirror is 3 nm rms. The mirror system produced a 2-D focal spot size of 150 nm x 150 nm with the focal length of 60 mm.

Reference:

X-ray topography study of sapphire and quartz single crystals for high-resolution x-ray spectroscopic analyzers

R. Khachatryan, X. Huang, M. Wieczorek, J. Maj, Argonne National Lab. (United States)

Single crystals of silicon and are most preferred conventional crystals for fabricating X-ray spectroscopic analyzers. While silicon and germanium have a highly symmetric, mono-atomic diamond crystal structure, sapphire [1] and quartz have more complex unit cells of lower symmetry with two different types of atoms. The reduced symmetry leads to more than one order of magnitude of more possible backscattering planes to match unique photon energies to be studied. The larger unit cells of sapphire or quartz with reduced symmetry also means that most of the reflections tend to have weaker scattering contributions per reflecting lattice plane, so more planes contribute to a Bragg reflection, resulting in a narrower bandwidth and better resolution. Therefore, sapphire and quartz are promising crystals for making next-generation spectroscopic analyzers, particularly for resonant inelastic X-ray scattering (RIXS) analysis with high energy resolution in the range from of 1-20 meV. Compared with silicon and germanium crystals which are generally defect free, however, commercial sapphire and quartz crystals may contain various crystalline defects, such as dislocations, inclusions, voids, and growth sector boundaries, that can significantly affect the bandpass, efficiency, and focusing properties of the analyzers [2]. In order to evaluate the general crystalline quality and to choose the best available crystals as substrates for analyzers, we have used synchrotron white beam X-ray topography to study sapphire crystals (as well as quartz) acquired from different vendors. In this presentation we will present the detailed results of X-ray topography and double-crystal rocking curve measurements from these crystals. In particularly, we will demonstrate how the defects affect the X-ray reflection efficiency and bandpass of the analyzers from comparison of different samples with different qualities.


Characterization of beryllium foils for coherent x-ray applications of synchrotron radiation and XFEL beamlines

S. Goto, S. Takahashi, Japan Synchrotron Radiation Institute (Japan); Y. Inubushi, K. Tono, T. Sato, M. Yabashi, RIKEN (Japan)

We characterized beryllium foils for synchrotron radiation beamline windows especially in coherent x-ray applications and reported that physical-vapor-deposited (PVD) beryllium shows the best performance compared with the conventional powder and ingot beryllium foils. In 2009, however, supplier of PVD foil, Brush Wellman, discontinued the fabrication due to loss of reproducibility by the old PVD machine. We sought an alternative PVD foil and tried to characterize the foils fabricated by NGK Insulators, Ltd. in Japan. Experiments were performed using spatially coherent x-rays at 1-km beamline BL29XU in SPring-8. We observed transmission x-ray images using Hamamatsu zooming tube with spatial resolution of 0.5 microns. X-ray wavelength was 0.1 nm and sample to detector distances were set to be 125 mm and 1580 mm to obtain direct near and diffraction-enhanced far images, respectively. We found that non-uniformity in the 300 microns x 300 microns field is 3% (rms) for the polished 60-micron-thick PVD foil which is almost similar value to that of Brush Wellman. We are reopening the way toward better beryllium window. New foils of NGK will be installed at the first beamline BL3 of XFEL in SPring-8 and will be characterized using fully coherent x-rays of XFEL.

Thermal-contact-conductance measurement for high-heat-load optics components at SPring-8

T. Takeuchi, Y. Senba, H. Ohashi, S. Goto, Japan Synchrotron Radiation Research Institute (Japan)

Thermal contact in water or cryogenic cooling is used for high-heat-load component at the synchrotron radiation beamline. Reliable data of the
thermal contact conductance (TCC) are crucial for the design of high-
heat-load components in term of insertion material, contact pressure,
temperature range, and surface condition. In SPRing-8, for example,
cryogenic cooling is used for silicon monochromator crystal with indium
insertion metal at interface between copper block and silicon crystal.
To reduce strain on the silicon crystal with lower contact pressure
and higher thermal conductivity, we are seeking the condition of the
silicon-indium-copper system and alternative insertion material such as
graphite foil. To measure the TCC in quick measurement cycle to obtain
under various TCC conditions, we are improving the TCC measurement
system regarding setup facilitation, precise temperature measurement,
and thermal insulation around sample. Several TCC results in the
low-contact-pressure region of 0.1-0.5 MPa will be presented for silicon-
indium-copper and silicon-graphite-copper systems.

8139-39, Poster Session
ESRF multilayer white beam test bench
K. Friedrich, C. Morawe, J. Peffen, M. Osterhoff, European
Synchrotron Radiation Facility (France)
The ESRF optics group has developed a versatile vacuum chamber to
study the impact of the white synchrotron beam on multilayer coatings.
The device is equipped with a cooling system for the multilayer samples
to distinguish thermal effects from pure radiation induced ones. Various
long term irradiation tests were performed on W/B4C, Ru/B4C, and Pd/
B4C systems using a high power undulator source with an incoming
load up to 200 W. This test bench allows for an in-situ observation of the
reflectivity spectrum, complemented by ex-situ measurements before
and after the exposure. In the future, the system can be equipped with a
Shack Hartmann wave front analyzer to perform in-situ metrology of the
multilayer surface.
The work will describe the concept of the white beam test bench and
present first experimental results.

8139-40, Poster Session
Experimental test of refractive lenses made
from shape memory polymers
G. Pavlov, Institute of Problems of Chemical Physics
(Russian Federation); I. I. Snigireva, A. A. Snigirev, European
Synchrotron Radiation Facility (France); T. Sagdullin, Institute of
Microelectronics Technology and High Purity Materials (Russian
Federation)
We present the first experimental study of the focusing properties of
two-dimensional parabolic refractive lenses made from shape memory
polymers. The lenses were manufacturing using a new technology
combining polymer synthesis and product forming at the same stage
under the UV radiation. Light activated shape memory polymers allow
to produce refractive lenses with high degree of accuracy. The tested
lenses have 0.05 mm radius of curvature at the apex of parabola and 2
mm aperture. The experiment was carried out at the Micro Optics Test
Bench of the ID06 beamline at the ESRF. The lenses were tested using
monochromatic X-rays of 10 keV. Two sets of lenses with focal distances
of 6 m and 4 m were used. The lens optical properties in terms of
resolution, efficiency and gain were measured. The radiation stability test
was performed.

8139-41, Poster Session
Progress on single crystal beryllium windows
(United States); A. Rack, European Synchrotron Radiation
Facility (France); S. Goto, Japan Synchrotron Radiation Research
Institute (Japan); O. Chubar, Brookhaven National Lab. (United
States)
Previously, we reported on the development of highly polished single
crystal beryllium windows for X-ray applications. Windows make of single
crystal beryllium, unlike the common windows, are essentially free from
granular boundaries, voids, impurities, and inclusions in the bulk, thus
we have been able to polish them (on both sides) to a few angstrom
rms roughness. With a uniform internal structure and smooth surfaces,
polished single crystal beryllium windows were expected to transmit an
incident X-ray beam without any significant phase perturbation.
In this paper, we report on our X-ray characterization of the single crystal
X-ray windows. We show that in comparison with the commercially
available windows, single crystal beryllium X-ray windows show
significantly less small angle scattering and all but preserve the beam
wave front. The cause of sporadic faint features in the transmitted images
is discusses and quantified using wave front simulation. Results of
brazing and pressure testing of the single crystal windows are presented
and discussed.

8139-42, Poster Session
Slumping monitoring of glass and silicone
foils for x-ray space telescopes
M. Mika, Institute of Chemical Technology (Czech Republic);
L. Pina, Czech Technical Univ. in Prague (Czech Republic); M.
Landova, Institute of Chemical Technology (Czech Republic);
L. Sveda, Czech Technical Univ. in Prague (Czech Republic);
V. Semencova, Rigaku Innovative Technologies Europe (Czech
Republic); R. Havlikova, Czech Technical Univ. in Prague (Czech
Republic); R. Hudec, Astronomical Institute, ASCR (Czech
Republic); A. J. Inneman, Rigaku Innovative Technologies Europe
(Czech Republic)
We focused on time monitoring of the thermal slumping of glass and
silicone foils. Our goal is the development of optimal technology for
producing high quality reflectors for the mirrors of large aperture x-ray
space telescopes. Observations delivered by these telescopes could
solve many puzzles of current astrophysics. The telescope’s crucial part
will be a high throughput heavily nested mirror array with the angular
resolution not bigger than 5 arcsec. Its construction requires precise
and light-weight segmented optics with surface micro-roughness of
only few 0.1 nm. Promising materials are glass or silicon foils shaped by
thermal forming. In our approach we formed the foils without a mandrel
supporting them only at their edges. The desired parameters can be
achieved only through optimizing the forming process. To reduce the
number of slumping experiments, we can supply some data by modeling.
For our model development, we recorded the changing shape of the foils.
For 3 hours, we were taking snapshots of the shape every five minutes
at constant temperature above the glass transition point. The final
shape was measured with the Taylor-Hobson mechanical profilometry.
Observed plastic deformation of the foils was controlled by viscous flow.
The deflection of the middle part increased practically linearly with time
and its speed strongly increased with temperature. We determined the
heat-treatment temperature and time for the manufacture of the foils with
the radius between 1 and 2 m. These data we utilize in the development
of the mathematical model for the optimization of the slumping process.
Conference 8140:
X-Ray Lasers and Coherent X-Ray Sources:
Development and Applications
Tuesday-Thursday 23-25 August 2011 • Part of Proceedings of SPIE Vol. 8140
X-Ray Lasers and Coherent X-Ray Sources: Development and Applications

8140-01, Session 1

FEL-pumped inner-shell photoionized x-ray laser
N. Rohringer, Lawrence Livermore National Lab. (United States)
Since the invention of the laser fifty years ago, laser amplification of atomic transitions have been extended to increasingly high power and shorter wavelength. We report on the first successful realization of an atomic x-ray lasing scheme based on photoionization of inner-shell electrons in Neon by the Linac Coherent Light Source (LCLS). By focusing LCLS pulses of 960 eV photon energy into a dense Neon gas sample to a micrometer sized spot, a long narrow plasma column is created on a fs time scale by photoionization of a K-shell electron. Thereby, a population inversion of the 2p-1s transition in singly ionized Neon is established, lasting for only 2.7 fs due to the subsequent Auger decay of the created core hole. Fluorescence photons emitted at the front end of the plasma column get amplified by stimulated emission, resulting in ultra bright, high-intensity x-ray pulses at 850 eV photon energy at fs duration at the exit of the plasma column. The experimental results will be discussed in conjunction with theory and self-consistent gain calculations.

8140-05, Session 1

Energetics, saturation, and scaling of atomic x-ray lasers pumped by photo ionization from a free electron laser
R. A. London, N. Rohringer, J. Dunn, F. Albert, Lawrence Livermore National Lab. (United States); J. J. Rocca, D. P. Ryan, M. A. Purvis, Colorado State Univ. (United States); J. Dozek, SLAC National Accelerator Lab. (United States)
We describe the output characteristics of a Ne K-alpha x-ray laser pumped by a free electron laser. Models are discussed for the geometry, output energy, and gainlength of the atomic laser as related to the density of the gain medium and basic characteristics of the pump, such as the wavelength, energy and focus. The gainlength and power at saturation are estimated. The wavelength scaling of this scheme is discussed.

8140-04, Session 1

Using the X-FEL to photo-pump x-ray laser transitions in He-like Ne
J. Nilsen, N. Rohringer, Lawrence Livermore National Lab. (United States)
Nearly four decades ago H-like and He-like resonantly photo-pumped laser schemes were proposed for producing X-ray lasers. However, demonstrating these schemes in the laboratory has proved to be elusive because of the difficulty of finding a strong resonant pump line. With the advent of the X-ray free electron laser (X-FEL) at the SLAC Linac Coherent Light Source (LCLS) we now have a tunable X-ray laser source that can be used to replace the pump line in previously proposed laser schemes and allow researchers to study the physics and feasibility of photo-pumped laser schemes. In this talk we use the X-FEL at 1174 eV to photo-pump the singly excited 1s2p state of He-like Ne to the doubly excited 2p3p state and model gain on the 2p3p-2p2s transition at 174 eV and the 2p3p-1s3p transition at 1018 eV. We explore possible quenching of the gain due to strong non-linear coupling effects from the intense X-FEL beam. We compare this with photo-pumping the He-like Ne ground state to the 1s3p singly excited state followed by lasing on the 3p-2s and 3d-2p transitions at 158 and 151 eV. Experiments are being planned at LCLS to study these laser processes and coherent quantum effects.

8140-06, Session 2

Advances in OFI soft x-ray lasers at LOA
S. Sebban, Ecole Nationale Supérieure de Techniques Avancées (France)
Thanks to the most recent works on x-ray laser and on high order harmonics (HHG), it is now possible to produce a 10 Hz soft x-ray energetic laser beam having very high optical qualities. The solution consists in seeding the XRL amplifier medium by a HHG beam. This concept was successfully realized in LOA and an extensive investigation of the source have been performed. Here we present experimental and numerical results on the spatial and spectral characterization of a Ni-like krypton laser seeded by a harmonic beam.

8140-07, Session 2

Spectral width of seeded and ASE XUV lasers: experiment and numerical simulations
A. Klisnick, L. Meng, Univ. Paris-Sud 11 (France); D. Alessi, Colorado State Univ. (United States); O. A. Guibaud, Univ. Paris-Sud 11 (France); Y. Wang, M. Berrill, B. M. Luther, S. Domingue, L. Urbanski, Colorado State Univ. (United States); D. Benredjem, Univ. Paris-Sud 11 (France); A. Calisti, Univ. de Provence (France); M. M. de Rossi, S. M. de Rossi, Institut d’Optique Graduate School (France); M. C. Marconi, J. J. Rocca, Colorado State Univ. (United States)
In this paper we will describe our recent progress in the investigation of the spectral properties of collisional XUV lasers, including both experimental measurements and numerical calculations. Using a wavefront-division, variable path-difference interferometer [1, 2], we have characterized the temporal coherence and the spectral width of an injection-seeded transient XUV laser emitted at 18.9 nm from a Mo plasma, developed at CSU (USA) [3]. Our results show that the temporal coherence of the beam is significantly increased by the injection-seeded operation, compared to the standard ASE mode, while the spectral linewidth is in both cases as small as ~3 mA. We show that our measurements are supported confirmed by detailed numerical simulations. Using the PPP code [4] we have calculated the linewidth of the 4d-4p
(J 0-1) lasing line in Ni-like Mo and Ag over a range of electron density and temperature which are relevant to collisional excitation pumping of XUV lasers. We discuss the relative contribution of homogeneous and inhomogeneous broadening to the overall profile. The variation of the calculated linewidth over with Ne and Te provides an estimate of the ultimate shortest duration that can be reached in the injection-seeded mode, depending on the conditions of density and temperature in the amplification zone.

References

8140-08, Session 2

Fully-coherent wake and ASE-suppressed 20-uJ 150-fs amplified high-order harmonic pulse demonstrated with 1D time-dependent Bloch-Maxwell code

E. Oliva, P. Zeitoun, Ecole Nationale Supérieure de Techniques Avancées (France); M. Fajardo, Univ. Técnica de Lisboa (Portugal); D. Ros, Univ. Paris-Sud 11 (France); S. Sebban, Ecole Nationale Supérieure de Techniques Avancées (France); P. Velarde, Univ. Politécnica de Madrid (Spain)

Seeding plasma-based soft-x-ray lasers (PBSXR) with high order harmonics (HOH) is a promising way to obtain fully coherent, short (hundreds of femtoseconds), tens of microJoules pulses. Nevertheless, up to date only 1 µJ, 1 ps pulses have been demonstrated seeding plasmas created from gas targets [1] and solid targets [2]. As the amplification process couples plasma hydrodynamics, atomic processes and the propagation of electromagnetic fields, a careful optimization of seed and amplifier properties is essential to reach multi-microJoule, hundreds of fs regime. Recent papers [3,4,5] showed that short and wide (up to 1 mm) plasmas present an optimal gain zone and up to 20 µJ could be extracted when seeding. Nevertheless, the temporal duration and profile of the output beam is still not optimal. Simulations show that the HOH is weakly amplified whereas most of the energy is within a long (several picoseconds) wake induced by the HOH [6,7]. In addition to this, these simulation pointed out the presence of deleterious Amplified Spontaneous Emission (ASE). In order to obtain intense pulses useful for practical applications is crucial to reduce the duration to hundreds of fs and obtain ASE-suppressed, structure-free (ideally only an amplified HOH) pulses. Using the 1D Bloch-Maxwell code DeepOne we will show that fully coherent, wake and ASE-suppressed, 20 µJ, 150 fs pulse can be obtained when optimizing at the same time both the seed and the plasma conditions.

8140-09, Session 2

Signal build-up from noise and seeding in plasma based x-ray lasers

C. M. Kim, K. A. Janulewicz, Gwangju Institute of Science and Technology (Korea, Republic of); H. Stiel, Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Germany); M. Nishikino, N. Hasegawa, T. Kawachi, Japan Atomic Energy Agency (Japan); J. Lee, Gwangju Institute of Science and Technology (Korea, Republic of)

In the spectral region of extreme ultraviolet (XUV) or soft x-rays, very successful and reasonably efficient CPA technique cannot be easily employed due to the lack of efficient optical components and sufficiently broadband (in absolute values) gain medium (X-ray laser shows at 10 nm delta lambda=0.001 nm). The typical situation in the current practice is as follows: the weak ultra-short pulse in the form of high harmonic signal has pulse width of few fs (delta lambda ≈0.2 nm) and is amplified in a spectrally much narrower gain medium (plasma) [1]. The relaxation time of the medium macroscopic polarization is longer than the width of the input pulse, and one faces the situation that amplification occurs in the coherent regime. This is a very unique experimental situation. The gain of the medium is very high, reaching 70 cm⁻¹, and the random character of strong spontaneous emission can significantly affect the amplification process. As a consequence, the proper description of the medium kinetics and the interaction process should reflect all these elements which usually are not observed in the optical region.

To take into account all of these elements in the most comprehensive way, we used the model based on Maxwell-Bloch equations without adiabaticity assumption. The model incorporates the random character of spontaneous emission [2,3], time-dependent gain by using the pump function obtained from laser-plasma simulation, and level degeneracy by treating the degenerate states separately. With this model, the complete information on the radiation field, i.e. both amplitude and phase can be obtained. This analysis provides a new perspective on the amplified spontaneous emission and coherent amplification of ultra-short pulses in a high-gain medium.

The typical pulse shape and polarization history of the injected amplified pulse can be traced using this model. Additionally, the same model is able to picture the pulse build-up from the spontaneous noise in an amplified spontaneous emission (ASE)-based x-ray laser (XRL). The experimental results on the XRL pulse shape give us a very useful bench-mark for the validity of the formulated model and its mathematical description. It was found that amplification of the spontaneous noise is accompanied by clear changes in the radiation polarization, however in a limited space (laser mode). These effects will be discussed in detail.


8140-10, Session 2

Strong field amplification of XUV: phase matching aspects

J. Seres, E. Seres, Friedrich-Schiller-Univ. Jena (Germany); B. Ecker, GSI Helmholtzzentrum für Schwerionenforschung GmbH (Germany); B. Landgraf, Friedrich-Schiller-Univ. Jena (Germany); D. C. Hochhaus, D. Zimmer, V. Bagnoud, B. Aurand, B. Zielbauer, T. Kuehl, GSI Helmholtzzentrum für Schwerionenforschung GmbH (Germany); C. Spielmann, Friedrich-Schiller-Univ. Jena (Germany)

The dependence of the yield of high-order harmonic generation (HHG) on several important experimental parameters has been successfully modelled [1]. We extended this description by adding a stimulated emission process and named it self-seeded x-ray parametric amplification (XPA) [2,3]. Beyond the super-quadratic increase of the XUV signal, which can be explained by HHG theory in a limited pressure range, other observed characteristics (exponential growth, gain narrowing, strong blue shift etc.) and their scaling with intensity and pressure [2,3] can only be explained accurately by the new XPA model. For an experimental verification, we used the femtosecond front-end of the PHELIX laser system delivering 350-fs-long 7 mJ pulses and the JETI laser system delivering 30-fs-long, 1 J pulses, both at a repetition rate of 10 Hz. We focused the laser beam to a diameter, which sufficed to reach the necessary peak intensity of about 1·10^14 W/cm² for realization of XPA in Argon gas in the spectral range of 40-50 eV. Aside atomic and free electron dispersion we included in our improved model also Gaussian beam, atomic and Gouy phase shifts, and the effect of the group velocity mismatch. This extended XPA theory fully describes the observed scaling.
of the XUV yield with pressure, intensity, jet position, etc. Further steps towards the development of bright X-ray source will be discussed.


8140-11, Session 3

Coherent x-ray generation in relativistic laser - gas jet interactions

A. S. Pirozhkov, M. Kando, T. Z. Esirkepov, Japan Atomic Energy Agency (Japan); P. Gallegos, Rutherford Appleton Lab. (United Kingdom); E. N. Ragozin, PN. Lebedev Physical Institute (Russian Federation); A. Y. Faenov, T. A. Pikuz, J. K. Koga, H. Kiriyama, Japan Atomic Energy Agency (Japan); P. McKenna, Univ. of Strathclyde (United Kingdom); M. Borghesi, Queen’s Univ. Belfast (United Kingdom); K. Kondo, H. Daido, Japan Atomic Energy Agency (Japan); Y. Kato, The Graduate School for the Creation of New Photonics Industries (Japan); D. Neely, Rutherford Appleton Lab. (United Kingdom); S. V. Bulanov, Japan Atomic Energy Agency (Japan)

We present experimental results, theory, and simulations concerning two novel sources of coherent x-ray radiation generated in the relativistic laser-plasma interactions (>10^18W/cm^2) employing gas jet targets.

The first source is based on a relativistic mirror reflecting a counter-propagating laser pulse. A strongly nonlinear breaking wake wave driven by an intense laser pulse can act as a partially reflecting relativistic mirror (the Flying Mirror). Such a mirror directly converts a laser pulse into a high-frequency (XUV or x-ray) ultrashort pulse due to the double Doppler effect. In the experimental demonstration with a 9TW J-KAREN laser, the Flying Mirror generated in a He gas jet partly reflected a 1TW pulse, providing up to ~10^10 photons, 60nJ (~10^12 photons/sr) in the XUV (12.8-22 nm).

The second source, demonstrated experimentally with the 9TW J-KAREN and 120TW Astra Gemini lasers, is based on a novel harmonic generation mechanism. Odd and even order harmonics are emitted forward out of the gas jet; such harmonics are generated by linearly as well as circularly polarized pulses. For example, the 120TW laser pulses produced harmonics with ~2 x 10^13 photons/sr (~300 uJ/sr) in the spectral range from 115 to 125eV. The experimentally demonstrated harmonics cannot be explained by previously known mechanisms (atomic harmonics, betatron radiation, nonlinear Thomson scattering, etc). We introduce a novel harmonic generation mechanism based on the relativistic laser-plasma phenomena (self-focusing, cavity evacuation, bow wave generation), mathematical catastrophe theory which explains the formation of electron density singularities (cusps), and collective radiation of a compact charge driven by a relativistic laser.

8140-12, Session 3

Ultrafast nanoscale imaging using high order harmonic generation

H. Merdji, Commissariat à l’Énergie Atomique (France)

Ultrafast coherent diffraction using soft and hard X-rays is actually revolutionizing imaging science thanks to new sources recently available. This powerful technique extends standard X-ray diffraction towards imaging of non-crystalline objects and leads actually to a strong impact in physics, chemistry and biology. New ultrafast pulses recently available hold the promise of watching matter evolving with unprecedented space and time resolution. Femtosecond coherent and intense radiation in the soft X-ray (λ = 10-40 nm) is currently produced in our laboratory, from highly non linear frequency conversion (high harmonic generation). A high intensity UV-X coherent beam is obtained using a loose focusing geometry, which allows coupling a very high amount of Ti:Sapphire laser system energy in the HHG process. Using a long gas cell and a long focal length lens, the emitting volume can be increased by orders of magnitude compared to standard HHG set-ups. This approach, allows reaching up to 1x1011 photons per shot for the 25th harmonic (λ = 32nm).

We have recently taken up the challenge of ultrafast coherent imaging of nanometric objects, such as nano-particles using our table-top soft X-ray source. We have very recently demonstrated nanoscale imaging in a single shot mode reaching 70 nm spatial resolution and 20 femtoseconds snapshot [1]. We then implemented a recently proposed holographic technique using extended references. This technique, easy to implement, allows a direct non iterative image reconstruction. In the single shot regime, we demonstrated a spatial resolution of 110nm.

This opens fascinating perspectives in imaging dynamical phenomena to be spread over a large scientific community. We will briefly present perspectives in the investigation of femtosecond phase spin-reversals of magnetic nano-domains or ultrafast molecular rearrangements.


8140-13, Session 3

Application of XUV high harmonics to attosecond nonlinear spectroscopy

K. Midorikawa, RIKEN (Japan)

There has been growing interest in applying high-order harmonic fields to atomic/molecular physics in the XUV region. However, the application of ultra-boardband nature of high harmonic spectra has not been explored yet. We have proposed and demonstrated Attosecond Nonlinear Fourier Transform Spectroscopy for investigating the ionization/ dissociation pathway induced by a two or more photon process with high-order harmonics [1, 2]. The unique feature of this method is the use of the autocorrelation technique for measuring the pulse shape of an attosecond pulse train and relies on the extremely broad harmonic spectra of the attosecond pulse train ranging from visible to extreme ultraviolet region.

This spectroscopy would be also beneficial for other intense extreme ultraviolet-soft X-ray light sources, such as X-ray free electron lasers, which are utilized for exploring the nonlinear interaction of high-energy photon with matter, because we can eliminate the strong background signals due to ions or electrons produced by one-photon absorption if we apply this spectroscopy.

References


8140-14, Session 3

Polarization control of high order harmonics in the EUV photon energy range

B. Vodungbo, Ecole Nationale Supérieure de Techniques Avancées (France)

Several attempts have been made to obtain circularly polarized harmonics. For example, already in the 1990’s, it has been shown that using an elliptically polarized driving laser, elliptically polarized harmonics could be obtained. The generation efficiency, however, drops dramatically with increasing ellipticity of the driving laser. More recently, elliptically polarized harmonics have been obtained in molecular gases, but the degree of circular polarization is low (~ 40 %). We also note that all these previous studies have focused on rather low order harmonics and only sparse data are available for wavelengths lower than 25 nm.

In contrast to these previous reports, we chose a two-step procedure to...
obtain circularly polarized harmonics. First, linearly polarized harmonics are generated as efficiently as possible by focusing a linearly polarized infrared laser (40 fs, 0.25 TW) into a neon filled gas cell. Second, these harmonics are circularly polarized by a four-reflector phase-shifter. By this method we obtained fully circularly polarized high harmonics in the extreme ultraviolet range (18 - 27 nm). The efficiency of the polarizer has been measured and is of the order of a few percents thus being significantly more efficient than currently demonstrated direct generation of elliptically polarized harmonics. This demonstration opens up new experimental capabilities based on high order harmonics, for example, to observe chiral molecules in biology or magnetic structures in materials science.

8140-15, Session 4

Stable and fully controlled long-time operation of a soft X-ray laser for user applications experiments

D. Ros, Univ. Paris-Sud 11 (France)

LASERIX is a high power laser facility intended to realize and use for applications transient collisional X-ray lasers at various wave-lengths. In addition new types of XRL schemes giving rise to emission at short wavelengths will be developed using the high energy LASERIX driver. Thus, this laser facility will both offer Soft X-ray lasers in the 30-7 nm range and auxiliary IR beam that could be also used to produce XUV sources. This experimental configuration highly enhances the scientific opportunities of the facility. In-deed it will be possible to realize both X-ray laser experiments and more generally pump/probe experiments, mixing IR and XUV sources.

8140-16, Session 4

Probing of high energy density plasmas using EUV and x-ray lasers

G. J. Tallents, L. Wilson, D. S. Whittaker, E. Wagenaars, The Univ. of York (United Kingdom)

Probing of high energy density plasmas using extreme ultra-violet (EUV) and x-ray lasers is shown to be a useful technique to deduce plasma parameters such as opacity. We will discuss potential pump-probe experiments which will be possible with plasma based EUV lasers and x-ray free electron lasers (XFELs). Our modelling studies show that solid carbon and iron can be heated by focused XFEL pulses of irradiance 1017 Wcm-2 so that after a picosecond or so equilibrium plasmas of temperatures up to 400 eV are produced in a uniform solid density of micron thickness. A low intensity probe pulse can then be used to measure the opacity or other parameters of such plasmas before expansion (on timescale > ps) causes departures from solid density. Similar experiments can be carried out with laboratory based EUV lasers and we will report an investigation being undertaken at the LASERIX facility in France.

8140-17, Session 4

Observation of the laser-induced surface dynamics by the single-shot x-ray laser interferometer

N. Hasegawa, Japan Atomic Energy Agency (Japan)

The dynamical processes of the laser-induced surface modifications such as laser ablation come to attract much attention for the micro processing by the ultra-short laser pulse. It is difficult to observe these phenomena directly, because they are non-repetitive, unrepeatable, and occur very rapidly (pico-second) in a very small (micron) area. We have developed a soft x-ray laser (SXRL) interferometer capable of the single-shot imaging of the nano-scale structure dynamics. The SXRL is suitable for probing the initial process of the surface morphological changes, because it has a short wavelength (Ni-like Ag, 13.9 nm) and short duration (< 10ps). It can precisely probe the surface, because the penetration depth for the material is very small (<10 nm). The interferometer consists of the reflection optics (Mo/Si multi-layer or Pt-plated mirrors) and the interference fringes are produced on the detector surface by a pair of mirrors having a relative incline angle (double Lloyd’s mirrors). The depth and lateral resolutions of the interferometer were around 1 nm and 1.8 μm, respectively. By using this interferometer, the very early stage of the ablation process was observed for the Pt surface irradiated with the 70 fs Ti:sapphire laser pulse.

In addition, we have developed a method of precise temporal synchronization between the SXRL and the pump laser (Ti:sapphire laser) by using the temporal fiducial light produced from the pump laser. The SXRL and the fiducial light were measured by the x-ray streak camera. The precision was better than a few pico-seconds, which is comparable with the SXRL pulse width.

8140-18, Session 4

Coherent XUV sources for applications

O. A. Guilbaud, S. Kazamias, K. Cassou, M. Pitmann, S. Daboussi, B. Cros, J. Lagron, G. Maynard, Univ. Paris-Sud 11 (France); S. Bastiani, Ecole Polytechnique (France); L. Meng, A. Kilsnich, D. Ros, Univ. Paris-Sud 11 (France)

During the last session of SPIE conference important progress in compact coherent XUV sources were presented. The practical adaptation of sources schemes to applications is now becoming an important issue for facilities proposing beam lines based on this kind of sources. In this paper we will describe recent work performed with the LASERIX facility in order to develop sources for applications. During the last SPIE conference, we presented a setup enabling the generation of soft x-ray laser with only one beam (D. Zimmer et al. Optics letters 2010) enabling a more stable operation. Comparison with the classical GRIP scheme will be discussed in terms of output energy, source size and reproducibility. The possibility of generating high order harmonic in parallel (i.e with the presence of an important long pulse before the main pulse) will also be discussed.

The presence of a small prepulse arriving prior to the two main pulses led to a longer target lifetime enabling real 10Hz soft x-ray laser operation on an hour timescale. Preliminary interpretation of this phenomenon will be presented.

We will also describe an hosted experiment dedicated to the temporal characterisation of a GRIP x-ray laser using a picosecond resolution streak camera.

Because the driving laser of LASERIX is a high energy Ti-Sa laser, it is possible to generate high order laser harmonic in parallel of soft x-ray laser. We will conclude this paper by a presentation of theoretical and experimental work performed on this subject. We will emphasize the experimental efforts undertaken to achieve high order harmonic generation in capillary waveguide and to obtain quasi-phase matching in multimode regime.

8140-19, Session 5

Advances in high repetition rate table-top soft x-ray lasers


We will discuss recent advances in the development of ASE-based and injection-seeded high repetition rate table-top soft x-ray lasers resulting from research conducted at Colorado State University. We have recently reported gain-saturated operation of a table-top 10.9 nm wavelength
laser operating at 1 Hz repetition in the 4d1S0→4p1P1 transition of nickel-like Te in a plasma excited by a newly developed high energy Ti:sapphire pump laser. Utilizing the same pump laser we obtained laser pulse energies of up to 10 µJ and an average power of 20 µW in the 13.9 nm line of Ni-like Ag. Efforts conducted to extend these results to shorter wavelengths will be discussed. We will also report results of studies conducted to characterize the properties of the beams resulting from injection-seeding solid-target plasma amplifiers with high harmonic pulses.

We will also discuss the development of all-diode-pumped soft x-ray lasers. Efficient pumping of the driver laser with diode lasers opens the possibility to develop a new generation of higher repetition rate, more compact, soft x-ray lasers for applications. In the first demonstration of a diode pumped soft x-ray laser we achieved lasing at 10 Hz repetition rate lasing in 18.9 nm wavelength line of Ni-like Mo ions using a cryo-cooled Yb:YAG chirped-pulse-amplification pump laser system. The status of the development of this new soft x-ray laser will be reviewed.

8140-20, Session 5
Towards high photon-number soft x-ray lasers
B. Ecker, Gesellschaft für Schwerionenforschung GmbH (Germany) and Johannes Gutenberg Univ. Mainz (Germany) and Helmholtz-Institut Jena (Germany); B. Aurand, Gesellschaft für Schwerionenforschung GmbH (Germany) and Johannes Gutenberg Univ. Mainz (Germany) and Extreme Matter Institute (Germany); D. C. Hochhaus, Gesellschaft für Schwerionenforschung GmbH (Germany) and Extreme Matter Institute (Germany) and Frankfurt Institute for Advanced Studies (Germany); T. Kuehl, Gesellschaft für Schwerionenforschung GmbH (Germany) and Johannes Gutenberg Univ. Mainz (Germany) and Helmholtz-Institut Jena (Germany); P. Neumayer, Gesellschaft für Schwerionenforschung GmbH (Germany) and Extreme Matter Institute (Germany) and Frankfurt Institute for Advanced Studies (Germany); H. Zhao, B. Zielbauer, Gesellschaft für Schwerionenforschung GmbH (Germany) and Helmholtz-Institut Jena (Germany); D. Zimmer, Gesellschaft für Schwerionenforschung GmbH (Germany) and Johannes Gutenberg Univ. Mainz (Germany); K. Cassou, S. Daboussi, O. A. Guilbaud, S. Kazamias, D. Ros, Univ. Paris-Sud 11 (France); P. Zeitoun, Ecole Nationale Supérieure de Techniques Avancées (France)

A novel route of soft x-ray laser (SXRL) development at GSI is aiming at an increase in photon numbers, pursuing the ambition of providing a high-brilliance XUV light source that can be used for plasma diagnostics like Thomson scattering [1], radiography or interferometry. In order to achieve this goal we designed a new pumping geometry called Butterfly configuration, which allows for simultaneously pumping two SXRL targets. The setup utilizes both the new double-beam option of the PHelix laser and a Mach-Zehnder interferometer to provide two individual double-pulse pump beams. We will report on two recent experimental campaigns investigating a single- and double-target configuration. The first will be dedicated to the study of the influence of the line focus width [5], with special interest in the losses due to transverse lasing. The second will concentrate on using the optimized output of the first SXRL target as a seed source for the second SXRL target. Former double-stage SXRL experiments have successfully proven an amelioration in the SXRL beam quality [2-4], however a gain in photon number by seeding is still to be demonstrated. We will present our newly developed pumping scheme and compare the results obtained from the experimental campaigns with ARWEN simulations.

3- Zeitoun P. et al, submitted for publication.

8140-21, Session 5
Bloch-Maxwell modelling of multi-mJ 100-fs fully-coherent amplified high-harmonic pulse
P. Zeitoun, E. Oliva, Ecole Nationale Supérieure de Techniques Avancées (France)

With their unmatched yield up to 1015 photons (12 mJ) per pulse [1], i.e. about 1,000 times the typical energy/pulse of soft X-ray free-electron lasers, laser-created plasma remained the most promising soft X-ray amplifier. However, such high energy is achieved so far only in the regime of Amplification of Spontaneous Emission (ASE) coupled with the so-called Quasi-steady-state (QSS) pumping scheme. Such conditions are known for producing weakly coherent and very long, 100 ps, pulses, limiting their attractiveness to some specific applications. Attempt in seeding with high harmonics such plasma led to weakly amplified seed overwhelmed by the ASE [2]. Using our 1D time-dependant Bloch-Maxwell code, DeepOne, we clarified the bottlenecks in seeding QSS amplifiers. We thus proposed and numerically tested a new seeding regime demonstrating unprecedented fully coherent pulse with multi-mJ energy and 100 fs duration [3].

3- Zeitoun P. et al, submitted for publication.

8140-22, Session 5
Coherent x-ray mirage
N. M. Nagorsky, S. A. Magnitskii, Lomonosov Moscow State Univ. (Russian Federation); A. J. Faenov, T. A. Pikuz, Joint Institute for High Temperatures (Russian Federation); M. Tanaka, M. Kishimoto, M. Ishino, M. Nishikino, Y. Fukuda, M. Kando, T. Kawachi, Japan Atomic Energy Agency (Japan); Y. Kato, The Graduate School for the Creation of New Photonics Industries (Japan)

Mirage in the X-ray spectral range has been detected for the first time. Experimentally interference rings in spatial profile of output radiation of the transient oscillator-amplifier X-ray laser were observed. The rings are consistently recorded both in a single laser shot and at averaging over many laser flashes. It is shown that a virtual X-ray point source emerges in the vicinity of the second plasma when amplification takes place. This virtual source is phased with the initial radiation of generator and is formed as optical mirages emerge in the earth atmosphere.

The experiment with the soft X-ray laser (SXRL) facility has been performed at Kansai Photon Science Institute (KPSI) of Japan Atomic Energy Agency (JAEA). The spatially coherent SXRL pulse was generated from the silver plasma mediums using an oscillator-amplifier configuration with Ag foil double targets. The generated SXRL beam from Ag double targets had a wavelength of 13.9 nm, bandwidth of less than 10-4, pulse duration time of 7 ps, and a beam divergence of 1.2 mrad (H) x 0.4 mrad (V). The SXRL system worked in 0.1 Hz regime with the output energy of about 1,000 times the typical energy/pulse of soft X-ray free-electron lasers, laser-created plasma remained the most promising soft X-ray amplifier. However, such high energy is achieved so far only in the regime of Amplification of Spontaneous Emission (ASE) coupled with the so-called Quasi-steady-state (QSS) pumping scheme. Such conditions are known for producing weakly coherent and very long, 100 ps, pulses, limiting their attractiveness to some specific applications. Attempt in seeding with high harmonics such plasma led to weakly amplified seed overwhelmed by the ASE [2]. Using our 1D time-dependant Bloch-Maxwell code, DeepOne, we clarified the bottlenecks in seeding QSS amplifiers. We thus proposed and numerically tested a new seeding regime demonstrating unprecedented fully coherent pulse with multi-mJ energy and 100 fs duration [3].

The registered effect can be used as a principle method of X-Ray lithography in the manufacture of large-scale integrated circuits.
8140-23, Session 6

**Applications of the LCLS x-ray free electron laser for high-energy density science**

R. W. Lee, Lawrence Livermore National Lab. (United States); P. Audebert, M. Gauthier, A. Levy, Ecole Polytechnique (France); M. Cammarata, D. M. Fritz, H. J. Lee, B. Nagler, SLAC National Accelerator Lab. (United States); F. Deneuville, C. Fourment, Univ. Bordeaux 1 (France); J. Gaudin, European XFEL GmbH (Germany); B. I. Cho, P. A. Heimann, Lawrence Berkeley National Lab. (United States); J. Dunn, A. Graf, S. J. Moon, R. L. Shepherd, A. Steel, Lawrence Livermore National Lab. (United States); H. Chung, International Atomic Energy Agency (Austria); M. Fajardo, G. Williams, Univ. Técnica de Lisboa (Portugal); O. Ciricosta, S. M. Vinko, J. S. Wark, Univ. of Oxford (United Kingdom)

LCLS, the first x-ray FEL has been operational since late 2009. The facility provides x-ray from 600 eV to 10 keV in the fundamental. The LCLS operates at 120 Hz, with pulses from 20 to 30fs containing up to 25mJ of energy. We will discuss the implementation of early High Energy density Science experiments that have been performed. These experiments cover LCLS-solid interaction which measured the spectral response, high pressure warm dense matter creation, self-Thomson scattering from solid and liquid jet samples, scattering from shocks, and x-ray generated cluster explosions. These experiments were performed in the external end station, while the MEC (Matter in Extreme Conditions) end station is being constructed. A brief discussion of the MEC, which will be ready for users in January 2012, will be presented.

8140-25, Session 6

**Spectroscopic studies of hard x-ray free-electron laser-heated foils at 1016 Wcm-2 irradiances**

J. Dunn, R. L. Shepherd, A. Graf, A. Steel, J. Park, R. W. Lee, Lawrence Livermore National Lab. (United States); P. Audebert, A. Levy, M. Gauthier, J. Fuchs, Ecole Polytechnique (France); D. M. Fritz, M. Cammarata, D. Milathianaki, H. J. Lee, B. Nagler, SLAC National Accelerator Lab. (United States); C. Fourment, F. Deneuville, Univ. Bordeaux 1 (France); G. Williams, M. Fajardo, Univ. Técnica de Lisboa (Portugal); J. Gaudin, European XFEL GmbH (Germany); S. M. Vinko, O. Ciricosta, J. S. Wark, Univ. of Oxford (United Kingdom)

We report a recent experiment where the first hard x-ray beamline, X-ray Pump Probe (XPP) instrument at the Stanford Linac Coherent Light Source (LCLS) free electron laser, was used to heat thin foils to high energy densities - 107 J/cm3. An intense 9 keV, 60 fs duration beam with energy of 2 - 4 mJ at the XPP beam line was focused using beryllium lenses to an irradiance approaching 1016 W/cm2. Targets of 0.5 - 4 µm thick foils of Ag and Cu were studied using a suite of diagnostics including Fourier Domain Interferometry, energy calorimetry and grating and crystal spectrometers. The experimental details and spectroscopic results from the campaign will be described.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. The experiment was carried out at the Linac Coherent Light Source, a National User Facility operated by Stanford University for the US Department of Energy.

8140-24, Session 6

**Coherent x-ray imaging at the Linac Coherent Light Source**

M. M. Seibert, G. J. Williams, S. Boutet, SLAC National Accelerator Lab. (United States)

Coherent x-ray imaging at the LCLS is supported by a dedicated instrument on the hard x-ray line in the far experimental hall. The CXI instrument combines X-ray focusing optics and diagnostics, a sample environment and a pixel array detector, i.e. all components necessary for coherent diffraction experiments. The optics provide 100nm, 1µm and 10µm focal spots at the sample interaction region through the use of Beryllium lenses and KB mirrors. The sample chamber houses a five degree of freedom holder for fixed targets, holds a gas-phase injector designed around an aerodynamic lens and provides various ports for integration of user supplied hardware, such as custom sample delivery systems and diagnostics. Diffraction patterns are recorded on the Cornell SLAC - Pixel Array Detector (CS-PAD). This modular detector consists of 32 silicon direct-detection chips bump bonded to Application Specific Integrated Circuits (ASICs) and arranged in four quadrants around a central hole. Each of the 2M pixels is 110 x 110 um in size and the dynamic range is greater than 10^3. The detector can be positioned at various distances from the interaction region. The distance available in the forward scattering geometry, with the detector downstream of the sample chamber ranges from 2.5m. Of this travel range, 0.5m is provided by an in-vacuum translation stage that allows moving the detector during the experiment. Additionally, the detector chamber can be mounted upstream of the sample to record backscattering.

First nanocrystallography experiments with the CXI instrument have shown diffraction from protein crystals to a resolution of better than 2Å.

8140-26, Session 6

**Hard X-FEL source diagnostics and beamline optics metrology at LCLS using a grating interferometer**

S. Rutishauer, O. Bunk, Paul Scherrer Institut (Switzerland); J. Grünert, H. Sinn, L. Samoylova, European XFEL GmbH (Germany); J. Krzywinski, M. Cammarata, D. M. Fritz, SLAC National Accelerator Lab. (United States); C. David, Paul Scherrer Institut (Switzerland)

X-ray grating interferometry is a method for differential X-ray phase measurements that has been deployed at several synchrotron sources. It is based on a phase shifting beam splitter and an absorbing analyzer grating. Due to its high sensitivity in the order of 10 nanorad, it is highly interesting for XFEL optics diagnostics.

We have implemented a grating interferometer at the XPP endstation of LCLS at a photon energy of 9 keV.

It has been used to measure XFEL source properties, such as induced longitudinal (accuracy < 5 m) and transverse source point displacements (accuracy < 5 µm) and shot-to-shot source point fluctuations. Shot-to-shot fluctuations are analyzed using a moiré technique. Using one-dimensional grating structures, this analysis can be carried out with high spatial resolution in one direction of interest, whereas the use of two-dimensional gratings allows a simultaneous measurement in two perpendicular directions.

Furthermore, the waveform distortions induced by beamline optics such as mirrors, monochromators or focusing lenses have been analyzed. Using a specifically adapted interferometer configuration, the waveform downstream of focusing elements has been recorded and propagated to the focus in order to determine the focal spot size.

For stationary phenomena, such as the influence of optical elements, high spatial resolution waveform data has been recorded by averaging...
over multiples shots and using a phase stepping technique. The technique is expected to develop into a useful diagnostics tool both for LCLS and future hard XFEL sources.

**8140-27, Session 6**

**Single-shot intensity/position monitor for hard x-ray FEL sources**


A non-destructive diagnostics device was developed to measure the intrinsic pulse-to-pulse intensity and position fluctuations of the SASE-based LCLS hard X-ray FEL, and was based on the detection of back-scattered X-rays from a partially-transmissive thin target using a quadrant X-ray diode array. This intensity/position monitor was tested on the X-ray Pump-Probe instrument of the LCLS, and shown to be capable of achieving a relative intensity precision of 0.1% and position sensitivity of 5 m limited only by the Poisson statistics of the X-rays collected in the diodes.

**8140-37, Poster Session**

**Ne-like Ti x-ray laser driven by a single femtosecond laser**

Y. Li, China Univ. of Mining and Technology (China); A. Teng, Y. Sun, China Univ. of Mining and Technology (United States)

The new scheme is presented for Ne-like Ti X-ray laser driven by a single laser pulse. According to the self-similarity method, we analyze the properties of Ne-like Ti slab plasma generated by irradiation of the femtosecond laser with various front edges. Scaling laws for the temperature, scale length, and electron density are obtained. The characteristics of scaling laws at different input parameters are analyzed. The results show that X-ray laser can be generated by a single femtosecond laser. During the period of pulse front edge, the characteristics of temperature, scale length, and electron density are affected by the growth tendency of light intensity. The femtosecond laser with a gentle front edge is profitable to drive X-ray laser. Our results provide a new program for experiments using a single laser pulse to drive X-ray laser.

**8140-38, Poster Session**

**Dynamics of the ultrashort laser pulse in a capillary discharge-preformed argon plasma channel**

S. Sakai, J. Miyazawa, T. Higashiguchi, N. Yugami, Utsunomiya Univ. (Japan)

The interaction of an ultrashort, intense laser pulse with a wide variety of optical waveguides has been demonstrated in various applications, including electron acceleration, nonlinear wavelength conversion, short wavelength laser, and high-order harmonic generation. In the high-order harmonics generation experiments, the blue-shifted spectra have been reported in the pinched plasma channel in the kA discharge current and the non-pinched plasma channel in the ampere region. The numerical simulation and the analyzed spectra of the spectral behavior of the ultrashort laser pulse in the pinched rare-gas-discharge channel, however, have not been reported. In order to understand the propagation dynamics of the ultrashort laser pulse, it is important to analyze of spectral behavior of the laser pulse in the capillary discharge-produced plasma channel in the stable propagation point of view.

We observed the spectra of the transmitted laser pulse without and with the plasma channel. The blue-shifted spectrum in the gas-filled capillary without plasma was shifted to be about 8 nm at the peak spectral intensity with the bandwidth of 15 nm (FWHM). In this case, the change of refractive index is large, because the ionization was induced from the neutral gas phase to the multi-charged state ions of Ar^10+. In the plasma channel the slight blue-shifted frequency component was also observed due to the more ionization by the laser field in the preformed argon plasma channel. A one-dimensional (1D) particle-in-cell (PIC) simulation is reproduced the experimental results of the spectral behavior propagating the ultrashort laser pulse.

**8140-39, Poster Session**

**Observation of water window soft x-ray radiation in elongated low-inductive capillary discharges**

V. A. Burtsev, D.V. Efremov Scientific Research Institute of Electrophysical Apparatus (Russian Federation) and A.F. Ioffe Physical Technical Institute (Russian Federation)

In this report, results of observation and experimental research of EUV and soft x-ray radiation, generated in elongated low-inductive capillary discharges with close spacing of electrode system and energy supply by the double forming line through the long transmitting line are presented. In carried out experiments, running waves of sliding avalanche discharge were used for preionization of working gas (Ar). After such wave achieves the outer circular electrode, the transformation of electrical field occurs and the component of radial field comes to longitudinal ones. In this moment longitudinal electrical field strength reaches maximum value, and then quickly falls because of high current low impedance discharge developing.

This maximal transient electrical field courses in sictete steps running away of a part of plasma electrons in a very narrow range of initial gas pressure (0.1-0.25 Torr) and for shot time interval (< 5 ns). These fast electrons in the process of inelastic collisions ionize and excite multiply charged ions, quantum transitions of which gave the generation not only EUV, but also SXR (2-4 nm) ranges. This is conformed by semiconductor filtered Si-diode measurements. We used the method of absorbing foils with different thickness for evaluation of photons energy. Discovered phenomenon allows looking otherwise on the problem of creation of discharge pumped short wave soft x-ray lasers and initiated further researches, namely spectroscopic measurements.

This work was supported by the grants 06-08-00828 and 09-08-00160 of Russian Foundation for Basic Research.

**8140-40, Poster Session**

**Strategies for EUV microscopy using a lab-scale top x-ray laser source**

D. Bleiner, F. Staub, J. E. Balmer, Univ. Bern (Switzerland)

High-brightness Extreme-Ultraviolet (EUV) sources for laboratory operation are needed in nano-fabrication and actinic (“at-wavelength”) inspection of the EUV masks for high-volume manufacturing in next generation lithography. Laser-plasma sources have the required compactness and power scalability to achieve the demanding requirements. The generation of coherent photons across a line plasma can dramatically improve the imaging quality. We evaluated the capabilities of a lab-scale amplified spontaneous emission (ASE) EUV laser source combined with different optical designs, namely an all-reflective design using multilayer optics and a diffractive design using Fresnel zone plates (FZP). The multilayer optics is characterized by a higher throughput and handiness of system alignment. However, high magnification demands high NA, which can lead to spherical aberration. Off-axis tilt of the condenser/objective pair has caused a distortion in the horizontal illumination profile. These drawbacks are potentially addressed using a Schwarzschild design. The spectral purity of the EUV laser overcomes limitations of FZP’s chromatic aberration. The high photon
flux of 1011 ph/shot mitigates throughout limitations of the FZP. The performance is benchmarked using a peculiar sample, i.e. a Siemens star, that allows determining the contrast at various spatial frequencies (modulation transfer function) in single-shot images.

8140-41, Poster Session

Repetitive XUV laser based on the fast capillary discharge


XUV lasers are new sources whose applicability to technological and scientific research appeared just only about twenty years ago. Our laboratory has been studying high-current capillary discharge as a potential XUV/soft X-ray laser source over the past 12 years. We have designed, assembled and built two experimental apparatuses CAPEX and CAPEX-U fed from one source (Marx generator). On both these devices we have observed a very strong amplification of Ne-like argon line at 46.9 nm. The experimental device CAPEX-U is more powerful and has laser-triggered spark gap in comparison with the older apparatus CAPEX. The both devices CAPEX and CAPEX-U are fully operational. Recently, for possible testing and application purposes we have built a new small Marx generator capable to run in a repetitive regime. Its repeating frequency is currently up to 1 Hz. The generator is covered by metal sheets and feeds CAPEX facility and ensures its full independence on CAPEX-U machine. This paper reports on the first experimental results of the new experimental set-up of CAPEX apparatus (repetitive lasing at 46.9 nm), mainly set-up description, electrical parameters, laser pulse stability, etc. This research has been supported by the MEYS (contract LC528 and LA08024), and GA AS CR (contract KAN300100702).

8140-42, Poster Session

Time-resolved XUV radiation diagnostics from nitrogen discharge Z-pinning plasma

M. Nevrkla, A. Jancarek, J. Hubner, Czech Technical Univ. in Prague (Czech Republic); D. Sheftman, Technion-Israel Institute of Technology (Israel); L. Pina, Czech Technical Univ. in Prague (Czech Republic); P. Vrba, Institute of Plasma Physics of the ASCR, v.v.i. (Czech Republic); M. Vrbová, Czech Technical Univ. in Prague (Czech Republic)

XUV radiation from nitrogen filled capillary discharge plasma was diagnosed using a 10^4 grooves/mm SiNx free-standing transmission grating. The resolution bandwidth 0.3 nm was achieved. Time dependence of 13.4 nm line emitted power was recorded by photomultiplier in order to verify inherence of resonant radiation emission corresponding to NVII 2-3 laser transition. An increase of the emitted power is expected during the pinch decay caused by recombination processes. We report here the results obtained with 90 mm long capillary discharge supplied by a current pulse with maximum amplitude of 50kA and quarter-period of 80 ns. This high-current pulse was generated by a 2.5 ohm water line high-voltage generator which is used for underwater wire explosion experiments and which was adjusted into capillary discharge design using results of PSPICE simulations. Initial nitrogen pressures were varied in the range of (20 - 500) Pa. According to MHD and kinetic simulations of the discharge plasma a feeble pumping is expected in this case. Results of our measurements proved the highest rate of upper laser recombination pumping of 4.5 10^8 sec^-1 for the initial pressure 180 Pa, which is not high enough for efficient amplification of spontaneous emission. Observations of time integrated spectra proved high electrode erosion and capillary wall ablation. Technological problems connected with high-current capillary discharges are pointed out and analyzed.

8140-43, Poster Session

Formation mechanism of non-uniform structure in the gain distribution and its effect to the plasma x-ray lasers

A. Sasaki, Japan Atomic Energy Agency (Japan)

Plasma x-ray lasers have been studied toward shorter wavelengths and higher output power. Using transient collisional excitation (TCE) scheme with grazing incidence pumping (GRIP), lasing has been obtained by small pumping energies, but the output power is still very limited. In the plasma, considerable non-uniformity of the gain distribution is sometimes seen, which limits the output power and coherence of the x-ray laser beam. In this presentation, formation of the spatial structure in the plasma is investigated on the basis of the detailed atomic and radiative processes. Firstly, the atomic energy levels and rate coefficients are calculated, and secondly the pressure of the plasma is calculated by coupled CR-model and radiation transport as a function of the temperature and density. The emissivity and opacity of the plasma decrease significantly when the ionization exceeds Ni-like state as the bound electrons in n=4 shell are lost; one may see the plasma changes from an opac low-ionized state to a transparent highly-ionized state at their characteristic radiation energy. This may cause the decrease in the radiation pressure in the plasma, resulting in a non-monotonic behavior of the isotherm in the PV plane. In this presentation, the pressure and free energy of the plasma are investigated, to find the possibility to have phase-transition like behavior in the plasma, and to identify the critical temperature to cause the structure formation, and then whether it has an effect on the gain distribution of the x-ray lasers is discussed. Segregation of the plasma is also investigated.

8140-44, Poster Session

Soft x-ray laser-ablation mass spectrometry depth profiling of compound semiconductor heterostructures

I. Kuznetsov, F. Dong, J. Filevich, E. R. Bernstein, D. C. Crick, M. McNeil, Colorado State Univ. (United States); W. Chao, E. H. Anderson, A. Sakdinawat, Y. Liu, D. T. Attwood, Univ. of California, Berkeley (United States); J. J. Rocca, C. S. Menoni, Colorado State Univ. (United States)

We exploit the unique interaction properties of 26.5 eV photons from intense focused soft x-ray laser pulses to analyze the chemical composition of nanofilms. We have investigated Si, GaAs, and InSnO semiconducting films; HfO2 and SiO2 dielectrics, Au and Cr, and others with depth profiling resolution of 20-50 nm. The experiments were carried out by using a mass spectrometry nanoprobe that uses a capillary discharge Ne-like Ar laser for ablation. The focused output from the soft x-ray laser creates a plasma mostly through single photon ionization. The short absorption length of most materials at 46.9 nm wavelength results in a depth resolution in the range 20 to 50 nm. Consecutive single shot absorption events are used to construct the depth profile.


8140-45, Poster Session

Complex numerical research and optimization of EUV laser on hydrogen-like ions of nitrogen in low-inductive discharges

N. V. Kalinin, V. A. Burtsiev, D.V. Efremov Scientific Research Institute of Electrophysical Apparatus (Russian Federation)
New results of complex numerical research of possibilities for creation of an effective recombination type 13.4 nm laser on hydrogen-like ions of nitrogen, obtained in plasma of low-inductive high-current pinching discharges, are presented. The attention mainly is focused on problems of obtaining plasma with needed non-equilibrium recombination ion composition and effective electron cooling. In carried out researches the 1D 2T RMHD code with account of dynamics, non-equilibrium ionization of plasma with complex composition, radiation transport in continuous and linear spectra and energy transmission from a generator of high voltage pulses to plasma load through a long line. The coefficient of amplification of a week signal was defined by means of non-stationary model of all-level kinetics.

One and two-stage compression of plasma column in pinching discharges was studied. The second regime allows to obtain more dense and high ionized plasma column. This regime consists from small expending of a plasma column after the first compression and its subsequent compression with using of the discharge current exceeding on amplitude the first wave. The similar behavior of discharge current is caused by changing of the condition matching plasma column with the transporting line.

One considered different mechanisms of electron cooling and forming recombination nonequilibrium many-component plasma of multicharge ions. Namely, by radial expansion of the plasma column and radiative heat efflux by proper radiation of plasma, and linear radiation of hard impurity ions. In the first case, typical for regimes with low initial gas pressure (< 10 torr) one observed more quick falling of plasma density than electron temperature. In the second case, realizing at high gas pressure (≥ 10 torr), when the proper radiation of plasma sufficiently influences on dynamics of column and characteristics of plasma, current-carry radiative collapsing shock waves are used for plasma compression and then electron cooling. Namely, such waves give possibilities to realize deep cooling in super dense plasma for nanosecond time.

Results of calculation of amplification coefficient for the line of the transition 3-2 in hydrogen-like ions of nitrogen at two-step compression of plasma column and radiative heat efflux by linear radiation of argon ions showed, that it is possible to have gm ~ 3 · 10⁻².

8140-47, Poster Session
Spectroscopic measurements of photo-excited highly charged ions of Fe and F
A. Graf, G. Brown, Lawrence Livermore National Lab. (United States); J. Crespo Lopez-Urrutia, S. Bernitt, Max-Planck-Institut für Kernphysik (Germany); P. Beiersdorfer, Lawrence Livermore National Lab. (United States); C. Beilmann, Max-Planck-Institut für Kernphysik (Germany); J. Clementson, Lawrence Livermore National Lab. (United States); S. Eberle, Max-Planck-Institut für Kernphysik (Germany); S. Epp, L. Foucar, Deutsches Elektronen-Synchrotron (Germany); M. Leutenegger, NASA Goddard Space FlightCtr. (United States); S. Kahn, SLAC National Accelerator Lab. (United States); K. Kubicek, V. Meeckel, Max-Planck-Institut für Kernphysik (Germany); F. S. Porter, NASA Goddard Space Flight Ctr. (United States); A. Rasmussen, SLAC National Accelerator Lab. (United States); J. Rudolph, M. Simon, R. Steinbrugge, Max-Planck-Institut für Kernphysik (Germany); E. Trabant, Lawrence Livermore National Lab. (United States)

We report on recent spectroscopic measurements of line emission from photo-excited highly charged ions. The FLASH portable EBIT ion cloud was used as a target for the LCLS free electron laser at the soft x-ray (SXR) end station. Numerous instruments were used to diagnose the plasma including an Iqlet calorimeter, a variable line spacing grating spectrometer and a Wien filter based ion extraction system. This work focuses mostly on data obtained with the grating spectrometer. Attention is given to line emission from highly charged Fe and F. Some details of the experiment and preliminary results will be given.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. The experiment was carried out at the Linac Coherent Light Source (LCLS) at the Stanford National Accelerator Laboratory. LCLS is an Office of Science User Facility operated for the United States Department of Energy by Stanford University.

8140-46, Poster Session
Characterization of the temporal duration of the XUV laser pulse at the LASERIX facility
L. Meng, Univ. Paris-Sud 11 (France); S. Bastiani, Ecole Polytechnique (France); O. A. Guibalb, M. Pittman, S. Kazamias, K. Cassou, S. Daboussi, D. Ros, A. Klisnick, Univ. Paris-Sud 11 (France)

We report recent experimental measurements of the duration of a Ni-like Mo transient XUV laser emitted at 18.9 nm and generated under GRIP geometry at the LASERIX facility. We have used an ultra-fast X-ray streak camera (AXIS Photronique), able to reach a resolution better than 1 ps. A new trigger line was implemented, yielding a shot-to-shot jitter of less than 50 ps. The KBr photocathode was positioned close to the plane of the magnified near-field image of the XUV laser emitting aperture. The focusing of the image, by translating the imaging mirror, was used to carefully adjust the signal level in order to avoid saturation induced by charge-space effects. The sweep speed was calibrated in-situ by generating a double-pulse XUV laser.

Durations as short as 3 ps were measured for a 23° GRIP angle and a 750 fs short pulse laser duration. We will also present and discuss our study of the effect of these two parameters on the measured pulse duration.

8140-48, Poster Session
Spectral modeling of Fe XVII pumped by a free-electron x-ray laser
J. Clementson, Lawrence Livermore National Lab. (United States)

The combination of electron beam ion traps (EBITs) with accelerator-based light sources allows for new regimes of atomic physics to be explored, such as line-formation processes in photo-ionized plasmas. Measurements where intense x-ray emission has been directed into an EBIT with trapped ions have previously been performed at the BESSY-II synchrotron and the FLASH free-electron laser in Germany [1, 2]. The novel Linac Coherent Light Source (LCLS) at the Stanford SLAC laboratory is the worlds brightest source of coherent x-rays. The very high spectral density of the LCLS beam may pump atomic resonances from ground or excited levels in highly charged ions that are created and trapped in an EBIT.

The atomic structure and x-ray pumping of neonlike Fe XVII have been calculated and modeled under LCLS conditions using the Flexible Atomic Code (FAC) [3]. Fe XVII is one of the most frequently observed species from astrophysical sources and therefore of interest for plasma diagnostics. The calculations include oscillator strengths, radiative transition probability rates, autoionization rates, photo-ionization cross sections, and line emissivities.

This work was performed under the auspices of the US DOE by LLNL under Contract No. DE-AC52-07NA27344.

8140-28, Session 7

Nano-scale imaging mass spectrometry of biological materials with soft x-ray lasers

C. S. Menoni, J. Filevich, I. Kuznetsov, F. Dong, E. R. Bernstein, D. C. Crick, M. McNeil, Colorado State Univ. (United States); A. Sakdinawat, Y. Liu, Univ. of California, Berkeley (United States); W. Chao, E. H. Anderson, Lawrence Berkeley National Lab. (United States); D. T. Attwood, Univ. of California, Berkeley (United States); J. J. Rocca, Colorado State Univ. (United States)

We describe a novel application of soft x-ray lasers that allows to identify the molecular composition of a single bio-organism at the sub-cell level. Our method uses a capillary discharge soft x-ray laser (SRXL) [1] whose pulse energy is focused onto a sample by means of a free standing Fresnel zone plate lens. The SRXL can efficiently ionize atoms and molecules via single photon ionization. The ions generated by SRXL ablation are accelerated through the opened central zone of the ZP towards a time of flight mass analyzer. The use of 46.9 nm SRXL light allows to achieve a lateral spatial resolution of < 200 nm and a depth resolution of ~20 nm, due to the small absorption depth of carbon-containing materials at this wavelength. Single shot mass spectra from uniform samples consisting of alanine, glycine, and lysine have been obtained. The spectra show signatures of the molecular ion and several fragment ions. The high spatial and lateral resolution and single shot ablation capabilities will enable to construct three dimensional mass images of cells and micro-organisms.

8140-29, Session 7

Table top nanopatterning by de-magnified Talbot Effect

L. Urbanski, Colorado State Univ. (United States) and NSF Engineering Research Ctr. for Extreme Ultraviolet Science & Technology (United States); P. W. Wachulak, Military Univ. of Technology (Poland); A. Isoyan, Synopsys, Inc. (United States); A. G. Stein, Brookhaven National Lab. (United States); C. S. Menoni, J. J. Rocca, M. C. Marconi, Colorado State Univ. (United States) and NSF Engineering Research Ctr. for Extreme Ultraviolet Science & Technology (United States)

We describe the extension of the coherent imaging by Talbot effect as an alternative to nanofabrication of periodic arrays of unit cells, each one with an arbitrary design. A periodic object composed of a two dimensional array of tiles, forms highly accurate real images of itself at distances that are integer multiples of the Talbot distance without the necessity of any optics. Illuminating the periodic transmission mask with a convergent coherent soft-x-ray (SRX) beam, we demonstrated the possibility to print de-magnified replicas of the mask. The Talbot mask was fabricated on a 25 nm thick membrane of Si3N4 using standard electron-beam lithography. The pattern was created in a 65 nm thick hydrogen silsesquioxane (HSQ) photoresist layer. A SXRL at 46.9 nm capillary discharge laser was used to replicate the Talbot mask. The laser beam was reflected in a spherical multilayer mirror close to normal incidence which spectrally filters the beam and simultaneously produces a convergent wavefront illumination. A photoresist coated Si wafer was placed in the calculated working distance of the first Talbot plane, approximately 1mm, where the self-image of the Talbot mask was generated. The clear replica of the mask produced by the Talbot effect was recorded in the photoresist using typically 100 laser shots. The convergent beam illumination produced a reduced replica of the mask as compared with the collimated beam illumination. The de-magnification can be controlled by changing the distance between the mask and the mirror.

Results showing different de-magnifications will be presented. This experiment opens the possibility to control the size of the printing with a very simple optical setup.
8140-30, Session 7

Movies of nanoscale dynamics using soft x-ray laser illumination

S. Carbajo, I. D. Howlett, F. Brizuela, M. C. Marconi, J. J. Rocca, C. S. Menoni, Colorado State Univ. (United States); W. Chao, E. H. Anderson, Lawrence Berkeley National Lab. (United States); A. Sakdinawat, Y. Liu, D. T. Attwood, Univ. of California, Berkeley (United States); A. V. Vinogradov, I. A. Artiukov, P.N. Lebedev Physical Institute (Russian Federation)

We report the first demonstration of stop-motion imaging with nanoscale spatial resolution using a compact soft x-ray laser. A Ne-like Ar capillary discharge laser operating at 46.9 nm wavelength was used in combination with in a full field soft x-ray microscope to capture sequences of images of a rapidly oscillating atomic force microscope tip with a spatial resolution of ~50 nm. The microscope is arranged in transmission configuration and employs reflective and diffractive optics to obtain full-field images with a single laser shot of ~1 ns duration. Snapshots of a magnetic force microscopy (MFM) tip oscillating at 82 kHz were acquired and used to make a movie that depicts the motion of the tip. This novel technique allows to make movies of nanoscale dynamic phenomena with high temporal resolution.

8140-31, Session 7

Recent results on x-ray imaging at Lebedev Physical Institute

I. A. Artiukov, A. N. Mitrofanov, N. L. Popov, A. V. Vinogradov, O. F. Yakushev, P.N. Lebedev Physical Institute (Russian Federation); A. V. Popov, Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation (Russian Federation); Y. A. Bugayev, O. Y. Devzenko, V. V. Kondratenko, Kharkov Polytechnic Institute (Ukraine)

The talk presents a number of recent results related to incoherent and coherent imaging in hard and soft X-ray regions. Special attention is paid to the development of theoretical framework of grazing reflection imaging with the coherent X-rays. Basically similar to coherent transmission, the grazing reflection mode proves to enable a quantitative X-ray microscopy including phase retrieval. In addition, the reflection X-ray microscopy can work with a wider class of samples (not necessarily thin) and produce images of the objects in natural environment. The developed theoretical approaches and computer codes are based on the parabolic wave equation and generalization of the Fresnel integral to obliquely illuminated objects. The results of simulation of coherent reflection imaging are given for the optical schemes with and without lenses. The second part of the presentation deals with soft X-ray microscopy based on multilayer mirrors operating at the wavelength near 4.8 nm ("carbon window" spectral region). Problems and findings related to construction of a compact microscope based on discharge X-ray source are discussed.

8140-32, Session 7

Assessment of illumination characteristics of soft x-ray laser-based full-field microscopes

I. D. Howlett, F. Brizuela, S. Carbajo, D. Peterson, M. C. Marconi, J. J. Rocca, C. S. Menoni, Colorado State Univ. (United States); A. Sakdinawat, Y. Lui, D. T. Attwood, Univ. of California, Berkeley (United States)

We present a method for analyzing the illumination of soft x-ray full-field microscopes. The method consists of imaging a set of periodic gratings and obtaining the Fourier spectra from these images in two perpendicular directions. Analysis of the cutoff frequency of the imaging system provides information on angular conditions of the illumination. Furthermore, the analysis allows the optical transfer function of the imaging system to be obtained when the object is well characterized, for example, from a scanning electron image. The results of the analyses compare well with independent measurements of the modulation contrast function from which half-pitch grating resolution values of ~55 nm and ~38 nm were obtained for microscopes that use 46.9 nm and 13.2 nm laser illumination respectively [1,2]. The ability to characterize the illumination conditions in the EUV/SXR microscopes with a fast and simple analysis is critical to adjust the illumination to achieve the best spatial resolution and obtain the highest quality images.

Work supported by the Engineering Research Centers Program of the National Science Foundation under NSF Award Number EEC-0310717


8140-33, Session 8

Sub-10-nm wavelength Ni-like-ion collisional x-ray lasers

J. E. Balmer, F. Staub, C. Imesch, D. Bleiner, Univ. Bern (Switzerland)

We report on recent progress achieved in x-ray laser research at the University of Bern. Using the existing 10-TW Nd:glass CPA (chirped-pulse amplification) laser system in the grazing-incidence pumping (GRIP) scheme, saturated x-ray lasing is demonstrated on the 4d - 4p, J = 0-1 line of Ba at a wavelength of 9.2 nm, using a main pumping pulse energy of ~9 J. A small-signal gain coefficient of ~30 cm-1 and a gain-length product of ~16 at saturation have been measured. Intense lasing was also observed on the 8.9-nm line of La at a main pulse energy of 12 J. Crucial to these results was the introduction of a second, relatively intense (~10%) prepulse less than ~100 ps before the 1.2-ps duration main pulse, in addition to the 2.8% prepulse that irradiated the target 2.4 ns earlier. Travelling-wave excitation was used throughout. For handling convenience, compound targets (BaF2, LaF3) were used, either in the form of windows or coated onto glass slides. Lasing on multiple lines (9.6 and 10.4 nm) was observed for CsI targets with lasing on the 10.4-nm line being very weak.

8140-34, Session 8

Line width measurement of a capillary discharge soft x-ray laser

M. C. Marconi, L. Urbanski, Colorado State Univ. (United States) and NSF Engineering Research Ctr. for Extreme Ultraviolet Science & Technology (United States); L. Meng, Univ. Paris-Sud 11 (France); M. Berril, Colorado State Univ. (United States) and NSF Engineering Research Ctr. for Extreme Ultraviolet Science & Technology (United States); O. Guilbaud, Univ. Paris-Sud 11 (France); J. J. Rocca, Colorado State Univ. (United States) and NSF Engineering Research Ctr. for Extreme Ultraviolet Science & Technology (United States); A. Klisnick, Univ. Paris-Sud 11 (France)

Compact capillary discharge soft x-ray lasers have become a true work horse for experiments with intense coherent short wavelength light on a table-top. They have enabled experiments in high resolution imaging, nano-scale patterning, dense plasma diagnostics, and photophysics and photochemistry. Practically every output beam parameter of these lasers has been characterized with one exception: the linewidth and temporal coherence.
We report the first measurements of the line width emission of a capillary discharge Ne-like argon soft x-ray laser operating at a wavelength of 46.9 nm. The measurements were conducted using a wavefront-division bi-mirror interferometer specifically designed to measure the temporal coherence of soft x-ray sources. The line profile was inferred from the measurements of the fringe visibility as a function of the optical path difference. The evolution of the linewidth was studied as a function of length of the amplifier plasma column.

The bi-mirror interferometer produced clear interference patterns which are recorded in a CCD camera. The interference is observed in a rectangular region where the reflections from the two bi-mirrors superpose. The relative alignment of the two beams determines the orientation and period of the interference fringes. Changing the optical path difference (OPD) between the two beams it is possible to obtain curves of the fringe visibility vs OPD. After fitting these data points with a Gaussian curve a typical bandwidth of $4 \times 10^{-5}$ was obtained.

The preliminary analysis of the experimental results shows a almost constant value of the linewidth for all capillaries lengths. The lack of inhomogeneous saturation re-broadening indicates that even in this relatively low density plasma the contributions of homogenous broadening and collisional redistribution effects are significant in determining the laser line profile.

8140-35, Session 8

Polarization measurements of plasma excited x-ray lasers

A. L. Aquila, Deutsches Elektronen-Synchrotron (Germany); D. Bleiner, Univ. Bern (Switzerland); S. Bajt, Deutsches Elektronen-Synchrotron (Germany); J. E. Balmer, Univ. Bern (Switzerland)

Plasma excited X-ray lasers are a developing technology for many scientific applications. The photon energies, and peak brilliance of these lasers sources are well suited for probing atomic, molecular and solid state systems. The development and improvement in these laser systems also drives a need for metrologies of the properties of these lasers. Our research implements X-ray optics, designed to operate at the Brewster’s angle, to measure the polarization state of a Ni-like Sm laser. The device determines the polarization state on a shot to shot basis and opens the possibility for polarization control of plasma excited X-ray lasers and thus probing spin polarized electronic states.

8140-36, Session 8

High energy density plasmas and x-ray lasers

V. N. Shlyaptsev, J. J. Rocca, Colorado State Univ. (United States); A. Pukhov, Heinrich-Heine-Univ. Düsseldorf (Germany); A. Noy, Univ. of California, Merced (United States)

We will be discussing the modeling of two novel regimes in laser produced plasma and electrical discharges which may allow to deposit very high energy densities (HED) into the plasma. Utilizing relatively small university-scale facilities these methods could reach HED up to 1 Gigajoule per cc - which so far was typically reachable only by spherical compressions in large installations. For the reference, by convention HED corresponds to energy densities exceeding 0.1 MJ per cubic centimeter, and, for example, laser produced plasma can be considered HED at the temperature 1 keV and electron density equal to critical density for 1 micron laser radiation.

We will also describe parameters of x-ray lasers which benefit from increased plasma energy density. Modeling results will be compared with our current experiments.
X-ray refractive optics: goals, challenges, and research opportunities

A. A. Snigirev, European Synchrotron Radiation Facility (France)

The latest advances in X-ray refractive optics developments bring new possibilities to the design of next generation beamlines. This paper outlines the main goals faced and the challenges to be addressed by researchers in this area. The main emphasis will be given to the growing needs for developing wave-optical modeling of coherent hard X-ray optics in multi-lens arrangements. In this way, the requirements for computational tools for new coherent microscopy and interferometry techniques will be discussed.

Hard x-ray nanobeam characterization by ptychographic imaging

C. G. Schroer, S. Höning, A. Goldschmidt, R. Hoppe, J. Patommel, D. Samberg, A. Schropp, S. Stephan, Technische Univ. Dresden (Germany); M. Burghammer, European Synchrotron Radiation Facility (France)

Modern hard x-ray scanning microscopes at synchrotron radiation sources generate x-ray beams with lateral sizes well below 100 nm. Characterizing these beams in terms of shape and size by conventional techniques, such as knife-edge scans, is tedious, requires highly accurate test objects and stages, and yields only incomplete information. Since recently, we use a ptychographic scanning coherent diffraction imaging technique in order to characterize hard x-ray nanobeams in scanning x-ray microscopes. In addition to a high resolution image of the test object used in the scan, a detailed quantitative picture of the complex wave field in the nanofocus is obtained with high spatial resolution and dynamic range. Both are the result of high statistics due to the large number of diffraction patterns. The method yields a complete description of the focus, is robust against inaccuracies in sample positioning, and requires no particular shape or prior knowledge of the test object. With this information, the exit wave field behind the nanofocusing optic can be reconstructed, giving detailed insight into its aberrations.

Next generation optics for high-resolution inelastic x-ray scattering: theory and experiment

Y. Shvyd’ko, Argonne National Lab. (United States)

Principles and optical schemes of the angular-dispersive backscattering monochromators and analyzers, will be presented, supported by numerical simulations based on dynamical theory of multiple-crystal x-ray Bragg diffraction. The novel x-ray optics has a potential of achieving sub-meV energy resolution, spectral functions with sharper tails, and better momentum transfer resolution in inelastic x-ray scattering (IXS) experiments, as compared to the state of the art IXS optics. Results of the first tests, at the APS, of the in-line angular-dispersive backscattering monochromators/analyzers, termed CDDW, will be presented, in which a 0.4 meV resolution have been demonstrated. Experimental results will be compared with theoretical predictions.

Theoretical modelling of coherence properties of hard x-ray synchrotron sources and free-electron lasers based on statistical optics approach

I. Vartaniants, A. Singer, Deutsches Elektronen-Synchrotron (Germany)

A general theoretical approach based on the results of statistical optics is used for the analysis of the transverse coherence properties of third generation hard x-ray synchrotron sources and x-ray free-electron lasers (XFEL). Correlation properties of the wavefields are calculated at different distances from an equivalent Gaussian Schell-model source. This model is used to describe coherence properties of the 5 m undulator source at the synchrotron storage ring PETRA III. In the case of XFEL sources the decomposition of the statistical fields into a sum of independently propagating transverse modes is used for the analysis of the coherence properties of these new sources. A detailed calculation is performed for the parameters of the SASE1 undulator at the European XFEL. It is demonstrated that only a few modes contribute significantly to the total radiation field of that source.

Modeling of coherence properties of the 3rd harmonic radiation (2.7 nm) at FLASH based on the wavefront propagation

A. Singer, I. Vartaniants, Deutsches Elektronen-Synchrotron (Germany)

With the advent of the free-electron lasers (FEL) highly coherent x-ray radiation has become available. New areas of research utilizing the high coherence properties of these sources emerged. The understanding of the coherence properties of the radiation and their dependence upon propagation through various optical elements is of vital importance for scientific community, including experimentalists planning experiments and beamline scientist designing the optical systems. Nowadays, most propagation codes used for propagation of FEL radiation are based on the Fourier optics approach, which is valid for the fully coherent radiation. This approach is, however, not well suited to describe the coherence properties of partially coherent sources, like FELs. Here we present a method for the propagation of partially coherent radiation using coherent mode decomposition and wavefront propagation. In our work the partially coherent radiation is decomposed into a sum of independent coherent modes. Each mode is propagated separately using conventional wavefront propagation techniques. In the end the summation of the modes gives the coherence properties of the propagated radiation. As an example, the 3rd harmonic radiation at the wavelength of 2.7 nm from FLASH was analyzed. In particular, the coherence properties of the plane grating monochromator (PG2) beamline at FLASH, which includes a set of focusing mirrors, were determined by this approach. The results of these simulations are compared with the transverse coherence and intensity measurements carried out at this beamline.
Development of partially-coherent wavefront propagation simulation methods for 3rd and 4th generation synchrotron radiation Sources

O. Chubar, Brookhaven National Lab. (United States); J. Balthsr, Univ. of Copenhagen (Denmark); L. Berman, Y. S. Chu, K. Evans-Lutterodt, A. Fluerasu, S. Hulbert, K. Kaznatcheev, M. Idir, R. Y. Reininger, D. A. Shapiro, Q. Shen, L. Wiegart, H. Yan, Brookhaven National Lab. (United States)

Partially-coherent wavefront propagation calculations have proven to be feasible and very beneficial for 3rd and 4th generation synchrotron radiation (SR) sources. This type of calculations uses the framework of classical electrodynamics for the description, on the same accuracy level, of emission by relativistic electrons moving in magnetic fields of accelerators, and propagation of the emitted radiation wavefront through beamline optical elements. This enables accurate prediction of performance characteristics for beamlines exploiting high SR brightness (including the beamlines targeting operation at or close to the diffraction limit) and/or high spectral flux. Detailed analysis of radiation degree of coherence, offered by the partially-coherent wavefront propagation method, is of paramount importance for modern storage-ring based SR sources, which, thanks to extremely small sub-nanometer-level electron beam emittances, produce substantial portions of coherent flux in X-ray spectral range. We will present examples of partially coherent wavefront propagation simulations using SRW code and the resulting optimization of the design parameters of beamlines at National Synchrotron Light Source II. We will also discuss directions of further related developments such as extension of libraries of physical-optics based propagators for beamline optical elements, applications for optical metrology, data processing for coherence experiments, parallelization of CPU-intensive calculations, combination of different complementary simulations techniques, and interfacing with other popular simulations packages such as SHADOW.

A Monte Carlo approach for simulating the propagation of partially coherent x-ray beams

A. Prodi, Univ. of Copenhagen (Denmark); E. Knudsen, P. Willendrup, Risø National Lab. (Denmark); C. Ferrero, European Synchrotron Radiation Facility (France); R. Feidenhans'l, K. Lefmann, Copenhagen Univ. (Denmark)

Advances at SR sources in the generation of nanofocused beams with a high degree of transverse coherence call for effective techniques to simulate the propagation of partially coherent X-ray beams through complex optical systems in order to characterize how coherence properties such as the mutual coherence function (MCF) are propagated to the exit plane [1].

We present an approach based on Monte Carlo sampling of the Green function. A Gauss-Shell Stochastic Source with arbitrary spatial coherence is synthesized by means of the “Gaussian copula” statistical tool [2]. The Green’s function is obtained by sampling Huygens-Fresnel waves with Monte Carlo methods and is used to propagate each source realization to the detector plane. The sampling is implemented with a modified Monte Carlo ray tracing scheme where the optical path of each generated ray is stored. Such information is then used in the summation of the generated rays at the detector to account for coherence properties. This approach is used to simulate the cases of propagation in free space and with reflective optics and compared with Physical Optics and theoretical results [3].

References

Cross-platform wave optics software for XFEL applications

L. Samoylova, European XFEL GmbH (Germany); A. Buzmakov, A.V. Shubnikov Institute of Crystallography (Russian Federation); O. Chubar, Brookhaven National Lab. (United States); G. Gelsoni, H. Sinn, European XFEL GmbH (Germany)

We present a project aimed at development of a novel and unique software environment, suitably and capable of solving a wide set of problems of X-ray FEL optics. The new software package will deliver a set of tools designed for: (1) calculation of spontaneous radiation from XFEL undulators and seamless tailoring and optimization of the output of XFEL radiation simulation codes (GENESIS, FAST) with wave front propagation code; (2) calculation of coherent and partially coherent X-ray beam propagation through basic elements of XFEL beamlines, in particular through long grazing incidence mirrors, and monochromator crystals; (3) a choice and composition of optical elements for experimental stations, e.g. KB mirrors, CRLs, zone plates, apertures, etc; (4) application examples for modeling of whole beamlines.

The complex of programs will be based upon SRW libraries [1] plus a set of Matlab scripts or Python binding to provide access to these libraries. A user-friendly graphical interface, GUI, will be developed on the basis of the existing script interface. The software can be used by the XFEL experimental groups and groups responsible for scientific instruments for planning experiments and processing the experimental data. It will be further developed and supported by the European XFEL and provided as such free of charge to the scientific community. Several application examples, specific for XFEL, will be presented. Possible ways for parallelization of calculations will also be discussed.


8141-07, Session 2

8141-09, Session 3

A software system has been developed for high-performance Computer Tomography (CT) reconstruction, simulation and other X-ray image processing tasks utilising remote computer clusters optionally equipped with multiple Graphics Processing Units (GPUs). The system has a streamlined Graphical User Interface for user interaction with the cluster. This differentiates it from most software available on today’s computer clusters, which typically require some familiarity with parallel computing environment from the user. Apart from extensive functionality related to X-ray CT in plane-wave and cone-beam forms, the software includes multiple functions for X-ray phase retrieval and simulation of phase-contract imaging (propagation-based, analyser crystal based and Talbot interferometry). Other facilities include several methods for image deconvolution, simulation of various phase-contrast microscopy modes (Zernike, Schlieren, Nomarski, dark-field, interferometry, etc.) and a large number of conventional image processing operations (such as FFT, algebraic and geometrical transformations, pixel value manipulations, simulated image noise, various filters, etc.). All operations can be applied to batches of images in a variety of standard image formats. Some scripting capabilities are also included. The architectural design of the system is briefly described, as well as the two-level parallelization of the most computationally-intensive modules utilising both the multiple CPU cores and multiple GPUs available in a local PC or a remote computer cluster. Finally, some results about the current system performance are presented. This system can potentially serve as a basis for a comprehensive toolbox for X-ray image analysis and simulation, that can efficiently utilise modern multi-processor hardware for advanced scientific computations.

8141-10, Session 3

Toolbox for advanced x-ray image processing

T. E. Gureyev, Y. Nesterets, D. Thompson, S. W. Wilkins, A. W. Stevenson, J. A. Taylor, Commonwealth Scientific and Industrial Research Organisation (Australia)

A software system has been developed for high-performance Computed Tomography (CT) reconstruction, simulation and other X-ray image processing tasks utilising remote computer clusters optionally equipped with multiple Graphics Processing Units (GPUs). The system has a streamlined Graphical User Interface for user interaction with the cluster. This differentiates it from most software available on today’s computer clusters, which typically require some familiarity with parallel computing environment from the user. Apart from extensive functionality related to X-ray CT in plane-wave and cone-beam forms, the software includes multiple functions for X-ray phase retrieval and simulation of phase-contract imaging (propagation-based, analyser crystal based and Talbot interferometry). Other facilities include several methods for image deconvolution, simulation of various phase-contrast microscopy modes (Zernike, Schlieren, Nomarski, dark-field, interferometry, etc.) and a large number of conventional image processing operations (such as FFT, algebraic and geometrical transformations, pixel value manipulations, simulated image noise, various filters, etc.). All operations can be applied to batches of images in a variety of standard image formats. Some scripting capabilities are also included. The architectural design of the system is briefly described, as well as the two-level parallelization of the most computationally-intensive modules utilising both the multiple CPU cores and multiple GPUs available in a local PC or a remote computer cluster. Finally, some results about the current system performance are presented. This system can potentially serve as a basis for a comprehensive toolbox for X-ray image analysis and simulation, that can efficiently utilise modern multi-processor hardware for advanced scientific computations.
8141-11, Session 3

**Partially coherent x-ray beam simulations: mirrors and more**

M. Osterhoff, Georg-August-Univ. Göttingen (Germany) and European Synchrotron Radiation Facility (France); C. Morawe, C. Ferrero, European Synchrotron Radiation Facility (France); T. Salditt, Georg-August-Univ. Göttingen (Germany)

Partially coherent x-ray beam simulations: mirrors and more

Penetration, micro-resolution, and scattering were the keywords of x-ray analyses in the 20th century. But in the last 15 years, a great class of coherent imaging techniques has emerged as new tools, allowing for low-dose imaging of biological specimen on the nanoscale.

Apart from experimental and technical challenges, a better understanding of partially coherent beam propagation is the key for exploiting the new methods’ full performance. We present a simulation framework to calculate the mutual intensity and the degree of spatial coherence of typical x-ray focusing and filtering devices used at 3rd generation synchrotron radiation sources.

We propose the following modeling scheme: A set of independent point-sources yield independent basic fields, which are superposed in a stochastic manner; by taking the ensemble average, both partially coherent intensity and degree of coherence can be obtained from the mutual intensity. By including real structure effects, like height deviations of focusing mirrors, and vibration of optical components, advanced predictions of x-ray beams can be made. This knowledge is expected to improve reconstruction results from coherent imaging experiments.

Coherence simulations of focusing mirrors are presented and validated with analytical results; experimental tests are shown, too. Coherence filtering by use of x-ray waveguides is shown both numerically as well as analytically. We also present first simulations for partially coherent focusing by compound refractive lenses. The influence of vibrations on the degree of coherence is discussed within our model.

8141-12, Session 3

**Polycapillary optics: comparison of computational modeling and experimental results**

C. A. MacDonald, R. Schmitz, Univ. at Albany (United States)

Polycapillary optics are commonly used for x-ray fluorescence and have been designed as focusing collectors for x-ray astronomy, to produce large area collimated beams for wafer analysis, and to provide small focused beams for protein crystallography with low power x-ray sources. They are also being developed for a number of medical applications, including mammography, scintigraphy and orthovoltage therapy.

Additional applications are extensions of measurements normally performed at synchrotrons into laboratory or clinical settings because of the increased efficiency of source utilization. The realization of these applications has been advanced by the recent marked improvement in available optic quality and reproducibility. Manufacturing progress has been assisted by the development of simulation analyses which allow for increasingly accurate assessment of optics defects. Three dimensional Monte Carlo models are based on interactions between photons and the walls of the optic, represented as surface normals. Extensive modeling is made of defects including profile error, roughness, and waviness (midrange spatial frequency slope errors). Comparison of focal spot size, angular divergence, and transmission from collimating and focusing lenses are compared with measured results.

8141-13, Session 4

**PHASE: a universal software package for the propagation of time dependent coherent light pulses along grazing incidence optics**

J. Bahrdt, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (Germany)

The software package PHASE includes routines for the propagation of coherent light within the stationary phase approximation (SPA). The code is based on nonlinear analytic transformations of electric field arrays across longitudinally extended optical elements. Recently, the representation of the optical elements (OEs) has been extended to 8th in the OE-coordinates. Each element is represented by an individual matrix and the combination of several elements is done by simple matrix multiplications. This method can be interpreted as a thick lens approach whereas the usual method which is based on Fourier optics is a thin lens approximation. Both methods have advantages and disadvantages. Recently, the package has been extended to Fourier optics algorithms. Now, the appropriate propagator can be selected from the same interface which is running under IDL. Furthermore, a direct comparison of both methods from the same interface is possible which helps to evaluate the advantages and limitations of both methods.

8141-14, Session 4

**Modeling the coherence properties of polycapillary optics**

A. M. Zysk, Illinois Institute of Technology (United States); R. W. Schoonover, M. A. Anastasio, Washington Univ. in St. Louis (United States)

Polycapillary x-ray optical devices may potentially be useful for coherence-based imaging techniques such as in-line phase-contrast imaging, but to date their analysis has been limited to output intensity alone. To assess the coherence properties of these devices, new simulation techniques have been developed to capture the phase information of propagating wavefields and allow for investigation of coherence properties from extended sources. These techniques employ the coherent mode decomposition and geometric propagation of individual modes through the optic. The result is a quantification of capillary-to-capillary coherence properties and correlation of output wavefield coherence to parameters of the optic and source.

8141-15, Session 4

**McXtrace: a modern ray-tracing package for x-ray instrumentation**

E. Knudsen, Risø National Lab. (Denmark); J. Baltser, A. Prodi, Univ. of Copenhagen (Denmark); P. Willendrup, Risø National Lab. (Denmark); M. Sanchez del Rio, C. Ferrero, European Synchrotron Radiation Facility (France); R. Feidenhansʼl, K. Lefmann, Copenhagen Univ. (Denmark)

Ray-tracing is a well established simulation method to characterize the propagation of x-ray beams through optical elements within the geometrical approximation.

Here we present the developments of the McXtrace project [1], a free, open source software package for simulations and optimization of complete instruments, designed to bring Monte Carlo ray tracing to a new level of performance.

The package adopts the principles and code structure of McStas [2], a software designed for neutron beams for the same purpose, now a de facto standard tool in the neutron scattering community.

In particular, McXtrace presents the following advantages over existing

---

170  SPIE Optics + Photonics 2011  ·  spie.org/op  Return to Contents
Optical design of the NSLS-II CHX beamline

K. Kazarinchev, O. Chubar, L. Wiegart, M. Carlucci-Dayton, K. Evans-Lutterodt, L. Berman, A. Fluerasu, Brookhaven National Lab. (United States)

Ultra-low emittance third-generation synchrotron radiation sources, such as NSLS-II offer excellent opportunities for a development of experimental techniques exploiting x-ray coherence. Among the first six beamlines to be constructed by 2014, the coherent hard x-ray (CHX) beamline is dedicated to measuring the time-evolution of nanometer-sized objects via x-ray photon correlation spectroscopy. For the optical design of such beamline, there is a trade-off between the light coherence needed to distinguish individual speckles and phase acceptance (high intensity) required to measure fast dynamics. In the past, phase-space filtering with pinholes placed in front of the sample was used to filter a single diffraction-mode, but such approach entangles the x-ray spot size with the required degree of coherence and imposes a severe penalty at non-optimum geometry. We proposed new design with an intermediate aperture placed after focusing optics. The size of intermediate horizontal aperture is defined by the highest mutual coherence required, and, for the current design, is restricted to 1.5λcoh (transverse coherence length) leading a fringe visibility of 0.6. Wave-front preserved optics (compound refractive lens (CRL)) projects the aperture image onto the sample. By employing the focusing in horizontally direction more light can be passed through the slit trading the visibility of the speckles for higher flux. Consequently, the proposed optical design will accommodate equally well the requirements of different techniques; from the high coherence needed for coherent-diffraction imaging to full flux approaching –1013ph/s for Si DCM energy window, as demanded by incoherent small-angle scattering. The beamline performance as validated by wave-propagation analysis will be discussed with an emphasis on realistic SR source and optics simulation.

Optical design of the NSLS-II SRX beamline

8141-18, Session 5

V. de Andrade, J. Thieme, O. Chubar, Y. Yao, Brookhaven National Lab. (United States)

The sub-micron resolution X-ray spectroscopy beamline (SRX) is one of the six project beamlines of NSLS-II at Brookhaven National Laboratory. SRX will benefit from the ultra low emittance of this new synchrotron radiation source and address a wide variety of scientific applications.

Optical design of the NSLS-II CHX beamline

8141-19, Session 5

K. Kazarinchev, O. Chubar, L. Wiegart, M. Carlucci-Dayton, K. Evans-Lutterodt, L. Berman, A. Fluerasu, Brookhaven National Lab. (United States)

Ultra-low emittance third-generation synchrotron radiation sources, such as NSLS-II offer excellent opportunities for a development of experimental techniques exploiting x-ray coherence. Among the first six beamlines to be constructed by 2014, the coherent hard x-ray (CHX) beamline is dedicated to measuring the time-evolution of nanometer-sized objects via x-ray photon correlation spectroscopy. For the optical design of such beamline, there is a trade-off between the light coherence needed to distinguish individual speckles and phase acceptance (high intensity) required to measure fast dynamics. In the past, phase-space filtering with pinholes placed in front of the sample was used to filter a single diffraction-mode, but such approach entangles the x-ray spot size with the required degree of coherence and imposes a severe penalty at non-optimum geometry. We proposed new design with an intermediate aperture placed after focusing optics. The size of intermediate horizontal aperture is defined by the highest mutual coherence required, and, for the current design, is restricted to 1.5λcoh (transverse coherence length) leading a fringe visibility of 0.6. Wave-front preserved optics (compound refractive lens (CRL)) projects the aperture image onto the sample. By employing the focusing in horizontally direction more light can be passed through the slit trading the visibility of the speckles for higher flux. Consequently, the proposed optical design will accommodate equally well the requirements of different techniques; from the high coherence needed for coherent-diffraction imaging to full flux approaching –1013ph/s for Si DCM energy window, as demanded by incoherent small-angle scattering. The beamline performance as validated by wave-propagation analysis will be discussed with an emphasis on realistic SR source and optics simulation.

Optical design of the NSLS-II SRX beamline

8141-20, Session 5

V. de Andrade, J. Thieme, O. Chubar, Y. Yao, Brookhaven National Lab. (United States)

The sub-micron resolution X-ray spectroscopy beamline (SRX) is one of the six project beamlines of NSLS-II at Brookhaven National Laboratory. SRX will benefit from the ultra low emittance of this new synchrotron radiation source and address a wide variety of scientific applications.
8141-21, Session 5

Cost-effective ray-tracing optimization of the design of a prototype x-ray optical unit

M. M. Civitani, P. Conconi, G. Pareschi, INAF - Osservatorio Astronomico di Brera (Italy)

The ray-tracing is power-full technique for the design and the prediction of the performances of an X-Ray optics. When working with traditional monolithic shells, the possible design is quite constrained once fixed the focal length, the dimensions of the module and the field of view: simulations are used to determine the effective area and optical performances of realized mandrels and shells, taking into account for example profile errors or roundness measurements. Instead, when the optics are segmented into two separate reflective surface, integration errors with respect to position and rotation of the plates play an important role and may be also used to recover intrinsic plate errors. Moreover when the mirror segments are produced by replica, it is possible to optimize the design of a module to be cost effective. In this paper we present the design of a prototype module for the International X-ray Observatory (IXO) resulting from a proprietary ray tracing code. The module will be composed by 20 plate pairs all made with the same integration forming mandrel. The degradation of optical performances of the prototype are expected to be limited to few arc seconds.

8141-22, Session 6

Reliable before-fabrication forecasting of expected surface slope distributions for x-ray optics

V. V. Yashchuk, Y. V. Yashchuk, Lawrence Berkeley National Lab. (United States)

Numerical simulation of the performance of new beamlines and those under upgrade requires sophisticated and reliable information about the expected surface slope and height distributions of planned x-ray optics before they are fabricated. Obtaining such information should be based on the metrology data measured from existing mirrors that are made by the same vendor and technology, but, generally, with different sizes and slope and height rms variations. In this work, we demonstrate a method for highly reliable forecasting of the expected surface slope distributions of the prospective x-ray optics. The method is based on an autoregressive moving average (ARMA) modeling of the slope measurements with a limited number of parameters. With the found parameters of the ARMA model, the surface slope profile of an optic with the newly desired specification could reliably be forecast. We demonstrate the high accuracy of this type of forecasting by comparing the power spectral density distributions of the measured and forecast slope profiles. Supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

8141-23, Session 6

Automated suppressed errors in LTP-II slope measurements with x-ray optics


Systematic error and instrumental drift are the major limiting factors of sub-microradian slope metrology with state-of-the-art x-ray optics. Significant suppression of the errors can be achieved by using an optimal measurement strategy suggested in [V. V. Yashchuk, Rev. Sci. Instrum. 80, 115101/1-10 (2009)]. Here, we report on development of an automated kinematic, rotational system that provides fully controlled flipping, tilting, and shifting of a surface under test. The system is integrated into the Advanced Light Source long trace profiler, LTP-II, allowing for complete realization of the advantages of the optimal measurement strategy method. We provide details of the system’s design, operational control and data acquisition. The high performance of the system is demonstrated via the results of high precision measurements with a spherical test mirror. This work is supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

8141-24, Session 6

X-ray optics shape error evaluation coupling innovative shape metrology and 3D ray-tracing

G. Sironi, INAF - Osservatorio Astronomico di Brera (Italy) and Media Lario Technologies (Italy)

We present the advances we achieved in simulating optical performance degradation due to shape errors. This study has been carried on in the context of the New Hard X-ray Mission optical module prototype developing. We reached an accuracy of 1 arcsec on the simulation of the geometrical angular resolution at the focal plane associating shape error measurements acquired by means of an innovative 3D profilometer expressly designed to a 3D ray-tracing developed for double reflection telescopes.

8141-25, Session 6

Using MapleSim to model a six-strut kinematic mount for aligning optical components

A. M. Duffy, B. W. Yates, Y. Hu, Canadian Light Source Inc. (Canada)

The performance of a synchrotron beamline depends on the accurate positioning of its optical components and often ray tracing simulations are done for an ideal situation of perfect alignment. During construction a lot of effort is put into precisely locating components and making necessary adjustments. After the initial survey it is still necessary to move optical components for various reasons - usually to improve focusing or change photon energy. The mounts that hold these components can be quite complicated and modeling their motion is vital to understanding how they affect the performance of the beamline. In this paper we examine the behavior of a six-strut kinematic mount using MapleSim (a drag-and-drop physical modeling tool that uses advanced symbolic computation techniques to produce simulation models and generates equations describing the system of interest). This software creates a dynamic simulation of the system with 3-D visualization and has a point-
probe feature that allows us to investigate and understand precisely how a mirror pole moves with its mount and quantify any cross-coupled motion that may occur during actuator adjustments. This positional information can be used to mitigate so called cosine errors and used in an x-ray tracing program such as Shadow.

8141-27, Session 7

**Theory and numerical simulations of x-ray nanofocusing by bent crystal in back diffraction geometry**

A. Suvorov, Brookhaven National Lab. (United States); H. Ohashi, S. Goto, T. Ishikawa, RIKEN (Japan)

A point-to-point x-ray focusing of a spherical wave by means of cylindrically bent crystal in symmetric Bragg back diffraction geometry was investigated theoretically and simulated numerically. To separate the focal plane from an incident x-ray beam, a thin flat crystal was introduced into the setup. The effect of flat crystal diffraction on the focusing performance of the double crystal setup is discussed. It is shown that the aberration free focusing can be achieved with aspherical surface shape of the strongly bent crystal. A correction term for the surface displacement function free from spherical aberrations is derived. Thorough numerical simulations demonstrated agreement with the theoretical analysis and excellent focusing performance of 2.4 nm.

8141-28, Session 7

**Temporal and coherence properties of hard x-ray FEL radiation following Bragg diffraction by crystals or multilayers**

V. A. Bushuev, Lomonosov Moscow State Univ. (Russian Federation); L. Samoylova, H. Sinn, T. Tschentscher, European XFEL GmbH (Germany)

Undulator systems of the novel X-Ray Free Electron Laser (XFEL) facilities, based on Self-Amplified Spontaneous Emission (SASE) principle, will provide hard X-ray radiation from 5-24 keV. Preservation, transport and tailoring of such X-ray pulses are a big challenge for X-ray optics systems. In this work, we explore the transformation of XFEL pulse radiation and its statistical properties in the process of diffraction on crystals in Bragg and Laue geometry and free-space propagation of incident and diffracted radiation. We present a statistical diffraction theory for limited in space SASE X-ray pulses, which allows to calculate spatial-temporal coherence function of the reflected and transmitted radiation.

The SASE XFEL radiation consists of pulses limited in three dimensions with irregular multi-spike structure [1]. Coherent and time-resolved experiments will strongly depend on the properties of the incoming radiation passed through beamline optical elements to experimental stations. The evolution of SASE XFEL pulses and its statistical properties during propagation through a double crystal monochromator in Bragg and Laue diffraction geometry [2] as well as through a double multilayer structure [3] are investigated analytically and by numerical modelling.


8141-29, Session 8

**X-ray imaging diagnostics for magnetically confined and laser-produced fusion plasmas**

N. A. Pablant, M. Bitter, L. F. Delgado-Aparicio, K. Hill, Princeton Plasma Phys. Lab. (United States); M. Sanchez del Rio, European Synchrotron Radiation Facility (France)

The use of x-ray emission from magnetic confinement and laser-produced fusion research plasmas has long been an essential non-perturbative diagnostic technique. Recent advances in x-ray detection technology have dramatically improved the ability of x-ray imaging and spectroscopic diagnostics to accurately measure plasma parameters. With these advancements, detailed characterization of the diagnostic system properties has become ever more important. We present an overview of current and future x-ray diagnostic requirements for fusion plasmas and describe, in particular, diagnostic systems employing spherically bent crystals and viewing characteristic x-ray lines from trace impurities with energies in the range 2-20keV. These include imaging x-ray crystal spectrometers which employ a single crystal in a 1D spectroscopic imaging configuration to measure profiles of the plasma ion and electron temperatures and plasma rotation velocities in devices such as the C-Mod and EAST tokamaks and on the LHD stellarator.

Design and simulation requirements for planned diagnostic installations on ITER will also be discussed. In addition, we present proposed diagnostics based on monochromatic 2D imaging using matched pairs of spherically bent crystals. Diagnostics utilizing both the 1D and 2D configurations have been proposed for use with laser-produced fusion plasmas at the National Ignition Facility (NIF). These proposed...
914-30, Session 8

X-ray wavefront modeling of Bragg diffraction from crystals

J. P. Sutter, Diamond Light Source Ltd. (United Kingdom)

The diffraction of an X-ray wavefront from a slightly distorted crystal can be modeled by the Takagi-Taupin theory, an extension of the well-known dynamical diffraction theory for perfect crystals. Maxwell's equations applied to a perturbed periodic medium yield two coupled differential equations in the incident and diffracted amplitude. These equations are discretized for numerical calculation into the determination of the two amplitudes on the points of an integration mesh, beginning with the incident amplitudes at the crystal's top surface. The result is a set of diffracted amplitudes on the top surface (in the Bragg geometry) or the bottom surface (in the Laue geometry), forming a wavefront that in turn can be propagated through free space using the Fresnel-Kirchhoff integral. The performance of the Diamond Light Source I20 bent-crystal dispersive spectrometer has here been simulated using this method. Methods are shown for transforming displacements calculated by finite element analysis into local lattice distortions, and for efficiently performing 3-D linear interpolations from these onto the Takagi-Taupin integration mesh, allowing this method to be extended to crystals under thermal load or novel mechanical bender designs.

914-31, Session 8

Simulation of diffraction profiles for sagittally bent Laue crystals

X. Shi, Brookhaven National Lab. (United States)

Sagittally bent Laue crystal monochromators have been developed and are being extensively used at the National Synchrotron Light Source, USA. The rocking curves of such crystals are known to be significantly wider than those of perfect crystals as a result of the lattice distortion introduced by the sagittal bending. The existing analytical model explains the rocking curve broadening as well as the reflectivity observed.

Many theoretical methods were developed for calculating diffraction profiles of meridionally (in the diffraction plane) bent crystals. In this work, we extend these methods to accommodate sagittally bent crystals. The total lattice distortion angle for anisotropic crystals under sagittal bending is adapted into the multi-lamellar approximation using the rotating crystal method, in which the incident angle changes through each lamella. In addition, the Penning-Polder theory is examined for sagittally bent crystals with the uniform strain gradient. Finally, examples of these simulation results are presented and the merit of each method is discussed.

914-32, Poster Session

Optimization software for the collimator of the Mars-XRD diffractometer: an update

C. Pelliciari, L. Marinangeli, International Research School of Planetary Sciences (Italy)

Mars-XRD is an X-ray diffractometer developed for the in situ mineralogical analysis of the Martian soil and it is a part of the payload of the ESA ExoMars mission. The main components of the Mars-XRD experiment are a Fe55 radioactive source, a collimator and a CCD-based detector system. For spectroscopic requirements, the beam section should not be larger than 0.5 x 10 mm2 at sample distance.

To improve the X-ray flux, we are studying a collimator with converging blades which permits to use the entire source emission and tune the beam section.

In order to better estimate the efficiency of this new collimator and because of the high number of variables, a C++ program has been written that look for the best blades configuration among billion of combinations. In addition to the collimator configuration, this software simulator gives the sample photons distribution for different angles of the tilt of the source and for each couple of blades.

The optimized collimator transmits a flux 30% higher than a system with converging blades with the same aperture each and 4 times higher than a two windows collimator. Tilting the source of 40 degrees the flux became 10% weaker but the angular resolution increase of 20%.

This software simulator could be used also for the optimization of collimator system for the other wavelength and applications (e.g. radiotherapy).

914-33, Poster Session

Combined charged-particle and x-ray simulations using Bmad

D. Sagan, J. Y. Chee, K. D. Finkelstein, G. H. Hoffstaetter, D. H. Bilderback, Cornell Univ. (United States)

The Bmad software library, developed at Cornell University, has proved to be a useful tool for accelerator simulations owing to its modular, objects oriented design. Bmad has been used to simulate the CESR storage ring for many years, and now, to design and analyze the proposed x-ray Energy Recovery Linac (ERL) at Cornell. One goal of recent Bmad development is to be able to do combined simulations of charged-particle beams and the x-ray beams that they create. Ultimately a complete framework to simulate an ERL from gun cathode (including space-charge) to photon generation & tracking through x-ray experimental stations will be developed. We are now developing photon tracking through crystal and focusing capillary optics. A further long-term goal is to integrate Bmad with the forthcoming revision of the Shadow tracking code. Discussed will be present status and future plans.

914-34, Poster Session

Monte Carlo simulations on the scattered power from irradiated mirrors and crystals

E. Secco, M. Sanchez del Rio, European Synchrotron Radiation Facility (France)

We developed a computer tool for accurate evaluation of the absorbed and re-scattered power from optical elements (mirrors, crystals and attenuators) in a synchrotron beamline. The results of these calculations are used for further heat load calculations using Finite Elements Methods. The radiation re-scattered from a mirror or a crystal receiving high power load can damage the opto-mechanical components placed in the chamber. A precise estimation of this power and its energy spectrum is necessary to assist in the design of the shielding inside the new optical chambers for the Upgrade Programme at the ESRF.

The Monte Carlo simulation package PENELAPE [1] was used to build a user code that uses the synchrotron spectrum or a monochromatic beam as input and calculates the spectrum and the amount of energy absorbed, transmitted, or back-scattered. The program output was tested against the NIST tabulated values of the mass energy absorption coefficient [2]. Some results for the heat load calculation will be presented for three cases: i) a Glidcop mirror for the SESAME Synchrotron [3], ii) a silicon crystal in use at the ESRF beamline ID06, and iii) a Laue crystal for the new monochromator of the ESRF ID17 beamline.

The xraylib library for x-ray-matter interaction cross sections: new developments and applications

T. Schoonjans, Univ. Gent (Belgium); M. Sanchez del Rio, European Synchrotron Radiation Facility (France); A. Brunetti, Univ. degli Studi di Sassari (Italy); C. Ferrero, European Synchrotron Radiation Facility (France); L. Vincze, Univ. Gent (Belgium)

X-ray based analytical techniques have seen a surge in popularity over the last decades. This has led to an increased interest in cross sections and atomic parameters, which are of fundamental importance in both quantitative and qualitative analysis. In X-ray fluorescence (XRF), for example, quantification using either the fundamental parameter method or Monte-Carlo simulations is only possible if accurate data of X-ray interactions with matter are available. Such data can be obtained in two ways: experimental and computational through quantummechanical calculations. Several authors have published databases and tabulations in the literature, but none of them are presented in the form of freely available library functions which can be easily included in software applications for X-ray techniques.

In an effort to solve the problem of interfacing the data to the user, Brunetti et al. designed a software package called xraylib based on a shared ANSI C language library. The physical data included in the package is a compilation of several popular datasets including for example photoionization-, Rayleigh-, and Compton cross sections as well as absorption edge energies, fluorescence line energies and fluorescence yields. In this work we will present not only the features of the original xraylib package, but also introduce some novelties that were recently added such as partial photoelectric effect cross sections, refractive indices, Compton broadening profiles and bindings with popular programming languages.

The xraylib package can be downloaded from http://github.com/tschoonj/xraylib

Advanced simulations of x-ray beam propagation through CRL “transfocators” using ray-tracing and wavefront propagation methods

J. Baltzer, Univ. of Copenhagen (Denmark); E. Knudsen, Risø National Lab. (Denmark); O. Chubar, Brookhaven National Lab. (United States); K. Lemmann, R. Feidenhans’l, Copenhagen Univ. (Denmark); A. A. Snigirev, European Synchrotron Radiation Facility (France)

Applying two complementary simulation methods -- geometrical ray-tracing and partially-coherent wavefront propagation -- guarantees solid results and provides complete description of X-ray beam propagation through the CRL and other optical elements present in a beamline. The ray-tracing offers high CPU efficiency and simplicity of the simulations and provides good accuracy in cases of low X-ray coherence. On the other hand, the partially-coherent wavefront propagation method allows for accurate description of X-ray beams at conditions of both low and high coherence, and enables for keeping track of the degree of coherence at the propagation through individual optical elements, for the expense of higher overall complexity and CPU-intensity of calculations.

In this work we used the newly developed McXtrace ray-tracing package [1] and the SRW wave-optics code [2] to simulate X-ray undulator radiation beam propagation through an in-vacuum transfocator (IVT) as it is implemented at ID-11 at ESRF [3]. The results of the simulations are in good agreement with the experimental data.

A new version (3.0) of SHADOW [1] has been developed. SHADOW3 is written in Fortran 2003 and follows the new computer engineering standards. The users can always execute the program in the traditional file oriented approach of the precedent version. Moreover, advanced users can create personalized scripts, macros and executables using the new Application Programming Interface (SHADOW3-API). It also allows binding of SHADOW3 with several popular programming languages such C, C++, python and IDL. We describe the SHADOW3 API structure, and illustrate its use with some examples.

SHADOW3 can be run in parallel machines under different environments. We implemented a version using the Open Message Parsing Interface (OpenMPI), to take full advantage of modern multi-core processors. The next plan is to accelerate SHADOW3 with the use of Graphics Processing Units (GPUs). This will open the door to extending the already very popular ray tracing tool to applications simulating 2D and 3D experiments (like imaging, tomography) and to integrating the optics calculations into a consistent synchrotron data analysis framework.

Characterization of hard X-ray beamlines can be accurately performed through ray tracing simulation methods, and ray-tracing based optical mis-alignment adjustment technique is practically useful for the beamline initial alignment and commissioning. We describe here the way and the tools we use at SOLEIL to develop hard X-ray beamlines such as Psiché, which is a high pressure diffraction beamline using a wiggler source in the range from 15keV to 50 keV. Ray tracing simulations are performed with Spox, taking into account the thermal surface deformations (from FEA calculations) and the surface defects due to the polishing and the bending (from the profilometer measurements) of the optics, to study carefully the defect effects on beam properties, to optimize the optical alignment process and to eliminate these defect effects by re-adjusting the optics, try to pursue the best performance of the beamline.

A toolkit for the x-ray optics simulation software package XOP/ShadowVui

B. C. Meyer, Lab. Nacional de Luz Sincrotron (Brazil)
The design of a synchrotron beamline is supported by various software simulation packages containing source simulation, characterization of X-ray optics, ray-tracing simulation and others separately. Beamline designers and operators often require instantly data of the beam parameter, which is only feasible with an unified and more user-friendly software package. The new developed toolkit is a first step in that direction.

Photon flux, bandwidth, beam size and beam divergence are the chosen parameters used for the beamline design and optimization. A tool was developed, which allows to scan these parameters by changing any input parameter, for example the photon energy, the vertical mirror position or the horizontal slit size. A tabular input allows scanning with arbitrary parameters or even different file names (e.g. filter material, surface profile).

We present two methods of calculating power density profiles on the optical components, one by ray-tracing and the other by transmission calculation using the DABAX library. The second method only considers flat optics, but is a good approximation and faster than the method based on ray-tracing.

The validation of the developed tools is shown by a comparison of the simulated beam parameters and the measured ones, which was performed at the Superconducting Wiggler Beamline (SCW) and the Undulator Beamline (PGM) recently turned into operation at the Brazilian Synchrotron Light Source (LNLS). We report also the capability of the parameterized scanning method for the alignment of the optics during the commissioning phase of the beamlines.

8141-41, Poster Session

**XOP v2.4: recent developments of the x-ray optics software toolkit**

R. J. Dejus, Argonne National Lab. (United States); M. Sanchez del Rio, European Synchrotron Radiation Facility (France)

XOP v2.4 consists of a collection of computer programs for calculation of radiation characteristics of x-ray sources and their interaction with matter. Many of the programs calculate radiation from undulators and wigglers, but others, such as x-ray tube codes, are also available. The computation of the index of refraction and attenuation coefficients of optical elements using user-selectable databases containing optical constants is an important part of the package for calculation of beam propagation. Coupled computations are thus feasible where the output from one program serves as the input to another program. Recent developments, including enhancements to existing programs, are described in detail.

* Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

8141-42, Poster Session

**Conceptual design for a dispersive XAFS beamline in the compact storage ring MIRRORCLE**

N. Canestrari, European Synchrotron Radiation Facility (France); V. Roger, P. Jeantet, O. Leynaud, L. Ortega, Institut NEEL (France); H. Yamada, T. Hanashima, Ritsumeikan Univ. (Japan); J. Lorenzo, Institut NEEL (France); M. Sanchez del Rio, European Synchrotron Radiation Facility (France)

We present the conceptual design of a XAFS beamline for MIRRORCLE [1], a new compact laboratory X-Ray source. This machine accelerates electrons to 20 MeV in a ring and produces x-rays when the electrons collide onto a thin target. The radiation emitted has a white spectrum due to both synchrotron and bremsstrahlung emission. The electrons are recovered after collisions, and the emitted light has high flux, large energy spectrum and an important angular dispersion.


The LABSYNC project (Laboratory compact light sources) has been funded by the European Commission under the Seventh Framework Programme (Grant No. 213126) "FP7-INFRASTRUCTURES."
Recent progresses in THM CZT detector for medical imaging and security applications

S. A. Awadalla, J. Mackenzie, P. M Barthamand, S. Taherion, J. Kumar, H. Chen, Redlen Technologies (Canada)

Recent works in the post growth annealing processes of CdZnTe using Traveling Heater Method (THM) for crystals of 10 and 15 mm thickness used for homeland security, has reduced the size and density of Te inclusions, which in turn resulted in improved crystal uniformity and performance of both 241Am and 137Cs spectra. In addition, more progress has been made on optimizing device metallization and geometry using extended cathode design which led to a perfect ohmic contact and improved device efficiency for thinner devices used in high flux x-ray and medical imaging applications respectively. Examples of the progress in the above mentioned areas will be presented.

Manipulation of charge transport and the internal electric field distribution in CdZnTe crystals using light

L. C. Teague, A. L. Washington II, M. C. Duff, Savannah River National Lab. (United States); M. Groza, V. Buliga, A. Burger, Fisk Univ. (United States)

CdZnTe (CZT) semiconducting crystals are of interest for use as room temperature X- and γ-ray spectrometers. Several studies have focused on understanding the various electronic properties of these materials, such as the surface and bulk resistivities and the distribution of the electric field within the crystal. Specifically of interest are how these properties are influenced by a variety of factors including structural heterogeneities, such as secondary phases (SPs) and line defects as well as temperature effects. We have used a variety of techniques to probe and manipulate the electrical properties of two CZT crystals that were grown using two types of methods and had substantially different defect densities and compositional volumes. We will describe and compare the variations observed in surface and bulk resistivities of these crystals as a function of light illumination at various wavelengths. Furthermore, we will correlate these results to changes in the internal electric field distribution that we observed through transmission images based on the Pockels effect. The specific responses of the two crystals and the observed changes in their electrical properties provide further insight into the detailed relationships between charge transport and material characteristics in CZT.

Characterizations of extended defects in CdZnTe detectors

A. E. Bolotnikov, G. Camarda, Y. Cui, R. Gul, A. M. Hossain, K. H. Kim, G. Yang, R. B. James, Brookhaven National Lab. (United States)

New results from testing of CdZnTe (CZT) detectors using IR transmission microscopy, white X-ray beam diffraction topography and chemical etching will be presented. Correlations with micron-scale X-ray mapping and gamma-ray spectral responses will also be provided. The particular roles of sub-grain boundaries and dislocations on charge transport in CZT material and CZT device performance will be emphasized.

The influence of steering electrodes on CZT pixellated x-ray detectors

D. Kitou, Univ. of Surrey (United Kingdom) and Science and Technology Facilities Council (United Kingdom); M. C. Veale, Science and Technology Facilities Council (United Kingdom); C. G. Allwork, P. J. Sellin, Univ. of Surrey (United Kingdom); P. Seller, Science and Technology Facilities Council (United Kingdom); A. Lohstroh, V. Perumal, Univ. of Surrey (United Kingdom); M. Wilson, Science and Technology Facilities Council (United Kingdom)

The use of steering, or inter-pixel, electrodes has been reported by various authors to improve the spectroscopic performance of both CZT single element [1, 2] and pixel detectors [3] by reducing inter-pixel charge sharing. Steering electrodes are used to influence the local weighting field close to the collecting electrode, which strongly improves the charge collection behaviour and spectroscopic performance of the device.

In this paper we use a dedicated ASIC, the PIXIE ASIC, to study charge sharing and the effect of steering electrodes on device performance. The PIXIE ASIC has been developed at RAL, as part of the HEXTEC collaboration [4], and contains 3 arrays of 9 pixels on a 250 µm pitch and a single array on a 500µm pitch; each pixel contains a low noise charge amplifier and output buffer [5].

The ASIC has been developed to directly investigate the effect of electrode geometry on charge induction, charge sharing and the spectroscopic performance of CZT small pixel detectors; specifically the influence of steering electrodes on device performance.

The device simulation software Silvaco ATLAS has been used to model the electric field distribution in the CZT devices and how steering electrodes locally modify the field in the near-pixel region. These simulations will be compared to experimental measurements to fully understand the effects of steering electrode geometries on CZT detector performance.

Results of CdTe pixel detectors using Medipix2 and Medipix3 read-out electronics

M. Fiederle, A. Fauler, S. Procz, A. Zwerg, Albert-Ludwigs-Univ. Freiburg (Germany)

Pixel detectors have been processed using 1 mm thick CdTe wafers. The detectors have two different pixel pitches of 55 and 110 µm and an active area of 14x14 sqmm. The detectors have been selected from THM grown CdTe wafers. The wafers have been characterized by infrared microscopy and Contactless Resistivity Mappings to obtain the material properties. The detectors have been flip-chip bonded to Medipix2 and the new Medipix3 read-out electronic chips. The correlation of the material properties with the performance of the pixel detectors is th focus of this work. The detectors have been characterized by x-ray tubes and gamma radiation. The performance of the pixel detectors will be discussed regarding spatial resolution by MTF, the efficiency and the possibility of energy resolving methods. The possibility of high spatial resolution of 55 µm will be evaluated regarding the thickness of 1 mm of the detector samples. The feature of the Medipix3 with five energy threshold will be used for spectroscopic images. The performance of a CdTe detector with the Medipix3 read-out will be discussed for the application in Colored X-ray Imaging.
8142-06, Session 2

Mapping the x-ray response of a CdTe sensor with small pixels using an x-ray microbeam and a single photon processing readout chip
E. Fröjd, C. Fröjd, B. Norlin, G. Thungström, Mid Sweden Univ. (Sweden)

CdTe is a promising material for X-ray imaging since it has high stopping power for X-ray photons. However defects in the material, non ideal charge transport properties and long range X-ray fluorescence can deteriorate the image quality, especially for applications of spectral imaging. In this project we have investigated the response of 1 mm thick CdTe sensors bonded to Timpix readout chips. The pixel pitch is 55 and 110 um. The measurements have been done using an X-ray microbeam entering the sensor at a small incident angle. The width of the beam was around 10 um. Due to the small size of the beam and the pixelation of the sensor the response around defects can be investigated by scanning. Also depth of interaction can be measured by the same method. The readout chip has been operating in Time over threshold mode thus measuring the energy of each x-ray interaction, also separating scattered and fluorescent photons interacting in different pixels. Measurements have been done in both electron and hole collection mode. The results give evidence of distorted electrical field around certain defects in the material and also show the small pixel effect.

8142-07, Session 2

Evaluation of characteristics of CdTe detector by laser pulses
Y. Suzuki, T. Ito, A. Koike, T. Okunoyama II, A. Miyake, Y. Neo, H. Mimura, T. Aoki, Shizuoka Univ. (Japan)

Measurements concerning the internal electric field, carrier generations, and transportation of electron are required to clarify the dynamic properties of CdTe gamma / X-ray detector. In addition, the position and the timing of the carrier generation should be controlled to obtain more accurate inner properties. Therefore, the focused pulse laser irradiated to side of CdTe detector was used to control the incident position and timing accurately. This amount of photon correspond to γ-ray energy and pulse frequency correspond to γ-ray dose.

In this study, we use Schottky diode type CdTe of 0.5 mm thickness and pulse laser with wavelength of 633 nm. As a result, the change of output pulse height is observed corresponding to distribution in depletion layer at the Schottky interface.

8142-08, Session 2

Energy discriminated x-ray CT using high count rate photon counting CdTe detector
T. Aoki, A. Koike, Shizuoka Univ. (Japan) and ANSeeN Inc. (Japan); T. Okunoyama II, Shizuoka Univ. (Japan) and Shizuoka Univ. (Japan); H. Morii, Shizuoka Univ. (Japan) and ANSeeN Inc. (Japan); S. Singh, M. Kimura, T. Yamakawa, H. Mimura, Shizuoka Univ. (Japan)

The high count rate photon counting type CdTe detector, which can take full spectrum (2048ch) at 500kcpss with X-ray tube source, was developed. The detector is small and stable for long time operation with very small polarization. The detector was mounted in CT system with micro-focused X-ray tube and XYZ-liner and rotation stages. We could obtained clear image with less beam hardening effect. We can change the energy - threshold or energy-band on software after imaging because each pixel has full energy spectrum. We could easily find optimized threshold by changing the threshold energy while watching the screen on computer. This result shows new energy discriminated X-ray CT performance.

8142-09, Session 2

High resolution CdTe X- and gamma-ray detectors with a laser-formed p-n junction
V. A. Gnytuk, V. Lashkaryov Institute of Semiconductor Physics (Ukraine) and Shizuoka Univ. (Japan); T. Aoki, Shizuoka Univ. (Japan); E. V. Grushko, L. A. Kosyachenko, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine); O. I. Vlasenko, V. Lashkaryov Institute of Semiconductor Physics (Ukraine)

Room temperature X- and gamma-ray detectors, fabricated on the basis of CdTe diodes, have been usually suffered from an increase in leakage current with rising reverse bias voltage that was applied to extend the depletion region and thus improve energy resolution and efficiency. The dominant charge transport mechanism in the In/CdTe/Au diodes formed by laser-induced doping of the surface region of high resistivity p-like CdTe crystals, is generation process in the space-charge region of the reverse-biased p-n junction near the In/CdTe contact. At higher bias voltages, an additional increase in leakage current is attributed to electron injection from the opposite Au/CdTe contact to the bulk of CdTe and hence into the p-n junction. In order to limit leakage current and improve the charge collection at the junction, a very steep high rectification barrier has been formed by extremely heavy n-type doping of a thin surface layer of crystals. This was achieved by carrying out laser-induced doping in liquid medium (water or methanol) to provide a high intensity of laser-induced stress and shock waves which had been considered as the main mechanism of solid phase doping. Moreover, the special processing was developed, including chemical and thermal procedures, to modify the surface state of the CdTe crystals before deposition of an In dopant film and electrodes. Finally, the room temperature In/CdTe/Au diode detectors have been obtained with record high energy resolution (0.7% at 662 keV peak of a Cs-137). The electrical and detection properties of the detectors have been investigated.

8142-02, Session 3

Characterization of CdTe and Cd(0.9)Zn(0.1) Te crystals grown from a low temperature solution process for radiation detector applications
K. C. Mandal, R. M. Krishna, T. C. Hayes, P. G. Muzykov, Univ. of South Carolina (United States); A. E. Mendez Torres, Savannah River National Lab. (United States)

Spectrometer grade CdTe and Cd(0.9)Zn(0.1)Te (CZT) crystals, grown at low temperature, have been characterized. The single crystals were grown from high purity Cd and zone refined Zn and Te in three zone furnaces installed in our laboratory. The furnaces feature custom pulling and rotation, using in-house electronics and software. The semi-insulating (SI) CdTe and CZT crystals exhibited high resistivity (5-8×10^10 Ω-cm) and low Te-inclusions. The crystals also showed good electron mobility-lifetime product (electron μτ = 6 × 10^-3 cm^2/V). Optical absorption/transmission, x-ray photoelectron spectroscopy (XPS), electrical characterization including deep level transient spectroscopy (DLTS) measurements, and nuclear radiation detection testing was performed on the surface modified and unmodified CdTe and CZT crystals. Nuclear detection measurements were performed with Am-241 (60 keV) and Cs-137 (662 keV) radiation sources, showing a 2.4% and 1.4% energy resolution (FWHM), respectively, for surface modified CZT detectors.
8142-10, Session 3

Performance evaluation on the first Polaris 3-D CdZnTe detector system

Z. He, F. Zhang, W. R. Kaye, Y. A. Boucher, W. Y. Wang, C. Wahl, J. M. Jaworski, S. J. Kaye, J. Berry, Univ. of Michigan (United States)

Each Polaris system consists of eighteen 2x2x1.5 cm^3 CdZnTe detectors, has a total detection volume of 108 cm^3 and is capable of real-time gamma-ray imaging in the energy range of about 40 keV up to 3 MeV. The first Polaris system was delivered to DOD DTRA in the middle of October 2010. Since then, this system has been tested by independent operators in Nevada during October to December of 2010, in Oak Ridge National Laboratory during January to March of 2011, and has been extensively tested by our research group at the University of Michigan. Test results on the first Polaris system will be summarized, including its energy resolution, detection efficiency, gamma-ray imaging angular resolution and gamma-ray imaging efficiency. Some new capabilities of the Polaris system will also be introduced.

8142-11, Session 3

Development of large-volume CZT cross-strip detectors

K. Lee, J. W. Martin, A. Garson, M. Belicke, Q. Guo, Washington Univ. in St. Louis (United States); M. Groza, A. Burger, Fisk Univ. (United States); H. S. Krawczynski, Washington Univ. in St. Louis (United States)

Cadmium Zinc Telluride (CZT) is the detector material of choice for the detection of hard X-rays with excellent spatial and energy resolutions without cryogenic cooling. We are developing large-volume (0.5×3.9×3.9 cm^3) cross-strip CZT detectors with the objective to combine the excellent performance achieved so far only with pixelated CZT detectors with a reduced number of readout channels. In this contribution, we present a detailed study of such large-volume CZT substrates from the company Orbotech contacted as cross-strip detectors. As readout contact dimensions can contribute to noise and affect the overall capabilities of a detector, we compare the detection efficiency and spectroscopic performance achieved with four different strip widths deposited simultaneously on the same substrate. In addition, we investigate the effects of a steering grid on the detection efficiency and energy resolution of the detector. Finally, we compare the experimental results with those from detailed detector simulations. Our results show that CZT cross-strip detectors combine excellent energy resolutions with high detection efficiencies and are a promising alternative to pixelated CZT detectors.

8142-13, Session 3

Performance characteristics of pixelated CZT crystals used on the GammaTracker project


The GammaTracker project at Pacific Northwest National Laboratory is a handheld radioisotope identification device which uses eighteen pixilated Cadmium-Zinc Telluride (CZT) crystals to provide energy resolution approaching that of high-purity germanium without cryogenic cooling. Additionally, these crystals can be used to provide directional and imaging capabilities that cannot be found in other handheld detectors. A significant number of CZT crystals have been procured during the development of the GammaTracker system. These crystals undergo a two-stage testing procedure in order to assure the crystal quality and meet project requirements. Key parameters that determine the quality of the crystals include the breakdown characteristics, pixel-by-pixel resolution, and mobility-lifetime product (µτ). This presentation will provide and discuss the results of the testing procedure and their implications.

The Information Release (IR) request entitled, “CZT Abstract” has been approved by all the reviewers. The IR number assigned to this product is: PNNL-SA-77708

8142-14, Session 3

Direct measurement of structural defects and their influence on CdZnTe detectors

A. M. Hossain, A. E. Bolotnikov, G. Camarda, Y. Cui, R. Gul, K. Kim, K. Kisslinger, D. Su, G. Yang, L. Zhang, R. B. James, Brookhaven National Lab. (United States)

Cadmium Zinc Telluride (CdZnTe) radiation detectors currently encounter a number of problems related to material uniformity and charge transport properties, which deteriorate the overall device performance and hence restrict their widespread deployment for potential applications in national security and medical imaging. Such deterioration in the detector’s performance results from various point- and extended-crystalline defects, like vacancies, impurities, dislocations, precipitates, etc., which are primarily generated during crystal growth and post-growth treatment. We are systematically investigating various extended crystalline defects, like dislocations, micro-twins, and precipitates, in CdZnTe crystals grown under various conditions. In this study, we employed high-resolution electron microscopy (TEM and STEM), along with energy/wavelength dispersive X-ray spectroscopy (EDS/WDS). Their combination facilitated our acquisition of comprehensive information on structural defects in detector-grade CdZnTe crystals. In addition, we probed the electron-beam-induced current (EBIC) across specific defects by introducing, for the first time, a high-precision tungsten probe that allowed us to differentiate those defects directly. We correlated our findings from these different characterization methods to assess the crystalline defects, and to identify their origin and their influence on the performance of the fabricated devices. Our endeavor demonstrated distinct structural defects in the crystals, such as stacking faults, dislocation loops, and precipitates that likely are major causes in degrading the electrical properties of the devices, and eventually limiting the detector’s performance.

8142-15, Session 4

Surface and defect correlation studies on high resistivity 4H-SiC bulk crystals and epitaxial layers for radiation detectors

K. C. Mandal, P. G. Muzykov, R. M. Krishna, T. C. Hayes, T. S. Sudarshan, Univ. of South Carolina (United States)

High resistivity silicon carbide (SiC) has potential applications for room temperature radiation detectors because of its wide band gap, good charge transport properties and high radiation hardness. Crystallographic defects and impurities in this material are the two major factors limiting the performance of SiC based radiation detectors. Therefore their study is highly demanded for the development of high resolution radiation detectors from this material. In this work, we present electrical and defect characterization studies of semi-insulating bulk 4H SiC crystals and epitaxial layers. Study of the extended defects was accomplished using electron beam induced current (EBIC) measurements and chemical etching in molten KOH in conjunction with optical microscopy, scanning electron microscopy (SEM), and atomic force microscopy (AFM) for defect identification and detailed study of the etch pit structure. Results of the investigation correlating SEM contrast with the etch pit structure for different types of threading dislocations will be presented. Study of the electrically active defects and impurities, and carrier transport...
properties, were conducted using glow discharge mass spectroscopy (GDMS), thermally stimulated current (TSC) measurements, high temperature resistivity (HTR) studies and Hall effect measurements. The TSC and HTR measurements revealed deep level centers at 1.1-1.2 eV and 1.56 eV in bulk 4H SiC samples, which we associate with intrinsic defects. The obtained results are correlated with the capability of bulk crystals and epitaxial layers for the detection of low energy x-rays, gamma rays, α-ray, and tritium detection.

8142-16, Session 4

Efficiency and decay time measurement of phosphors for x-ray framing cameras usable in harsh radiation background


Phosphors are key components of x-ray framing camera and x-ray/ optical streak cameras. In these cameras, incoming x-rays or optical signals are converted to electrons that are multiplied, gated, or deflected, then converted back to optical signals again using phosphors. On implosion experiments at the National Ignition Facility, these instruments must operate in a harsh ionizing radiation background environment (mostly neutrons and gamma-rays produced by inelastic scattering of neutrons). In this environment, a significant improvement in signal-to-background ratio can be obtained by utilizing a phosphor with a high optical output and fast decay time. We present measurements of conversion efficiency and decay times for various phosphor materials, enabling optimal design of framing cameras and streak cameras for implosion experiments. Prepared by LLNL under Contract DE-AC52-07NA27344.

8142-17, Session 4

Long-term room temperature stability of TlBr gamma detectors


TlBr is a material of interest for use in room temperature gamma detector applications due to its wide bandgap 2.7 eV and high average atomic number (TI 81, Br 35). Researchers have achieved energy resolutions of 1.2 % at 662 keV, demonstrating the potential of this material system. However, these detectors are known to polarize using conventional electrodes at room temperature will be presented.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This work was supported by The Domestic Nuclear Detection Office in the Department of Homeland Security.

8142-18, Session 4

comparison of SEM and optical analysis of DT neutron tracks in CR-39 detectors

P. A. Boss, SPAWARSYSCEN Pacific: San Diego (United States); L. Forsley, JWK International Corp. (United States); P. Carbonnelle, Univ. Catholique de Louvain (Belgium); M. S. Morey, J. R. Tinsley, J. P. Hurley, National Security Technologies, LLC (United States)

Columbia Resin 39 (CR-39), a polyallyldiglycol carbonate polymer, has been used as a solid state nuclear track detector (SSNTD) to detect energetic nuclear particles. As an energetic, charged particle traverses through CR-39, it creates along its path an ionization trail that is more sensitive to chemical etching than the bulk material. After etching, the tracks due to energetic particles have the appearance of holes or pits. The most common method employed to analyze these tracks is optical microscopy. However, atomic force microscopy (AFM) and scanning electron microscopy (SEM) have also been used by others to analyze tracks in CR-39 resulting from exposure to either alpha or proton sources. In this communication, tracks resulting from exposure to a DT neutron source were examined both optically and by SEM. The purpose of the analysis was to compare the two techniques and to determine whether additional information on track geometry could be obtained by SEM analysis. The use of these techniques to examine trime tracks, diagnostic of ∼9.6 MeV neutrons, observed in CR-39 used in Pd/D co-deposition experiments will also be discussed.

8142-19, Session 4

Position sensitive gamma ray measurements using mercuric iodide strip detectors

S. K. Chaudhuri, A. Lohstroh, Univ. of Surrey (United Kingdom); A. Hardie, L. L. Jones, P. Seller, Rutherford Appleton Lab. (United Kingdom); P. J. Sellin, Univ. of Surrey (United Kingdom)

Mercuric iodide, because of its high Z components and high resistivity, has presented itself as a suitable x- and gamma-ray detector material for spectroscopic purposes. Because of excellent absorption coefficients for hard x-rays even for small volume detectors, HgI2 detectors can be suitably used as very compact position sensitive devices. In addition, recent availability of superior detector grade material has renewed the interest of application of HgI2 crystals for imaging.

In the present work we report the performance of two HgI2 strip detectors, designed at University of Surrey, as one dimensional position sensitive devices. The two devices were designed so as to sit side by side to form a prototype array. Each device consists of 13 palladium strips and a planar Pd back contact deposited on a 27 x 13 x 1.4 mm HgI2 crystal, fabricated by Constellation Technologies, USA. The strips were pitched at 2 mm and are 1.7 mm wide and 10 mm long. Gamma spectroscopy has been performed on all strips separately at various energies up to 662 keV. It was found that the detectors have a moderate energy resolution and all the strips have more or less similar characteristics. For position sensitive measurements, an analog readout system has been designed in collaboration with Rutherford Appleton Laboratory. The read-out system consists of an ASIC which collects and processes the signal from all the strips of the two-detector array simultaneously. We will present a comprehensive summary of the spatial resolution and spectroscopic performance of the system.

8142-20, Session 5

CMOS solid-state photomultipliers for high energy resolution calorimeters

Inc. (United States); F. Augustine, Augustine Engineering (United States); R. Miskimen, Univ. of Massachusetts Amherst (United States); J. F. Christian, Radiation Monitoring Devices, Inc. (United States)

High-energy, gamma-ray calorimetry typically employs large scintillation crystals coupled to photomultiplier tubes. To achieve valued physics measurements, these calorimeters are segmented to the limits associated with the costs of the crystals, photomultiplier tubes, and support electronics. A cost-effective means for construction of a calorimeter system is to use solid-state photomultipliers (SSPM) with front-end electronics, which has roughly half the cost, but the SSPM must provide the necessary energy resolution defined by the physics goals. We have develop a large-area SSPM (1 cm × 1 cm) for readout of large scintillation crystals, and one particular application of reading out PbWO4 crystals in a gamma-ray calorimeter pushes the limits of the solid-state photomultiplier. The nature of PbWO4 requires high-energy (> 1 GeV) gamma-rays for device evaluation, as the light yields are low, and a high energy deposition also requires a large volume to completely absorb the gamma-ray energy characterized by the Molière radius. These two constraints restrict device evaluation with test sources, such as 22Na. The SSPM and readout electronics have been developed for the calorimeter with supporting front-end electronics for readout of four scintillation crystals for complete instrument evaluation with a high-energy gamma ray, but initial tests with test sources and bright scintillation materials (LYSO, CLLB) indicate that the detector will provide sufficient energy resolution. We will review each signal and noise contribution from the large-area SSPM and provide predicted device performance as a function of light intensity and operating conditions, providing the baseline information on expected detector performance.

8142-21, Session 5

A hybrid reflective/refractive/diffractive achromatic fiber-coupled radiation resistant imaging system for use in the spallation neutron source (SNS)

L. C. Maxey, Oak Ridge National Lab. (United States); J. Kummer, JENOPTIK Optical Systems, Inc. (United States); T. R. Ally, A. M. Brunson, F. D. Garcia, K. C. Goetz, K. E. Hasse, M. A. Mitchell, M. L. Simpson, T. J. Shea, Oak Ridge National Lab. (United States); T. Lindsay, D. Brown, T. Victorio, JENOPTIK Optical Systems, Inc. (United States)

A fiber-coupled imaging system for monitoring the proton beam profile on the target of the Spallation Neutron Source was developed using reflective, refractive and diffractive optics to focus an image onto a fiber optic imaging bundle. The imaging system monitors the light output from a chromium-doped aluminum oxide (Al203:Cr) scintillator on the nose of the target. Metal optics are used to relay the image to the lenses that focus the image onto the fiber. The material choices for the lenses and fiber were limited to high-purity fused silica, due to the anticipated radiation dose of 108 R. In the 1st generation system (which had no diffractive elements), radiation damage to the scintillator on the nose of the target significantly broadened the normally monochromatic (694 nm) spectrum. This created the need for an achromatic design in the 2nd generation system. This was achieved through the addition of a diffractive optic for chromatic correction. An overview of the target imaging system and its performance, with particular emphasis on the design and testing of a hybrid refractive/diffractive high-purity fused silica imaging triplet, is presented.

8142-22, Session 5

Cryogenic CMOS avalanche diodes for nuclear physics research


Exploration in nuclear physics may require extreme conditions, such as temperatures down to a few Kelvin, high magnetic fields of several Tesla, or the small physical dimensions of a few centimeters. As a standard for radiation detection uses scintillation materials, it is desirable to develop photodetectors that can operate under these harsh conditions. Though photomultiplier tubes (PMTs) have been used for most applications for readout of scintillation materials, they are bulky, highly susceptible to magnetic fields, and present a large heat load in cryogenic environments. Avalanche photodiodes are a reasonable alternative to PMTs in that they are extremely compact and less susceptible to magnetic fields. Photodiodes have been developed in a commercial CMOS process for operation at temperatures below 100 Kelvin. We present the overall operation of the photodiodes approaching 5 Kelvin. The diodes show an overall decrease in quantum efficiency with respect to room temperature operation with a wave length dependence, the decrease from room temperature to 5 Kelvin is no more than roughly 50%. A gain of 100 is achieved at reasonably low biases rough 30 V. At about 30 Kelvin, the diodes exhibit an internal resistive term, which generates a second breakdown point. Though these characteristics are not ideal, the prototype diode shows a proportional response to the intensity of light pulses down to 150 detected photons. The properties of the photodiodes and the readout electronics will be discussed for general photon detection below 100 K.

8142-23, Session 5

A prototype high detective quantum efficiency imaging panel based on fiber-optic scintillation glass array (FOSGA) for megavoltage imaging

S. S. Samant, A. Gopal, Univ. of Florida (United States); J. E. Baciaik, Jr., Pacific Northwest National Lab. (United States)

Megavoltage imaging has applications in nondestructive imaging for homeland security, radiotherapy, and industrial manufacturing. Current commercial systems are limited by low image quality as measured by detective quantum efficiency (DQE). These systems yield measured DQE=0.01-0.02, limiting efficacy for detection based on automated signal processing. Past efforts to improve DQE have included novel scintillators and manufacturing of large crystal structures. An alternative novel design for a 2D x-ray imager, based on a modification of existing amorphous silicon (a:Si) or flat-panel imagers, is presented. The panel utilizes a fiber-optic scintillation glass array (FOSGA) consisting of scintillation fibers bundled within a pixilated thick sintered tungsten housing. The tungsten housing is constructed using a lithographic manufacturing technique for high fabrication accuracy. The Tb-doped fibers emit light in the 555–565nm range (matched to the sensitive region of current a:Si photodiodes), with a decay time of 2ms (100-to-40%). Monte Carlo simulations, linear cascaded systems analyses, and film studies have been carried out to validate and optimize image quality for radiation beams in the 1-6MV range. An 8cmx8cm prototype array was fabricated using Tb-doped fibers (9mm length, 0.9mm diameter) loaded into a tungsten matrix (1.1mm pixel pitch, 0.1mm septa), yielding measured DQE=0.05 (vs theoretical DQE=0.07) for 6MV imaging , an order of magnitude improvement in image quality over current commercial imagers. Design parameters of a large field-of-view FOSGA imager for cargo container security imaging are presented: 5cm thick FOSGA array, 0.4-1mm pixel pitch, 50-70% fill factor, DQE>0.2 for 1-6MV range.
Covariance spectroscopy applied to nuclear radiation detection

R. Trainham, National Security Technologies, LLC (United States)

Covariance spectroscopy is a method of processing second order moments of data to obtain information that is usually absent from average spectra. In nuclear radiation detection the techniques of covariance spectroscopy represent a generalization of nuclear coincidence techniques. Correlations and fluctuations in data streams encode valuable information about radiation sources, transport media, and detection systems, and gaining access to the extra information can aid many problems in radiation detection and source identification. Covariances can be used to de-noise data, untangle complicated spectra, uncover overlapping peaks, accelerate source identification, and sense directionality.

Correlations existing at the source level are particularly valuable since many radioactive isotopes emit correlated gammas and neutrons. Correlations also arise from interactions within detector systems, as well as in the environment. In particular, correlations from Compton scattering and pair production within a detector array can be usefully exploited even in detection scenarios where direct measurement of source correlations would be unfeasible. We present a covariance analysis formalism, with particular emphasis on its connection to traditional coincidence techniques, and we present experimental results to illustrate the utility of the concepts.

Recognition of 235U enrichment based on autocorrelation function of source-driven neutron pulse signal

J. Jin, W. Biao, F. Peng, Chongqing Univ. (China)

This paper describes a recognition mechanism of 235U enrichment based on the relationship between the autocorrelation function of neutron pulse signal and the 235U enrichment in source-driven nuclear material identification system (NMIS). The mechanism includes two steps: First, obtains the curve distance between autocorrelation functions of the signal to be measured and the reference signal. Meanwhile, the wavelet de-noising on autocorrelation functions is introduced into this step to get more accurate curve distance. Second, derives the relationship between the curve distance and the 235U enrichment by linear fitting or artificial neural network (ANN) to accomplish the recognition of 235U enrichment. The experimental results show that the wavelet de-noising can reduce the negative influence of the fluctuation in neutron pulse signal, and ensures the ability of autocorrelation functions to reflect the varying 235U enrichment. The linear fitting and the ANN can both determine the distance-enrichment relation curve to identify the 235U enrichment in different conditions. The experimental results prove the reliability and validity of the recognition mechanism which provides guarantee for the recognition of 235U enrichment by NMIS.

Prompt neutron multiplicity measurements with portable detectors

S. Mukhopadhyay, R. S. Wolff, R. J. Maurer, S. E. Mitchell, P. Guss, National Security Technologies, LLC (United States)

Rapid detection of kilogram quantities of SNM during maritime transportation is a challenging problem for the U.S. Department of Homeland Security. Counting neutrons emitted by the SNM and partitioning them from the background neutrons of various origins is the most effective passive means of detecting the SNM. Unfortunately, neutron detection, counting, and partitioning in a maritime environment is complex due to the presence of spallation neutrons and to the complicated nature of the neutron scattering in that environment.

A prototype fission meter is being designed by National Security Technologies, LLC, using a thin uniform coating of 10B as a neutron converter inside a large array of thin (4 mm diameter) copper tubes. The copper tubes are only 2 mil thick, and each holds the stretched anode wire under tension and high voltage. The tubes are filled with proportional counter gas (a mixture of 90%/10% of Ar/CO2). The tubes operate in proportional counter mode and attract mobile charged particles () created in the nuclear interaction 10B(n, ) 7Li. Several MCNPX calculations covering substantial design parameter space of neutron multiplicity detectors have been performed and are presented here. The efficiency of thermal neutron detection of this proposed detector will be compared to that of the commercially available Fission Meter (manufactured by ORTEC). Pulse height spectra originating from the charged particles created in the nuclear reaction 10B(n, ) 7Li* + 2.310 MeV (94%) - excited state 10B(n, ) 7Li + 2.792 MeV (6%) - ground state will be examined, and the response to incident gamma rays will be demonstrated.

Acknowledgment

This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy.

Transparent oxyhalide glass and glass ceramics for gamma-ray detection

C. Han, M. Barta, D. J. Nador, R. Rosson, B. Wagner, B. Kahn, Georgia Tech Research Institute (United States); Z. Kang, Georgia Tech Research Institute (United States) and Georgia Institute of Technology (United States)

Nuclear radiation detection is a popularly-discussed topic with increasing importance in today's society. Conventional scintillator based gamma ray detectors use single-crystal materials such as NaI:Tl, LaBr3:Ce, which provide excellent radiation detection properties, but suffer from their environment-related fluctuation, high cost and size limitation. The incorporation of nano-phosphors or Quantum Dots (QD) into a transparent host matrix has been studied recently as a cost-saving alternative that may solve the scalability and stability problems while still providing considerable optical performance. In this work, a new glass based detecting material with promising gamma ray detection performance will be reported. Transparent oxyhalide alumino-silicate glasses containing cerium doped gadolinium halide nanocrystal were prepared by a melt-quenching method followed by anneal at different temperatures to control the density of nano-crystals precipitate. Samples were then casted and polished for optical characteristic tests. The preliminary results indicated a similar gamma ray detection efficiency compared to a conventional NaI:Tl detector and a gamma-ray peak resolution of ~27% at 662 KeV from some of these samples. By controlling element composition and ratio/ size of the in-situ precipitated nano-particles, radiation detection performance is expected to be further optimized and will be studied by X-ray diffraction (XRD), Energy dispersive X-ray Spectroscopy (EDS), Differential Thermal Analysis (DTA), photoluminescence (PL), photo-luminescent excitation (PLE) and scintillation spectral measurements.
particularly ceramic scintillators. Recent developments, including new density functions that accurately predict band gaps, have made it possible to perform quantitative calculations of optical properties of scintillator materials. We used these techniques to obtain optical properties of a large number of high light output halide and oxide scintillators. These calculations showed that many halide scintillators have remarkably little optical anisotropy and may be good candidates for development as ceramic scintillators. These include materials such as CeI2:Eu that have very high light output and other favorable properties but are difficult to develop due to crystal growth issues.

8142-30, Session 7
Proportionality studies of multivalent metal halide scintillators
K. S. Shah, Radiation Monitoring Devices, Inc. (United States)

In this paper, experimental results of proportionality of various multivalent metal halide scintillators are presented. These proportionality measurements have been conducted using isotopic sources with gamma-ray energy ranging from 14 keV to 1275 keV. Proportionality results are presented for various sub-groups within the multivalent metal halides (with Ce3+ and Eu2+ and in some instances, Pr3+ activators) to illustrate clear trends that have been observed for these sub-groups. Some proportionality results for selected compositions with varying activators are also presented. For example, Ce3+ and Pr3+ activators have been studied in LaBr3 with little change in proportionality. Effect of microstructure of a given scintillator on its proportionality has also been explored by comparing results for single crystals with those for ceramics.

8142-31, Session 7
Performance of SrI2(Eu) Gd-based transparent ceramics and bismuth-loaded polymer scintillators
N. J. Cherepy, S. A. Payne, Z. M. Seeley, B. L. Rupert, B. W. Sturm, R. D. Sanner, T. A. Hurst, S. E. Fisher, O. B. Drury, P. Thelin, Lawrence Livermore National Lab. (United States); A. Burger, Fisk Univ. (United States); K. S. Shah, Radiation Monitoring Devices, Inc. (United States); L. A. Botheer, Oak Ridge National Lab. (United States)

For gamma ray spectroscopy, we have discovered a new single crystal scintillator, Strontium Iodide doped with Europium, SrI2(Eu), that offers energy resolution for gamma spectroscopy comparable to that of Lanthanum Bromide doped with Cerium, and considerably better than Thallium-doped Sodium Iodide, NaI(Tl). Encapsulated 1 in3 SrI2(Eu) crystals routinely provide energy resolution at 662 keV of <3%.

Transparent ceramics are fully dense monoliths of micron-scale crystallites, formed by sintering high purity ceramic nanopowders, generally of a single pure phase cubic crystal structure. While the best energy resolution is obtained with single crystal scintillators, such as SrI2(Eu), transparent ceramics offer the possibility of low-cost, net-shape fabrication of oxide scintillators, with benefits of mechanical ruggedness, stability in air and radiation hardness. Transparent ceramic Cerium-doped Gadolinium Garnet, GYGAG(Ce), fabricated at LLNL, offers 4.8% resolution at 662 keV with PMT readout, and with low-noise silicon photodetector readout, <4% can be obtained. For radiographic imaging applications, we are developing transparent ceramic Europium-doped Gadolinium Lutetium Oxide, (Gd,Lu)2O3(Eu), which offers high density of 8.9 g/cm3 and a high light yield of 70,000 Photons/MeV. Key to its performance for imaging applications is attaining extremely low optical scatter by optimizing fabrication conditions.

Due to their availability in large sizes at low cost, plastic scintillators, generally based on Polyvinyltoluene, are used in many applications where a higher density material exhibiting a photopeak would be preferred. Recently, we demonstrated that a cm-scale Bismuth-loaded polymer scintillator can provide energy resolution of <7% at 662 keV.
8142-34, Session 8

Electron cascades and stopping power in scintillator materials


The development of new and improved materials for radiation detection is driven by unmet detector requirements for nuclear non-proliferation, homeland security, imaging for medical diagnosis and treatment, and fundamental science. An advanced Monte Carlo code (NWEGRIM - Northwest Electron and Gamma Ray Interactions in Matter) has been further developed and applied to study electron cascades and energy transfer efficiencies and to calculate stopping power and its fluctuation in NaI and LaBr3, and the results are compared to those published by our group for CsI. These simulations provide information on the creation and spatial distribution of electron-hole pairs, allowing some important intrinsic properties and energy resolution to be evaluated. Also, the stopping power (dE/dx) in a number of scintillator materials has been calculated for energies ranging from 50 eV to 1 MeV, and the results have been compared with those obtained by the Bethe-Block theory, which is an important component for phenomenological model of scintillation processes. The calculated stopping powers are in good agreement with the Bethe-Block theoretical values at high energies, but show some deviations in the low energy regions. The simulations also yield the fluctuations of dE/dx, which have been compared with the Landau fluctuations. Furthermore, the spatial and energy distributions of electrons at the end of the electron cascade determined by NWEGRIM are used as inputs to study the spatial distribution of thermalized electrons in CsI as a function of incident γ-ray energy using a semi-classical theory of electron thermalization model, as implemented in a Monte Carlo transport code of electron-hole pairs. The possible implications of the present results to the study of nonlinearity have been discussed.

8142-35, Session 8

Physics of scintillator nonproportionality

S. A. Payne, S. Sheets, B. W. Sturm, N. J. Cherepy, L. Ahle, S. Dazeley, Lawrence Livermore National Lab. (United States); W. W. Moses, G. A. Bizarri, Lawrence Berkeley National Lab. (United States)

We have developed a phenomenological model of scintillator nonproportionality that requires only two parameters be adjusted to fit the nonproportionality curves of over 30 scintillators, for which experimental data was obtained on our facility known as the Scintillator Light Yield Nonproportionality Instrument (SLYNCI). The two parameters entail accounting for the: (1) fraction of mobile electrons and/or holes produced following the cascade, and (2) exciton-exciton annihilation loss mechanism (based on the classical Birks model). We find that the materials naturally group according to the composition of the host medium, as alkali halides, multivalent halides, fluorides, silicates, simple oxides, and organics. In other words, the nonproportionality curves for each of these material groups are quite similar, although there is a significantly smaller, yet measurable, impact by the identity and concentration of the activator. We also briefly review the work of other researchers on the possible mechanistic under-pinning of this model. Lastly, we deduce the predicted degradation in the resolution from nonproportionality by incorporating the influence of Landau fluctuations, or the instantaneous variance in stopping power as the electron is losing energy and coming to rest. This work was supported by the Department of Energy, NA-22 and the Department of Homeland Security (DHS), and was performed by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344 and by Lawrence Berkeley National Laboratory under contract DE-AC02-05CH11231.

8142-36, Session 8

Bond order potential-based molecular dynamics model for CZT melt-growth simulations

X. Zhou, D. K. Ward, B. M. Wong, F. P. Doty, Sandia National Labs. (United States)

CdTe-based Cd1-xZnTe (CZT) alloy compound is the leading semiconductor for [gamma]-ray detection. The wide-spread deployment of the CZT detectors, however, is currently limited by the high costs of detector-grade materials due to their low manufacturing yields. The formation of defects such as grain boundaries, tellurium inclusions / precipitates, and dislocations during crystal growth has been the limiting factor for the property non-uniformity and the resulting low manufacturing yields. The problem is that while these defects can easily form and are prevalent in the material, their formation mechanisms are not well understood and hence they are difficult to remove. To enable the study of correlation between growth conditions and defect generation on a fine scale using high fidelity molecular dynamics simulations, we have been developing an analytical bond-order potential for the CZT system. The functional forms of the potential were directly derived from the tight-binding theory under the condition that the first two levels of the expanded Green function for the (sigma)- and (pi)- bond orders are retained. The potential incorporates primary (f[sigma]) and secondary (f[pi]) bonding and the valence-dependence of the heteroatom interactions. The potential parameters are parameterized considering properties of a variety of elemental and compound configurations (with coordination varying from 1 to 12) including small clusters, bulk lattices, defects, and surfaces. As a first stage for modeling CZT, preliminary parameterization has been completed for the CdTe system. It is demonstrated that this CdTe bond-order potential not only predicts a structural and binding energy trend close to that seen in experiments and ab initio calculations, but also reasonable melting temperatures for equilibrium Cd, Te, and CdTe phases and various CdTe (001) surface reconstructions. Most importantly, we have validated this potential by demonstrating its ability to predict the liquid phase growth of zinc-blende CdTe crystals. The emergence of such a BOP-based method begins to enable defect formation mechanisms in CZT crystals to be studied at a fidelity level comparable to ab initio methods and a scale level comparable to empirical molecular dynamics simulation methods. This work is supported by the NNSA/DOE Office of Nonproliferation Research and Development, Proliferation Detection Program, Advanced Materials Portfolio. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

8142-37, Session 9

New approach for high quality CZT crystals

D. J. Knuteson, N. B. Singh, A. Berghmans, D. Kahler, B. Wagner, M. King, S. McLaughlin, Northrop Grumman Electronic Systems (United States); A. E. Bolotnikov, R. B. James, Brookhaven National Lab. (United States)

Results will be presented for the growth of CdZnTe by the low pressure Bridgman growth technique utilizing novel choked seeding. CZT detectors are the current state of the art for high resolution, portable room temperature gamma-ray detectors, but widespread use has been slowed due to low yields and limited availability and the resulting high prices. We expect to reduce grain boundaries with choked seeding, which will increase yield and lower prices. In addition, the high purity commercial raw materials will be further refined to remove impurities and deep level traps. The crystals will be grown in the programmable multi-zone furnace (PMZF), which was designed and built at Northrop Grumman's Bethpage facility to grow CZT on Space Shuttle missions. Results of the purification and crystal growth will be presented as well as characterization of crystal quality and detector performance.
8142-38, Session 9

Residual stress determination in CZT and CMT ingots using synchrotron white beam x-ray diffraction topography

K. Kim, A. E. Bolotnikov, G. Camarda, A. M. Hossain, G. Yang, Y. Cui, R. Gul, R. B. James, Brookhaven National Lab. (United States)

CdTe-based CZT (CdZnTe) and CMT (CdMnTe) material show excellent X-ray and gamma-ray detector performance at room temperature. Residual stress generated during crystal growth by extended defects and thermal gradients play an important role in the micro-structural details and associated detector-performance properties. SWBXT (synchrotron white beam X-ray diffraction topography) is a non-destructive technique capable of providing information on the nature and distribution of structural defects such as dislocations, inclusions/precipitates, stacking faults, growth sector boundaries, twins, and low-angle grain boundaries in crystals. CZT and CMT ingots were grown by the Bridgman method using facilities at Brookhaven National Laboratory. We will present data on the evolution and distribution of residual stress in CZT and CMT slabs taken from the tip to heel of the ingots.

8142-39, Session 9

A traveling magnetic field (TMF) for active control of the Bridgman growth of CZT crystals

G. Samanta, A. Yeckel, J. J. Derby, Univ. of Minnesota, Twin Cities (United States)

Large, single crystals of cadmium zinc telluride (CZT) are needed for portable, low-cost, and sensitive devices to monitor radioactive materials. However, while CZT improvements are needed, the growth of these crystals is not well understood. We aim to advance the practice of crystal growth by applying physics-based, computational process models along with modern process control theory. Specifically, we are developing model-based control for the growth of cadmium zinc telluride crystals via the Bridgman method.

In this presentation, we describe a novel approach that may be employed to actively control features of CZT growth in Bridgman systems, namely the application of a traveling magnetic field (TMF). The application of TMF produces Lorentz forces through the molten phase, and these forces can be tuned in magnitude and spatial orientation to profoundly impact melt flows. In turn, these flows modify heat and mass transfer, influencing the shape of the melt-solid interface and segregation along the interface. Since the applied TMF can be instantaneously changed, it provides for a potentially ideal control action, if its complicated effects can be predicted and understood. This is the immediate goal of our work; we discuss the mathematical formulation of our TMF analysis and, more importantly, our initial results on the effects of TMF applied to a prototypical CZT growth system.

Supported in part by DOE/NNSA, DE-FG52-08NA28768, the content of which does not necessarily reflect the position or policy of the United States Government, and no official endorsement should be inferred.

8142-40, Session 9

Growth, characterization, and fabrication of thick detectors from As-grown Cd0.9Zn0.1Te:In by traveling heater method

U. N. Roy, S. Weiler, J. Stein, ICx Technologies Inc. (United States); M. Groza, V. Buliga, A. Burger, Fisk Univ. (United States)

CdZnTe, commonly known as CZT is the material of paramount importance for hard X-ray and gamma ray spectroscopy and imaging applications at room temperature. Over the years, the quality of CZT crystals and its charge transport properties has improved significantly making it an attractive detector material especially for homeland security applications. The applications for homeland security demand large and thick detectors to provide a sufficient stopping power for fast detection of high energy gamma photons. The availability of large (µm) CZT (greater than 500 cm²) material makes it possible to fabricate long-drift (larger thickness) detectors with high resolution. Traveling heater method (THM) has proven to be the best technique for mass production of CZT with good compositional uniformity. However, THM grown CZT has mainly been reported to require post growth annealing to achieve detector grade material. Elimination of the post growth annealing process is a challenge, which will reduce the production cost and increase the availability of material for large detectors. In order to meet this challenge, we are continuously putting our effort to improve our THM growth technique in order to achieve as-grown detectors with reasonable resolution. In this paper, we will report the characterization of as-grown CZT by our variant of THM and fabrication of thick detectors in order to evaluate the as-grown CZT crystals. Performance of the devices with different device geometry will also be discussed.

8142-41, Session 9

Segregation and interface shape control during EDG growth of CZT crystals

N. Zhang, A. Yeckel, J. J. Derby, Univ. of Minnesota, Twin Cities (United States)

The availability of large, single crystals of cadmium zinc telluride (CZT) with uniform properties is key to improving the performance of gamma radiation detectors fabricated from them. Toward this goal, crystal growth modeling is a powerful tool to complement experiments and characterization.

In this presentation, we discuss the validation of our computational models by comparison with experimental zinc distributions via photoluminescence measurements of Burger (Fisk University) and Lynn (Washington State University) for a CZT crystal grown using the electrodynamic gradient-freeze (EDG) method. Furthermore, we predict non-classical zinc distributions for crystals grown in larger-scale EDG systems using classical thermal growth profiles. This surprising result is consistent with many prior growth outcomes where “anomalous” zinc distributions have been observed, quite different from the segregation behavior exhibited by traditional Bridgman growth systems.

We follow with a novel analysis to optimize EDG growth profiles to promote the growth of CZT crystals with a uniformly convex interface shape. Such interface shapes may be very beneficial toward reducing the probability of new grain formation, thus improving the single-crystal yield for a growth run. We also demonstrate that growth under these optimized thermal profiles results in zinc composition that is much more uniform than achieved using classical profiles. We make the case that these results can be put directly into practice using existing EDG growth systems.

Supported in part by DOE/NNSA, DE-FG52-08NA28768, the content of which does not necessarily reflect the position or policy of the United States Government, and no official endorsement should be inferred.

8142-42, Session 9

Effects of thermal annealing on the structural- and opto-electronic properties of CdZnTe crystals

G. Yang, A. E. Bolotnikov, Brookhaven National Lab. (United States); P. M. Fochuk, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine); G. Camarda, Y. Cui, A. M. Hossain, K. Kim, R. Gul, R. B. James, Brookhaven National Lab. (United States)
Thermal annealing is a promising approach to improve the property of CdZnTe (CZT) crystals. We will report on the structural- and opto-electronic properties of as-grown and annealed CZT crystals using white X-ray beam diffraction topography, IR transmission microscopy, current-voltage measurements, and low-temperature photoluminescence spectroscopy. New results from recent multi-step and long-term annealing experiments will be presented and discussed.

8142-43, Session 10

Testing hybrid contacts for CZT Frisch ring detectors

G. Camarda, A. E. Bolotnikov, Y. Cui, R. Gul, A. M. Hossain, K. H. Kim, G. Yang, R. B. James, Brookhaven National Lab. (United States)

The edge effects and the electron trapping still represent two limitations in the current design of virtual Frisch ring CZT detectors and need to be solved before they can be successfully commercialized. We proposed a novel design of the anode contact which helps to reduce the edge effects by focusing the electric field towards the central axes of the detector. The measurements techniques and the new results are presented.

8142-44, Session 10

Deep-level transient spectroscopy measurements of traps in CdZnTe crystals due to extended defects

R. Gul, A. E. Bolotnikov, K. Kim, G. Camarda, Y. Cui, A. M. Hossain, G. Yang, R. B. James, Brookhaven National Lab. (United States)

In the present research highly resistive CdZnTe detectors are investigated for defects by means of I-DLTS (current deep level transient spectroscopy). Various experiments are performed in different crystals by changing the applied bias voltage and filling time. The study is focused on traps in the temperature range of 300-400 K, previously related to defects associated with Te-rich phases. The energies of the traps found in the range 10-300 K are almost constant among different samples and vary within the experimental and systematic error of the measurement except for the deep trap at high temperature. This behavior is different than the other traps present in the crystals. Based on the experimental results and theoretical predictions, this particular trap is identified as an extended-defect-induced trap.

8142-45, Session 10

Evaluation of CdZnTe material for the NuSTAR flight detectors using x-ray diffraction topography

P. H. Mao, V. Bhalerao, B. W. Grefenstette, F. A. Harrison, H. Miyasaka, V. R. Rana, California Institute of Technology (United States)

The (em Nuclear Spectroscopic Telescope Array (NuSTAR)) mission will carry the first hard X-ray (5 - 80 keV) focusing telescopes to orbit. Each of the two NuSTAR focal planes contains a $2\times$2 array of four CdZnTe hybrid pixel detectors. Each hybrid consists of a CdZnTe detector procured from Endicott Interconnects Detection & Imaging Systems (formerly eV Products) with the anode patterned in a 32 x 32 array of 0.6-μm pixels, bonded to Caltech’s custom low-noise (em NuCIT) ASIC readout. (em NuSTAR’s) requirements for sub-arcminute imaging and spectral resolution better than 1.5 –keV FWHM (from 60 - 80 keV) over the entire field of view place tight constraints on the uniformity and quality of acceptable CdZnTe material. During the (em NuSTAR) program, we found white beam x-ray diffraction topography (WXDT) to be the most efficient and reliable means of selecting candidate CdZnTe crystals for hybridization. Gamma-ray source scanning of crystals with a monolithic readout proved to be time-consuming and insufficient given the poor spectral resolution possible in such a setup, and IR imaging alone proved to be an insufficient tool for selection of high-quality material. During the (em NuSTAR) program, we fabricated and tested a total of 41 hybrids. In this paper we present performance results, including spectral resolution, leakage current, and uniformity of spatial response of both flight and flight-reject detectors, and we correlate these with features evident in the WXDT images.

8142-46, Session 10

Etch pit density in single crystal CdZnTe and CdTe correlated with growth parameters

C. J. Havrilak, Washington State Univ. (United States); K. A. Jones, Raytheon Co. (United States); K. G. Lynn, Washington State Univ. (United States)

Surface dislocations were revealed in single crystal CdZnTe and CdTe using chemical etching by the Everson etch (W.J. Everson et al.). Dislocation etch pits on the (111)B face were studied and photographed under both optical and scanning electron microscopes. The crystal ingots were grown using the modified vertical Bridgman (MVB) technique with different chemical compositions and growth parameters. For these ingots, etch pit density, shape and distribution were examined and compared with the varying growth techniques. Charge transport properties of the detectors were measured by current-voltage measurements and mobility-lifetime products, $\mu \tau$, were also correlated and included in the conclusive analysis. A combination of detector grade and non-detector grade ingots were tested. Near infra-red microscopy was used to compare the amount of secondary phases present in the bulk of the crystals with dislocation etch pits on their surface. The average etch pit density (EPD) for the samples in this study was found to be 5.0x104 cm-2. It was concluded that a low EPD is required for an ingot to have quality detector properties. Location of a sample inside of an ingot also played an important role in the EPD, the farther away from the crucible wall and the heel of the ingot - the lower the EPD and the better the detector properties. It was also shown that the rate of the ingot cool down following growth affected the EPD, quenched ingots had a lower EPD than non-quenched. Statistical data and analysis on all the above mentioned results will be provided.

8142-47, Session 10

Fabrication and characterization of Cd(0.9) Zn(0.1)Te Schottky diodes for nuclear radiation detectors

K. C. Mandal, P. G. Muzykov, R. M. Krishna, T. C. Hayes, T. S. Sudarshan, Univ. of South Carolina (United States)

Semi-insulating cadmium zinc telluride (CZT) has been the primary semiconductor material used in room-temperature high resolution x-ray and γ-ray detectors for Homeland security, infrared focal plane array, space astronomy, medical imaging, and environmental monitoring applications. In spite of the high performance of radiation detectors based on CZT, the CZT crystal quality has not been fully optimized adversely affecting the detector performance. Therefore further studies of electrically active defects and correlations with the crystal structure and device performance are highly demanded for improved CZT radiation detectors. The fabricated Schottky diodes showed very good rectification properties with low reverse bias leakage current. The diodes were also characterized using electron beam induced current (EBIC) measurements to investigate crystallographic defects. The EBIC images, obtained for the first time, were correlated with transmission infra-red images of CZT.
crystals and the EBIC contrast was attributed to the nonuniformities in spatial distribution of Te inclusions. Further characterization included current-voltage (I-V), capacitance-voltage (C-V), Hall effect measurements, and thermally stimulated current (TSC) measurements. The TSC measurements revealed shallow and deep level centers with activation energies 0.25–0.4 eV and 0.65–0.8 eV respectively, which we attribute to intrinsic defects mostly associated with excess of Te (Te anisite and its complexes). In this work, we will present crystal growth process, structural, electrical, optical and defect characterization, fabrication of CZT Schottky diodes, and testing using Am-241 (60 keV) and Cs-137 (662 keV) radiation sources.

8142-24, Poster Session

Detector array with improved spatial resolution for digital radiographic system

O. D. Opolonin, V. D. Ryzhikov, Sr., S. A. Galkin, V. G. Volkov, O. K. Lysetska, Sr., Institute for Scintillation Materials (Ukraine); S. A. Kostioukevitch, V. Lashkaryov Institute of Semiconductor Physics (Ukraine)

A detector array of "scintillator-photodiode" type with improved spatial resolution has been developed.

For obtaining shadow X-ray images, a receiving-detecting circuit (RDC) with a detector array was developed for 200 mm scanning field. The circuit was integrated into two digital radiographic system models. The first model consisted of RDC, linear motor (minimum movement step less than 1 micron) and X-ray source (Ua max=160 kV, la max=45 mA). The second model consisted of RDC, mechanism for movement and rotation of the inspected object, and X-ray source (Ua max=140 kV, la max=1 mA). The presence of the rotation mechanism allowed realization of multi-view scanning mode (60 views), resulting in substantially higher informativity of non-destructive testing and technical diagnostics. Using these model digital radiographic systems and standard testing objects - EN 462-5 (set of wire pairs), grooving sensitivity reference No.2 (GOST 7512-82), set of iron wires DIN 62 Fe (10 ISO 16 ), we have evaluated spatial resolution (not worse than 1.25 line pairs/mm) and detecting ability (better than 0.2 mm steel wire behind 6 mm steel).

Thus, our studies have shown that the developed detector array for obtaining shadow X-ray images with high spatial resolution can be successfully used with X-ray sources of up to 160 kV anode voltage.

8142-49, Poster Session

Structure distortions and scintillation properties of elpasolite halide scintillators

P. Yang, Sandia National Labs. (United States); F. P. Doty, X. Zhou, Sandia National Labs., California (United States); M. A. Rodriguez, C. B. DiAntonio, Sandia National Labs. (United States); T. Chavez, Sandia National Labs., California (United States); J. V. Branson, Sandia National Labs. (United States); E. Von Loef, W. M. Higgins, U. Shiriwadkar, K. S. Shah, Radiation Monitoring Devices, Inc. (United States)

The crystal structure, thermal properties, and scintillation properties of several new elpasolite halide compounds (A2BCX6) and their solid solutions are studied. These materials, based on a cubic, double perovskite structure, are particularly attractive for advanced gamma-ray spectroscopy applications due to a unique combination of high energy resolution and excellent proportionality recently discovered in the elpasolite halide family. These cubic compounds are relatively easy to grow in large sizes and have the potential to be made in polycrystalline forms for radiation detectors. When substituting ions with different sizes, a small lattice distortion can be introduced. The distortion changes the crystal symmetry, and affects the optical, thermal and elastic properties. These changes can have profound implications on material manufacturability and costs. Therefore, it is advantageous to develop a material model that can effectively predict the crystal structure of favorable new compounds that are highly manufacturable for practical applications. In this study, we will compare the structural change predicted by a classic Goldschmidt tolerance factor, SPuDs calculation1, and our own embedded ion method (EIM), using the structural information of these new materials and literature data for validation purposes. Correlations of these structural changes with respect to their scintillation properties will be explored.


This work is supported by the NNSA/DOE Office of Nonproliferation Research and Development, Proliferation Detection Program, Advanced Material Portfolio. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin company, for the United States Department of Energy’s National Nuclear Security Administration under contract DE-AC04-94AL85000.

8144-50, Poster Session

Growth of GaGdN by MOVPE for semiconductor neutron detector


We have aimed at the achievement of the new neutron imaging device by compound semiconductor with Gd converter. We have suggested a neutron detector by using internal conversion electrons, which are generated by Gd atom. The wide bandgap semiconductor GaN, which has less gamma-ray sensitivity, is selected to distinguish neutron from background gamma-ray. GaN has been widely researched for optoelectronic devices. Therefore, basically growth and processing techniques about GaN have already been developed.

We could estimate that GaGdN for neutron detectors is possible to be fabricated by mixing Gd to GaN, because the GaGdN multiple quantum wells have been achieved in the field of spin electronics. In this work, GaGdN has been grown by metal organic vapor phase epitaxy (MOVPE) using the precursors; trimethylgalium (TMG), triscyclopentadienyl gadolinium (Cp3Gd) and NH3 for the Ga, Gd and N, respectively. The epitaxial structure of films consisted of a 450nm-thick GaN buffer layer, a 300nm-thick GaGdN layer, and a 150nm-thick GaN
cap layer on c-plane Al2O3 substrate. The GaGdN were structurally characterized by XRD, and the GaGdN (0002) peak was observed as the lower angle peak than the GaN (0002) peak from buffer and cap layers. This result indicated that Gd-doping makes lattice constant enlarge and we can estimate the composition of Gd is about 1% from the GaGdN (0002) peak in XRD.

8142-51, Poster Session

E-beam electron mobility study on CZT and CsI

S. A. Baker, National Security Technologies, LLC (United States); A. Burger, Fisk Univ. (United States); L. A. Franks, Consultant (United States); M. Groza, Fisk Univ. (United States); D. Schwellenbach, J. A. Young, National Security Technologies, LLC (United States)

DOE/NV/25946--1152 Cadmium zinc telluride (CZT) semiconductor material is at the forefront of much research on room-temperature radiation detection. This poster presents a study of electron beam charge induced mobility in the solid-state crystal CZT. The intent is to correlate conductivity characteristics with crystal CZT mix ratio in the compound of cadmium, zinc and tellurium. We examine electrical charge (pulse) propagation in room-temperature CZT versus bias voltage. Tests are conducted on monolithic CZT 15 x 15 x 10 mm3. Initial tests induce charge excitation with a pulsed laser source. Further tests utilize pulsed, nanosecond range, electron beam excitation in the tens of keV. Experimental results will be discussed. Follow on tests will study thallium-doped cesium iodide, CsI(Tl), scintillator material. Optical emission to electron beam excitation is observed for scintillators in correlation with bias voltage and electron beam energy.

8142-52, Poster Session

Synthesis of a potential semiconductor neutron detector crystal LiGa(Se/Te)2: materials purity and compatibility effects

A. C. Stowe, K. Joyce, J. Morrell, Y-12 National Security Complex (United States); P. Battacharya, E. Tupisyn, A. Burger, Fisk Univ. (United States)

Recent years have seen an increase in need for radiation detection materials for scientific and security applications. The standard technology is 3He gas tube detectors; however, the increased usage has resulted in a pending global shortage of 3He gas. Many alternative radiation detector materials are being considered, including semiconductor-based detectors. For neutron detection, a 6Li or 10B-based neutron absorber layer is added to the semiconductor crystal in order to efficiently detect the neutrons. The efficiency is limited by the thickness of the absorber layer which must remain small to allow the alpha particle created during the reaction of a neutron with the absorber to reach the semiconductor. If, however, the semiconductor crystal contains the neutron absorber directly within its crystal lattice, the number of absorber atoms can be larger thus increasing the theoretical neutron detection efficiency. Lithium containing chalcopryite crystals (I-III-VI2) such as LiGaSe2 and LiGaTe2 have electronic band gaps appropriate for detection of thermal neutrons. One of the primary challenges in growing a high quality crystal of such a material is the reactivity of lithium metal. The presence of nitrides, oxides, and a variety of alkali and alkaline earth metal impurities prevent pure synthesis and truncate crystal growth by introducing multiple nucleation centers during growth. Multiple lithium metal purification methods have been investigated which ultimately raised the metal purity to 99.996%. Multi-cycle vacuum distillation removed all but 40 ppm of metal impurities in lithium metal. LiGa(Se/Te)2 were then synthesized with the high purity lithium metal by a variety of conditions. Lithium metal reacts violently with many standard crucible materials. Thermodynamic studies were undertaken to insure that an appropriate crucible choice was made, with high purity iron and boron crucibles being the least reactive practical materials. Once conditions were optimized for synthesis of the chalcopryite, vertical Bridgman crystal growth resulted in red crystals. The optical, electronic, and thermodynamic properties were collected.

8142-54, Poster Session

Gamma ray nonvolatile sensor comparison between SONOS and SNOS capacity device

W. Hsieh, Minghsin Univ. of Science and Technology (Taiwan); H. D. Lee, ETOMS Electronics Corp. (Taiwan); S. Wu, National Nano Device Labs. (Taiwan); F. Jong, Southern Taiwan Univ. of Technology (Taiwan)

The typical Silicon-Oxide-Nitride-Oxide-Silicon (SONOS) and Silicon-Nitride-Oxide-Silicon (SNOS) capacity devices can be candidate for nonvolatile Gamma radiation sensors. In case of SONOS and SNOS Gamma Radiation sensors, the Gamma ray radiation induces significant decrease of threshold voltage. The changes of threshold voltage for SONOS and SNOS after Gamma ray exposure can be correlated to the dose of Gamma ray exposure as well. In this paper, the changes of threshold voltage for SONOS and SNOS after Gamma ray exposure were compared. This capacity device with ONO gate dielectric in this study has demonstrated the better feasibility of using SONOS capacity device for Gamma Ray dosimeter.

1. INTRODUCTION

When a MOS structure is irradiated by gamma rays, the positive charges build-up at Si-SiO2 interface and the interface state creation occur [1]. The irradiation effects of a Metal-Nitride-Oxide-Silicon (MNOS) device with stacked insulation layers composed silicon nitride and silicon dioxide has been reported [2]~[5]. However the detailed mechanism of the charged trappings has not been understood yet. In this study, the radiation-induced trapped charges in the insulation layer of SONOS and SNOS capacity structure are investigated. This Gamma ray radiation induces significant decrease of threshold voltage for SONOS and SNOS. It is considered that these changes are due to significant increase of positive trapped charges in the gate dielectric ONO and NO after Gamma ray irradiation. In this paper, the changes of threshold voltage for SONOS and SNOS after Gamma ray exposure were compared. The change of threshold voltage for SONOS is more than the one for SNOS. This capacity device with ONO gate dielectric in this study has demonstrated the better feasibility of using SONOS capacity device for Gamma Ray dosimeter.

2. PROPOSED MECHANISM

In case of MOS structure, a MOS structure is irradiated by gamma rays, the positive charges build-up at S-O interface and the interface state creation occur. It is considered that the amount of trapped holes due to irradiation is greater than the amount trapped electron near the S-O interface. For writing data in the SONOS and SNOS capacity, Gamma ray radiation and fixed gate voltage was applied on these SONOS and SNOS capacity devices simultaneously. When these SONOS and SNOS capacity structure are irradiated by gamma rays , the electron-hole pairs are generated throughout the gate insulation layers. These free carriers are swept by electric field, and some of them are captured by the charge trap centers, especially at the Oxide-Nitride (O-N) interface and Silicon-Oxide (S-O) interface. The amounts of captured charge depend on the local density and capture cross section of the trap centers. When a positive gate voltage was applied on these SONOS and SNOS capacity devices, the holes generated by radiation in the insulation layers are swept toward Silicon base side by electric field and some of the holes are captured by the charge trap centers at the O-N interface. As shown in experiment data, the Gamma ray radiation induces significant decrease of threshold voltage for SONOS and SNOS capacity. It is considered that the amount of trapped holes due to irradiation in gate insulator is greater than the amount trapped electron. It is suggested that the amount of hole traps at O-N interface and S-O
interface is higher than the electron traps at O-N interface. The trapped charges change the electrical characteristic of these SONOS and SNOS capacity devices in terms of gate diode capacity, gate threshold voltage, and drain current. For the data read, the change of gate threshold voltage in this case can be correlated to the amount of trapped charges and the exposure dosage of Gamma radiation as well. These trapped charges can be always accumulated in gate dielectric layer, so dose record can’t be destroyed by data write and read. For the dosage data erase, data in these SONOS and SNOS capacity devices can be erased to original null state by charges injection. In this paper, the change of threshold voltage for SONOS and SNOS after Gamma ray exposure were compared. As shown in experiment data, the change of threshold voltage for SONOS is more than the one for SNOS. It is suggested that the amount of positive trapped charges in the O-N gate dielectric layer is greater than the one in NO gate dielectric layer, so the decrease of threshold voltage for SONOS is more than the one for SNOS. This capacity device with ONO gate dielectric in this study has demonstrated the better feasibility of using SONOS capacity device for Gamma Ray dosimeter.

3. EXPERIMENTAL
In this study, the N type SiS capacity structures were fabricated on P-type Si substrate. Two kind of SiS capacity with gate dielectric SiO2-Si3N4-SiO2 (ONO) & Si3N4-SiO2 (NO) were compared. The thickness of gate dielectric for the capacity with N-O gate dielectric is 200Å-50Å. The thickness of gate dielectric for the device with O-N gate dielectric is 50Å-200Å-50Å. In this paper, the changes of threshold voltage between SONOS & SNOS after Gamma ray exposure were compared. To write data on these SONOS and SNOS capacity devices, Gamma radiation was exposed and a positive six volts gate voltage was applied on these SONOS and SNOS capacity devices simultaneously. For the data read, the change of gate threshold voltage in this case can be correlated to the exposure dosage of Gamma radiation as well. These trapped charges can be always accumulated in gate dielectric layer, so dose record can’t be destroyed by data write and read. For the dosage data erase, data in these SONOS and SNOS capacity devices can be erased to original null state by opposite charges injection.

4. RESULTS AND DISCUSSIONS
As illustrated in figure 1 it can be seen that the capacity to voltage curves (C-V curve) of SONOS shifted to the left after 5 Mrad Gamma ray irradiation. This implies that Gamma ray radiation induces a decrease of threshold voltage for SNOS. The amount of decrease of threshold voltage is about 0.6 volts. It is considered that the change is due to increase of positive trapped charges in the gate dielectric NO layer after Gamma ray irradiation. From figure 2, it also can be seen that the capacity to voltage curves (C-V curve) of SONOS shifted far to the left after 5 Mrad Gamma ray irradiation. This implies that Gamma ray radiation induces a significant decrease of threshold voltage for SONOS. The amount of decrease of threshold voltage is up to about 0.9 volts. It is considered that the change is due to significant increase of positive trapped charges in the gate dielectric NO layer after Gamma ray irradiation. The electron-hole pairs are generated throughout the insulation layers, when these SONOS and SNOS capacity devices structure are irradiated by gamma rays. These free carriers are swept by electric field, and some of them are captured by the charge trap centers, especially at the Oxide-Nitride (O-N) interface and Silicon- Oxide (S-O) interface. As shown in experiment data, the change of threshold voltage for SONOS is more than the one for SNOS. The dependencies of threshold voltage shifts on radiation dose in ONO gate dielectric is more than the one in NO gate dielectric. It can be explained that the amount of positive trapped charges in the O-N gate dielectric layer is greater than the one in NO gate dielectric layer, so the decrease of threshold voltage for SONOS is more than the one for SNOS. It is suggested that the amount of hole traps at O-N interface in ONO gate dielectric layer is more than the one in the NO gate dielectric layer. This capacity device with ONO gate dielectric in this study has demonstrated the better feasibility of using SONOS capacity device for Gamma Ray dosimeter.

8142-55, Poster Session

Synchrotron radiation studies of spectral features caused by Te inclusions in CdZnTe

C. C. T. Hansson, A. Owens, European Space Research and Technology Ctr. (Netherlands); F. Quaranti, Technische Univ. Delft (Netherlands); V. Gostilio, Baltic Scientific Instruments (Latvia); D. Lumb, European Space Research and Technology Ctr. (Netherlands); A. Kozorezov, Lancaster Univ. (United Kingdom); A. Webb, DESY (Germany)

The use of CdZnTe (CZT) as a high energy X-ray and γ-ray detection medium has been recognised for a long time due to its high stopping power and wide band gap, potentially allowing for fano-limited spectroscopy and room temperature operation [1].

Fano-limited spectroscopy for CZT crystals is currently limited by defects in the crystal structure, including twins and sub-grain boundaries; Te inclusions and dislocations, introduced during growth of the material [2]. For mined crystals the most detrimental defects affecting the spectroscopic performance in thick detectors has been shown to be Te inclusions [3].

While the effects of small inclusions, <3μm, can be compensated for by depth sensing techniques (assuming concentrations below 10^6 cm⁻¹) [3], larger inclusions introduce a variation in the collected charge carrier number that can not be corrected for. The lower band gap and increased impurity solubility of Te [3][4] is believed to introduce trapping levels, and possibly affecting the electric field profile inside the detector [2], leading to a varied trapping probability in the area of inclusions.

In this experiment a 10mm CZT coplanar grid detector having large Te inclusions [5] were exposed to pencil beam synchrotron radiation in order to study spectroscopic features introduced by the defect structure of Te inclusions at different X-ray energies.

The analysis of the detector spectral response and the potential use of the technique to investigate inclusions in wide band gap semiconductors will be discussed.

References:
8142-56, Poster Session
Computational assessment of the impact of gamma-ray detector material properties on spectroscopic performance
D. V. Jordan, B. S. McDonald, J. E. Baciak, Jr., E. A. Miller, W. Hensley, E. Siciliano, Pacific Northwest National Lab. (United States)

Pacific Northwest National Laboratory (PNNL) is performing a computational assessment of the impact of several important gamma-ray detector material properties (e.g., energy resolution and intrinsic detection efficiency) on the scenario-specific spectroscopic performance of these materials. The research approach combines 3D radiation transport calculations, detector response modeling, and spectroscopic analysis of simulated energy deposition spectra to map the functional dependence of detection performance on the underlying material properties. This assessment is intended to help guide formulation of performance goals for new detector materials within the context of materials discovery programs, with an emphasis on applications in the threat reduction, nonproliferation, and safeguards/verification user communities. The research results will also provide guidance to the gamma-ray sensor design community in estimating relative spectroscopic performance merits of candidate materials for novel or notional detectors.

The research design comprises a parameter study in the composition, size, and effective response characteristics of a set of notional, homogenous detector materials. We model the energy deposition spectrum registered in a cylindrical gamma-ray spectrometer deployed in a variety of application scenarios relevant to wide-area radiosotope anomaly detection and identification, safeguards (material holdup in a uranium-processing facility; UF6 cylinder enrichment assay), and active interrogation (delayed-gamma emission from neutron or photon-induced fission). We subject ensembles of Poisson-blurred spectra to peak location and peak-area analysis, and map appropriate statistical metrics (e.g., detection probability or assay precision) of spectroscopic performance as functions of the underlying material parameters. The paper describes the computational methods and discusses representative results for each deployment scenario.

8142-57, Poster Session
Peculiarities of the melting and cooling processes in the CdTe-ZnTe system near CdTe side
L. P. Shcherbak, O. V. Kopach, P. M. Fochuk, I. Nakonechnyj, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine); A. E. Bolotnikov, R. B. James, Brookhaven National Lab. (United States)

The investigations of peculiarities of the melting and cooling processes in the CdTe-ZnTe system with ZnTe content up to 10 mol. % by the Differential Thermal Analysis (DTA) was carried out. The influence of heating and cooling conditions (heating/cooling rate, melt maximum temperature, melt holding duration at maximum temperature) on melting and crystallization processes parameters was investigated. Using the Kissinger equation \( \ln(Vh/Tm^2) = A + Ea/(RTm) \), which shows interrelation between heating rate \( Vh \) and maximal temperature of the melting process endothermic effect \( Tm \) the melting process activation energy \( Ea \) is estimated. Based on the obtained data the liquidus and solidus lines of the CdTe-ZnTe system with ZnTe content up to 10 mol. % are constructed.

8142-58, Poster Session
High-temperature study of the detector-grade CZT under the zinc overpressure
P. M. Fochuk, I. Nakonechnyj, O. V. Kopach, O. E. Panchuk, Yuriy Fedkovych Chernivtsi National Univ. (Ukraine); A. E. Bolotnikov, R. B. James, Brookhaven National Lab. (United States)

Many publications appeared in recent years on CZT properties as material for \( \gamma \)-detector application. But still, there is a gap in understanding of its point defects structure. The high-temperature treatment of CZT samples under Cd and Te overpressure had been described in several papers. However its properties under Zn overpressure has not been studied yet. We measured the Hall effect of several Cd1-xZnxTe:In samples under the zinc overpressure at 500-1100 K. It was shown that long-term annealing results in obtaining of high-resistive material that can be used in producing of inclusion-free detector-grade material.

8142-59, Poster Session
Characterization of the surfaces of CdTe(111) single crystals after laser processing
D. Gnatyuk, L. V. Poperkon, I. V. Yurgelevych, National Taras Shevchenko Univ. of Kyiv (Ukraine); T. Aoki, Shizuoka Univ. (Japan)

Chemical etching and laser irradiation have been widely used for surface processing of CdTe and such treatments modify the structure and state of the crystal surface. The optical properties of opposite sides of CdTe(111) single crystals subjected to irradiation with nanosecond single pulses of the second harmonic of a YAG:Nd laser with energy density below and above the melting threshold have been studied by multiple-angle-of-incidence single-wavelength ellipsometry. The ellipsometric parameters \( \Delta \) and \( \Psi \) were obtained at several light incidence angles and the principal angle and minimum value of the azimuth of the restored linear polarization were calculated. The data were interpreted by the semi-infinite medium model and it is assumed that there were no films or layers on the crystal surface. Also the one-layer model was applied and the relief of the crystal was considered as a top layer. The refraction \( n \) and absorption \( k \) indexes of the surface layer were calculated using the fundamental ellipsometric equation and method of thickness curves. The obtained effective thickness \( d \) (~10-20 nm) in the chemically etched samples was in agreement with the root mean square height of the roughness obtained by AFM technique. The applicability of both models is an evidence of an increase in the refractive index of the CdTe surface layer due to laser-induced effects and it is associated to enriching of the modified surface with tellurium which has larger refraction (n ~ 6 at 632.8 nm). The laser irradiation effects on polar sides of CdTe(111) crystals are analyzed.

8142-60, Poster Session
Correlations of secondary phases (SPs/inclusions) with mobility lifetime (\( \mu_r \)) of the electrons in CZT crystals using IR microscopy
S. Bhadhahare, W. G. Munge, K. G. Lynn, Washington State Univ. (United States)

Cadmium Zinc Telluride (CdZnTe/CZT) crystals were grown using a modified vertical Bridgman growth technique with 10 % Zn concentration at Washington State University (WSU). Analyses of the effects of volume (vol.) %, number density (cm-3), mean diameter (\( \mu \)) of secondary phases (SPs) and thickness (mm) of the CZT crystals on single crystal properties such as carrier mobility lifetime (\( \mu_r \)) and resistivity (\( \rho \)) were performed. Correlations were observed between \( \mu_r \) (cm2 V-1) of
different CZT crystals and vol. %, number density, mean diameter of secondary phases and thickness of the crystals. High µτe and lower SP vol. % values were obtained for the ingots grown with rapid cool down times and with no intentional amounts of excess Te/Cd. The effects of the SPs on the µτe values were established for the SPs whose mean diameters were <4 µm and >4 µm. These studies indicate vol. % and mean diameter of SPs are the important parameters for CZT crystal performance as a radiation detector.

8142-62, Poster Session

**Lithium and boron based semiconductor detectors for thermal neutron counting**


Thermal neutron detectors in planar configuration were fabricated from LiInSe2 and B2Se3 crystals grown at RMD Inc. All fabricated semiconductor devices were characterized for the current-voltage (I-V) characteristic and neutron counting measurement. Pulse height spectra were collected from 241AmBe (neutron source on all samples), 137Cs and 60Co. In this study, the resistivity of all crystals is reported and the collected pulse height spectra are presented for all fabricated devices. The current-voltage (I-V) characteristic curves obtained for planar devices fabricated from the LiInSe2 crystals showed resistivity around 1.1 x 1011 Ω cm to 5.8 x 1011 Ω cm. The resistivities of B2Se3 samples were estimated to be around 2.3 x 1013 Ω cm to 3.8 x 1013 Ω cm. The discrimination of the neutrons and gamma rays was performed by shielding the device from the 241AmBe with two ¼-inch layers of boron shielding materials. As a result of shielding the detector from 241AmBe source with neutron absorbing materials, the counting curve was suppressed significantly. This proves the neutron counting through 6Li(n,α)3H reaction for LiInSe2 crystals and neutron counting through 10B(n,α)7Li reaction for B2Se3 crystals. Note that, the 241AmBe neutron source was custom designed with polyethylene around the source as the neutron moderator, mainly to thermalize the fast neutrons before reaching the detectors. In summary, both LiInSe2 and B2Se3 crystals showed reasonable response to thermal neutron of 241AmBe source.

8142-63, Poster Session

**A large area x-ray imager with online linearization and noise suppression**

R. Durst, B. L. Becker, J. Kaercher, T. He, G. Wachter, Bruker AXS, Inc. (United States)

A new large area imager for X-ray crystallography is described based on active pixel sensor technology. In order to meet the demanding requirements for crystallography the detector is designed with real time correction for reset noise, nonlinearity, spatial uniformity and bad pixels. The design of the detector is described along with its operating characteristics including noise, DQE and quantum gain. We describe new techniques to rapidly calibrate and characterize the X-ray imager.

8142-64, Poster Session

**Electric field in Au/CdTe/In under x-ray and laser radiation**

V. Dedic, J. Franc, Charles Univ. in Prague (Czech Republic); P. J. Sellin, Univ. of Surrey (United Kingdom); R. Grill, Charles Univ. in Prague (Czech Republic); P. Veeramani, Univ. of Surrey (United Kingdom)

Accumulation of space charge at deep levels resulting in deformation of internal electric field represents one of the main factors affecting the charge collection efficiency in CdTe and CdZnTe X-ray and gamma ray semiconductor detectors. In this contribution we present the dependence of electric field profiles acquired by Pockels effect on the wavelength of the laser used for generation of free carriers. The result are compared to profiles acquired with the continuous spectrum of X-rays from X-ray tube. We demonstrate both experimentally and theoretically the possibility to control the profile of the internal electric field by compensation of the space charge formed by carriers trapped at deep levels QT with space charge QM present due to band bending at the Au/CdTe and In/CdTe interfaces.

The electric field decreases from the cathode forming a dead layer below the anode, when no X-ray radiation was applied. This situation corresponds to a prevailing positive space charge QT. The profile of the electric field approaches a constant value with an increasing X-ray flux. Further increase of radiation flux results finally in the formation of a dead layer below the cathode. The results can be explained by accumulation of negative space charge trapped at deep levels that compensates the positive QM.

The demonstrated mechanism represents a way to address the problems associated with electric field modification and reduced charge collection efficiency in CdTe X-ray detectors operated at high fluxes of X-ray photons.
8143-22, Poster Session

Test apparatus to monitor time-domain signals from semiconductor-detector pixel arrays

K. Haston, H. B. Barber, L. R. Furenlid, E. Salcin, The Univ. of Arizona (United States)

No abstract available

8143-23, Poster Session

Design considerations for MAPMT-based monolithic scintillation camera

L. R. Furenlid, H. B. Barber, E. Salcin, Ctr. for Gamma-Ray Imaging, The Univ. of Arizona (United States)

No abstract available

8143-01, Session 1

Performance tests of CdZnTe-based compact gamma camera

Y. Cui, Brookhaven National Lab. (United States); T. Lall, Hybridyne Imaging Technology, Inc. (Canada); B. Tsui, The Johns Hopkins Outpatient Ctr. (United States); J. Yu, The Johns Hopkins Univ. (United States); G. Mahler, A. Bolotnikov, P. Vaska, G. De Geronimo, P. O’Connor, G. Meinken, Brookhaven National Lab. (United States); J. Joyal, J. Barrett, Molecular Insight Pharmaceuticals (United States); G. Camarda, A. Hossain, K. H. Kim, G. Yang, R. B. James, Brookhaven National Lab. (United States); M. Pomper, S. Cho, The Johns Hopkins Outpatient Ctr. (United States); K. Weisman, Midstate Medical Ctr. (United States); Y. Seo, Univ. of California, San Francisco (United States); J. Babich, N. LaFrance, Molecular Insight Pharmaceuticals (United States)

In this presentation, we will introduce a compact gamma camera for high-resolution prostate cancer imaging using Cadmium Zinc Telluride (CdZnTe or CZT) radiation detectors. CZT is a semiconductor material with wide band-gap and relatively high electron mobility thus can operate at room-temperature without cooling. CZT detector is a photon-electron direct conversion device, thus it potentially can offer high energy resolution in gamma-ray detection, enables energy-resolved imaging, and reduces the background of Compton scattering events. In addition, CZT material has high stopping power for gamma-ray; in medical imaging applications, a few mm thick CZT material can provide sufficient detection efficiency and high signal-to-noise advantage relative to conventional scintillation materials. Because of these advantages, CZT detectors are becoming popular for several SPECT medical imaging applications. Most recently, we designed a compact gamma camera using CZT detectors coupled to an application-specific-integrated-circuit (ASIC). This camera works as an inter-rectal probe to image the prostate gland at a short distance of 1-5 cm, offering high detection efficiency and high spatial resolution, and potentially can detect prostate cancers at an early stage. In this presentation, we will report the performance test results of this gamma camera.

8143-02, Session 1

A novel SPECT camera for molecular imaging of the prostate

A. Cebula, D. Gilland, Univ. of Florida (United States); D. Wagenaar, Gamma Medica, Inc. (United States); A. Bahadori, Univ. of Florida (United States)

The objective of this work is to develop an improved SPECT camera for dedicated prostate imaging. Complementing the recent advancements in molecular imaging agents for prostate cancer, this device has the potential to assist in distinguishing benign from aggressive cancers, to guide biopsy, and to aid in focal therapy procedures. The camera is designed to achieve better spatial resolution, photon detection sensitivity, energy resolution and overall signal-to-noise ratio relative to conventional SPECT cameras. This is achieved using a multi-pinhole collimator that has a saddle-shaped contour upon which the patient sits, thus greatly reducing the source-to-detector distance. The prostate gland and surrounding pelvic region project through 16 tungsten pinholes onto the detector comprised of cadmium zinc telluride modules (1” x 1”) that are tiled in a 2D matrix. In addition to improving collimator spatial resolution, the small source-to-detector distance allows image magnification, which improves the effective intrinsic spatial resolution.

Theoretical calculations show that the spatial resolution/detection sensitivity of the proposed SPECT camera can rival or exceed high resolution, 3D PET, and further signal-to-noise advantage is attained with the better energy resolution of the CZT modules. Photon transport simulation studies have been performed to evaluate the system design of the dedicated prostate camera. Realistic source distributions are created using virtual human models, which are combined with attenuating objects representing the multi-pinhole collimator and detector array. Further work will focus on developing multi-pinhole iterative reconstruction and optimizing system design parameters based on reconstructed image quality.

8143-03, Session 1

Stereo-viewing collimator system for breast cancer lesion localization

B. L. Welch, Dillon Technologies (United States); C. Lorino, D. Chiarella, T. Hodge, Montgomery Cancer Ctr. (United States)

A number of dedicated gamma camera systems are being used in the diagnostic workup of breast cancer patients and have demonstrated the ability to detect cancers missed by mammography and ultrasound. To become a standard of care, these systems need a mechanism to localize suspected tumors for biopsy. A stereotactic lesion localization system has been developed to allow gamma guided needle biopsy. The purpose of this work is to present the results of the clinical performance of this system on a group of patients. Twenty three patients who were indicated for needle biopsy based on clinical findings of an abnormality on a diagnostic gamma image as part of their clinical workup were imaged with the stereotactic system. The area of concern was then localized with the stereotactic lesion localization system. The lesion was located in each stereo image and the X, Y and Z coordinates were calculated. The resulting location was correcced to a specific (X, Y) location within a grid in the paddle and to a specific depth (Z) using a needle guide. The resulting pathology was compared to the clinical evidence to determine concordance. This work presents several case examples including clinical imaging and the results of pathology. This stereotactic lesion localization system provides a clinically viable method for localizing lesions seen in gamma imaging and addresses an important limitation to the broad acceptance of this imaging technique by allowing accurate...
lesion localization and biopsy under the guidance of a set of gamma camera images of the breast.

8143-04, Session 1

**Dose reduction in molecular imaging**

D. J. Wagenaar, S. Chowdhury, J. W. Hugg, Gamma Medica, Inc. (United States); R. A. Moats, Children’s Hospital of Los Angeles (United States) and The Univ. of Southern California (United States); B. E. Patt, Gamma Medica, Inc. (United States)

No abstract available

8143-05, Session 1

**Ultrahigh resolution CZT/CdTe detectors with a hybrid pixel-waveform readout system**

L. Meng, L. Cai, Univ. of Illinois at Urbana-Champaign (United States); F. K. Tang, The Univ. of Chicago (United States)

In this paper, we will report on the development of a hybrid pixel-waveform (HPWF) readout system for highly pixelated (with a few hundred um pitch size) CZT and CdTe gamma ray detectors. This readout system is based on an energy-resolved photon counting (ERPC) ASIC for reading out the anode pixels, working in coincidence with a high-speed circuitry for sampling the cathode waveform. This approach could provide an ultrahigh spatial resolution, an excellent timing resolution and a reasonable spectroscopic performance at the same time. The rationale behind the HPWF readout system are the following. First, the cathode waveform could provide precise energy information using digital processing techniques that takes into account the effect of charge trapping. This helps to alleviate the difficulties in extracting energy information from the tiny anode pixels, with the presence of severe charge sharing and charge loss. Second, the cathode waveform could provide a timing information at a precision well beyond that available with anode pixel readout. The latter is limited by the intrinsic uncertainties in charge collection process. Finally, it could also provide reliable DOI information, by measuring the electron drifting time in sampled waveforms. In contrast, deriving DOI information from the cathode-to-anode ratio is unreliable for detectors having pixel sizes similar to or smaller than the anticipated signal electron cloud size in the detector. In summary, the proposed readout system provides a relatively practical solution for extracting precise energy, timing and spatial information from CZT or CdTe detectors, which could offer a promising candidate for future high-performance multi-modality gamma ray imaging systems.

8143-06, Session 2

**Computer simulations to demonstrate new inversion methods for Compton camera data**

B. D. Smith, The Univ. of Texas at San Antonio (United States)

New inversion methods for image reconstruction from Compton camera data are presented here. These methods depend upon which of two models is assumed for the data. Both of these models have been proposed previously by other researchers. Using these methods require measuring new sets of data that have not been measured before. Measuring these sets of data require using a new camera design. Intriguingly, this new design has the potential of having more sensitivity than the conventional camera design. To illustrate these inversion methods computer simulations are used to reconstruct a mathematical phantom.

One set of reconstructed images demonstrates that a parallel projection of the distribution of the radioactivity can be produced from one positioning of the camera. A second set illustrates that a three-dimensional reconstruction of the distribution can be obtained by moving the camera 180 degrees around the distribution. In addition, possible improvements in these inversion methods to make them more practical are discussed. In particular, the quality of the images could be improved by incorporating more than the minimum amount of data required by the inversion methods into the reconstruction process. Undoubtedly, incorporating the imaging physics (e.g., Doppler broadening and Klein-Nishina distribution) and the instrumentation issues (e.g., finite spatial, energy, and temporal resolution) that are known to degrade the performance of Compton cameras into the reconstruction process will additionally improve the quality of the resulting images.

8143-07, Session 2

**Application of 3-D CdZnTe detectors on proton cancer therapy**

Z. He, Univ. of Michigan (United States); T. Polf, F. Zhang, The Univ. of Texas M.D. Anderson Cancer Ctr. (United States); W. R. Kaye, Y. A. Boucher, W. Y. Wang, J. M. Jaworski, Univ. of Michigan (United States); D. Maklin, The Univ. of Texas M.D. Anderson Cancer Ctr. (United States)

Three-dimensional position-sensitive CdZnTe detectors can perform excellent gamma-ray spectroscopy, achieving energy resolutions better than 1% FWHM at 662 keV, and real-time gamma-ray imaging. This work describes our exploratory research to extend the dynamic range of current 3-D CdZnTe detectors from 3 MeV to 9 MeV, and initial measurements on positron annihilation and characteristic prompt gamma-ray emissions in a clinical proton therapy environment. These measurements will shape design considerations on future systems for treatment verification and assessment based on the measurement of secondary gamma emissions during proton treatment delivery.

8143-08, Session 2

**Spect imaging onboard radiation therapy systems**

J. E. Bowsher, Duke Univ. Medical Ctr. (United States) and Duke Univ. (United States); S. Yan, Duke Univ. (United States); J. R. Roper, Duke Univ. Medical Ctr. (United States); W. M. Giles, Duke Univ. (United States); F. Yin, Duke Univ. Medical Ctr. (United States) and Duke Univ. (United States)

Radiation therapy machines now frequently include onboard x-ray transmission imaging systems which can image patients as they are in position for radiation therapy. These onboard systems have advanced radiation therapy, fostering techniques such as stereotactic body radiation therapy, and more generally improving targeting of treatment regions and sparing of healthy tissue. However, these onboard x-ray transmission systems primarily image physical characteristics such as electron density. Herein we consider SPECT as a method for onboard imaging. Such technology could enable accurate and precise radiation therapy targeting, as well as real-time modulation of radiation therapy, based on molecular and functional properties. It is molecular and functional properties that primarily distinguish tumor from surrounding healthy tissue and that relate directly to appropriate radiation dose. However, onboard SPECT is challenged by clinical time frames of about 4 minutes. To address this, we consider a multi-pinhole system for SPECT imaging of the target vicinity. A robotic arm is proposed to navigate the detector through the tight onboard geometry and to optimize detector trajectory about the target region. Computer-simulation studies suggest that effective imaging can be achieved with 4-minute scan times. This imaging approach also has applications beyond radiation therapy.
Fast regional readout CMOS active pixel sensor for radiotherapy treatment verification
H. Zin, E. J. Harris, J. P. F. Osmond, P. M. Evans, Institute of Cancer Research (United Kingdom) and Royal Marsden NHS Trust (United Kingdom)

Advanced radiotherapy techniques such as intensity modulated radiation therapy (IMRT) and velocity modulated arc therapy (VMAT) require verification of complex treatments and tracking of multileaf collimators (MLC). Current techniques using electronic portal imaging devices (EPID) or fluoroscopic based imaging have several limitations such as low image contrast and slow imaging speed or unnecessary skin dose. Novel complementary metal oxide semiconductor active pixel sensor (CMOS APS) have the potential to overcome these limitations by utilising fast, region of interest (ROI) readout functionality of up to 400 frames per second. Performance of the sensor region of interest readout was examined and sensor dead time was measured using a novel technique via a high-speed fast moving light source. Characterisation of the sensor provides further understanding of the sensor characteristics, and allows corrections for sensor non-linearity, non-uniformities and dead time to be applied in radiotherapy treatment verification and tracking. Application of the sensor in radiotherapy imaging to verify and track the multileaf collimator (MLC) was made in camera configuration coupled to a gadolinium oxide (Gadox) scintillator screen. The sensor was first calibrated using open field beam of various dose rates and later used to verify complex Volumetric Modulated Arc Radiotherapy Treatment (VMAT). Automatic leaf tracking algorithm has demonstrated CMOS APS ability to track complex VMAT delivery beyond 50 sampling per second.

Promising new drug delivery architectures enabled by precise silicon micro- and nanofabrication
D. Fine, Methodist Hospital Research Institute (United States); C. Chiappini, The Univ. of Texas at Austin (United States); T. Hu, B. Godin-Vilentchouk, R. Serda, E. Tasciotti, P. Decuzzi, A. Grattoni, X. Liu, Methodist Hospital Research Institute (United States); M. Ferrari, Methodist Hospital Research Institute (United States) and Rice Univ. (United States)

The application of nanotechnology towards the diagnosis and treatment of disease seeks to exploit the unique properties of nanoscale and nanopatterned materials and devices, including enhanced energy conversion, increased permeability, and the modulation of diffusive transport. In the context of drug delivery, nanotechnology approaches can provide sustained targeted release of therapeutic agents while improving the circulation of biological barriers and protecting the payload from the immune system. Two promising drug delivery platforms will be presented: the nanochannel drug delivery system (nDS) and the multi-stage drug delivery vector (MSV). The nDS is an implantable drug reservoir interfaced to a silicon-based nanofluidic membrane capable of modifying diffusive transport from a classical concentration dependent regime described by Fick’s law to a concentration independent zero-order release. Such a zero-order release profile stems from nanoflconfinement where surface effects at the solution/channel wall interface dominate over bulk fluid properties. MSVs are systemically delivered and loaded with multiple delivery stages (i.e. drug loaded liposomes) for the sequential circulation of biobarriers. Porous silicon particles comprise stage 1 with controlled size, shape, porosity, and pore size whose surface is biochemically functionalized to control particle degradation rates, improve immune system evasion, and enable specific targeting of the vasculature. Silicon micro- and nanofabrication, a mature technology developed for over 40 years for the semiconductor industry, provides the platform to manufacture these devices with precision and accuracy.

Depth of interaction compensation for high resolution SPECT imaging using crystalline microcolumnar films
V. V. Nagarkar, H. Bhandari, S. R. Miller, H. Kudrolli, Radiation Monitoring Devices, Inc. (United States); B. Miller, H. B. Barber, The Univ. of Arizona (United States)

No abstract available

High-performance imaging of stem cells using single-photon emissions
D. J. Wagenaar, Gamma Medica, Inc. (United States); R. A. Moats, Children’s Hospital of Los Angeles (United States) and The Univ. of Southern California (United States); N. E. Hartsough, DxRay, Inc. (United States); D. Meier, J. W. Hugg, Gamma Medica, Inc. (United States); D. Gazit, G. Pelled, Cedars-Sinai Medical Ctr. (United States); B. E. Patt, Gamma Medica, Inc. (United States)

No abstract available

High-resolution, anamorphic, adaptive small-animal SPECT imaging with silicon double-sided strip detectors
H. L. Durko, College of Optical Sciences, The Univ. of Arizona (United States); T. E. Peterson, Vanderbilt Univ. (United States); H. H. Barrett, L. R. Furenlid, College of Optical Sciences, The Univ. of Arizona (United States)

Recent advances in radiotracers for amyloid plaques, coupled with the development of suitable mouse models for Alzheimer’s disease motivate the need for high-resolution small-animal brain imagers capable of monitoring disease progress and/or response to therapy. Silicon-based devices are ideal for the detection of the low-energy photons from iodinated radiotracers, and photolithographic fabrication techniques allow for the production of high-resolution double-sided strip detectors, in which the measurements of very large numbers of virtual pixels are read out by separate x and y position-sensitive electrodes. We are developing a prototype imaging system that consists of two sets of movable, keel-edged copper-tungsten blades configured as crossed slits. These apertures can be positioned independently between the object and detector, producing an anamorphic image in which the axial and transaxial magnifications are not equal. The detector is a 60 x 60 mm2, millimeter-thick megapixel silicon double-sided strip detector. The flexible nature of this system allows the application of adaptive imaging techniques. For example, a series of low-magnification projections could be used to determine and define a region of interest. For each high-resolution projection, the system could then calculate the optimal axial and transaxial magnifications to project the object in such a way that an anamorphic image fills the detector area. We will discuss system details, calibration and acquisition methods, and our progress towards biological imaging applications.
TIBr gamma-ray spectrometers for SPECT

H. Kim, A. Kargar, L. J. Cirignano, A. V. Churilov, G. Ciampi, W. M. Higgins, S. Kim, Radiation Monitoring Devices, Inc. (United States); F. Olschner, Cremat, Inc. (United States); K. S. Shah, Radiation Monitoring Devices, Inc. (United States)

Thallium bromide appears to be a very promising semiconductor material for gamma-ray detectors in small animal SPECT imaging. It has the potential to provide very high detection efficiency, low noise and high energy as well as spatial resolution. TIBr has high atomic number constituents and high density, wide semiconducting band gap, and based on recent measurements, good charge transport parameters. Furthermore, the material melts congruently at a modest temperature (460 degC), which allows use of melt-based crystal growth approaches such as Bridgman and Czochralski to produce large volume TIBr crystals. The cubic crystal structure of TIBr also simplifies crystal growth.

Grazing angle Mach-Zehndner interferometer using reflective gratings and a polychromatic uncollimated light source

C. K. Kemble, J. Auxier, S. Lynch, E. E. Bennett, N. Y. Morgan, H. H. Wen, National Institutes of Health (United States)

Grating-interferometer based phase-contrast x-ray imaging promises improved sensitivity over absorption radiography. For greater phase sensitivity, however, interferometer gratings need periods below 2 microns. Two challenges inhibit using x-ray transmission gratings with periods below 2 microns: difficult fabrication, and low interference-fringe visibility. The latter challenge occurs when ultra-dense gratings are used with a polychromatic source. To solve both problems, we propose a symmetric Mach-Zehnder interferometer that utilizes grazing-angle reflective gratings.

First, our interferometer setup has a grazing x-ray incidence angle on the reflective gratings, making the gratings’ effective periods significantly smaller than their physical periods. We are therefore able to realize effective periods below 2 microns using standard photolithography techniques (NPL, Gratings for X-ray Spectroscopy, L. A. Sayce and A. Franks, Proc. Royal Society, Series A, 282(1390), pp. 353-357(1964)).

Second, current polychromatic-source Talbot-interferometer designs operate in the near field range. Near-field operation limits phase sensitivity because decreasing the grating’s period quadratically decreases the Talbot distance. We instead use a far-field interferometer, a grazing-angle symmetric Mach-Zehnder interferometer, which provides near ideal fringe contrast with polychromatic and un-collimated sources in the far field.

After presenting this idea’s visible light analog (Grazing angle Mach-Zehnder interferometer using reflective phase gratings and a polychromatic, un-collimated light source, C. K. Kemble et al., Optics Express, 18(26), pp. 27481-27492 (2010)), we now present the first x-ray interferometer results using a bench top tungsten-target x-ray source of 0.15 mm spot size. We also address the limitation of small vertical field of view from the grazing angle geometry.

Optimizing CdTe detectors and ASIC readouts for high-flux x-ray imaging

W. C. Barber, DxRay, Inc. (United States); E. Nygard, Interon AS (Norway) and DxRay, Inc. (United States); J. C. Wessel, N. Malakhov, Interon AS (Norway); N. E. Hartsough, T. Ghandi, DxRay, Inc. (United States); G. Wawrzeniak, Interon AS (Norway); J. S. Iwanczyk, DxRay, Inc. (United States)

Developments in room temperature cadmium telluride (CdTe) based solid state imaging arrays for energy-resolved single photon counting in medical x-ray imaging are discussed. A number of x-ray imaging applications can benefit from these developments including mammography, radiography, and computed tomography (CT). Energy resolved photon counting can provide reduced dose through optimal energy weighting, compositional analysis through multiple basis function material decomposition, and contrast enhancement through spectroscopic x-ray imaging of metal nanoparticles. Extremely high flux can occur in x-ray imaging and energy integrating detectors with a large dynamic range and good detection efficiency have been conventionally used. To achieve the benefits of energy resolved photon counting, imaging arrays with a large count rate range and good detection efficiency are required. Compound semiconductor radiation detectors with pixelated anode arrays electrically connected to application specific integrated circuits (ASICs) can provide fast, efficient, low-noise performance with adequate energy resolution however this can only be achieved with a careful optimization of the CdTe sensors and ASICs together.

We have designed and constructed a CdTe imaging array, 3 mm thick with a 16 x 16 grid of electrical contacts inter-connected to a 256 channel ASIC, with a counting range up to 2 x 10^7 counts per second per mm^2. Result description of the from this device as well as a description of the optimization methods used in the design are presented and discussed.

Mcps-range photon-counting x-ray computed tomography system

E. Sato, Y. Oda, Iwate Medical Univ. (Japan); A. Abudurexiti, Toreck, Inc. (Japan); O. Hagiwara, T. Enomoto, The Toho Univ. (Japan); S. Sugimura, Tokyo Denpa Co. Ltd. (Japan); H. Endo, Iwate Industrial Research Institute (Japan); S. Sato, A. Ogawa, Iwate Medical Univ. (Japan); J. Onagawa, Tohoku Gakuin Univ. (Japan)

Although the count rate has been increased to sub-Mcps using a CdTe detector system, the rate can be increased to approximately 20 Mcps using a short-decay-time scintillator in conjunction with a high-speed photoelectric detector. Therefore, we performed fundamental study on high-speed photon counting and energy discrimination. We also constructed a first-generation photon-counting X-ray CT system to confirm the energy-discrimination effect using a comparator in a multipixel-photon-counter (MPPC) module.

A photon-counting X-ray CT system consists of an X-ray generator, a turntable, a translation stage, a two-stage controller, a multipixel-photon-counter (MPPC) module, a 1.0-mm-thick Lu2(SiO4)O (LSO) single crystal (scintillator), a counter card (CC), and a personal computer (PC). Tomography is accomplished by repeating the linear scan and the rotation of an object, and projection curves of the object are obtained (PC). The pulses of the event signal from the module are counted by the CC in conjunction with the PC. The lower level of the photon energy is roughly determined by a comparator circuit in the module, and the unit of the level is the photon equivalent (pe). Thus, the average photon energy of the X-ray spectra for imaging increases with increasing the pe value. The maximum count rate was approximately 10 Mcps, and energy-discrimination CT was roughly carried out.

Cancer diagnosis using a conventional x-ray fluorescence camera with a cadmium-telluride detector

E. Sato, Iwate Medical Univ. (Japan); T. Enomoto, O. Hagiwara, The Toho Univ. (Japan); A. Abudurexiti, K. Sato, Toreck, Inc.
8143-19, Session 4
Color management and calibration techniques at the University of Arizona
S. F. Hashmi, H. Roehrig, E. A. Krupinski, The Univ. of Arizona (United States)

Purpose: The purpose of a research project at the Radiology Research Lab at the University of Arizona is to address consistent color and grayscale presentation for digital color displays used in medical image interpretation.

Currently color monitors are quickly entering the market for displaying grayscale and color information as they are ubiquitous and also less costly. Color displays are being used in a lot of disciplines in medicine, such as Pathology, Ophthalmology, dermatology, etc because of the inherent color associated with these fields. The absence of any validated methods available to reliably calibrate these color displays prompted us to build a laboratory with equipment capable of developing and implementing such a color calibration protocol.

The expectation is that once such a protocol is developed, it can be standardized and is easy to implement across the board. This standardization will help in diagnosing a disease in an early and correct manner.

Methods: The proposed method starts with the calibration of the display under test. Calibration parameters are defined and all the necessary measurements are done with the help of a PR670 Spectroradiometer. This ensures that the calibration is well controlled and conforms to our specifications.

The next steps are “Characterization and Profiling” as well as “Verification” of the profile. This is done using some known color samples and comparing the measurements with PR670 Spectroradiometer.

The next step is to calculate color accuracy and delta-E values and we are still on course to do it and hopefully the results will be available very soon.

Our laboratory setup includes a computer using an AMD Phenom-II processor and a Windows XP operating system with SP3 update on it. In addition, the computer’s CPU has a 4 GB Ram. There is a state of the art NVIDIA Quadro FX3700 graphics card. The CPU handles two displays at the same time.

The primary display is a Samsung display, which is usually our display number-1 and the secondary display is our Display under Test. A variety of programs related to our Research Project are installed in the CPU; the most important one of them is MatLab.

At this time three medical image displays are available and have been used already for our work: NEC-2690 WUXI2, NDS-DOME E3chB and EIZO- RX320. Software for their operation and associated Pucks for their calibration are installed in the computer. The native resolution, response time and Luminance values of these displays is shown in the table below:

<table>
<thead>
<tr>
<th>Display</th>
<th>Luminance</th>
<th>Resolution</th>
<th>Response time</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEC</td>
<td>150 cd/m2</td>
<td>1920X1200</td>
<td>16ms</td>
</tr>
<tr>
<td>NDS-DOME300</td>
<td>1536X2048</td>
<td>24ms</td>
<td></td>
</tr>
<tr>
<td>EIZO</td>
<td>300 cd/m2</td>
<td>1536X2048</td>
<td>20ms</td>
</tr>
</tbody>
</table>

The Spectro-Radiometer, PR-670, have we is used to make corrections for the errors of the Pucks. The spectral region of the Spectroradiometer ranges from 380 nm to 780 nm. It provides spectra in steps of 1.56 nm. It is basically a very sensitive and accurate detector array. The Spectroradiometer is connected to the computer through a USB connection and is controlled through MatLab.

Results: At this moment, we are testing our profiles for their accuracy and the next step is to go towards color difference calculation.

Conclusions: A calibration facility for Color LCDs has been developed at the University of Arizona and is operating. Preliminary results are encouraging.

8143-20, Session 4
Calibration and verification of DICOM software at the University of Arizona
S. F. Hashmi, H. Roehrig, The Univ. of Arizona (United States)

At the University of Arizona a research project is underway which addresses consistent color and consistent grayscale presentation for digital color displays used in medical image interpretation, specifically for Pathology. Since there were no validated methods available to reliably calibrate color displays we decided to build a laboratory with equipment capable to develop and implement a color calibration protocol. One of the most important items is a spectro-radiometer PR-670.

For our first experiment we concentrated on verification of the QUBYX Perfuction Calibration Software. The specific objectives were:

1. Verify if the “PerfectLum” software from “Qubyx Ltd.” would calibrate an LCD Display to DICOM GSDF part 14 standards. FIT and LUM tests were performed to verify the conformance and the deviation was quantified.
2. On the calibrated display, quantitative evaluation of Luminance response done and deviation quantified. Also the deviation was checked for class A or class B threshold, 10% and 20% deviation respectively.
3. Verify if the “Display Conformance” function in “PerfectLum” software returns the correct values for FIT, LUM and AAPM luminance response test.

All three objectives were met and PerfectLum calibrated display confirmed to the AAPM TG18 standards.

8143-21, Session 4
An x-ray tube based room-temperature Compton spectrometer with application to material characterization
S. Olesinski, G. Harding, Morpho Detection Germany GmbH (Germany)

A description is given of the principle of operation, design and technical realization of a Compton spectrometer. In contrast to many other devices that have been discussed in the literature, the Compton spectrometer
described here combines an electron-impact x-ray source with a room-temperature semiconductor detector.

It is shown that the momentum resolution (0.6 au) of the Compton spectrometer for the K characteristic lines emitted by the tube anode is adequate to resolve the Doppler broadening originating in electron momentum distributions of low atomic number elements, such as carbon, nitrogen and oxygen. Experimental Compton-broadened spectra from a range of common materials are presented. Methods to extract Compton profiles from the experimental spectra, by accounting for the continuous component of the x-ray tube emission and the multiplet nature of the characteristic lines, are illustrated. The application of this Compton spectrometer to material characterization is briefly discussed.
Preliminary investigation of lanthanum-cesium bromide self-activity removal

D. Yuan, P. Guss, National Security Technologies, LLC (United States)

It has been reported that detectors made of lanthanum-cesium halides [LaBr₃:Ce and CeBr₃] have superior energy resolution for gamma-radiation detection compared to what is offered by conventional sodium iodide [NaI:Tl] detectors. Although superior energy resolution may be observed, one major barrier that has hindered the rapid adaptation of lanthanum halides is their self-activity, due primarily to the presence of isotope 138La, and the α contamination, due to the trace amount of actinides. It has also been observed that the lanthanum-cesium halides contain a substantial amount of self-activity caused by the radioactive isotope. Additionally, LaBr₃:Ce spectra are also affected by β contaminations in the low-energy regime. To use either LaBr₃:Ce or CeBr₃ for high-sensitivity gamma detection, it may be necessary to have the self-activity as well as α and β contaminations removed or reduced. This paper describes a novel algorithmic approach for self-activity and contamination reduction for LaBr₃:Ce and CeBr₃ detectors using a third reference NaI:Tl detector. We present a computational procedure for separating self-activity from the gamma spectra obtained by LaBr₃:Ce detectors. With the self-activity spectra pre-calculated, it is possible to perform real-time self-activity removal. This procedure can be implemented as an automatic self-activity subtraction module for gamma radiation detectors made of LaBr₃:Ce and/or CeBr₃ crystals. With this approach, it is possible to develop a new generation of LaBr₃:Ce detectors capable of producing spectra as clean as those obtained by conventional NaI(Tl) detectors, but with much improved energy resolutions.

A fissionable scintillator for neutron flux monitoring

S. Stange, E. I. Esch, Los Alamos National Lab. (United States); E. Burgett, Idaho State Univ. (United States); R. Del Sesto, R. Muenchausen, F. Taw, F. K. Tovesson, Los Alamos National Lab. (United States)

Neutron flux from linear accelerators is conventionally monitored using ionization chambers containing one or more foils thinly coated with a fissionable or fissile material. Due to the long pulse rise times resulting from the ionization mechanism, fission chambers are prone to pulse pile-up in high-neutron-flux environments. In addition, their relatively low efficiencies result in extremely long counting times in low-flux environments. To ameliorate these effects, a novel type of neutron flux monitor, consisting of fissionable material loaded in a liquid scintillator, has been developed, characterized, and tested in the beam line at the Los Alamos Neutron Science Center. This is a rugged, cost-efficient detector with high efficiency, a short signal rise time, and the ability to be used in low-neutron-flux environments. Compared with a conventional fission chamber, the fissionable scintillator displays a significantly higher event rate. Related research on nanocomposite scintillators for gamma-ray detection suggests the possibility of extending this approach by synthesizing fissionable material nanoparticles and loading them into an organic scintillator. We will present results of the design and characterization process and an analysis of the results of the beam line experiments.

Light yield measurement method for milled nanosized inorganic crystals

A. Li, North Carolina State Univ. (United States) and Los Alamos National Lab. (United States); E. A. McKigney, Los Alamos National Lab. (United States); R. P. Gardner, North Carolina State Univ. (United States); N. A. Smith, M. P. Hählen, Los Alamos National Lab. (United States)

In an effort to improve currently available scintillators, composite scintillators consisting of nanosized inorganic crystals embedded in a matrix have been explored by McKigney et al (2007). In the process of producing such a detector, several steps are involved: the preparation of the nanosized inorganic crystals, the characterization of the inorganic crystals, and the dispersion of the crystals in a permanent matrix. In this work, the preparation of nanosized inorganic crystals involves milling the inorganic crystals in powder form to the appropriate size. However, since milling is known to introduce defects in the milled material, the performance of the milled material must be characterized. One of the most important quantities of the milled inorganic crystals is their light yield, and it may be measured by the radioluminescence technique. However, the common radioluminescence light yield measurement technique does not take into account the concentration of the inorganic crystals in individual samples, which may vary during processing. In this work, a new method of characterizing the light yield of the processed inorganic crystals will be explored and discussed; this method will take into account explicitly the concentration of the inorganic crystals.

Investigation into nanostructured lanthanum halides and CeBr₃ for nuclear radiation detection

P. Guss, R. E. Guise, S. Mukhopadhyay, D. Yuan, National Security Technologies, LLC (United States)

Nanocomposites may enable the use of scintillator materials such as cerium-doped lanthanum fluoride and cerium bromide (CeBr₃) without requiring the growth of large crystals [1]. Nanostructured detectors may allow us to engineer immensely sized detectors of flexible form factors that will have a broad energy range and an energy resolution sufficient to perform isotopic identification. Furthermore, nanocomposites are easy to prepare and very low in cost. It is much less costly to use nanocomposites rather than grow large whole crystals of scintillator materials; with nanocomposites fabricated on an industrial scale, costs are even lower. Nanostructured radiation scintillator detectors may improve quantum efficiency and provide vastly improved detector form factors. Quantum efficiencies up to 60% have been seen in photoluminescence from silicon nanocrystals in a densely packed ensemble [2]. We have fabricated nanoparticles with sizes <10 nm and characterize their nanostructure radiation detector properties. This work also attempted to extend the gamma energy response on both low- and high-energy regimes by demonstrating the ability to detect low-energy x-rays and relatively high-energy activation prompt gamma rays simultaneously using nanostructured lanthanum bromide, lanthanum fluoride, or CeBr₃. Nanoscale properties of lanthanum halides and CeBr₃ promise to extend the gamma energy response on both low- and high-energy regimes. Nanostructured lanthanum halides and CeBr₃ may be able to detect low-energy x-rays and relatively high-energy activation prompt gamma rays simultaneously. Preliminary results of this investigation are consistent with a significant response of these materials to nuclear radiation. Index Terms-CeBr₃, LaBr₃:Ce, LaCl₃:Ce, Nanoparticle Detector, Resolution.
ACKNOWLEDGEMENT
This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy.

REFERENCES

8144-05, Session 1
Defect creation by swift heavy ion induced secondary electrons
N. C. Mishra, R. Biswal, Utkal Univ. (India); D. Kanjilal, D. K. Avasthi, Inter Univ. Accelerator Ctr. (India)
Evolution of 150 nm thick c-axis oriented YBa2Cu3O7-y (YBCO) thin films under 200 MeV Ag ion irradiation is studied by in situ temperature dependent resistivity, and in situ low temperature x-ray diffraction. Irradiation at extremely low ion fluxes (108 to 109 ions cm-2) and at low temperature (79 K) revealed a new mode of materials modification by these swift heavy ions (SHI). In addition to amorphized latent tracks directly induced by the SHI and a strained region around each ion track, point defects in the form of oxygen disorder were found to be created selectively in the CuO basal planes of YBCO structure by secondary electrons emanating from the ion paths. The radius of this newly found oxygen disordered region is 97 nm, which is much larger than the radius (1.9 nm) of the amorphized ion tracks determined from the fluence dependence of the intensity of XRD peaks. The secondary electrons could thus induce global change in the structure and superconducting transition of YBCO, and provided a way of creating oxygen disorder in YBCO matrix even with oxygen content close to 7, which was not possible earlier. Conventional low energy electron irradiation permits the penetration of the electrons only up to a few nanometers from the surface of a target material, thus precluding its efficacy in modifying the bulk. SHI induced secondary electrons however are created all along the ion path up to a depth of few tens of microns and hence can create defects well inside the bulk region.

8144-06, Session 2
Investigation of the possibility of gamma-ray diagnostic imaging of target compression at NIF
D. Lemieux, College of Optical Sciences, The Univ. of Arizona (United States); G. P. Grim, Los Alamos National Lab. (United States); H. B. Barber, The Univ. of Arizona (United States)
At the National Ignition Facility (LLNL), 14.1 MeV neutrons produced by the fusion burn can interact with carbon nuclei in the polymer ablator via 12C(n,n'gamma)12C to make 4.44 MeV gamma-rays. The number of gamma-rays produced by this process is expected to be of order 10-3 of the neutrons produced. High-resolution gamma-ray imaging of the 12C distribution should provide useful diagnostic imaging of the remaining ablator material during compression and hence it’s spatial distribution. The multiple-pinhole optics and detector technologies required for such a gamma-ray imaging system appear to be quite similar to LANL’s existing neutron imaging system at NIF. Over the ~30 m flight path, the gamma rays precede the fusion neutrons by $\geq$ 400 ns, so the detector signals are separable. We will describe the results of simulations of three candidate imaging detectors using GEANT4. The three configurations include a scintillator slab with focusing optics, a pixelated scintillator with fiber optics and a pixelated Cherenkov radiator with fiber optics. We will discuss simulation results, criteria for choosing the best system and further prospects.

8144-07, Session 2
Radiation induced noise in x-ray imagers for high-yield inertial confinement fusion experiments
The large fluence of energetic neutrons produced in high-yield inertial confinement fusion (ICF) experiments creates a variety of backgrounds in x-ray imagers viewing the implosion. Electrons scattered by secondary gammas produce Cherenkov and possibly scintillation in the fiber optic of the imager as well as excitation of the phosphor screen. Noise is also produced in the image recorder itself (film or CCD) via energy deposition by electrons and heavy charged particles such as protons and alphas. We will present results from background measurements performed at the OMEGA facility in Rochester, NY and compare them to Monte Carlo calculations. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

8144-08, Session 2
Advanced gated x-ray imagers for experiments at the National Ignition Facility
S. M. Glenn, P. M. Bell, R. Benedetti, D. K. Bradley, J. R. Celeste, R. F. Heeter, C. A. Hagmann, J. P. Holder, N. Izumi, Lawrence Livermore National Lab. (United States); J. D. Kilkenny, General Atomics (United States); J. R. Kimbrough, G. A. Kyralla, N. Simonovskaia, R. Tommasini, Lawrence Livermore National Lab. (United States)
X-ray imaging is integral to the measurement of the properties of hot plasmas. To this end, a suite of gated x-ray imagers have been developed for use in a wide range of experiments at the National Ignition Facility (NIF). These instruments are sensitive to x-rays over the range of 0.7-90keV and can acquire images at 20ps intervals for source intensities ranging over several orders of magnitude. We review the design, technology, and construction of these instruments and present recent results obtained from NIF experiments in which gated x-ray imagers have played a key role.
The radiation environment associated with Inertial Confinement Fusion (ICF) experiments presents unique challenges for x-ray imaging. We report on the performance of gated imagers that have been optimized for this harsh environment and describe diagnostics to be deployed in the near future that will provide x-ray images of imploding ICF capsules in the presence of backgrounds associated with neutron yields above 10^16. Such images will provide crucial data that will enable even higher neutron yields and successful ignition.
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

8144-09, Session 2
Prompt radiochemical diagnostics for inertial confinement fusion experiments
8144-10, Session 3
Compact pyroelectric-driven gamma generator
A. J. Antolak, K. Leung, D. H. Morse, T. N. Raber, Sandia National Labs., California (United States)
No abstract available

8144-13, Session 3
Compact coaxial microwave neutron generator
W. C. Johnson, A. J. Antolak, K. Leung, T. N. Raber, Sandia National Labs., California (United States)
No abstract available

8144-14, Session 3
Burst-mode 4 MHz CMOS-hybrid imaging system for multi-frame proton radiography
K. Kwiatkowski, P. Nedrow, C. Morris, F. Merrill, A. Saunders, Los Alamos National Lab. (United States)
The performance of a 4-Mframe/s burst-mode imager with 3-frame in-pixel storage will be discussed. The 720×726px ultra-fast hybrid FPA and camera were fabricated by Rockwell Scientific (now Teledyne Imaging Sensors). Six cameras have been in operation for several years, in a variety of static and dynamic experiments at the 800MeV proton radiography (pRAD) facility at the LANSCE accelerator. The cameras can operate with per-pulse adjustable inter-frame time of 250ns to 2s, with an exposure/integration-time as short as 180ns. With a 70 ms readout time, the camera can be externally synchronized to 0.1-to-5Hz, 50-ns wide proton beam pulses, and record 1000-frame radiographic movies of 5-to-30 minute duration. The effectiveness and dependence of the global electronic shutter on the pixilated Si-sensor bias voltage and other parameters will be discussed. The spatial resolution dependence of the imaging system on various monolithic and “structured” scintillators and phosphor screens will be presented.

We will also describe features of a new-generation 10-frame 1024×1024 pixel, 50-ns shutter, 12-bit dynamic range imager, which is now in a final design stage.
8144-16, Session 4

Compton imaging tomography technique for NDE of large nonuniform structures

V. Grubsky, V. Romanov, T. Jannson, Physical Optics Corp. (United States)

We describe a new NDE technique called Compton Imaging Tomography (CIT) for reconstructing the complete three-dimensional (3D) internal structure of an object, based on the registration of multiple two-dimensional Compton-scattered x-ray images of the object. A CIT NDE system is typically based on a 200-kV x-ray source and a sensitive x-ray camera. Unlike the traditional Computed Tomography (CT), CIT does not rely on Radon transform for 3D data reconstruction. Instead, other specific image processing approaches are required for optimum 3D data interpretation and beam attenuation artifact removal. Currently, CIT provides high resolution (<1 mm) and sensitivity (<5% of material density difference) with virtually any materials, including lightweight structures and organics, which normally pose problems to conventional x-ray computed tomography due to low contrast. CIT technique requires only one-sided access to the object, has no limitation on the object’s size, and can be applied to high-resolution real-time in-situ NDE of large structures, for example aircraft/spacecraft components. Theoretical and experimental results will be presented.

8144-18, Session 4

Shipping container interrogation using a dense plasma focus device

R. P. Keegan, F. Tsang, E. C. Hagen, National Security Technologies, LLC (United States); R. O’Brien, D. Lowe, Univ. of Nevada, Las Vegas (United States)

Work is underway at National Security Technologies, LLC (NSTec), to test the feasibility of using a 2.45 MeV Dense Plasma Focus Device (DPF) to interrogate full-scale ISO shipping containers to identify smuggled fissionable material. The DPF produces a single pulse of 5 X 10^11 neutrons within a time window that is about 100 ns wide, so that the effective yield is 5 x 10^11 neutrons per second. This pulse generates fission in any fissionable material present, and then delayed gamma rays and neutrons are gross counted for up to 60 seconds starting at 1-3 seconds after the pulse. These delayed radiations are counted using large area (109 cm x 118.6 cm x 5.1 cm) EJ-200 polyvinyl toluene (PVT) detectors placed around the outside of the shipping container. The concept for operations involves placing the shipping container in the interrogation system and then gross counting background for five minutes. The DPF is then pulsed once and the delayed radiations are gross counted. The five-minute background is then subtracted from each raw delayed measurement to give the decay profile of the radiation from the shipping container. The concept has been modeled using MCNPX and the ideas will be experimentally tested at the DPF laboratory in early 2011. At the time of presentation of this paper a comparison will be made between the model and the experimental data. Issues related to induced radioactivity in the laboratory after the DPF pulse will be known and addressed. MCNPX simulations already performed indicate that the technique has significant potential.

8144-19, Session 4

FTIR and UV-VIS spectroscopic studies of high gamma irradiated Poly(vinylidene fluoride-hexafluoropropene) (PVdF-HFP)

O. S. Liz, Sr., A. Medeiros, L. O. Faria, Univ. Federal de Minas Gerais (Brazil)

Poly(vinylidene fluoride) [PVdF] is a semicrystalline linear homopolymer composed by the repetition of CH2-CF2 monomers. The Poly(vinylidene fluoride-co-hexafluoropropene) [PVdF-HFP] is a copolymer which is obtained with the random introduction of fluorinated [- CF2-CF-CF3 -] monomers, with 6 fluorine atoms, in the PVdF main chain. Gamma radio-induced changes in the physical and chemical properties were investigated using Fourier Transform Infrared Spectroscopy (FTIR) and Ultraviolet / Visible Spectroscopy (UV-VIS). In a first investigation, for doses ranging from 1 to 100kGy, the FTIR spectra revealed the radio-induction of an absorption band at 1852 cm^-1. This peak, generally attributed to stretching of the C=O bonds in carbonyl compounds, is probably originated by the oxidation of the polymer chains, as it is irradiated free in the air. We believe that the irradiation causes breaking of C-F bonds, thus leaving holes to be filled by oxygen atoms. A systematic investigation has shown that the band intensities increase as the gamma dose increases, presenting a linear relation between the gamma delivered dose and the absorption peak intensities, which can be used for detecting gamma doses ranging from 10 to 100kGy. The signal fading was also measured and it is 5% in a period of 60 days.

The UV-VIS Spectroscopy has been also used in this investigation in order to verify the appearing of C=C conjugated bonds, once some fluorinated PVdF copolymers have been reported to show linear behavior of UV absorption intensities with the exposed gamma dose. However, the spectra showed no unambiguous correlation with dose. The FTIR studies have showed that the PVdF-HFP copolymers are a great promise for the use in high dose radiation dosimetry.

8144-20, Session 4

6 MeV electron beam induced diffusion of iodine in isotactic polypropylene

N. L. Mathakari, V. N. Bhoraskar, S. D. Dhole, Univ. of Pune (India)

Thin films of polypropylene having size 15 mm X 15 mm X 350 µm immersed in 1 N iodine solution were irradiated with 6 MeV electron beam from the Microtron accelerator at the fluences varying from 0.5 X 10^15 to 2.5 X 10^15 electrons/cm^2. A few samples were also directly irradiated with the 6 MeV electron beam in the same fluence range. The electron irradiated and electron-beam-iodinated samples were characterized by using several techniques such as weight gain, weight loss, Energy Dispersive Spectroscopy (EDS), SEM, FTIR, UV-Visible spectroscopy and XRD. The analysis based on weight gain and EDS indicates that the electron beam increases the iodine intake in the samples increases with the electron fluence. The SEM analysis also indicates that the iodine clusters decrease in size and increase in number with electron fluence. The weight loss analysis carried over the period up to 159 hours at various intervals indicates that the weight loss due to volatile nature of iodine decreases with the fluence. The increase in iodine intake and prevention in its reverse diffusion is attributed to the electron beam induced free volume, defects and increases chemical activity in the polypropylene. The UV-Visible analysis reveals that, the band gap of directly irradiated polypropylene decreases from 4.96 to 4.13 eV. This is attributed to radiation induced carbonization process. On the contrary, the band gap of radiation-iodinated polypropylene decreases from 4.96 to 3.38 eV. This indicates that iodine supports the radiation induced band gap reduction process. FTIR indicates that presence of iodine during irradiation prevents the oxidation of polypropylene which usually takes place after irradiation. XRD analysis shows that direct electron irradiation does not affect the crystallinity to a notable extent. But the intensity of XRD peaks significantly decreases in case of electron-beam-iodinated samples. This indicates that the iodine causes the distortion in the crystalline structure of polypropylene due to its electronegative properties.

8144-21, Poster Session

The melting latent heat of semicrystalline PVDF: an efficient tool for evaluating high gamma doses

A. Medeiros, O. S. Liz, Sr., L. O. Faria, Univ. Federal de Minas Gerais (Brazil)
The use of dosimetric systems based on polymers has several advantages such as atomic composition, which can be closer to the material of interest for radiation processing industry, among others. One of the main drawbacks is related to signal loss over time (Fading). This limitation is not unique to polymeric dosimeters and it is present in all chemical dosimeters. In this paper, we shall describe the results of our investigation of a new proposed polymeric dosimeter for high gamma dose dosimetry. Now the dosimetry is based on the measurement of the heat of fusion (Hmelt) of the crystalline part of the homopolymer Poly(vinylidene fluoride) (PVDF). We have found that Hmelt, measured by DSC scan, is unambiguously related to the delivered doses ranging from 100 to 3,000 kGy. On the other hand, further systematic fading analysis has proved that the Hmelt of PVDF has no significant change up to eight months after irradiation, maintaining a linear relationship with the absorbed dose. In order to explain the results of this investigation in terms of the formation of new chemical bonds and the decrease in the crystalline order, we have simultaneously taken FTIR and XRD spectrograms together with the DSC scans. Both the very large range of dose measurement (1 to 3,000 kGy) and also the possibility of evaluating high gamma doses until eight months after irradiation make PVDF homopolymer a very good candidate to be investigated as commercial high gamma dose dosimeters.

8144-23, Poster Session

Apodized aperture imaging optics for Compton-scattered x-ray and gamma-ray imaging systems

V. Romanov, V. Grubsky, T. Jannson, Physical Optics Corp. (United States)

To improve the resolution and field of view of high-energy Compton-scattered x-ray and gamma-ray imaging systems, we have developed and tested apodized imaging optics, based on apertures with depth-dependent cross sections fabricated in an x-ray absorbing material (typically, lead or tungsten). By ray-tracing modeling, we determined the optimum aperture shapes (apodizations) that maximize the field of view and/or resolution of the system. Such optimized apodized apertures can increase the field of view by a factor of 4-5, compared to cylindrical-pinhole optics having the same resolution. Although such apodized apertures can be used in single-aperture x-ray optics, they are particularly suitable in high-resolution, high-energy coded-aperture arrays, where they help to achieve the optimum imaging performance due to the negligible variation of their point spread function with the angle of incidence. Potential applications of this technology include non-destructive evaluation (NDE) of materials and structures, in particular Compton imaging tomography (CIT), x-ray and gamma-ray astronomy, and medical imaging. We will demonstrate our modeling and experimental results for both single-aperture and coded-aperture apodized optics.

8144-24, Poster Session

X-ray imaging in an environment with high-neutron background on National Ignition Facility


X-ray imaging diagnostics instruments will operate in a harsh ionizing radiation background environment on implosion experiments at the National Ignition Facility. These backgrounds consist of mostly neutrons and gamma rays produced by inelastic scattering of neutrons. Imaging systems based on x-ray framing cameras with film and CCD’s have been designed to operate in such harsh neutron-induced background environments. Some imaging components were placed inside a shielded enclosure that reduced exposures to neutrons and gamma rays. Modeling of the signal and noise of the x-ray imaging system will be presented and compared with experimental data.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

8144-26, Poster Session

SSPM scintillator readout for gamma radiation detection

S. A. Baker, National Security Technologies, LLC (United States); C. J. Stapels, Radiation Monitoring Devices, Inc. (United States); J. A. Young, J. A. Green, R. E. Guise, National Security Technologies, LLC (United States); L. A. Franks, Consultant (United States)

Silicon-based photodetectors offer several benefits relative to photomultiplier tube based scintillator systems. Solid-state photomultipliers (SSPM) can realize the gain of a photomultiplier tube (PMT) with the quantum efficiency of silicon. The advantages of the solid-state approach must be balanced with adverse trade-offs, for example from increased dark current, to optimize radiation detection sensitivity. We are designing a custom SSPM that will be optimized for green emission of CsI(Tl). A typical field gamma radiation detector incorporates NaI(Tl) and a radiation converter with a PMT. A PMT’s sensitivity peaks in the blue wavelengths and is well matched to NaI(Tl). We present results of photomultiplier sensitivity relative to conventional SSPMs and have modeled design improvements. Prototype fabrications are in progress. This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy.
8145-01, Session 1

Status of the CCD camera for the eROSITA space telescope

N. Meidinger, Max-Planck-Institut Halbleiterlabor (Germany)

The approved German X-ray telescope eROSITA will be accommodated on the Russian satellite SRG. The general scientific goal is the exploration of the X-ray Universe in the energy band from 0.3 keV up to 10 keV with excellent energy, time and spatial resolution and large effective telescope areas. After launch to Lagrange point L2, the observational program divides into an all-sky survey and pointed observations.

We present the design of the seven flight cameras and describe the detector configuration. Focus is set on important recent amendments concerning the camera. A 3cmx3cm large, back-illuminated, 450μm thick and fully depleted PNCCD is the main item of the camera. The eROSITA flight CCD chips have been developed and produced in the MPI semiconductor laboratory in the course of further development of the XMM-Newton PNCCD. Their performance was at first tested on chip-level by means of a so-called ‘cold chuck probe station’ permitting even spectroscopic measurements. Based on these results, we select the flight-CCDs for integration into the seven eROSITA detector modules.

For a detailed characterization of the CCD and its dedicated analog readout ASIC, various tests were carried out. Another aim of the tests was to evaluate the optimum detector operating conditions in terms of operating sequence, supply voltages and operating temperature.

Furthermore, substantial part of testing were radiation hardness tests of the eROSITA CCD and its readout ASIC with protons. This is essential to evaluate the long-term stability of the detectors.

8145-02, Session 1

Development of the data acquisition system for the X-ray CCD camera (SXI) on board ASTRO-H

T. Fujinaga, Japan Aerospace Exploration Agency (Japan); N. Anabuki, Osaka Univ. (Japan); S. Aoyama, Univ. of Miyazaki (Japan); H. Kawano, Yokohama National Univ. (Japan); K. Matsuda, M. Ozaki, T. Dotani, C. Natsukari, K. Shimizu, Japan Aerospace Exploration Agency (Japan); H. Nakajima, K. Hayashida, H. Uchida, S. Ueda, S. Komatsu, Osaka Univ. (Japan); T. Murayoshi, K. Mori, Univ. of Miyazaki (Japan); J. S. Hiraga, The Univ. of Tokyo (Japan); S. Ikeda, T. Watanabe, Kogakuin Univ. (Japan)

Development of the X-ray CCD (SXI) on board ASTRO-H is presented focusing on the data acquisition system. Basic functions of the system were verified with the BBM, and we are currently developing the EM. The functions implemented in the BBM are generation of the timing clocks, delta-sigma-ADC, and SpaceWire communication. The ADC was realized combining ASIC and FPGA. The verification test of the digital part showed that the SpaceWire communication was stable over 24 hours, and the data transfer speed was 4.4 Mbps. We performed the 55Fe irradiation test using a prototype CCD cooled down to -30 degrees Celsius. After tuning the sampling timing and installing low-pass filters, we obtained the energy resolution of 164 eV at 5.9 keV (FWHM). This resolution is slightly worse than the requirement to SXI. The final-version BBM, which is under verification, was designed to have the digital and analog architecture identical to the flight model except for the FPGA and parts specification.

8145-03, Session 1

Development of the X-ray CCD for SXI on board ASTRO-H

S. Ueda, K. Hayashida, H. Nakajima, N. Anabuki, H. Uchida, H. Tsunemi, M. Fujikawa, H. Mori, Osaka Univ. (Japan); T. Kohmura, T. Watanabe, K. Kawai, S. Ikeda, K. Kaneko, Kogakuin Univ. (Japan); K. Sakata, S. Todoroki, H. Mizuno, N. Yagihashi, Rikkyo Univ. (Japan); T. Dotani, M. Ozaki, Japan Aerospace Exploration Agency (Japan); T. G. Tsuru, Kyoto Univ. (Japan)

We have been developing X-ray CCD for the Soft X-ray Imager (SXI) on board ASTRO-H, an X-ray astronomy mission to be launched in FY2013. The SXI employs P-channel Bi CCDs with a thick depletion layer of 200μm. Each CCD has an imaging area of 31 mm square, and 4 chips covers a wide FOV of 38 arcmin. Basic performance of the prototype P-channel Bi CCD was verified to meet or close to the SXI requirements, including the fact that the device was fully-depleted with depletion thickness over 200 μm. Nevertheless, its soft X-ray (below 1 keV) response showed significant low energy tail with comparable or larger magnitude than the main peak component. The tail was more enhanced for the lower energy X-rays, indicating its origin is charge loss in the surface layers of the CCD. We have made several test CCD chips with different treatment or structures of the layers beneath the entrance window. At least one of the test chip showed reduced low energy tail. We confirmed this by irradiating fluorescent X-rays, first. We also irradiated monochromatic X-rays of various energies from 0.25keV to 1.8keV at the KEK-PP Synchrotron Facility, and confirmed the low energy tail of this test CCD was reduced by about one order of magnitude. In addition, we will report the basic performance of the SXI EM CCD, and a charge injection technique for it.

8145-04, Session 1

Development of the soft x-ray imager (SXI) for ASTRO-H

H. Tsunemi, K. Hayashida, Osaka Univ. (Japan); T. G. Tsuru, Kyoto Univ. (Japan); T. Dotani, Japan Aerospace Exploration Agency (Japan); J. S. Hiraga, The Univ. of Tokyo (Japan); N. Anabuki, Osaka Univ. (Japan); A. Bamba, Japan Aerospace Exploration Agency (Japan); I. Hatsukade, Univ. of Miyazaki (Japan); T. Kohmura, Kogakuin Univ. (Japan); K. Mori, Univ. of Miyazaki (Japan); H. Murakami, Rikkyo Univ. (Japan); H. Nakajima, Osaka Univ. (Japan); M. Ozaki, Japan Aerospace Exploration Agency (Japan); H. Uchida, Osaka Univ. (Japan); M. Yamauchi, Univ. of Miyazaki (Japan)

ASTRO-H will be launched in FY2013, carrying X-ray mirrors for the X-ray calorimeter (SXS), the hard X-ray imager (HXI) and the soft X-ray imager (SXI). We are developing an X-ray CCD camera (SXI). The biggest advantage of the SXI is that it has a large field of view (38° square). We have developed the CCD, CCD-NoXT4, that is a P-channel type CCD. It has a thick depletion layer of 200μm with an imaging area of 30.72mm square. Since it is back-illuminated, it has a good low energy response and is robust against the impact of micro-meteorites. We will employ 4 chips to cover the area more than 60mm square. We will employ a mechanical cooler so that we can cool the CCD to -120°C. The basic design of the cooler is identical employed for previous satellites (SUZAKU and Akari) while we will add a balancer to reduce the vibration environment. The cold part of the SXI is completely isolated from the interior of the satellite to avoid the contamination. We will also introduce an analog ASIC that is placed very close to the CCD. It performs well,
having a similar noise level to that assembled by using individual parts used on SUZAKU. We decided to employ a radio-active source rather than a modulated X-ray source for onboard calibration. The SXI passed the CDR and will get into the FM production phase.

8145-05, Session 2

Design and tests of the hard X-ray polarimeter X-Calibur

M. Beilicke, P. Dowkontt, A. Garson, O. Guo, K. Lee, Washington Univ. in St. Louis (United States); J. Tueller, NASA Goddard Space Flight Ctr. (United States); H. S. Krawczynski, Washington Univ. in St. Louis (United States)

X-ray polarimetry promises to give qualitatively new information about high-energy sources, such as binary black hole systems, rotation and accretion powered neutron stars, Microquasars, Active Galactic Nuclei and Gamma-Ray Bursts. Furthermore, hard X-ray polarimetric observations of galactic sources can place uniquely sensitive constrains on Lorentz Invariance violations. We designed, built and tested a hard X-ray polarimeter X-Calibur to be used in the focal plane of the InFOCuS grazing incidence hard X-ray telescope. The polarimeter combines a low-Z Compton scatterer with a high-Z Cadmium Zinc Telluride (CZT) detector assembly to measure the polarization of 10-80 keV X-rays. X-Calibur makes use of the fact that polarized photons Compton scatter preferentially perpendicular to the electric field orientation. In contrast to competing designs, which use only a small fraction of the incoming X-rays, X-Calibur achieves a high detection efficiency of order unity. We report on the technical design of X-Calibur, the X-Calibur and InFOCuS sensitivity on short and long duration balloon flights, and present detailed laboratory calibration measurements.

8145-06, Session 2

Balloon test flight of a fast scintillator Compton telescope

P. Bloser, M. Julien, J. Ryan, J. Legere, M. McConnell, The Univ. of New Hampshire (United States); R. M. Kippen, S. Torniga, Los Alamos National Lab. (United States)

The field of medium-energy gamma-ray astronomy urgently needs a new mission to build on the success of the COMPTEL instrument. This mission must achieve a sensitivity significantly greater than that of COMPTEL in order to advance the science of relativistic particle accelerators, nuclear astrophysics, and diffuse backgrounds and bridge the gap between current and future hard X-ray missions and the high-energy Fermi mission. Such an increase in sensitivity can only come about via a dramatic decrease in the instrumental background. We are currently developing a concept for a low-background Compton telescope that employs modern scintillator technology to achieve this increase in sensitivity. Specifically, by employing LaBr3 scintillators, for the calorimeter, one can take advantage of the unique speed and resolving power of this material to improve the instrument sensitivity and simultaneously enhance its spectroscopic performance and thus its imaging performance. We have constructed a small scientific balloon payload consisting of a prototype of such an instrument. We present the preliminary results from the first flight of this prototype in Summer 2011.

8145-07, Session 2

Spectral calibration and modeling of the NuSTAR CdZnTe pixel detectors

T. Kitaguchi, H. Miyasaka, V. Bhalerao, R. W. Cook, B. W. Grefenstette, F. A. Harrison, P. H. Mao, V. R. Rana, California Institute of Technology (United States); S. Boggs, A. Zoglauer, Univ. of California, Berkeley (United States)

The Nuclear Spectroscopic Telescope Array (NuSTAR) mission will carry the first focusing hard X-ray telescopes to orbit. The NuSTAR focal plane consists of four CdZnTe hybrid pixel detectors, each with an active collecting area of 2cm x 2cm on a side, 2mm thick. Each hybrid consists of a 32 x 32 array of 600 micron pixels, read out with the Caltech custom low-noise NuCIT ASIC. In order to characterize the spectral response of each pixel to the degree required to meet the science calibration requirements, we have developed a model based on Geant4 together with the Shockley-Ramo theorem customized to the NuSTAR hybrid design. This model combines a Monte Carlo of the X-ray interactions with subsequent charge transport within the detector. The combination of this model and calibration data taken using radioactive sources of 57Co, 155Eu and 241Am enables us determine electron and hole mobility-lifetime products for each pixel, and compare actual to ideal performance expected for defect-free material. In this paper we describe the NuSTAR spectral calibration program, the charge transport model, and we present results obtained by fitting data from NuSTAR flight and engineering model detectors.

8145-08, Session 3

Development micro-satellite TSUBAME for polarimetry of gamma-ray bursts

Y. Yatsu, T. Enomoto, K. Kawakami, K. Tokoyoda, T. Toizumi, N. Kawai, K. Ishizaka, S. Matsuura, Tokyo Institute of Technology (Japan); T. Nakamori, J. Kataoka, Waseda Univ. (Japan)

We are developing an university class micro-satellite “TSUBAME” to measure polarizations of gamma-ray bursts in hard X-ray energy band. For this mission we designed and optimized a compact and high sensitive hard X-ray polarimeter utilizing anisotropy of the Compton scattering. Unsurprisingly, any micro-satellites have critical limitations on size, mass, and power consumption, that constrain the effective area of detectors. However high luminosities of GRBs allow us to measure their polarizations only if we start observations just after the ignitions. TSUBAME overcomes this problem by using compact and high-tone actuators of Control Moment Gyros, that enables high speed attitude control faster than 6 deg/s. For real-time detection and localization of GRBs, we also developed wide field burst monitor, that consists of scintillation gamma-ray counters mounted on five different surfaces of the satellite. Cooperating with the attitude control system, TSUBAME can start a pointing observation within 15 s since the detection for any GRBs that explode in the burst monitor’s half-sky field of view. In this presentation the status of development and feasibility study of this satellite program are reported.

8145-09, Session 3

The Cosmic Vision M3 mission studies: status and overview of the astrophysics candidates

M. Gehler, L. Puig, A. Stankov, N. Rando, European Space Research and Technology Ctr. (Netherlands)

Within the framework of the European Space Agency’s Cosmic Vision 2015-2025 programme, a third call for mission proposals (M3) was released to identify candidate missions for a launch slot in 2020-2022 that are to be studied in detail. The progress on the M3 astrophysics mission candidate studies is presented in this paper. The third medium-sized launch opportunity of the Cosmic Vision programme limits the candidates to VEGA or Soyuz-compatible spacecraft to be launched from Kourou with a cost ceiling of 470 M. Following the first down-selection by the advisory structure, the selected proposals are undergoing internal studies in the Concurrent Design Facility. The mission concepts of the proposals are developed, the requirements refined, and the feasibility of the missions is assessed. The paper provides a summary of the status of these studies and
8145-10, Session 3

First results from the Far-ultraviolet Imaging Rocket Experiment (FIRE)

B. L. Gantner, J. Green, M. Beasley, R. Kane, Univ. of Colorado at Boulder (United States); T. Schultz, The Univ. of Iowa (United States)

The Far-ultraviolet Imaging Rocket Experiment (FIRE) is a sounding rocket payload that is designed to search for young, hot stars at 900-1000 Å. FIRE is a prime-focus system where the mirror is parabolic and coated with silicon carbide. It also uses 5 multi-channel plates in a charge amplification detector with the top plate coated with rubidium bromide (RbBr) to give the highest response over the desired wavelengths. Since the noise from Lyman-alpha photons would swamp the signal, a 2000 Å pure indium filter sits in front of the detector. To ensure that the filter would survive the acoustic vibrations of launch, a small vacuum canister was built around the filter and detector that opened during ascent to allow the collection of data. Imaging at 900-1000 Å allows us to study the star formation rate within different regions of target galaxies. FIRE was also designed to compliment the GALAX mission with similar resolution and field-of-view. Combined with GALEX data, FIRE can create three-color images of the FUV.

FIRE launched for the first time on January 28th, 2011 from the Poker Flat Research Range in northern Alaska. The first flight targeted the Whirlpool galaxy (M51) and used G191B2B as a calibration target. I will present the scientific motivation, design, calibration and initial results of the FIRE instrument and its first flight.

8145-11, Session 3

Fabrication and calibration of FORTIS


The Johns Hopkins University sounding rocket group is nearing completion of the Far-ultraviolet Off Rowland-circle Telescope for Imaging and Spectroscopy (FORTIS); a sounding rocket borne multi-object spectro-telescope designed to provide spectral coverage of 43 separate targets in the 900-1800 Å bandpass over a 30' x 30' field-of-view. Using “on-the-fly” target acquisition and spectral multiplexing enabled by a GSFC microshutter array, FORTIS will be capable of observing the brightest regions in the far-UV of nearby low redshift (z = 0.002 - 0.02) star forming galaxies to search for Lyman alpha escape, and to measure the local gas-to-dust ratio. A large area (~ 45 mm x 170 mm) microchannel plate detector from Sensor Sciences provides an imaging channel for targeting flanked by two redundant spectral outrigger channels. The grating is ruled directly onto the secondary mirror to increase efficiency. In this paper, we discuss the recent progress made in the development and fabrication of FORTIS, as well as the results of early calibration and characterization of our hardware, including mirror/grating measurements, detector performance, and early operational tests of the microshutter arrays.

8145-12, Session 4

The Warm-Hot Intergalactic Medium Explorer (WHIMex) Mission

C. F. Lillie, Northrop Grumman Aerospace Systems (United States); W. C. Cash, Univ. of Colorado at Boulder (United States); R. L. McEntaffer, The Univ. of Iowa (United States); W. W. Zhang, NASA Goddard Space Flight Ctr. (United States); S. L. O’Dell, NASA Marshall Space Flight Ctr. (United States); M. S. Elvis, Harvard-Smithsonian Ctr. for Astrophysics (United States); M. Bautz, Massachusetts Institute of Technology (United States)

This baryonic matter is thought to result from gravitational collapse of moderately over-dense, dark-matter filaments of the Cosmic Web. The chemical enrichment of the Cosmic Web appears to arise from galactic super winds and early generations of massive stars. WHIMex will test these theories, distinguish between competing models, and provide new insights into galaxy evolution and the structure of the universe. At a resolution of $R = \lambda/\delta \lambda = 4000$, absorption lines in the spectra of distant X-ray sources are resolved down to their thermal width, providing the temperature and velocity information needed to attack astrophysical problems. WHIMex will measure absorption lines from species such as O VII and O VIII, the primary tracers of 400,000 to 3,000,000 K gas. These lines, which are too weak and narrow to confidently study with existing instruments, become accessible with the high sensitivity of WHIMex.

High-resolution X-ray spectroscopy has been identified by the ASTRO2010 decadal panel as a high-priority capability in the coming decade for a wide variety of science goals. Unfortunately, no other planned mission can address this science until the International X-ray Observatory flies, no earlier than the late 2020s. WHIMex achieves its high level of performance in a single-instrument, affordable package using X-ray optical technologies developed for flight on IXO and NuSTAR by academic, industrial and government research centers. The technology readiness levels of all the components are high. We plan to build an optical test module and raise the optical system readiness level to TRL 6 during Phase A.

8145-14, Session 4

eROSITA

P. Predehl, Max-Planck-Institut für extraterrestrische Physik (Germany)
eROSITA (extended REntgen Survey with an Imaging Telescope Array) will be the core instrument on the Russian Spektrum-Roentgen-Gamma (SRG) mission. The mission will consist of an all-sky survey lasting for four years plus a phase of pointed observations on selected objects. eROSITA consists of seven Wolter-I telescope modules, each equipped with 54 Wolter-I shells having an outer diameter of 360 mm. In the focus of each mirror module, a framemore pn-CCD provides a field of view of 1° in diameter. eROSITA is fully approved and funded by the German Space Agency DLR and Max-Planck-Society. The instrument is now in phase C/D: The flight mirror production is ongoing, the telescope structure is built and ready for the integration of subsystems. In parallel, the work in house (cameras, electronics etc.) is running, many components are already qualified.

8145-29, Session 4

The DUAL mission concept

P. von Ballmoos, Institut de Recherche en Astrophysique et Planétologie (France)

During a 3-year exposure of every γ-ray source in the sky, DUAL’s All-Sky Compton Imager (ASCI) performs sensitive γ-ray spectroscopy and
polarimetry in the energy band 100 keV-10 MeV. The ASCI measures polarization in a large number of γ-ray bursts; it unveils the distribution and ultimately the origin of galactic positrons; it performs a detailed all-sky survey of the radioactive Milky Way, clarifying long-lived activities from supernovae and novae; and it studies excitation lines from as yet unknown MeV cosmic-rays interacting with the interstellar medium. The deep all-sky survey naturally monitors galactic black holes, neutron stars, pulsars, magnetars, and simultaneously, a full sky of Active Galactic Nuclei. DualAL's capability of measuring polarization provides a powerful new diagnostic of magnetic fields - for studying acceleration in neutron star magnetospheres and for their role in the origin of γ-ray emission and jets from accreting BHs, both galactic and extragalactic.

Simultaneous with its all-sky survey, the ASCI serves as a low-background focal plane detector for two optical modules, the Laue-Lens Optic (LLO) and the Coded-Mask Optic (CMO). DualAL will, for the first time ever, make use of focusing optics to concentrate high-energy photons onto a small focal spot. With its Laue-Lens Optic (LLO), during dedicated pointings, DualAL will observe radioactive 56Ni and 56Co in a sizable sample of SNIA at distances of up to 30-40 Mpc. Focusing will bring the long awaited sensitivity leap needed to answer pressing astrophysical questions of our age: What are Type la Supernova progenitors? How do their nuclear flames burn in degenerate matter? Are the ancient ones from which we infer an accelerating Universe well calibrated using a local sample?

The Coded-Mask Optic (CMO) dramatically enhances ASCI’s imaging capabilities in the Galactic Center and Bulge. During deep, dedicated, observations high angular resolution (10'-40') will be achieved in this single region. DualAL’s CMO will be able to disentangle the emission of compact objects in the Galactic Center, and most importantly, map out the, as yet, unresolved bulge of e+ e- annihilation radiation in order to identify the sources of positrons that have puzzled high-energy astronomers for over 30 years.

8145-15, Session 5

Progress in New Ultraviolet Reflective Coating Techniques

M. Beasley, Univ. of Colorado at Boulder (United States); S. Nikzad, F. Greer, Jet Propulsion Lab. (United States)

Our project investigates the capabilities of Atomic Layer Deposition (ALD) to create very thin, high-efficiency coatings of MgF2 over aluminum. Significant improvement over existing coatings is predicted by theory. Our work will create several coated small samples to verify that technique reliably prevents the oxidation of aluminum, and will subsequently be expanded to larger substrates to prove our technique’s scalability to larger optical components. An improved coating therefore would enable the production of vastly more sensitive instruments in the 90 - 200 nm range. The durability of these coatings will also be verified by accelerated lifetime testing that exposes the samples to extremes of temperature, humidity, and reactive oxygen environments.

8145-16, Session 5

Atomically Precise Surface and Interface Engineering via Atomic Layer Deposition to Enable High-Performance Materials, Detectors, and Instruments

F. Greer, M. Hoenk, B. Jacquot, T. J. Jones, S. Monacos, Jet Propulsion Lab. (United States); E. Hamden, Columbia Univ. (United States); M. Beasley, B. L. Gantner, Univ. of Colorado at Boulder (United States); S. Nikzad, Jet Propulsion Lab. (United States)

Future UV instruments have the potential to revolutionize our understanding of the formation and habitability of the modern universe.

8145-17, Session 5

Semitransparent GaN-based Photocathode Structures for High-Sensitivity UV Imaging

A. M. Dabiran, A. M. Wowchak, P. P. Chow, SVT Associates, Inc. (United States); J. Hull, A. S. Tremsin, O. H. Siegmund, Univ. of California, Berkeley (United States)

Negative electron affinity (NEA) semiconductor photocathodes are commonly used in combination with electron multipliers, such as microchannel plates (MCPs), to fabricate sensitive phototubes. In recent years, there have been significant improvements in the performance of these detectors by enhancing photocathode quantum efficiency (QE), and by advances in MCPs and readout techniques. We have previously fabricated high efficiency GaN-based UV photocathodes, grown by RF plasma-assisted molecular beam epitaxy (MBE), with QE as high as 80% at 120 nm for operation in the opaque mode. However, these devices generally show much lower QE in semitransparent mode (i.e., backside illumination) which is most suitable for integration with MCPs. To improve the QE, both the photoelectron generation by light absorption and electron emission processes need to be optimized. The latter requires thinner photocathode films for semitransparent mode to allow efficient extraction of photoelectrons generated at the back of the film. The common wisdom is that the thinner films also mean less light absorption hence the measured QE values of 20% for very thin films (<50 nm). In this presentation, we will discuss new photocathode structures that take advantage of thinner p-GaN films without suffering from charging effects due to the low in plane conductivity. We will also present other GaN-based photocathode structures that show NEA photoemission, without the need for surface activation by Cs evaporation, for stable and long-life operation in harsh environments.

8145-18, Session 5

FUV Quantum Efficiency Degradation of Cesium Iodide Photocathodes Caused by Exposure to Thermal Atomic Oxygen

J. B. McPhate, Univ. of California, Berkeley (United States); J. Anne, Lockheed Martin Space Systems Co. (United States); J. Bacinski, Lockheed Martin Corp. (United States); B. A. Banks, NASA Glenn Research Ctr. (United States); C. Cates, P. Christensen, Lockheed Martin Space Systems Co. (United States); B. A. Cruden, NASA Ames Research Ctr. (United States); L. Dunham, PPI (United States); E. Graham, Lockheed Martin
The color dependence of the measured decline of the on-orbit sensitivity of the FUV channel of the HST Cosmic Origins Spectrograph (HST-COS) indicated the principal loss mechanism to be degradation of the cesium iodide (CsI) photocathode of the open-faced FUV detector. A leading contender for this degradation is contamination by atomic oxygen (AO), prompting an investigation of the interaction of AO with CsI. To address this question, opaque CsI photocathodes were deposited on stainless steel substrates employing the same deposition techniques and parameters used for the photocathodes of the HST-COS FUV detector. The as-deposited FUV quantum efficiency of these photocathodes was measured in the 117-174 nm range. Several of these photocathodes were exposed to varying levels of thermalized, atomic oxygen (AO) fluence (produced via an RF plasma). The post-AO exposure QE's were measured and the degradation of sensitivity verses wavelength and AO fluence are presented.

8145-19, Session 5

Advances in microchannel plates and photocathodes for ultraviolet photon counting detectors

O. H. Siegmund, Univ. of California, Berkeley (United States)

Microchannel plate imaging detectors with photon counting capability have been employed for numerous NASA missions dedicated to spectroscopy and imaging in the ultraviolet. Recent advances in microchannel plate and photocathode materials and processes have begun to enhance the performance and scope of these tools. We will discuss the potential of these advances and their application to large format devices up to 20 x 20 cm, improvements in secondary emission coefficient and its effect on quantum detection efficiency, and the results for new materials providing longer lifetimes.

8145-20, Session 6

UV/optical/NIR detectors for photon counting and high-efficiency applications in astronomy and other fields

S. Nikzad, Jet Propulsion Lab. (United States)

Discoveries beyond the current UV/optical NASA missions require new instrument capabilities. Such missions under planning and review will search for Earth like exo-planets, search for life in planets far from our own, perform spectroscopic studies of intergalactic medium, and perform planetary atmospheric studies. These new instruments place exacting requirements on detectors. One such requirement is the ability to detect single photons. Until now, the combination of high signal to noise ratio requirement, requirement of gain, coupled with large format, uniformity, and linearity has made these requirements out of reach for solid-state detectors. We report on our latest results on detectors with high QE response in far UV and near UV for photon counting applications. We will also discuss our end-to-end back illumination processes at JPL's Microdevices Laboratory and the various applications of the detectors under development.

8145-21, Session 6

The use of CCDs and EM-CCDs on the off-plane x-ray grating spectrometer readout camera system on the International X-ray Observatory

J. H. Tutt, A. D. Holland, R. D. Harriss, D. J. Hall, N. J. Murray, S. J. Barber, The Open Univ. (United Kingdom); J. Endicott, M. Robbins, e2v technologies plc (United Kingdom); R. L. McIntaffer, The Univ. of Iowa (United States)

The OP-XGS on the International X-ray Observatory is designed to produce spectroscopic data in the soft X-ray energy range of 300 eV to 1,000 eV with a resolution $\Delta E/E > 3,000$. As well as using conventional CCDs for the XGS grating readout camera system, the possibility of extending the range of the proposed band-pass, through the use of EM-CCDs, down to 200 eV has been considered. Amplifying the signal before the readout register effectively suppresses the devices readout noise allowing lower energy X-ray photons, which produce low numbers of $e^{-}/h$ pairs per interaction, to be detected allowing the band-pass to be extended. In order for the instrument to achieve the necessary resolution across the band-pass, multiple orders of dispersed light from the XGS are used. As different orders will fall onto the same part of the CDD array, the energy resolution of the device is used in order to differentiate between these orders. However, due to the stochastic nature of the gain amplification process in an EM-CCD, this energy resolution (FWHM) is degraded and so an investigation into whether or not the necessary energy resolution can be achieved was conducted at BESSY II with the results presented. The degradation of the X-ray peak FWHM is described by the spectral resolution factor which is analogous to the Excess noise factor, but for Fano adjusted regimes. The technology development achieved in this study may also have an outlet in the recently proposed WHIM-EX mission at NASA.

8145-23, Session 6

Radiation testing of mini-orthogonal transfer array CCDs

B. J. LaMarr, M. Bautz, S. Kissel, G. Prigozhin, Massachusetts Institute of Technology (United States); B. E. Burke, V. Suntharalingam, M. J. Cooper, MIT Lincoln Lab. (United States)

Orthogonal transfer array CCDs were originally developed by the University of Hawaii and MIT Lincoln Laboratory for use in the focal planes of the ground-based Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). These devices may also be useful in space-based applications in X-ray astronomy, so we have conducted a series of tests to determine their sensitivity to proton radiation encountered on-orbit. We report effects of typical on-orbit proton exposure on charge transfer efficiency, dark current, noise and spectral resolution as a function of device operating temperature and readout parameters.

8145-24, Session 6

High-sensitivity and high-stability silicon photodiode for the DUV, VUV, and EUV spectral ranges

S. Nithianov, L. Shi, Technische Univ. Delft (Netherlands); F. Scholze, A. Gottwald, Physikalisch-Technische Bundesanstalt (Germany)

In the paper, the optical and electrical performances of a newly developed silicon photodiode, with delta-doped boron surface, are introduced. Due to its extremely shallow p-n junction, with depletion...
zone starting only a few nanometers below the top surface, the photodiode demonstrates very high responsivity in all sub-visible ultraviolet (UV) ranges: DUV (deep ultraviolet), VUV (vacuum ultraviolet) and EUV (extreme ultraviolet), covering a spectrum from 220 nm down to 1 nm wavelength and below. To our best knowledge, it is the only solid state photo-detector (based on silicon, III-V materials or diamond), which performs well in all UV ranges. Particularly, the B-photodiode demonstrates simultaneously high responsivity in all UV ranges, approaching the theoretical maximum at 13.5 nm wavelength (EUV) of ~0.27A/W, in combination with high radiation hardness. The B-photodiode has excellent electrical characteristics, with saturation current values typical for high-quality silicon diodes, and a high breakdown voltage. Experimental results prove the extremely high radiation hardness of the B-photodiode, when exposed to high EUV dose in the order of a few hundred kJ/cm². No change of the responsivity is noticed within the measurement uncertainty. In the DUV and especially VUV ranges, which are more challenging with respect to radiation hardness, the B-photodiode demonstrates an initial slight drop of responsivity (<1%), after which it stabilizes its performance. The drop of responsivity recovers with time. The recovery process can be accelerated by a short thermal treatment (1-2 hours) at 100-200°C. The homogeneity of responsivity over the active diode area is very high and without additional top capping layers, it is within the measurement uncertainty.

8145-25, Poster Session

**An EUV spectrometer on earth-orbiting satellite for planetary science**

I. Yoshikawa, K. Sakai, G. Murakami, H. Ishii, K. Yoshioka, The Univ. of Tokyo (Japan)

An earth-orbiting Extreme Ultraviolet spectroscopic mission, EXtreme ultraviolet spectrosCope for ExosphEric Dynamics explore (EXCEED) that will be launched in 2012 is now under development. The EXCEED mission will carry out observations of Extreme Ultraviolet (EUV: 60 -145 nm) emissions from tenuous plasmas around the planets (Mercury, Mars, Venus, and Jupiter). It is necessary for planetary EUV spectroscopy to avoid the Earth's atmospheric absorption, therefore we have to observe above the Earth's atmosphere. In this paper, we will introduce the general mission overview, the instrument, and the scientific targets.

8145-26, Poster Session

**The opto-mechanical design of the Colorado High-resolution Echelle Stellar Spectrograph**

R. Kane, M. Beasley, K. France, E. Burgh, J. Green, Univ. of Colorado at Boulder (United States)

We present the Colorado High-resolution Echelle Stellar Spectrograph. The design uses a mechanical collimator made from a grid of square tubing, an objective echelle grating, a holographically ruled cross-disperser, with a new 40 mm MCP with a cross strip anode. The optics are suspended using carbon fiber rods epoxied to titanium inserts to create a space frame structure. A preliminary design is presented.

8145-27, Poster Session

**Gain sag in the FUV detector of the Cosmic Origins Spectrograph**

D. J. Sahnow, The Johns Hopkins Univ. (United States); A. Aloisi, P. E. Hodge, D. Massa, C. Oliveira, R. Osten, C. Proffitt, A. Bostroem, Space Telescope Science Institute (United States); J. B. McPhate, Univ. of California, Berkeley (United States); S. Beland, S. N. Osterman, S. V. Penton, Univ. of Colorado at Boulder (United States)

The Cosmic Origins Spectrograph (COS) on the Hubble Space Telescope (HST) uses a large-format cross delay line (XDL) detector in its Far Ultraviolet (FUV) channel. While obtaining spectra, light falls non-uniformly on the detector due to the optical design and the spectral properties of the object being observed; in particular, bright emission lines from geocoronal Lyman-alpha can fall on the detector in more than 20 locations. As a result, some areas of the detector have received a much greater exposure than others. This non-uniform illumination has led to a time- and position-dependent change in the gain of the microchannel plates, which causes variations in the overall detector performance. We will discuss the effects of this gain sag on the science data, and discuss mitigation strategies which are being implemented in order to maximize the detector lifetime.
8146-01, Session 1

Commissioning and in-flight calibration results of the lunar reconnaissance orbiter’s Lyman alpha mapping project (LRO/LAMP) UV imaging spectrograph

M. W. Davis, R. Gladstone, M. H. Versteeg, T. K. Greathouse, A. Stern, J. W. Parker, A. Steffl, K. D. Retherford, D. C. Slater, Southwest Research Institute (United States)

The Lunar Reconnaissance Orbiter’s Lyman Alpha Mapping Project (LAMP) is a lightweight (6.1 kg), low-power (4.5 W), ultraviolet spectrograph based on the Alice instruments now in flight aboard the European Space Agency’s Rosetta spacecraft and NASA’s New Horizons spacecraft. Its primary job is to identify and localize exposed water frost in permanently shadowed regions (PSRs) near the Moon’s poles, and to characterize landforms and albedos in PSRs. We describe the in-flight radiometric performance and commissioning results and compare them to the ground calibration measurements.

Lunar Reconnaissance Orbiter (LRO) launched on June 18, 2009 and reached lunar orbit four days later. LAMP commissioning activities began on July 27, 2009 and were completed on September 9, 2009. LAMP has since been routinely observing the lunar surface from LRO’s 50-km altitude polar orbit. The commissioning measurements described herein, along with monthly stellar observations, serve to calibrate the LAMP science results throughout the mission.

8146-02, Session 1

Radiometric performance results of the Juno ultraviolet spectrograph (Juno-UVS)


We describe the radiometric performance and ground calibration results of the Juno mission’s Ultraviolet Spectrograph (Juno-UVS) flight model. Juno-UVS is a modest power (9.0 W) ultraviolet spectrograph based on the Alice instruments now in flight aboard the European Space Agency’s Rosetta spacecraft, NASA’s New Horizons spacecraft, and the LAMP instrument aboard NASA’s Lunar Reconnaissance Orbiter. Its primary job will be to characterize Jupiter’s UV auroral emissions and relate them to in situ particle measurements.

8146-03, Session 1

Real scale ray tracing simulation of space earthshine measurement with improved BRDF model of lunar surface

J. Yu, D. Ryu, S. Kim, Yonsei Univ. (Korea, Republic of)

The discrepancy in annual changes of Earth albedo anomaly among the HadCM prediction, ground and low earth orbit measurements attracts great academic attention world-wide. As a part of our on-going study for better understanding of such discrepancy, we report a new Earthshine measurement simulation technique. It combines the light source (the Sun), targets (the Earth and the Moon) and a hypothetical detector in a real scale integrated Monte-Carlo ray tracing (IRT) computation environment. The Sun is expressed as a Lambertian scattering sphere, emitting 1.626*10^26W over 400nm-700nm in wavelength range. Whilst we are in the process of developing a complex Earth model consisting of land, sea and atmosphere with appropriate BRDF models, a simplified Lambertian Earth surface with 0.3 in uniform albedo was used in this study. For the moon surface, Hapke’s BRDF model is used with double Henry-Green phase function. These elements were then imported into the IRT computation of radiative transfer between their surfaces. First, the radiance levels of Earthshine and Moonshine lights were computed and then confirmed that they agree well with the measurement data from Big Bear Solar Observatory. They were subsequently used in determination of the Earth bond albedo of about 0.3 that is almost identical to the input Earth albedo of 0.3. These computations prove that, for the first time, the real scale IRT model was successfully deployed for the Earthshine measurement simulation and, therefore, it can be applicable for other ground and space based measurement simulation of reflected lights from the Earth and the Moon.

8146-04, Session 2

JWST science and system overview

M. C. Clampin, NASA Goddard Space Flight Ctr. (United States)

The James Webb Space Telescope (JWST) is a large aperture (6.5 meter), cryogenic space telescope with a suite of near and mid-infrared instruments covering the wavelength range of 0.6 µm to 28 µm. JWST’s primary science goal is to detect and characterize the first galaxies. It will also study the assembly of galaxies, star formation, and the formation of evolution of planetary systems. JWST is a segmented mirror telescope operating at ~40K, a temperature achieved by passive cooling of the observatory, via a large, 5-layer membrane-based sunshield. We present an overview of the observatory design, the mission science objectives, the integration and test program and review the concept for science operations of JWST. With construction of the observatory progressing rapidly across all elements of the observatory, we will report on recent highlights such as the completion of the first JWST primary mirror segment. We will also review the predicted performance of the JWST observatory, based on initial measurements of the telescope optics and instrumentation.

8146-05, Session 2

Status of the James Webb space telescope integrated science instrument module system


The Integrated Science Instrument Module (ISIM) of the James Webb Space Telescope (JWST) is discussed from a systems perspective with emphasis on development status and advanced technology aspects. The ISIM is one of three elements that comprise the JWST space vehicle and is the science instrument payload of the JWST. The major subsystems of this flight element and their build status are described.

8146-06, Session 2

JWST mirror production status

L. D. Feinberg, NASA Goddard Space Flight Ctr. (United States); B. B. Gallagher, Ball Aerospace & Technologies Corp. (United States)
The James Webb Space Telescope is a three mirror anastigmat (TMA) telescope with a primary mirror, a secondary mirror, and a tertiary mirror. The JWST mirrors are constructed from lightweight beryllium substrates and the primary mirror consists of 18 hexagonal mirror segments each approximately 1.5 meters point to point. Ball Aerospace and Technologies Corporation leads the mirror manufacturing team and the team utilizes facilities at 6 locations across the U.S. The manufacturing process for each individual mirror assembly takes approximately six years due to limitations dealing with the number of segments and manufacturing & test facilities. The 18 flight primary mirrors, the secondary mirror, and the tertiary mirror are all advanced in the mirror production process with many segments through the final polishing process, coating process, assembly, vibration, and acceptance testing. Presented here is a status of where all the flight mirrors are in the manufacturing process.

8146-07, Session 2
James Webb space telescope primary mirror integration: testing the multiwavelength interferometer on the test-bed telescope
G. Olczak, D. J. Fischer, ITT Corp. Geospatial Systems (United States)

The James Webb Space Telescope (JWST) integration includes a center of curvature test on its 18 primary mirror segment assemblies (PMSAs). This necessary test is the only ground test that will demonstrate the ability to align all 18 PMSAs. Using a multi-wavelength interferometer (MWIF) integrated to the test bed telescope (TBT), a one-sixth scale model of the JWST, we verify our ability to align and phase the 18 PMSAs. In this paper we will discuss data analysis and test results when using the MWIF to align the segments of the TBT in preparation for alignment of the JWST.

The data flow is unique because of the necessity to determine the relative piston between segments over a large range and with high precision. We will show that using the two wavelengths per measurement provided by the MWIF it is possible to reduce the piston error from over a millimeter to less than a micron, while simultaneously controlling all other degrees of freedom. This data flow includes built-in diagnostics such as the ability report the uncertainty in the current pose estimation.

8146-08, Session 2
Measuring the cryogenic optical alignment between the telescope element and the instruments module of the James Webb space telescope
T. L. Whitman, G. Olczak, ITT Corp. Geospatial Systems (United States)

The alignment between the Aft Optical Subsystem (AOS) and the Integrated Science Instruments Module (ISIM) is non-adjustable in orbit, so the alignment must be carefully verified in a cryogenic vacuum environment prior to launch. Optical point source locations calibrated by optical metrology instruments are imaged through the AOS onto the Science Instruments to determine focal, lateral, and clock angle alignment. The pupil image of the AOS is overlaid onto the pupil image of the NIRCam to determine the tip and tilt alignment. In addition, an image from fiducial lights at the Primary Mirror checks the pupil alignment between the telescope entrance pupil, the telescope pupil mask, and the NIRCam aperture stop. The image positions are combined to determine the relative alignment between the Optical Telescope Element (OTE) and the ISIM in all six degrees of freedom with corresponding alignment uncertainties. Uncertainties in the position of focused images of the ISIM in all six degrees of freedom with corresponding alignment uncertainties. Additional uncertainty in the pupil alignment measurement is due to uncertainty in the analytical removal of gravity effects that simulate the on-orbit alignment environment.

8146-09, Session 2
In-process testing for cryo-figuring 1.5 meter diameter auto-collimating flats
D. J. Fischer, ITT Corp. Geospatial Systems (United States)

Three auto-collimating flats (ACFs) of 1.5 meter clear aperture are being manufactured for use in the JSC Cryo-Optical Metrology test of the James Webb Space Telescope. In-process interferometric testing of the ACFs is used to guide their surface-figure processing. The surface measurement is performed in a vacuum chamber at both room (+20 °C) and cryogenic (-240 °C) temperatures. With a 12-inch beam diameter FizCam interferometer, sub-aperture measurements are taken across the ACF diameter at multiple rotations. These measurements are stitched together to compute the surface figure. The figure change between room-temperature and cryogenic temperature is measured and used to enable cryo-figuring based on room-temperature measurements. The data analysis is calibrated to account for gravity sag on test-set optics and surface aberrations caused by vacuum pressure and temperature gradients on vacuum-chamber windows. The first ACF is complete and meets specification with surface error of less than 75 nm RMS.

8146-10, Session 2
JWST-NIRSpec optics polishing and integration
R. Geyl, Sagem SA (France)

In the beginning of 2010, SAGEM-REOSC delivered to Astrium GmbH the last model of the optics for Near InfraRed SPECTrograph (NIRSPEC) instrument to be installed on-board the James Webb Space Telescope (JWST) and constituting a key European contribution to this challenging project. We will report the various steps of polishing, coating, integration and cryo test of this rather unusual all-SiC optics for such a high performance space spectrographic instrument.

8146-11, Session 3
Summary of the NASA science instrument, observatories, and sensor systems (SIOSS) technology assessment roadmap
H. P. Stahl, NASA Marshall Space Flight Ctr. (United States)

In August 2010, the NASA Office of Chief Technologist (OCT) commissioned an assessment of 15 different technology areas of importance to the future of NASA. Technology Assessment #8 (TA8) was Science Instruments, Observatories and Sensor Systems (SIOSS). SIOSS assessed the needs for optical technology ranging from detectors to lasers, x-ray mirrors to microwave antenna, in-situ spectrographs for on-surface planetary sample characterization to large space telescopes. This needs assessment looked across the entirety of NASA and not just the Science Mission Directorate. This paper summarizes the SIOSS findings and recommendations.

8146-12, Session 3
Key enabling technologies for future space telescopes
C. F. Lillie, R. S. Polidan, Northrop Grumman Aerospace Systems (United States)
Future Space Telescope missions need new technologies to meet their requirements for increasingly higher performance at an affordable cost. With the constrained budgets that are forecast for NASA and the DoD for the next several years, this decade is the time to develop the key technologies that will enable the orders of magnitude in performance that will be required by missions in the 2020’s. Among these technologies are large, deployable space structures; low-cost, lightweight optics; more sensitive, large area detectors; and wave front sensing and control methods.

In this paper we review the requirements for future missions, discuss the current state of the art, and outline a roadmap for future technology developments.

8146-13, Session 3

Metamaterials for optical and photonic applications for space: preliminary results

L. M. G. Venancio, European Space Research and Technology Ctr. (Netherlands); S. Hannemann, cosine Research B.V. (Netherlands); G. Lubkowski, M. Suhrke, Fraunhofer-Institut für Naturwissenschaftlich-Technische Trendanalysen (Germany); H. C. Schweizer, L. Fu, P. Schau, H. W. Giessen, K. Frenner, Univ. Stuttgart (Germany)

A new domain of optical effects is nowadays within reach thanks to structured metallo-dielectric materials (metamaterials) demonstrating optical properties unknown in nature. The European Space Agency (ESA) in the frame of its General Study Program (GSP) has started to investigate the opportunity of using metamaterials in space applications. In that context, ESA has initiated two GSP activities which main objectives are 1) to identify the metamaterials and associated optical properties which could be used to improve in the future the performances of optical payloads in space missions, 2) to design metamaterial based devices addressing specific needs in space applications.

The range of optical functions for metamaterials to be investigated is wide (spectral dispersion, polarisation control, light absorption, straylight control . . .) and so is the required spectral range, from 0.4µm to 15µm.

In the frame of these activities several applications have been selected and the designs of metamaterial based devices are proposed.

8146-14, Session 3

Update on parametric cost models for space telescopes

H. P. Stahl, NASA Marshall Space Flight Ctr. (United States)

Since the June 2010 Astronomy Conference, an independent review of our cost data base discovered some inaccuracies and inconsistencies which can modify our previously reported results. This paper will review changes to the data base, our confidence in those changes and their effect on various parametric cost models.

8146-15, Session 4

Optical performance of the 100 sq deg FOV telescope for NASA's Kepler exoplanet mission

D. C. Ebbets, P. D. Atcheson, C. K. Stewart, P. T. Spuhler, Ball Aerospace & Technologies Corp. (United States)

Kepler is NASA’s first space mission dedicated to the study of exoplanets. The primary scientific goal is statistical - to estimate the frequency of planetary systems associated with sun-like stars, with particular interest in the detection of earth-size planets in the habitable zone. The approach is to monitor a large number of stars, approximately 150000, continuously for 3 ½ years with a 30 minute cadence to detect the faint photometric signals of transiting planets across the stellar disks of those systems in Kepler’s line of sight. An Earth-Sun analog is expected to produce a transit depth of about 80 parts per million, lasting for at most a few tens of hours, and repeating once per “year”. The instrumentation for Kepler was designed to provide photometric data with a precision of 20 ppm in 6.5 hours for 12th magnitude stars, resulting in an SNR of 4 for an Earth-Sun analog transit. This paper reviews the considerations that were included in the overall architecture, detailed design, fabrication and testing of the instrument that led to the expected performance at the time of launch. The exquisite precision of the flight data has revealed additional effects, both instrumental and astrophysical, that have provided a deeper understanding of the performance of the flight hardware, to enhanced operational procedures, and to novel post-processing of the data stream. The current state-of-the-art is providing data approaching the sensitivity needed to detect transits of terrestrial planets orbiting 12th magnitude stars and fainter.

8146-17, Session 5

Fiber-based imaging and interferometry


The phased array coronagraph is based on combining the light from an array of small collecting telescopes with an array of single mode fibers, thus potentially eliminating the need for a large monolithic or segmented telescope. However, the use of a fiber bundle enables a range of architectures, from interferometric beam combination to direct imaging, and from the use with monolithic or segmented telescopes to telescope arrays. Here we describe several potential configurations and uses, both on the ground and in space, and delineate the resultant requirements imposed on the fiber array.
8146-18, Session 5

An optical fiber-based high contrast imager
S. R. Martin, K. M. Liewer, A. Ksendzov, E. Serabyn, Jet Propulsion Lab. (United States)

Arrays of single mode fibers can be used to form segmented pupils of almost arbitrary geometry. Such pupil arrays can be used both for interferometric imaging, for example by non-redundant aperture masking or in direct imaging systems such as the phased array coronagraph. Achieving control over the optical coupling, phase and dispersion for fiber arrays of reasonable size is a technological challenge. Progress has been made using a monolithic block of single mode fibers, lens arrays and masks, and mirror arrays. On one testbed, arrays of up to 37 beamlets are being combined to form a single image. On a second testbed, control of dispersion between fibers of slightly different length is being evaluated. The combination of the techniques being demonstrated has a range of potential uses in astronomy. In this paper we discuss the results from the testbeds.

8146-19, Session 5

Improving images from an adaptive optics system
D. Mozurkewich, Seabrook Engineering (United States)

This Fourier camera is an optical interferometer but lacks the complexity usually associated with one. It uses a micro-lens array to divide the aperture into segments. Optical fibers followed by another micro-lens array rearrange the pupil. A beam combiner takes the rearranged pupil and forms spectrally-dispersed fringes. Even though it can handle a large number of apertures, the beam combiner is simple, consisting of three lenses and a prism. The beam combiner has been built and tested; it works as advertised. I am still assembling the micro-lens/optical fiber array.

The prototype divides the input aperture into 90 sub-apertures. No light is thrown away except from coupling efficiency issues. I combine those sub-apertures to measure just over 600 spatial frequencies (not all independent), each in about 200 spectral channels. All data fits onto a single, 1500x2000 pixel CCD.

As long as the wavefront output of the AO system is better than about a quarter wave, I can take long exposures, limited only by the well depth of the detector and changes in the shape of the target. Detector quantum efficiency and number of pixels are not issues. Wavefront errors from the AO system reduce my fringe contrast, but that can easily be calibrated. This calibration removes the systematics that were in the image formed by the AO system. Wavefront errors do reduce the signal to noise of the fringe measurement but that noise is essentially white and can be reduced by combining multiple images.

8146-22, Session 5

Six-fold spectral resolution boosting using TEDI at the Mt. Palomar near-infrared Triplespec spectrograph
D. J. Erskine, Lawrence Livermore National Lab. (United States); J. Edelstein, Univ. of California, Berkeley (United States); P. S. Muirhead, Cornell Univ. (United States); M. W. Muterspaugh, Tennessee State Univ. (United States); K. R. Covey, Cornell Univ. (United States); D. Mondo, A. Vanderburg, P. M. Andelson, D. Kimber, M. M. Sirk, Univ. of California, Berkeley (United States); J. P. Lloyd, Cornell Univ. (United States)

An interferometric optical technique called ‘spectral reconstruction’ is capable of increasing a spectrograph’s resolution performance by large factors, well beyond its classical limits. We have demonstrated a 6-fold increase in the Triplespec effective spectral resolution, from R=2,700 to R= 16,000 by applying special Fourier processing to a delay series of exposures taken with the near-infrared TEDI interferometer and the Triplespec spectrograph at the Mt. Palomar Observatory 200 inch telescope. The performance improvement is observed in both stellar and telluric features simultaneously over the entire spectrograph bandwidth (0.9-2.45 micron). By expanding the delay series, we anticipate achieving resolutions of R= 30,000. The technique, processing and results are described.

8146-23, Session 6

A low-cost, high-performance 1.2m off-axis telescope built with NG-Xinetics silicon carbide
J. J. Rey, J. A. Wellman, R. J. Wollensak, R. G. Egan, Northrop Grumman Xinetics (United States)

The search for extrasolar habitable planets is one of three major astrophysics priorities identified for the next decade. These missions demand very high performance visible-wavelength optical imaging systems. Such high performance space telescopes are typically extremely expensive and can be difficult for government agencies to afford in today’s economic climate, and most lower cost systems offer little benefit because they fall short on at least one of the following three key performance parameters: imaging wavelength, total system-level wavefront error, and aperture diameter. Northrop Grumman Xinetics has developed a simple, lightweight, low-cost telescope that will address the near-term science objectives of this astrophysics theme with the required optical performance, while reducing the telescope cost by an order of magnitude. Breakthroughs in SiC mirror manufacturing, integrated wavefront sensing, and high TRL deformable mirror technology have finally been combined within the same organization to offer a complete end-to-end telescope system in the lower end of the Class D cost range. This paper presents the latest results of real OAP polishing and metrology data, an optimized optical design, and finite element derived WFE estimates to describe the predicted optical performance of the Zodiac II mission proposed to NASA Goddard in February 2011.

8146-20, Session 5

Recent progress in vector vortex coronagraphy
E. Serabyn, D. P. Mawet, J. K. Wallace, Jet Propulsion Lab. (United States)

The vortex coronagraph has great potential for enabling high-contrast observations very close to bright stars, and so for reducing the size of space telescopes needed for exoplanet characterization missions. Here we discuss recent developments in vortex coronagraphy, including the production of vector vortex masks, their measured performance, and unique wave front sensing architectures that vortex phase masks enable. In particular, we describe optical techniques that allow the effective use of vortex phase masks with on-axis telescopes, and the direct measurement of speckle phase.
polarization which effects image quality. We present the design and modeling of a nano-structure consisting of birefringent layers. Analysis shows a device that functions across a 400nm bandwidth tunable from 300nm to 1200nm. This Fresnel compensator device has a cross leakage of less than 0.001 retardance.

8146-25, Session 6

ZERODUR: new results on bending strength and stress corrosion
P. Hartmann, SCHOTT AG (Germany)

ZERODUR® strength data and information are required for the design of structures, which will be subject to mechanical loads throughout their lifetime or at least during some periods thereof such as lightweight mirrors for space telescopes. Comparison of data acquired twenty years ago with recent ones show astonishing reproducibility. An influence of the specimen preparation process on the width of the breakage stress distribution generally leading to higher values has been observed.

New data are available for diamond grain D25 fine ground surface condition.

The stress corrosion coefficient, an important parameter needed to calculate the long time behavior of structures subject to tensile stress in their surface has been determined from breakage data sets obtained with different stress load increase rates.

Conditioning of Zerodur specimen with stress free storage under varying humidity and humidity exposure times has shown no influence on strength.

8146-26, Session 7

The SPICA Coronagraph Instrument (SCI) and its use for the study of exoplanets
K. Enya, Japan Aerospace Exploration Agency (Japan)

We present an introduction to the Space Infrared Telescope for Cosmology and Astrophysics (SPICA) mission, emphasizing the SPICA Coronagraphic Instrument (SCI) and its use for the study of exoplanets. SPICA is a JAXA-ESA mission with a 3m class telescope cooled to 6K, with launch planned for 2018. The SPICA mission provides us with a unique opportunity to make high contrast observations because of its large telescope aperture, simple pupil shape, and the capability for making infrared observations from space. The SCI is one of the proposed focal plane instruments for SPICA: it is designed especially for a concentrated study of exoplanets.

The primary objectives for the SCI are the direct coronagraphic detection and spectroscopy of Jovian exoplanets in the infrared, while monitoring transiting planets is another important target.

The specifications and an overview of the design of the instrument are shown. In the SCI, coronagraphic and non-coronagraphic modes are applicable both to imaging and spectroscopy.

We include a report on current progress in the development of key technologies for the SCI in the infrared.

8146-27, Session 7

The Euclid-NISP instrument optics and tolerancing approach
F. U. Grupp, Max-Planck-Institut für extraterrestrische Physik (Germany) and Univ. Sternwarte München (Germany); A. E. Prieto, Observatoire Astronomique de Marseille-Provence (France); R. Bender, Max-Planck-Institut für extraterrestrische Physik (Germany) and Univ. Sternwarte München (Germany)

The Euclid satellite as a potential part of the ESA cosmic vision programme will carry the Near Infrared Spectrometer and Photometer as one of its two instruments. NISP is fed by a 1.2m Korsch type telescope and covers a field of 0.5 square degrees. This makes Euclid-NISP one of the largest scientific space optical systems ever flown with respect to FoV and optics size.

With this paper we present the instruments optical concept and a tolerancing approach that takes into account the separation in responsibilities between telescope and instrument. A practice-oriented way of incorporating the surface irregularities of the 4 aspheric surfaces in the lens system of NISP is shown.

8146-28, Session 7

Enhancing undergraduate education in engineering and science at MIT through the development of a CubeSat space telescope
M. W. Smith, D. W. Miller, S. Seager, Massachusetts Institute of Technology (United States)

CubeSats are a class of extremely small satellites that conform to a standardized 10 cm x 10 cm x 10 cm, 1 kg form factor. This miniaturization, along with a standardized deployment device for launch vehicles, allows CubeSats to be launched at low cost by sharing the trip to orbit with other spacecraft. Part of the original motivation for the CubeSat platform was also to allow university students to participate more easily in space technology development and to gain hands-on experience with flight hardware. The Department of Aeronautics and Astronautics along with the Department of Earth, Atmospheric, and Planetary Studies (EAPS) at the Massachusetts Institute of Technology (MIT) recently initiated a three semester-long course that uses the development of a CubeSat-based science mission as its core teaching method. Serving as the capstone academic experience for undergraduates, the goal of this class is to design and build a CubeSat spacecraft that serves a relevant science function, such as the detection of exoplanets transiting nearby stars. This project-based approach gives students essential first hand insights into the challenges of balancing science requirements and engineering design. Students are organized into subsystem-specific teams that refine and negotiate requirements, explore the design trade space, perform modeling and simulation, manage interfaces, test subsystems, and finally integrate prototypes and flight hardware. In this work we outline the heritage of capstone design/ building classes at MIT, describe the class format in greater detail, and give first semester results on the ability to meet learning objectives using this pedagogical approach.

8146-29, Session 7

The primordial inflation explorer (PIXIE)
A. J. Kogut, D. T. Chuss, NASA Goddard Space Flight Ctr. (United States); J. L. Dotson, NASA Ames Research Ctr. (United States); D. J. Fixsen, Univ. of Maryland (United States); M. Halpern, G. F. Hinshaw, The Univ. of British Columbia (Canada); S. S. Meyer, The Univ. of Chicago (United States); S. H. Moseley, NASA Goddard Space Flight Ctr. (United States); M. D. Seiffert, Jet Propulsion Lab. (United States); D. N. Spergel, Princeton Univ. (United States); E. J. Wollack, NASA Goddard Space Flight Ctr. (United States)

The Primaldo Inflation Explorer is an Explorer-class mission to measure the gravity-wave signature of primordial inflation through its distinctive imprint on the linear polarization of the cosmic microwave background. PIXIE uses an innovative optical design to achieve background-limited sensitivity in 400 spectral channels spanning 2.5 decades in frequency...
from 30 GHz to 6 THz (1 cm to 50 micron wavelength). Multi-modal non-imaging optics feed a polarizing Fourier Transform Spectrometer to produce a set of interference fringes, proportional to the difference spectrum between orthogonal linear polarizations from the two input beams. The differential design and multiple signal modulations spanning 11 orders of magnitude in time combine to reduce the instrumental signature and confusion from unpolarized sources to negligible levels. PIXIE will map the full sky in Stokes I, Q, and U parameters with angular resolution 2.6 deg and sensitivity 0.2 μK per 1 deg square pixel. The principal science goal is the detection and characterization of linear polarization from an inflationary epoch in the early universe, with tensor-to-scalar ratio $r < 10^{-3}$ at 5 standard deviations. In addition, the rich PIXIE data will constrain physical processes ranging from Big Bang cosmology to the nature of the first stars to the physical conditions within the interstellar medium of the Galaxy. We describe the PIXIE instrument and mission architecture needed to detect the signature of an inflationary epoch in the early universe using only 4 semiconductor bolometers.

8146-30, Session 7

C3D (compact CMOS camera demonstrator) for UKube-1

R. D. Harriss, A. D. Holland, S. J. Barber, S. Karout, B. J. Dryer, N. J. Murray, The Open Univ. (United Kingdom)

The Open University, in collaboration with e2v technologies PLC and XCAM Ltd, have been selected to fly an EO (earth observation) technology demonstration and in-orbit radiation damage characterisation instrument on board the UK Space Agency’s UKube-1 pilot Cubesat programme. Cubesat payloads offer a unique opportunity to rapidly build and fly space hardware for minimal cost providing easy access to the space environment. Based around the e2v 1.3 MPixel 0.18 micron process eye-on-Si CMOS devices, the instrument consists of a radiation characterisation imager as well as a narrow field imager (NFI) and a wide field imager (WFI). The narrow and wide field imagers are expected to achieve resolutions of 25 m and 350 m respectively from a 650 km orbit, providing sufficient swathe width to view the southern UK with the WFI and London with the NFI. The radiation characterisation experiment has been designed to verify and reinforce ground based testing that has been conducted on the e2v eye-on-Si family of devices and includes TEC temperature control circuitry as well as RADPET in-orbit dosimetry. Of particular interest are SEU and SEL effects. The novel instrument design allows for a wide range of capabilities within highly constrained mass, power and space budgets providing a model for future use on similarly constrained missions, such as planetary rovers. Scheduled for launch in December 2011, this 1 year low cost programme should not only provide valuable data and outreach opportunities but also help to prove flight heritage for future missions.

8146-31, Session 7

ESA M3 mission candidate ECHO

L. Puig, K. Isaak, I. Escudero-Sanz, D. Martin, P. Crouzet, N. Rando, European Space Research and Technology Ctr. (Netherlands)

The Exoplanet Characterisation Observatory is an M-class mission candidate within the science program Cosmic Vision 2015-2025 of the European Space Agency. It was selected in February 2011 as one of 4 missions to enter an assessment phase (phase 0/A). This process involves the definition of science and mission requirements as well as a preliminary model payload, followed by an internal Concurrent Design Facility study planned for July 2011. Parallel industrial studies will follow in 2012, after which the 4 missions will be reviewed to identify candidates entering Phase A/B1 studies in 2013.

The ECHO mission aims at characterising the atmospheric content of known transiting exoplanets, potentially from giant Hot Jupiters down to Super Earths orbiting in the habitable zone of M-dwarf stars. For this purpose, it will use a 1 m class telescope, feeding a Vis-NIR spectrometer and covering the wave lengths from 0.4 micron to 9 microns, with a potential extension up to 16 microns. While spatial differential of the exoplanet and its host star is not necessary, spectral differentiation will be achieved by making differential measurements of in- and out-of-transit frames to cancel the star signal.

This paper describes critical science and mission requirements, and gives an overview of the model payload design. It also reports on the results of a Concurrent Design Facility (CDF) study, providing a description of the spacecraft design, including critical subsystems such as AOCS and thermal/cryogenics.

8146-32, Session 7

Optical design trade study for the Wide Field Infrared Space Telescope [WFIRST]

D. Content, J. M. Howard, J. E. Mentzell, J. P. Lehan, NASA Goddard Space Flight Ctr. (United States)

The WFIRST mission concept was created by the Astro2010 Decadal Survey from multiple science white papers and the JDEM Omega payload concept; the Astro2010 report “New Worlds, New Horizons” [NWNH] was released in August 2010. This mission will be a flagship space telescope at L2 studying exoplanets (via gravitational microlensing), probing Dark energy, and surveying the near infrared sky. Since the release of NWNH the WFIRST project has been working with the newly formed WFIRST science definition team (SDT) to refine mission and payload concepts. We present the driving requirements as currently understood for the WFIRST payload optical design. Examples of designs potentially consistent with the requirements are given, and the trade space is discussed.

8146-43, Session 7

The JWST near-infrared spectrograph NIRSpec: results from the first set of instrument-level cryogenic testing

P. Ferruit, G. Bagnasco, S. M. Birkmann, T. Böker, European Space Research and Technology Ctr. (Netherlands); G. Cresci, INAF - Osservatorio Astrofisico di Arcetri (Italy); G. de Marchi, European Space Research and Technology Ctr. (Netherlands); B. Dorner, Observatoire de Lyon (France) and Ctr. de Recherche Astrophysique de Lyon (France); R. Ehrenwinkler, EADS Astrium GmbH (Germany); M. Falcolini, G. Giardino, European Space Research and Technology Ctr. (Netherlands); X. Gnata, EADS Astrium GmbH (Germany); P. Jakobsen, P. L. Jensen, European Space Research and Technology Ctr. (Netherlands); M. Kolm, H. Maier, M. Maschmann, P. Mosner, A. Rödel, EADS Astrium GmbH (Germany); F. Rosales-Ortega, Univ. Autónoma de Madrid (Spain); P. Rumler, J. Salvigoni, P. Strada, European Space Research and Technology Ctr. (Netherlands); M. Stuhlinger, European Space Astronomy Ctr. (Spain); M. B. J. te Plate, European Space Research and Technology Ctr. (Netherlands); T. Wettmann, EADS Astrium GmbH (Germany)

The Near-Infrared Spectrograph NIRSpec is one of the four instruments of the James Webb Space Telescope (JWST). NIRSpec will cover the 0.6-5.0 micron range and will be capable of obtaining spectra of more than 100 objects simultaneously in its multi-object spectroscopy (MOS) mode. It also features a set of slits for high contrast spectroscopy of individual sources, as well as an integral-field unit (IFU) for 3D spectroscopy. Manufactured in Europe by EADS Astrium for the European Space Agency (ESA), it is scheduled for delivery to NASA at the end of 2011. In the first months of 2011, the flight model has undergone its first set of instrument-level cryogenic testing. After providing an update on the
8146-33, Poster Session

**The space instrument SODISM, a telescope to measure the solar diameter**

M. M. Meftah, Ctr. National de la Recherche Scientifique (France)

PICARD is a satellite dedicated to the simultaneous measurement of the absolute total and spectral solar irradiance, the diameter and solar shape, and to the Sun's interior probing by the helioseismology method. These measurements obtained throughout the mission will allow study of their variations as a function of solar activity. The objectives of the PICARD mission are to improve our knowledge of the functioning of our star through new observations and the influence of the solar activity on the climate of the Earth.

PICARD was launched on June 15, 2010 on a Dnepr-1 launcher from Dombarovsky Cosmodrome, near Yasny, Russia. The satellite was placed into the heliosynchronous orbit of 730 km with inclination of 98.28 degrees.

SODISM (SOLar Diameter Imager and Surface Mapper), an instrument of the PICARD payload, is an 11-cm Cassegrain imaging telescope developed at CNRS (Centre National de la Recherche Scientifique) by LATMOS (Laboratoire, Atmosphere, Milieux, Observations Spatiales) associated with a 2Kx2K CCD (Charge-Coupled Device), taking solar images at five wavelengths. It carries a four-prism system to ensure a metrological control of the optics magnification.

The first image of the Sun was taken by SODISM instrument on July 22, 2010. It is a raw image, level L0, thus obtained before processing, at 607 nm wavelength in a very narrow band of 0.7 nm width. SODISM allows us to measure the solar diameter and shape with an accuracy of a few milliarcseconds, and to perform helioseismologic observations to probe the solar interior. SODISM is an innovative technology.

The helioseismology program consists in two observing modes at a wavelength of 535 nm in the continuum. The first one generates images of the whole solar disc at low resolution and is aimed at studying the properties of the medium degree eigenmodes of oscillations. The second one is focusing on a narrow corona centered around the limb. In this region where the granulation signal is weak and where the modes of oscillation are expected to be amplified, helioseismic measurements in intensity should bring new information on the deep internal structure of the Sun.

In this article, we describe the instrument concept and design and give an overview of the thermal stability of the telescope.

8146-34, Poster Session

**Measured aspheric surface irregularities as input to the Euclid-NISP tolerancing**

U. Fuchs, asphericon GmbH (Germany); F. U. Grupp, Univ.-Sternwarte München (Germany); S. Kiontke, asphericon GmbH (Germany); R. Bender, Max-Planck-Institut für extraterrestrische Physik (Germany) and Univ.-Sternwarte München (Germany)

From this we present the approach of using measured surface irregularities and departures from design parameters of already manufactured lenses as input to the Euclid-NISP instrument tolerancing. Representative lenses have been precisely characterized and their deviations from initial design parameters have been measured and then modelled by ZEMAX optical design software. In a second step these simulations are taken as a realistic input to a future system performance evaluation and system tolerancing approach.

8146-36, Poster Session

**A filter mount for the Euclid dark-energy mission**

R. Holmes, U. Grözing, P. Bizenberger, O. Krause, Max-Planck-Institut für Astronomie (Germany)

The Euclid dark energy mission is competing in the European Space Agency’s Cosmic Vision Program. The satellite survey mission will image the entire extragalactic sky in the visible and near infrared. The Near-Infrared Imaging Photometer (NIP) requires large transmissible optics, including three NIR filters (Y: 920-1146 J: 1146-1372 and H: 1372-2000nm) with a diameter of ~130 mm and a thickness of 12 mm. The mounting of these massive, 330 g per element, fused silica filters into the filter wheel mechanism is challenging.

In this paper we present work undertaken at the Max-Planck-Institut für Astronomie, Germany during the Euclid Phase A Study, ending in the summer of 2010. We present two designs of the filter mounting structure. In both designs, the filters are mounted in an Invar element, which is fixed into a recess in the titanium filter wheel. Kapton foil is included between the fused silica and the metal elements to prevent small protrusions in these hard materials causing high localized stresses in the optical glass. These two designs differ at their interface between the Invar element and the filter wheel. In one design we implement a rigid interface and in the other we create flexible elements in the Invar to accommodate the different thermal contraction between the components.

The design considerations, finite element analysis and prototyping results, both cool down and vibration tests, are detailed. The down-selection between the two designs, based on the results from the prototyping campaign, is also discussed. We conclude with recommendations on future developments of mounts of this type.

8146-37, Poster Session

**Laboratory prototype camera for the Whipple mission: a mission to detect and categorize small objects in our solar system**

A. T. Kenter, R. Kraft, Harvard-Smithsonian Ctr. for Astrophysics (United States); S. S. Murray, The Johns Hopkins Univ. (United States); C. Alcock, Harvard-Smithsonian Ctr. for Astrophysics (United States)

The proposed Whipple mission will detect and categorize the size and distance of small objects in the outer Solar system by detecting the characteristic diffraction pattern created when they pass between the observatory and a distant star. Since such a transit is a rare occurrence, the light curves of several tens of thousands of stars will be monitored simultaneously at video rates to look for these “occultations”.

The time signature of such a diffraction event has a total duration of ~1 -10 seconds, and depends on the size and distance of the object. The Whipple focal plane consists of nine Teledyne H2RG HyVISI detectors and nine dedicated Teledyne SIDECAR ASICs. The time signature of a and event is detected by a simple algorithm implemented in an on-board FPGA signal processor.

As part of a proposal preparation effort, we have made a prototype working engineering model of one facet of the Whipple focal plane. This facet consists of a HyVISI H2RG and a SIDECAR laboratory cryo-
development kit.
To test the entire detection process we constructed a light curve simulator that projects a field of stars on the detector. The projected stars have representative size to reflect the quality of the expected telescope. The "projected" stars are temporally modulated to mimic the light curve of an occultation/diffraction event.
We present details of system construction, performance, and light curve simulations.

8146-38, Poster Session
The space instrument SOVAP of the PICARD mission
M. M. Meflah, Ctr. National de la Recherche Scientifique (France); C. Conscience, A. Chevalier, Royal Meteorological Institute of Belgium (Belgium)

PICARD is a Satellite dedicated to the simultaneous measurement of the absolute total and spectral solar irradiance, the diameter and solar shape, and the Sun’s interior observed by helioseismology method. Its objectives are the study of the origin of the solar variability and the study of the relations between the Sun and the Earth’s climate. PICARD was launched on June 15, 2010. The Satellite was placed into the heliosynchronous orbit of 730 km with inclination of 98.28 degrees. The payload consists in two absolute radiometers measuring the TSI (Total Solar Irradiance) and an imaging telescope to determine the solar diameter, the limb shape and asphericity.

SOVAP (SOLar VAriability Picard) is an experiment developed by the Belgian STCE (Solar Terrestrial Center of Excellence) with a contribution of the CNRS (Centre National de Recherche Scientifique) composed of an absolute radiometer provided by the RMIB (Royal Meteorological Institute of Belgium) to measure the TSI and a bolometer provided by the ROB (Royal Observatory of Belgium) used to increase the TSI sampling. The continuous observation of the solar irradiance at the highest possible precision and accuracy is an important objective of the earth climate change. This requires: high quality metrology in the space environment. In this article, we describe the SOVAP instrument, its performances and uncertainties.

8146-39, Poster Session
Ray tracing based on finite element model and geometry of Ha and white light telescope
Z. Chen, M. Wu, S. Yang, X. Gu, S. Wang, F. Zhao, National Astronomical Observatories (China)
The Ha and White Light Telescope(HWT)is one of the payloads of the Chinese Space Solar Telescope(SST). To evaluate the optical performance of the telescope system under complex environment, ray tracing based on finite element model and geometry were introduced. The principles and processes of ray tracing algorithm combining FEM and GEM(Geometry model) are presented, which based on the traditional ray tracing algorithm and the shape function interpolation concept of Finite Element Model (FEM). The surface normal vector transformation relation between the deformed surface and the un-deformed surface is given, which is a pre-requisite for ray tracing combining FEM and GEM. The principles and processes make possible and practicable a new way to perform Structural Thermal Optical Performance(STOP) Analysis of diffraction limited opt-mechanical systems, which are easily influenced by elastic deformation. Application of the method to Ha solar telescope shows an MTF degradation when the system experiences an overall temperature rise of 5 and 10.

8146-40, Poster Session
Astronomical telescope with holographic primary objective
T. D. Ditto, 3DeWitt LLC (United States)
A dual dispersion telescope with a plane grating primary objective was previously disclosed that can overcome intrinsic chromatic aberration of dispersive optics while allowing for unprecedented features such as million object spectroscopy, extraordinary étendue, flat primary objective with a relaxed figure tolerance, gossamer membrane substrate storable as an unsegmented roll inside a delivery vehicle, and extensibility past 100 meter aperture at optical wavelengths. The novel design meets many criteria for space deployment. Other embodiments are suitable for airborne platforms as well as terrestrial and lunar sites. One problem with this novel telescope is that the grazing exodus configuration necessary to achieve a large aperture is traded for throughput efficiency. Now we show how the hologram of a point source used in place of the primary objective plane grating can improve efficiency by lowering the diffraction angle below grazing exodus. An intermediate refractive element is used to compensate for wavelength dependent focal lengths of the holographic primary objective.

8146-41, Poster Session
NIRAM: a near-infrared spectrometer project design for the Brazilian Aster mission
A. Hetem, Univ. Federal do ABC (Brazil)
The Aster mission consists in a spacecraft to rendezvous with a near-earth asteroid, 2001 SN263, in 2018. In this work, we present the first outlines of our project which uses the expertise of space engineers together with astrophysicists, working on solar systems small bodies, who are proposing the Near-Infrared Spectrometer for the Aster mission, the first brazilian mission to deep space. The results from this instrument will help to characterize the surface composition and its relations to the mineralogical properties within the surface morphology. Analysis of these spectra, in combination with other parameters, shall provide diagnosis of the presence and species composition of minerals and several other molecules that may be present. The most interesting minerals have absorption characteristics due to electron vibration in their reflection infrared spectral bands. The chosen spectral band, from 1 to 3.5 microns, allows recognizing the presence of water, carbon dioxide, olivines and other important elements. An important achievement will be the involvement of brazilian industry and universities in the conception, design and construction of this instrument. The technologies to be developed involves the areas of infrared optics, electronic sensors, automation and control of space systems, structures and new materials, thermal devices and data and image processing.

8146-42, Poster Session
A second generation tunable spatial heterodyne spectrometer for observing diffuse emission line targets
S. S. Hosseini, W. M. Harris, Univ. of California, Davis (United States)
We report on progress toward development of a second-generation tunable spatial heterodyne spectrometer (TSHS) at the fixed focus of the Coudé Auxiliary Telescope (CAT) in the Shane observatory at Lick Observatory. SHS instruments are a class of interferometric sensor capable of providing a combination of large étendue, high resolving power ($R = \lambda/\Delta\lambda \sim 10^5$) and wide field of view (FOV–0.5 degree) at Optical and UV wavelengths in a compact format. The TSHS implementation addresses the bandpass limitation of the basic SHS through controlled rotation of pilot mirrors in the interferometer. The use...
of a single grating as both a dispersing and beam-splitting element in the all-reflective SHS greatly relaxes the precision required in the alignment of the other optical elements relative to a more typical scanning Fourier Transform Spectrometer and allows the TSHS implementation to be accomplished with low-cost commercial rotation stages. The new design builds on a previous design originally tested in 2007, and will address several issues identified with the input beam, output imaging, and grating efficiency (Dawson and Harris, 2009). Here we will discuss the design considerations going into this new system and the initial results of the installation and testing of the TSHS and the future plans.
8147-01, Session 1

ASTRO-H soft x-ray telescope (SXT)

Y. Soong, The Ctr. for Research and Exploration in Space Science (United States) and Universities Space Research Association (United States); T. Okajima, P. J. Serlemitsos, NASA Goddard Space Flight Ctr. (United States)

ASTRO-H is an X-ray astrophysics satellite that will be built with US-Japanese collaborative effort. On board are four Wolter-type X-ray mirrors, among which two of them are soft X-ray mirrors, energy range from a few hundred eV to 15 keV, currently being fabricated in the X-ray Optics Lab at Goddard Space Flight Center, NASA. The focal point instruments will be a calorimeter (GSFC) and a CCD camera (Osaka U.), respectively. The reflectors of the mirror are made of aluminum substrate, of which the thickness gauged at 152 µm, 229 µm, and 305 µm of the alloy 5052, with epoxy replication on smooth Pyrex cylindrical mandrels to acquire the X-ray reflective surface. The epoxy layer is 10 µm nominal and surface gold layer of 0.2 µm. Improvements on angular response over the Astro-E/Suzaku mirrors come from reducing the figure, the roundness, and the grazing angle/radius mismatching errors of the reflectors, and tighter specs on supporting structure to reduce the reflector positioning and the assembly errors. In this paper, we report the results of calibration of the engineering module of soft X-ray Telescope, and project the quality of the flight mirrors.

8147-02, Session 1

Development of ultra-thin thermal shield for ASTRO-H x-ray telescopes

Y. Tawara, S. Sugita, A. Furuzawa, Nagoya Univ. (Japan)

Thermal environment of ASTRO-H X-ray telescopes will be controlled by using both a metal-coated thin plastic film called a thermal shield(TS) placed in front of each telescope and a heater installed in the telescope housing. In order to keep high X-ray transmission, plastic film should be very thin. Thickness of the film for HXT(Hard X-ray Telescope)-TS is 2.5 micron and that for SXT(Soft X-ray Telescope)-TS is 0.2 micron. This paper discusses engineering difficulties related to using very thin film and properties related to thermal control. Discussions are designing the TS assembly to survive launch environment such as acoustic oscillation and vibration, deal with issues related to surviving direct solar, space debris, and atomic oxygen irradiation in orbit, and testing the TS integrity.

8147-03, Session 2

The Focusing Optics X-ray Solar Imager (FOXSI)

S. Christe, NASA Goddard Space Flight Ctr. (United States); S. Krucker, L. Glesener, Univ. of California, Berkeley (United States); M. V. Gubarev, B. Ramsey, NASA Marshall Space Flight Ctr. (United States); S. Ishikawa, S. Saito, T. Takahashi, Univ. of Tokyo (Japan)

The Focusing Optics X-ray Solar Imager (FOXSI) is a sounding rocket payload (NASA LCAS) to test hard x-ray focusing optics and position-sensitive solid state detectors for solar observations. Today’s leading solar hard x-ray instrument, RHESSI, provides excellent spatial and spectral resolution. Yet, due to its use of indirect imaging, the derived images have a low dynamic range (<30) and sensitivity. This makes it difficult to study faint x-ray sources in the solar corona which are crucial for understanding particle acceleration at the Sun. Grazing-incidence x-ray focusing optics combined with position-sensitive solid state detectors can overcome both of these limitations and will enable the next breakthrough in understanding impulsive solar energy release. FOXSI is a collaboration between the Space Science Laboratory at the University of California, Berkeley, the NASA GSFC, the NASA MSFC, which is providing the grazing-incidence optics, and JAXA/ISAS, which is providing double-sided silicon strip detectors. Scheduled for its first launch in October 2011, FOXSI will be a pathfinder for the next generation of solar hard x-ray observatories.

8147-04, Session 2

SRG/ART-XC


Spectrum Roentgen Gamma (SRG) is an X-ray astrophysical observatory, developed by Russia in collaboration with Germany. The mission will be launched in 2013 from Baikonur, by a Zenit rocket with a Fregat upper stage. SRG will be placed in a 6 months period halo orbit around L2. The scientific payload is made of two independent telescopes. The former, a soft-x-ray survey instrument eROSITA, is being provided by Germany, while the latter, is a medium-x-ray-energy survey instrument ART-XC whose development by Russia. ART-XC will consist of seven independent, co-aligned, telescope modules with seven corresponding cadmium-telluride focal plane detectors. Each will operate over the approximate energy range of 6-30 keV (pointing mode), with an angular resolution of 1 arcmin, field of view of 30 arcmin and energy resolution about 10% on 14 keV. The NASA Marshall Space Flight Center (MSFC) will fabricate part of the mirror modules, to complement mirror modules which will be fabricated in Russia.

8147-05, Session 2

Performance of mirror shell replicated from new flight quality mandrel for eROSITA mission

D. Vernani, Media Lario Technologies (Italy)

Focusing mirrors manufactured via galvanic replication process from negative shape mandrels is the chosen solution for eROSITA X-ray mission. Media Lario Technologies (MLT) is the industrial enabler manufacturing, in collaboration with Max Planck Institute (MPI) and German Space Agency (DLR), the Optical Payload for eROSITA including the flight quality mandrels. The mandrel manufacturing holds a crucial role in the process of fabrication of the optics. In fact, the shape accuracy and the roughness of the replicated mirrors are strongly affected by the mandrel starting quality. For the mandrels production an evolution of the approach used for the manufacturing of past mission mandrels (JET-X, XMM) has been developed. The low energy angular resolution of the eROSITA mirror payload needs to be 15 arcsec HEW or better and HEW of 20 arcsec at 8.05keV. Replicated mirrors with performance in this
range for low energy have been obtained in the past by using mandrels that have superior geometrical shape accuracy (i.e. typically a factor of two or more better). A proprietary multistep surface finishing process has now been developed for reaching the aggressive performance requirements demanded by the mission. The status and the metrology of the eROSITA series mandrels manufactured so far, by using the advanced polishing process, are presented. In the paper, the x-ray performance of mirror shells (as measured at MPE PANTER facility) replicated from flight quality eROSITA mandrel, are reported.

8147-06, Session 2
Development and testing of the eROSITA mirror modules

MPE will provide the X-ray Survey Telescope eROSITA for the Russian Spektr-Roentgen-Gamma Mission to be launched in 2012. It consists of a compact bundle of 7 co-aligned mirror modules with a focal length of 1600 mm and 54 nested mirror shells each. Therefore, its sensitivity in terms of effective area, field-of-view (61'), and angular resolution (15'' HEW on-axis) will yield a high grasp of about 1000 cm^-2 deg^-2 around 1 keV with an average angular resolution of ~26'' HEW over the field-of-view (30' including optical and spacecraft error contributions).

After an extended test program on single mirror shells, assembled test modules (6 shells) and a qualification model we have now started integration of flight mirror modules. We will give a résumé on the development and test program including key improvements to the shell integration method. Moreover, we will report on the integration progress and present first results on the X-ray performance of partially integrated mirror modules.

8147-07, Session 2
The optics system of the New Hard X-ray Mission: status report
S. Basso, G. Pareschi, O. Citterio, G. Tagliaferri, D. Spiga, L. Raimondi, B. Salmaso, V. Cotroneo, INAF - Osservatorio Astronomico di Brera (Italy); G. Borghi, G. Valsecchi, A. Orlandi, D. Vernani, R. Binda, F. Marioni, S. Moretti, Media Lario Technologies (Italy); G. Sironi, INAF - Osservatorio Astronomico di Brera (Italy); P. Attiná, Thales Alenia Space (Italy); B. M. Negri, Agenzia Spaziale Italiana (Italy)

The New Hard X-ray Mission (NHXM) is a mission focussed on a broad energy band, from 0.2 to 80 keV, coupled with a sensitive polarimeter. The mission is currently undergoing the Phase B study and it has been proposed to ESA as a small-size mission to be further studied in the context of the M3 call. The performance is reached with a focal length of 10m and with 4 modules, each composed by 70 mirror shells obtained with the electroforming process. The substrate of the mirror shells is NiCo and they are multilayer coated. The focal plane is mounted on an extensible bench. Three of the four modules are equipped with a couple of detectors, a low energy detector covering a range from 0.2 to 15 keV and a high energy detector efficient until 80 keV. The fourth module is dedicated to the polarimetry with imaging capabilities. In this article, the latest development in the design and manufacturing of the optics is presented. The design has been optimizing in order to increase as more as possible the effective area in the high energy band and the manufacturing of the mirror shells benefits from the latest development in the mandrel production (figuring and polishing), in the multilayer deposition and in the integration improvements.

8147-08, Session 2
Angular resolution measurements of a hard x-ray optic for the New Hard X-ray Mission at SPring-8
D. Spiga, INAF - Osservatorio Astronomico di Brera (Italy); L. Raimondi, INAF - Osservatorio Astronomico di Brera (Italy) and Universita’ degli Studi dell’ Insubria (Italy); A. Furuzawa, Nagoya Univ. (Japan); S. Basso, INAF - Osservatorio Astronomico di Brera (Italy); R. Binda, G. Borghi, Media Lario Technologies (Italy); V. Cotroneo, Smithsonian Ctr. for Astrophysics (United States); G. Grisoni, Media Lario Technologies (Italy); H. Kunieda, H. Matsumoto, H. Mori, T. Miyazawa, Nagoya Univ. (Japan); B. M. Negri, Agenzia Spaziale Italiana (Italy); A. Orlando, Media Lario Technologies (Italy); G. Pareschi, B. Salmaso, G. Tagliaferri, INAF - Osservatorio Astronomico di Brera (Italy); K. Uesugi, Japan Synchrotron Radiation Research Institute (Japan); G. Valsecchi, D. Vernani, Media Lario Technologies (Italy)

The realization of X-ray telescopes with imaging capabilities in the hard (≥10 keV) X-ray band requires the adoption of optics with shallow (< 0.25 deg) grazing angles to enhance the reflectivity of reflective coatings. On the other hand, to obtain large collecting area large mirror diameters (< 350 mm) are necessary. This implies that mirrors with focal lengths ≥10 m shall be produced and tested. Full-illumination tests of such mirrors are usually performed with on-ground X-ray facilities, aimed at measuring their effective area and the angular resolution; however, they in general suffer from effects of the finite distance of the X-ray source, e.g. a loss of effective area for double reflection. These effects increase with the focal length of the mirror under test; hence a “partial” full-illumination measurement might not be fully representative of the in-flight performances. Indeed, a pencil beam test can be adopted to overcome this shortcoming, because a mirror at a time is exposed to the X-ray flux, and the beam divergence can be compensated by tilting the optic. In this work we present the result of a hard X-ray test campaign performed at BL20B2 beamline of the SPring-8 synchrotron radiation facility, aimed at characterizing the Point Spread Function (PSF) of a multilayer-coated Wolter-I mirror shell manufactured by Nickel electroforming. The mirror shell is a demonstrator for the NHXM hard X-ray imaging telescope (0.3 - 80 keV), with a predicted HEW (Half Energy Width) close to 20 arcsec. We also show the results of the reconstruction of the PSF at monochromatic X-ray energies of 15 to 63 keV.

8147-09, Session 2
From x-ray telescopes to neutron focusing
M. V. Gubarev, NASA Marshall Space Flight Ctr. (United States); B. Khaykovich, Massachusetts Institute of Technology (United States)

In the case of neutrons the refractive index is slightly less than unity for most elements and their isotopes. Consequently, thermal and cold neutrons can be reflected from smooth surfaces at grazing-incidence angles. Hence, the optical technologies developed for x-ray astronomy can be applied for neutron focusing. The focusing capabilities of grazing incidence neutron imaging optics have been successfully demonstrated using nickel mirrors. The mirrors were fabricated using an electroformed nickel replication process at Marshall Space Flight Center. Results of the neutron optics experiments will be presented. Challenges of the neutron imaging optics as well as possible applications of the optics will be discussed.
8147-10, Session 3

ESA led IXO optics development status

M. Bavadz, E. Wille, K. Wallace, B. Shortt, N. Rando, ESTEC (Netherlands); M. J. Collon, cosine Research B.V. (Netherlands); G. Pareschi, Osservatorio Astronomico di Brera (Italy); F. Christensen, DTU-space (Denmark); M. Krumrey, Physikalisch-Technische Bundesanstalt (Germany); M. Freyberg, Max-Planck-Institut für extraterrestrische Physik (Germany)

The International X-ray Observatory (IXO) is a candidate mission in the ESA Space Science Programme Cosmic Visions 1525, and is being studied as a joint mission with NASA and JAXA.

The mission is building on novel optics technologies to achieve the required performance for this demanding astrophysics observatory. The Silicon Pore Optics (SPO) is the baseline technology and is being developed by an industrial consortium. As a back-up technology, slumped glass optics is being developed in Europe and the USA, and work is progressing on improved reflective coatings.

This paper will present the status of the developments led by ESA, which are being implemented in a phased approach, addressing the performance, environmental compatibility and industrial production. Further, the progress with the X-ray test facilities and associated beamlines will be reported.

8147-11, Session 3

Design, fabrication, and characterization of silicon pore optics for IXO

M. J. Collon, R. Günther, M. D. Ackermann, R. Partapsing, G. Vacanti, M. W. Beijersbergen, cosine Research B.V. (Netherlands); M. Bavadz, K. Wallace, E. Wille, European Space Research and Technology Ctr. (Netherlands); M. Olde Riekerink, J. Haneveld, A. Koelwijn, Micronit Microfluidics BV (Netherlands); C. van Baren, SRON Nationaal Instituut voor Ruimteonderzoek (Netherlands); M. Krumrey, Physikalisch-Technische Bundesanstalt (Germany); M. Freyberg, Max-Planck-Institut für extraterrestrische Physik (Germany)

Silicon pore optics is a technology developed to enable future large area X-ray telescopes, such as the International X-ray Observatory (IXO), a candidate mission in the ESA Space Science Programme ‘Cosmic Visions 2015-2025’. IXO uses nested mirrors in Wolter-I configuration to focus grazing incidence X-ray photons on a detector plane. The IXO optics will have to meet stringent performance requirements including an effective area of >2.5 m² at 1.25 keV and ~0.65 m² at 6 keV and angular resolution better than 5 arc seconds. To achieve the collecting area requires a total polished mirror surface area of ~1300 m² with a surface roughness better than 0.5 nm rms. By using commercial high-quality 12” silicon wafers which are diced, structured, wedged, coated, bent and stacked, the stringent performance requirements of IXO can be attained without any costly polishing steps. Two of these stacks are then assembled into a co-aligned mirror module, which is a complete X-ray imaging system. Included in the mirror module are the isostatic mounting points, providing a reliable interface to the telescope. Hundreds of such mirror modules are finally integrated into petals, and mounted onto the spacecraft to form an X-ray optic of approximately 4 m in diameter.

In this paper we will present the silicon pore optics mass manufacturing process and latest X-ray test results of mirror modules mounted and tested in flight configuration.

8147-12, Session 3

Mass production of silicon pore optics for the International X-ray Observatory

E. Wille, K. Wallace, M. Bavadz, European Space Research and Technology Ctr. (Netherlands)

Silicon Pore Optics (SPO) provide a high angular resolution with a low areal density as required for the International X-ray Observatory (IXO). The present baseline consists of populating the IXO mirror assembly with about 2000 SPO mirror modules. During the development of the process steps of the SPO technology, the specific requirements of a future mass production have been considered right from the beginning. The manufacturing methods heavily utilise off-the-shelf equipment from the semiconductor industry, robotic automation and parallel processing. This allows to upscale the present production flow in a very cost effective way, to produce hundreds of mirror modules per year.

Considering manufacturing predictions based on the current status of the SPO technology, we present an analysis of the time and resources that will be required for the IXO mirror mass production within a future flight programme. This includes the full production process starting with 300 mm Si wafers up to the integration of the mirror modules. We present the times required for the individual process steps and deduce the number of machines that will be required to produce 4 mirror modules per day. A preliminary timeline for building and commissioning the infrastructure, and for the production of the mirror modules required for a flight project, is presented.

8147-13, Session 3

Silicon pore optics for astrophysical missions

G. Vacanti, M. J. Collon, R. Günther, M. D. Ackermann, R. Partapsing, M. W. Beijersbergen, cosine Research B.V. (Netherlands); M. Olde Riekerink, Micronit Microfluidics BV (Netherlands); J. Haneveld, Micronit Microfluidics BV (United States); A. Koelwijn, Micronit Microfluidics BV (Netherlands); C. van Baren, SRON Nationaal Instituut voor Ruimteonderzoek (Netherlands); P. Müller, M. Krumrey, Physikalisch-Technische Bundesanstalt (Germany); M. Freyberg, Max-Planck-Institut für extraterrestrische Physik (Germany)

The establishment of Silicon Pore Optics (SPO) as the technology of choice for the implementation of future large X-ray space optics has opened up the road to its use in all classes of X-ray missions with varying scientific goals. This interest has given us the possibility to broaden the design parameter space which is normally considered for SPO optics. In doing so a number of classical space X-ray optics design issues (e.g., field of view, stray light, baffling, aberrations) have been tackled. In this paper we report on recent results achieved in this effort. Particular attention will be given to the issues of stray light and baffling, a topic upon which a combination of analytical, simulation, and data analysis means can be effectively brought to bear. Missions considering the use of SPO optics have requirements spanning more than 2 orders of magnitude in energy, and a factor 20 in focal length. The possibilities that can be considered and the trade offs that must be made when applying SPO to such a wide range of optical designs will be illustrated, and some of the possible solutions discussed.

8147-14, Session 3

Compatibility of silicon pore optics with launchers and operation conditions

M. D. Ackermann, M. J. Collon, cosine Research B.V. (Netherlands); C. van Baren, SRON Nationaal Instituut voor Ruimteonderzoek (Netherlands); R. Günther, R. Partapsing,
The Nuclear Spectroscopic Telescope Array (NuSTAR) is a NASA Small Explorer mission that will carry the first focusing hard X-ray (5-80keV) telescope to orbit. The ground calibration of the three flight optics was carried out at the Rainwater Memorial Calibration Facility (RaMCaF) built for this purpose.

In this article we present the facility and its use for the ground calibration of the three optics.

8147-17, Session 4

First results from the ground calibration of the NuSTAR flight optics

J. Koglin, H. An, Columbia Univ. (United States); D. Barret, Institut de Recherche en Astrophysique et Planétologie (France); N. M. Barrière, Univ. of California, Berkeley (United States); K. L. Blaedel, Columbia Univ. (United States); N. F. Brejnholt, F. E. Christensen, DTU Space (Denmark); T. A. Decker, Columbia Univ. (United States); W. W. Craig, Univ. of California, Berkeley (United States) and Lawrence Livermore National Lab. (United States); B. W. Craigh, California Institute of Technology (United States); C. J. Hailey, Columbia Univ. (United States); F. A. Harrison, California Institute of Technology (United States); A. C. Jakobsen, C. P. Jensen, DTU Space (Denmark); K. K. Madsen, California Institute of Technology (United States); K. Mori, M. Nynka, Columbia Univ. (United States); M. J. Pivovaroff, Lawrence Livermore National Lab. (United States); A. Ptak, NASA Goddard Space Flight Ctr. (United States); C. Seles, Columbia Univ. (United States); J. K. Vogel, Lawrence Livermore National Lab. (United States); P. von Ballmoos, Centre d’Etude Spatiale des Rayonnements (France); N. J. S. Westergaard, DTU Space (Denmark); D. R. Wik, NASA Goddard Space Flight Ctr. (United States); D. L. Windt, Columbia Univ. (United States); W. W. Zhang, NASA Goddard Space Flight Ctr. (United States)

We describe initial results from the ground calibration of the NuSTAR flight optics. NuSTAR is a hard X-ray satellite experiment to be launched in 2012. Two optics with 10.15 m focal length focus X-rays with energies between 6 and 79 keV onto CdZnTe detectors located at the end of an extendible mast.

Analysis will be presented on the angular resolution and effective area of the flight optics. The X-ray data was acquired at the Rainwater Memorial Calibration Facility (RaMCaF) at Columbia University. RaMCaF has an X-ray source located approximately 150 meters from the NuSTAR optics, and provides X-rays up to nearly 100 keV. A variety of detectors including a Silicon Drift detector, a Germanium spectrometer and a phosphor-imaging CCD camera are available for diagnostics. Results for the angular resolution will be compared with ray trace predictions of performance based on mechanical stylus metrology of the glass obtained during construction of the optics, and laser interferometry of the glass pieces obtained prior to mounting. The effective area of the optics will be compared with predictions based on a detailed optics and detector response model, augmented by reflectivity measurements on witness samples.
segments. We will also report on a plan and strategy on how to meet IXO requirements in the next few years so that a rigorous implementation schedule and cost estimate can be made in time for IXO to enter the next decadal survey. Toward the end of this presentation we will attempt to go beyond IXO requirements to look into the possibility of making x-ray optics with angular resolutions better than 1" and effective areas well above 1 m².

8147-19, Session 4

IXO glass mirrors development in Europe

G. Pareschi, M. Ghigo, O. Citterio, M. M. Civitani, L. Proserpio, P. Conconi, G. Tagliaferri, A. Zambra, S. Basso, D. Spiga, INAF - Osservatorio Astronomico di Brera (Italy); G. Parodi, F. Martelli, BCV Progetti S.r.l. (Italy); D. Gallieni, M. Tintori, A.D.S. International S.r.l. (Italy); M. Bavdaz, E. Wille, European Space Research and Technology Ctr. (Netherlands)

The mirrors of the International X-ray Observatory (IXO) consist of a large number of high quality segments delivering a spatial resolution better than 5 arcsec. A study concerning the slumping of thin glass foils for the IXO mirrors is under development in Europe, funded by ESA and led by the Brera Observatory. After a preliminary trade-off study, we have focused the effort on the “Direct” slumping approach, based on the use of convex moulds. In this case during the thermal cycle the optical surface of the glass is in direct contact with the mould surface. The thin plates are made of thin glass sheets (0.4 mm thick), with a reflecting area of 200 mm x 200 mm. The adopted integration process foresees the use of reinforcing ribs for bonding together the plates and forming in that way a rigid and stiff stack of segmented mirror shells; the stack is supported by a thick backplane. During the bonding process the plates are constrained to stay in close contact with the surface of the master (i.e. the same mould used for the hot slumping process) by the application of a vacuum pump suction. In this way the spring-back deformations and low frequency errors still present on the foil profile after slumping can be corrected. In this paper we will give an overview and a status report of the project.

8147-20, Session 4

Production of the IXO glass segmented mirrors by hot slumping with pressure assistance: tests and results

M. Ghigo, INAF - Osservatorio Astronomico di Brera (Italy); L. Proserpio, INAF - Osservatorio Astronomico di Brera (Italy) and Univ. Degli Studi dell’Insubria (Italy); S. Basso, INAF - Osservatorio Astronomico di Brera (Italy); M. Bavdaz, European Space Research and Technology Ctr. (Netherlands); O. Citterio, INAF - Osservatorio Astronomico di Brera (Italy); M. M. Civitani, INAF - Osservatorio Astronomico di Brera (Italy) and Univ. Degli Studi dell’Insubria (Italy); P. Conconi, INAF - Osservatorio Astronomico di Brera (Italy); F. Martelli, BCV Progetti S.r.l. (Italy); R. Negri, G. Pagano, INAF - Osservatorio Astronomico di Brera (Italy) and Politecnico di Milano (Italy); G. Pareschi, INAF - Osservatorio Astronomico di Brera (Italy); G. Parodi, BCV Progetti S.r.l. (Italy); D. Spiga, L. Raimondi, INAF - Osservatorio Astronomico di Brera (Italy); L. Terzi, INAF - Osservatorio Astronomico di Brera (Italy) and Politecnico di Milano (Italy); E. Wille, European Space Research and Technology Ctr. (Netherlands); A. Zambra, INAF - Osservatorio Astronomico di Brera (Italy)

The Astronomical Observatory of Brera (INAF-OAB), with the support of ESA, is involved in the study of a glass shaping technology for the production of the IXO grazing incidence segmented optics. This paper reports on the production by means of hot slumping technology with pressure of the mirror plates that are produced for the realization of prototypes. In particular, a new experimental set-up is described. In order to optimize the slumping process, in addition to Fused Silica (already investigated in the past) two new materials are considered for making the convex slumping mould: Zerodur K20 and Silicon. We will report on the latest performed slumping tests and results.

8147-21, Session 4

Fabrication update on non-contact mirror slumping technology for the International X-ray Observatory mirrors

A. M. Al Hussein, M. L. Schattenburg, R. K. Heilmann, Massachusetts Institute of Technology (United States)

Glass sheets with high surface quality and angular resolution of 5 arcsec are in demand for the International X-Ray Observatory. A method of thermally shaping individual sheets of glass using porous mandrels as air bearings has been developed which eliminates the problems of sticking and dust particle-induced distortion which plague traditional slumping methods. Initial experiments have focused on the shaping of flat sheets. A detailed mathematical model of the process has been developed, allowing prediction of final surface quality based on process parameters including air pressure, glass thickness variations and orientation of the gravity vector during the process. Improvements over earlier surface quality results are reported through achieving feedback control of process pressure, and issues with the repeatability of these results are investigated and addressed through the next generation of our slumping platform.

The design process and fabrication of our new slumping facility will be presented. In addition to scaling the design to accommodate larger flats, slumps are horizontally to float the glass and minimize contact during the process. New capabilities also include active gap control and air-flow temperature control. Preliminary results of slumped glass with the new platform will be presented for different process parameters.

8147-22, Session 5

Design and analysis of mirror modules for IXO and beyond

R. S. McClelland, Stinger Ghaffarian Technologies, Inc. (United States); C. Powell, NASA Goddard Space Flight Ctr. (United States)

Advancements in X-ray astronomy demand thin, light, and closely packed optical elements which lend themselves to segmentation of the annular mirrors and, in turn, a modular approach to the mirror design. A baseline modular concept for the International X-Ray Observatory (IXO) Soft X-Ray Telescope (SXT) consisting of 14,000 segmented glass mirrors divided into 60 modules was developed and extensively analyzed. Through this development, our understanding of module loads, mirror stress, shock sensitivity, thermal performance, and gravity distortion have greatly progressed. The latest progress in each of these areas is discussed herein. Gravity distortion during horizontal X-ray testing, on-orbit thermal performance, and accommodation of large mirror spans have proved especially difficult design challenges. In light of these challenges, fundamental trades in modular X-ray mirror design have been performed. Based on the driving requirements of minimal distortion during horizontal X-ray testing and launch mass, an alternate FMA design utilizing smaller modules was developed and analyzed. This alternate design better accommodates horizontal X-ray testing, improves thermal performance, and allows for the use of smaller mirror segments while maintaining the required FMA mass. The cost and production schedule implications of fabricating a larger number of smaller modules were explored. Smaller modules have significant advantages in mass production but increase the effort required to align modules into the FMA structure.
Alignment and integration of lightweight mirror segments

T. C. Evans, Stinger Ghaffarian Technologies, Inc. (United States); K. C. Chan, Univ. of Maryland, Baltimore County (United States); J. Mazzarella, Stinger Ghaffarian Technologies, Inc. (United States); T. T. Saha, NASA Goddard Space Flight Ctr. (United States)

The International X-Ray Observatory (IXO) observatory has requirements of effective area of 2.5 square meters combined with an angular resolution of five arc-seconds. To accomplish both of these goals, thin glass optics must be used to minimize weight and observatory size. The challenge of constraining thin optics without distortion is being investigated. Two separate approaches are being studied, using actuators to form the mirror into a desired shape at the Smithsonian Astrophysical Observatory (SAO), and preserving the fabricated mirror without distortion at NASA's Goddard Space Flight Center (GSFC). The latter approach focuses on minimizing distortion added during alignment and bonding of the mirror segment to the permanent housing. Within GSFC, two separate strategies are being pursued simultaneously with one focusing on bonding flat tabs on the back surface of the optic and the other focusing on bonding small pins to the side edges of the optic. Both technologies are proving to show promise going through many test cycles culminating in x-ray test results. Based on current error budget allocation and future goals, technology development will continue panning the way towards demonstrating thin glass optics capabilities.

Design of the IXO optics based on thin glass plates connected by reinforcing ribs

M. Ghigo, S. Basso, INAF - Osservatorio Astronomico di Brera (Italy); M. Bavdaz, European Space Research and Technology Ctr. (Netherlands); O. Citterio, INAF - Osservatorio Astronomico di Brera (Italy); M. M. Civitani, INAF - Osservatorio Astronomico di Brera (Italy); F. Martelli, BCV Progetti S.r.l. (Italy); G. Pareschi, INAF - Osservatorio Astronomico di Brera (Italy); G. Parodi, BCV Progetti S.r.l. (Italy); L. Proserpio, INAF - Osservatorio Astronomico di Brera (Italy); E. Wille, European Space Research and Technology Ctr. (Netherlands); A. Zambra, INAF - Osservatorio Astronomico di Brera (Italy)

Effective area requirements for the large X-ray mirror of the International X-Ray Observatory (IXO) are about 3 m2 at 1 keV, 0.65 m2 at 6 keV and 150 cm2 at 30 keV. Because of its large dimension, the telescope cannot be realized as a monolithic structure but rather it requires the integration of slumped-glass segments into an x-ray module. The module is assembled as a stack of thin mirror shells and spacers made of glass and glued together. Therefore the epoxy is a crucial component in determining the structural and optical performance of the X-Ray module. It foresees the development of a stacking integration concept based on the use of reinforcing ribs connecting the glass segments in order to create very stiff structures. This paper reports on the last design of the single optical module and describe the results of FEM analyses that show how it is possible to use an innovative approach to the integration of the slumped glass foils.

The integration machine: design, development and validation of an alternative process for the integration of slumped-glass segments into an x-ray module

M. M. Civitani, S. Basso, O. Citterio, P. Conconi, M. Ghigo, G. Pareschi, L. Proserpio, D. Spiga, G. Tagliaferri, A. Zambra, INAF - Osservatorio Astronomico di Brera (Italy); D. Gallieni, M. Tintori, A.D.S. International S.r.l. (Italy); F. Martelli, G. Parodi, BCV Progetti S.r.l. (Italy); M. Bavdaz, E. Wille, European Space Research and Technology Ctr. (Netherlands)

The International X-ray Observatory (IXO) is being studied as a joint mission by the NASA, ESA and JAXA space agencies. The main goals of the mission are large effective area (>3m2 at 1 keV) and a good angular resolution (<3 arcsec HEW at 1 keV). The Brera Astronomical Observatory (Italy), under the support of ESA, is developing an alternative method for the realization of the X-Ray Optical Units, based on the use of slumped thin glass segments to form densely packed modules in a Wolter type I optical design, so that each plate pair focus x-ray onto the focal plane in two reflections. In order to reach the very challenge integration requirements, it has been developed an innovative assembly approach for aligning and mounting the IXO mirror segments, making use of glass reinforcing ribs that connect the facets to each-other and guarantee an active correction for major existing figure errors. The Integration Machine (IMA) that has been developed to allow the integration of the Plate Pairs into prototype XOU stacks. In this paper we present the design, the development and the validation status of the system. Moreover are presented the results obtained with the first integrated stack prototype, called Proof of Concept (POC) and consisting in two integrated Plate Pairs.

Evaluation of the epoxy for the integration of slumped-glass segments into an x-rays module

M. M. Civitani, M. Riva, G. Pagano, B. Salmaso, S. Basso, G. Pareschi, INAF - Osservatorio Astronomico di Brera (Italy); G. Parodi, F. Martelli, BCV Progetti S.r.l. (Italy)

The International X-ray Observatory (IXO) is under study as a joint mission by the NASA, ESA and JAXA space agencies. The main goals of the mission are to obtain a large effective area (>3m2 at 1 keV) and a good angular resolution (<5 arcsec HEW at 1 keV). The Brera Astronomical Observatory (Italy), under the support of ESA, is developing an alternative method for the realization of the X-Ray Optical Units. Each module is assembled as a stack of thin mirror shells and spacers made of glass and glued together. Therefore the epoxy is a crucial component in determining the structural and optical performance of the X-Ray module. In this paper we describe the characterization process that has been followed to evaluate the epoxy selected for the IXO module prototype assemblies.

Coating design and developments for the International X-ray Observatory

A. C. Jakobsen, D. Della-Monica Ferreira, F. E. Christensen, DTU Space (Denmark); M. Krumrey, Physikalisch-Technische Bundesanstalt (Germany); B. Shortt, European Space Research and Technology Ctr. (Netherlands); M. Collon, M. D. Ackermann, cosine Research B.V. (Netherlands)
We present a novel coating design for the International X-ray Observatory (IXO). The design makes use of both simple bilayer coatings of Ir and B4C, more complex constant period multilayer coatings and finally graded period multilayer coatings to enhance the effective area and cover the energy range from 0.1 to 40 keV. We also present the coating technology used for these designs and present test results from coatings deposited on realistic IXO wafers and show compatibility with masking technologies on flat and bent substrates.

8147-29, Session 6

NuSTAR flight coatings: what did we really do

F. E. Christensen, A. C. Jakobsen, DTU Space (Denmark); K. K. Madsen, California Institute of Technology (United States); N. F. Breijnholt, A. Hornstrup, DTU Space (United States); A. Fabricant, Columbia Univ. (United States); J. N. S. Westergaard, DTU Space (Denmark); J. Koglin, Columbia Univ. (United States); J. Momberg, DTU Space (Denmark); W. W. Craig, M. J. Pivovaroff, Lawrence Livermore National Lab. (United States); D. L. Windt, Reflective X-Ray Optics LLC (United States)

The NuSTAR mission will be the first satellite mission to carry focusing telescopes reaching into the hard X-ray band above 10 keV. This is accomplished by using depth graded multilayer coatings on thin slumped glass segments precision aligned in a double cone approximation to a Wolter I geometry. Three flight optics have been completed. Each flight optic carries 2340 mirror segments. The first flight optic was coated with W/Si and Pt/SiC multilayers, while the two subsequent flight optics were coated with W/Si and Pt/C coatings. In this paper we give the updated multilayer recipes we used in each case, describe lessons learned relating to the preparation and cleaning of the slumped glass substrates before coating, describe details of the planar magnetron sputtering technique used for the coating including uniformity and show representative data and modeling from witness samples taken at 8 keV at DTU-Space and at higher energies at the Rainwater Memorial Calibration facility (RaMCaF) at Columbia and the NSLS at Brookhaven.

8147-30, Session 6

Release coatings for replication of x-ray optics

S. E. Romaine, Harvard-Smithsonian Cent. for Astrophysics (United States); J. L. Boike, Jacobs Technology (United States); R. Bruini, Harvard-Smithsonian Cent. for Astrophysics (United States); D. Engelhaaupt, The Univ. of Alabama in Huntsville (United States); P. Gorenstein, Harvard-Smithsonian Cent. for Astrophysics (United States); B. D. Ramsey, NASA Marshall Space Flight Ctr. (United States)

X-ray astronomy grazing incidence telescopes use the principle of nested shells to maximize the collecting area. Some of the more recent missions, such as XMM-Newton, have used an electroformed nickel replication process to fabricate the mirror shells. We have been developing coatings to simplify and improve this electroforming process. We have reported previously on our results using flat mandrels. This paper presents our recent results on using this same process to separate uncoated replicas and replicas with multilayer coatings from Wolter-1 mandrels. We present AFM and X-ray reflectivity data on mandrels and replicas.

8147-31, Session 6

Differential deposition to correct surface figure deviations in astronomical grazing-incidence x-ray optics

K. Kilaru, B. D. Ramsey, M. V. Gubarev, NASA Marshall Space Flight Ctr. (United States)

A coating technique is being developed to correct the surface figure deviations in reflective-grazing-incidence X-ray optics. These optics are typically designed to have precise conic profiles, and any deviation in this profile, as a result of fabrication, results in a degradation of the imaging performance. To correct the mirror profiles, physical vapor deposition has been utilized to selectively deposit a filler material inside the mirror shell. The technique, termed differential deposition, has been implemented as a proof of concept on miniature X-ray optics developed at MSFC for medical-imaging applications. The technique is now being transferred to larger grazing-incidence optics suitable for astronomy and progress to date is reported.

8147-32, Session 7

A user-friendly web interface for x-ray telescopes design and simulation

V. Cotroneo, Harvard-Smithsonian Cent. for Astrophysics (United States); D. O. Di Pasquale, CNR Istituto per le Tecnologie della Costruzione (Italy)

The design of a Wolter X-ray telescope takes into account the geometrical dimensioning of the shells and the choice of the coatings for each of them. In this work we present a user-friendly web interface aimed to the design of multi-shell Wolter telescopes and the calculation of their effective area. Some example of use cases are presented.

8147-33, Session 7

Point spread function computation of Wolter-I x-ray mirrors from surface profile and roughness

L. Raimondi, Univ. degli Studi dell’Insubria (Italy) and INAF - Osservatorio Astronomico di Brera (Italy); D. Spiga, INAF - Osservatorio Astronomico di Brera (Italy)

The mirror Point Spread Function (PSF) degradation in the X-ray band is determined by the optical quality of its focusing optics. When the surface profile is analyzed in terms of Fourier components, figure errors comprises the spectral regime of long spatial wavelengths, whilst microroughness falls in the regime of short spatial wavelengths. Usually, the first effect is simulated by means of geometrical optics, while the second contribution - strongly dependent on the energy of X-rays - is derived from the first order scattering theory. This classical approach, however, suffers from some uncertainties in the determination of the boundary of the two regimes.

The aim of this work is to overcome this limitation and compute the PSF of an X-ray mirror shell in a typical Wolter-I configuration at any energy, given the complete surface topography. The adopted method applies the Huygens-Fresnel principle to the measured/simulated profiles and fully accounts for the surface roughness PSD (Power Spectral Density). We already applied this method to single reflection mirrors. In this work, we extend it to the case of Wolter-I mirror shells.

We present the PSF simulations at several energies, from the UV band (dominated by aperture diffraction) to hard X-rays (dominated by scattering). In particular, we analyze the impact of different spatial regimes on the PSF degradation as a function of energy in the X-ray and UV bands. Our results are in full agreement with ray-tracing simulations and with analytical results based on scattering theory (where these
approaches are applicable. Moreover, we analyze the aperture diffraction contribution in the UV band and study how different spatial regimes contribute to the Half Energy Width of the PSF. Finally we compare our predictions with the PSF of a real mirror shell.

8147-34, Session 7
Right-sizing the mirror segment for x-ray optics
M. Biskach, NASA Goddard Space Flight Ctr. (United States)
The flight mirror assembly (FMA) for the International X-Ray Observatory (IXO) consists of 14,000 mirrors that reflect incoming X-Rays at a small grazing angle to the onboard instruments and detectors. The 0.4 mm thick mirror segments require precise alignment and secure final placement with a low amount of distortion to meet IXO requirements. Mirror size affects how the mirrors are supported throughout the metrology, alignment, and bonding stages. Larger size mirrors are more susceptible to distortions caused by gravity and other factors which in part ultimately determine the final performance characteristics of the IXO FMA. This paper outlines a comprehensive study using Finite Element Analysis (FEA) on the size of the X-Ray optics currently used for IXO to determine the optimal size of mirrors that balances the amount of distortion introduced in the handling and bonding processes with outside factors such as module size, equipment / facility factors, and mirror fabrication. A broad list of considerations is also presented for optics sizing related to future X-Ray missions that will have increasingly stringent optical requirements.

8147-35, Session 8
Forming mandrels for x-ray mirror substrates
Future X-ray astronomical missions, like the International X-ray Observatory (IXO), will likely require replicated mirrors to reduce both mass and production costs. Accurately figured and measured mandrels - upon which the mirror substrates are thermally formed - are essential to enable these missions. The challenge of making these mandrels within reasonable costs and schedule has led the Goddard and Marshall Space Flight Centers to develop in-house processes and to encourage small businesses to attack parts of the problem. Both Goddard and Marshall have developed full-aperture polishing processes and metrologies that yield high-precision axial traces of the finished segments. Outside technologists have been addressing challenges presented by subaperture CNC machining processes: particularly difficult is the challenge of reducing mid-spatial frequency errors below 2 nm rms. The end-product of this approach is a realistic plan for the economically feasible production of mandrels that meet program requirements in both figure and quantity.

8147-36, Session 8
Progress on precise grinding and polishing of thin-glass monolithic shell
O. Citterio, G. Motta, V. Cotroneo, M. M. Civitani, L. Proserpio, G. Pareschi, INAF - Osservatorio Astronomico di Brera (Italy); E. Mattaini, INAF - IASF Milano (Italy); P. Conconi, INAF - Osservatorio Astronomico di Brera (Italy); J. Arnold, LT Ultra Precision Technology GmbH (Germany); G. Parodi, BCV Progetti S.r.l. (Italy)
The production of lightweight, thin monolithic shells for high angular resolution X-ray telescopes requires the use of a material with good mechanical and thermal properties, easy to sustain optical grinding and polishing and available on the market. Fused Silica satisfies these requirements and it has been selected for the present investigation. The challenge manufacturing process of thin (<2 mm for 500 mm diameter) glass Wolter-I like shells is to reach a precise profile (<1 micron shape error) with a very low surface microroughness (<0.1 nm) and avoiding the presence of subsurface damages which could increase the brittleness of the glass. Starting from a double cone profile quartz glass tube a sequence of grinding, fine grinding and polishing processes is performed in order to progressively reach the desired quality of the shell. This process needs a very stiff and precise CNC machine and a good metrology system. On the other hand the shape and the thinness of the concerned shell introduce a series of bending related problems. This paper reports on the development activities on going at OAB to set this kind of process.

8147-37, Session 8
Progress on the magnetic field-assisted finishing of MEMS micropore x-ray optics
R. E. Riveros, M. A. Tan, H. Yamaguchi, Univ. of Florida (United States); I. Mitsushi, Japan Aerospace Exploration Agency (Japan); K. Ishizu, T. Moriyama, T. Ogawa, Y. Ezoe, Tokyo Metropolitan Univ. (Japan); M. Horade, S. Sugiyama, Ritsumeikan Univ. (Japan); Y. Kamonari, Tohoku Univ. (Japan); N. Yamasaki, K. Mitsuda, Japan Aerospace Exploration Agency (Japan)
Microelectromechanical systems (MEMS) micropore X-ray optics were proposed as an ultralightweight, high-resolution, and low cost X-ray focusing optic alternative to the large, heavy and expensive optic systems in use today. Their monolithic design which includes high-aspect ratio curvilinear micropores with minimal sidewall roughness has proved difficult to realize. When made by either deep reactive ion etching or X-ray LIGA, the micropore sidewalls (reflecting surfaces) exhibit unacceptably high surface roughness. A magnetic field-assisted finishing (MAF) process was proposed to reduce the micropore sidewall roughness of MEMS micropore optics and improvements in roughness have been reported. At this point, the best surface roughness achieved is ~3 nm Rq on nickel optics and ~0.2 nm Rq on silicon optics. These improvements bring MEMS micropore optics closer to their realization as functional X-ray optics. This paper details the manufacturing and post-processing of MEMS micropore X-ray optics including results of recent polishing experiments with MAF.

8147-38, Session 9
Metrology of IXO mirror segments
K. C. Chan, NASA Goddard Space Flight Ctr. (United States)
The high angular resolution of 5” (half-power diameter) for the International X-ray Observatory (IXO) is to be achieved with lightweight modular optics compactly populated with thin mirror segments. The resolution requirement posts unique challenges for fabrication, mounting and metrology of these segments. In this paper, we shall discuss the metrology of a single pair of these segments. We shall present our current metrological methods, prediction of the performance, and measurements of the state-of-the-art segments of which the performance of single bonded pairs approaches 5”. We also address our approach in metrology for future optics beyond 5”.

8147-39, Session 9
Grazing incidence wavefront sensing and verification of x-ray optics performance
Evaluation of interferometrically measured mirror metrology data and characterization of a telescope wavefront can be powerful tools in understanding of image characteristics of an x-ray optical system. In the development of soft x-ray telescope for the International X-Ray Observatory (IXO), we have developed new approaches to support the telescope development process.

Interferometrically measuring the optical components over all relevant spatial frequencies can be used to evaluate and predict the performance of an x-ray telescope. Typically, the mirrors are measured in a mount that minimizes the mount and gravity induced errors. In the assembly and mounting process the shape of the mirror segments can dramatically change. We have developed wavefront sensing techniques suitable for the x-ray optical components to aid us in the characterization and evaluation process of these chances.

Hartmann sensing of a telescope and its components is a simple method that can be used to evaluate low order mirror surface errors and alignment errors. Phase retrieval techniques can also be used to assess and estimate the low order axial errors of the primary and secondary mirror segments.

In this paper we describe the mathematical foundation of our Hartmann sensing technique and phase retrieval technique. We show how these techniques can be used in the evaluation and performance prediction process of x-ray telescopes.

8147-40, Session 9

MPR: innovative 3D free-form optics profilometer

G. Sironi, O. Citterio, INAF - Osservatorio Astronomico di Brera (Italy) and Media Lario Technologies (Italy); A. Ritucci, R. Subbranni, Media Lario Technologies (Italy); M. Stroebel, LT Ultra Precision Technology GmbH (Germany); G. Borghi, A. Orlandi, Media Lario Technologies (Italy); R. Widemann, LT Ultra Precision Technology GmbH (Germany); G. Pareschi, INAF - Osservatorio Astronomico di Brera (Italy); B. M. Negri, Agenzia Spaziale Italiana (Italy)

This paper presents the huge advance in metrology represented by a new free-form profilometer/rotondimeter (MPR). This metrological machine was developed by Media Lario Technologies and LT Ultra Precision Technology in the frame of the Italian Space Agency (ASI) contract for the manufacturing of a New Hard Xray Mission (NHXM) optical module prototype. The need of a new high performances metrological machine is a direct consequence of the tightening of the tolerance on hard X-ray optics shape errors. In the case of NHXM the aim to maintain an angular resolution of 15 arcsec up to 30 keV implies a requirement for the optics shape error of maximum 100 nm on dynamical range of the whole optics, up to 600 mm.

The realized MPR is a non-contact versatile machine respecting these specifications, with the capability to measure a large variety of optics with free-form profile, from the cylindrical-like shapes for grazing incidence optics to normal incidence geometries. A solid mechanical design based on the use of stable X-Y hydrostatic bearings combined with a high resolution optical detection unit, i.e. a chromatic optical sensor and laser interferometers, allows the achievement of low noise level and high profile measurement repeatability.

These characteristics make the MPR extremely precise and accurate, insomuch as measurements can be acquired in flight at relatively high speed maintaining the shape error below 100 nm.

The paper is organized as follow: firstly, a brief description of the hard X-ray astronomy context and the requirements settled for the related optics is given (Section 1). Secondly, a description of the MPR design and operation is shown (Section 2). Finally, the experimental results are presented (Section 3). In conclusion, a synthesis of the achieved metrological innovation is drown (Section 4).

8147-41, Session 9

Development of multi-beam long trace profiler

K. Kilaru, NASA Marshall Space Flight Ctr. (United States); D. J. Merthe, Z. Ali, Lawrence Berkeley National Lab. (United States); M. V. Gubarev, T. J. Kester, NASA Marshall Space Flight Ctr. (United States); W. R. Mckinney, Lawrence Berkeley National Lab. (United States); P. Z. Takacs, Brookhaven National Lab. (United States); V. V. Yashchuk, Lawrence Berkeley National Lab. (United States)

In order to fulfill the angular resolution requirements and make the performance goals for future NASA missions feasible, it is crucial to develop instruments capable of fast and precise figure metrology of x-ray optical elements for further correction of the surface errors. The Long Trace Profilometer (LTP) is an instrument widely used for measuring the surface figure of grazing incidence X-ray mirrors. In the case of replicated optics designed for x-ray astronomy applications, such as mirrors and the corresponding mandrels have a cylindrical shape and their tangential profile is parabolic or hyperbolic. Modern LTPs have sub-microradian accuracy, but the measuring speed is very low, because the profilometer measures surface figure point by point using a single laser beam. The measurement rate can be significantly improved by replacing the single optical beam with multiple beams. The goal of this study is to demonstrate the viability of multi-beam metrology as a way of significantly improving the quality and affordability of replicated x-ray optics. The multi-beam LTP would allow one- and two-dimensional scanning with sub-microradian resolution and a measurement rate of about ten times faster compared to the current LTP. The design details of the instrument's optical layout and the status of optical tests will be presented.

8147-61, Poster Session

The current status of reflector production and hard x-ray characterization for ASTRO-H/HXT

T. Miyazawa, A. Furuzawa, Y. Kanou, K. Matsuda, M. Sakai, N. Yamane, H. Kato, Y. Miyata, K. Sakanobe, M. Sasaki, T. Yamagishi, Y. Haba, K. Ishibashi, H. Matsumoto, Y. Tawara, H. Kunieda, Nagoya Univ. (Japan); N. Ishida, A. Suzuki, Tamagawa Engineering Co., Ltd. (Japan); N. Ohtsu, Tamagawa engineering Co., Ltd. (Japan); K. Mori, K. Tamura, Y. Maeda, M. Ishida, Japan Aerospace Exploration Agency (Japan); H. Awaki, Ehime Univ. (Japan); T. Okajima, NASA Goddard Space Flight Ctr. (United States); K. Uesugi, Y. Suzuki, Japan Synchrotron Radiation Research Institute (Japan)

Japan’s sixth X-ray satellite mission ASTRO-H, which is planned to be launched in 2014, is designed to carry four science payloads to cover the wide energy range between 0.3 keV to 600 keV. One of the key instruments is Hard X-ray Telescope (HXT) to cover hard X-rays up to 80 keV. The HXT is thin-foil, multi-nested conical optics as well as Suzaku XRT. To reflect hard X-rays efficiently, reflector surfaces are coated with depth-graded Pt/C multilayer. The diameter and focal length are 450 mm and 12000 mm, respectively. We need to fabricate more than 5000 foil reflectors for the two flight telescopes in consideration of yield ratio of 50%. The mass production of the reflectors for the flight model has been going on since August 2010. The screening of replication mandrels with profilometer is ongoing. In addition, we have introduced new screening method with optical image reflected from mandrel surface. We have adopted new type replication mandrel, we called “glass coated mandrel”, which consists of glass tube coated with thin glass sheet for large size mirrors. The selected 74 pairs of multilayer mirrors which consist of six bands (13 pairs at 65 mm and 90 mm, 15 pairs at 100 mm and 120 mm, 10 pairs at 135 mm, 8 pairs at 160 mm in radius, respectively) have been characterized at a large synchrotron radiation facility, SPring-8 beamline
8147-62, Poster Session

New multilayer design for ASTRO-H/hard x-ray telescope and missions beyond

Y. Miyata, H. Kunieda, Nagoya Univ. (Japan); K. Tamura, Japan Aerospace Exploration Agency (Japan)

Japan's sixth X-ray satellite missions, ASTRO-H, features two hard X-ray telescopes with depth-graded, multilayer reflectors. Our laboratory has advanced the technology for multilayer reflectors through development of a balloon-borne experiment, InFOCUS. While its base model for the multilayer design (with the minimum incident angle of 0.11 degrees and 8μm focal length) is adequate for the ASTRO-H mission, we opt to improve it further so that better performance can be derived with the minimum incident angle of 0.07 degrees and 12μm focal length. The improved design has resulted in the reduction of layers from 28 to 10-21 layers per reflector while gaining higher reflectivity by 3-5% at 40-70 keV.

A multilayer optics will be used in IXO, a joint project by NASA, ESA and JAXA. I XO's principal design requires its energy bandpass of 0.1-40 keV with the minimum incident angle of 0.18 degrees and 20μm focal length. With the narrower bandpass and the larger incident angles, it necessitates following changes in the multilayer design: adjustment of top Pt layer thickness and a total number of top layers to boost reflectivity (especially in the lower energy band), and refinement of Pt/C-layer spacing and depth-graded period below the third layer to bunch up the Bragg peaks tightly in the required hard X-ray band. In this presentation, we discuss the key parameters for IXO's multilayers to achieve a larger effective area at 30-40 keV.

8147-63, Poster Session

Mathematical formalism for designing wide-field x-ray telescopes: mirror nodal positions and detector tilts

R. F. Elsner, S. L. O'Dell, B. D. Ramsey, M. C. Weisskopf, NASA Marshall Space Flight Ctr. (United States)

We report on the present status of our continuing efforts to develop a method for optimizing wide-field nested x-ray telescope mirror prescriptions. Utilizing extensive Monte-Carlo ray trace simulations, we find an analytic form for the root-mean-square dispersion of rays from a Wolter I optic on the surface of a fiatfocal plane detector as a function of detector tilt away from the nominal focal plane and detector displacement along the optical axis. The configuration minimizing the ray dispersion from a nested array of Wolter I telescopes is found by solving a linear system of equations for tilt and individual mirror pair displacement. Finally we outline our initial efforts at expanding this method to include higher order polynomial terms in the mirror prescriptions.

8147-64, Poster Session

MT_RAYOR: a versatile raytracing tool for x-ray telescopes

N. J. S. Westergaard, Technical Univ. of Denmark (Denmark)

A raytracing tool, MT_RAYOR, for the analysis of X-ray telescopes based on the Wolter-1 design and approximations has been developed in the Yorick interpreted language. The optical properties of the reflecting surfaces are modelled by coefficients of reflection and tables for the micro-roughness scattering so that there is no model dependency involved. Mirror deformations on a length scale larger than 1 mm may be included. The photon source can be a celestial point source with a given spectrum and additional functions make the simulation of extended sources rather straightforward. The detector properties such as pixelization, RMF, and quantum efficiency can be added to simulate a complete observation. An X-ray source of any shape at a finite distance for the simulation of calibration experiments can also be modelled. Results from preliminary analyses of the Indian SXT on Astrosat, NuSTAR, and IXO are presented.

8147-65, Poster Session

Accurate modeling of the x-ray multilayer scattering from surface microroughness characterization

B. Salmaso, D. Spiga, R. Canestrari, L. Raimondi, INAF - Osservatorio Astronomico di Brera (Italy)

Several hard X-ray imaging telescopes of the next future will be characterized by a high angular resolution. To this end, it is necessary to produce optics with a very low surface microroughness, as this is responsible of X-ray scattering, which results in image quality degradation especially at the higher energies. To the smooth surface approximation, it is possible to compute the X-Ray Scattering (XRS) from the Power Spectral Density (PSD) of the surface roughness. Indeed, multilayers coatings will be used to reflect X-rays beyond 10 keV; in this case the scattering pattern is more complicated but it can still be computed from the PSDs of each interface and the cross-correlation functions of the rough profiles. A growth model able to describe the roughness evolution of the surfaces enables us to compute the XRS of the multilayer, which can be directly compared to the experimental data. With this approach we aim to validate the roughening model assumed and to accurately predict the scattering pattern we expect on the focal plane. In this work we show the application of this formalism: direct measurements of the PSDs for substrates and the outermost layer of several multilayers samples are used as input for the code to model the PSD growth. XRS measurements of these samples, performed at the energy of 8.05 keV, are presented to validate the modeling achieved.

8147-66, Poster Session

The Marshall grazing incidence x-ray spectrograph (MaGIXS)

K. Kobayashi, The Univ. of Alabama in Huntsville (United States); J. Curtain, NASA Marshall Space Flight Ctr. (United States); L. Golub, E. Hertz, P. Cheimets, D. Caldwell, K. Korreck, Harvard-Smithsonian Ctr. for Astrophysics (United States); B. M. Robinson, P. Reardon, The Univ. of Alabama in Huntsville (United States); T. J. Kester, C. Griffith, M. R. Young, NASA Marshall Space Flight Ctr. (United States)

The Marshall Grazing Incidence X-ray Spectrograph (MaGIXS) is a stigmatic grazing-incidence spectrograph experiment designed to observe spatially resolved soft X-ray spectra of the solar corona for the first time. The instrument consists of a Wolter Type-1 sector telescope and a slit spectrograph. The telescope mirror pair is a monolithic Zerodur mirror with both the parabolic and hyperbolic surfaces. The spectrograph comprises a pair of paraboloid mirrors acting as a collimator and re-imaging mirror, and a planar varied-line-space grating, with reflective surfaces operate at a graze angle of 2 degrees. This produces a flat spectrum on a detector covering a wavelength range of 0.6 to 2.4 nm (0.5 to 2.0 keV). The design achieves 1.5 pm spectral resolution and 5 arcsec spatial resolution (2.5 arcsec / pixel) over an 8 arcminute long slit. The spectrograph is currently being fabricated as a laboratory prototype. A flight candidate telescope mirror is also under development. The entire experiment is designed to fit a NASA sounding rocket payload, and is being proposed for flight.
Development of a EUV test facility at the Marshall Space Flight Center

E. A. West, S. Pavelitz, NASA Marshall Space Flight Ctr. (United States); K. Kobayashi, B. M. Robinson, The Univ. of Alabama in Huntsville (United States); J. Curtian, J. A. Gaskin, A. Winebarger, NASA Marshall Space Flight Ctr. (United States)

This paper will describe a new EUV test facility that is being developed at the Marshall Space Flight Center (MSFC) to test EUV telescopes. Two flight programs, HIC - high resolution coronal imager (sounding rocket) and SUVI - Solar Ultraviolet Imager (GOES-R), set the requirements for this new facility. This paper will discuss those requirements, the EUV source characteristics, the wavelength resolution that is expected and the vacuum chambers (Stray Light Facility, Xray Calibration Facility and the EUV test chamber) where this facility will be used.

Laue lenses for hard x- and gamma-ray: new prototype results

F. Frontera, Univ. degli Studi di Ferrara (Italy); V. Liccardo, Univ. degli Studi di Ferrara (Italy) and Univ. de Nice Sophia Antipolis (France); G. Loffredo, Univ. degli Studi di Ferrara (Italy); V. Valsan, Univ. degli Studi di Ferrara (Italy) and Univ. de Nice Sophia Antipolis (France); E. Virgilli, V. Carassiti, F. Evangelisti, Univ. degli Studi di Ferrara (Italy); S. Squerzanti, A. Cotta Ramusino, Istituto Nazionale di Fisica Nucleare (Italy); E. Caroli, J. B. Stephehn, INAF - IASF Bologna (Italy)

Laue lenses are the most efficient technique to focus hard X-rays above 70-100 keV. We report on new results on the development activity of broad band Laue lenses for hard X-/gamma-ray astronomy (70/100-600 keV).

After the development of first prototype, whose building method and performance was presented at the SPIE conference on Astronomical Telescopes (Frontera et al. 2008), we have improved the lens assembling technology. We present the results obtained from the new prototype and we will also show results obtained in terms of focal spot with respect to the theoretical expectations.

The LAUE project for broadband gamma-ray focusing lenses

E. Virgilli, F. Frontera, C. Guidorzi, Univ. degli Studi di Ferrara (Italy); V. Liccardo, Univ. degli Studi di Ferrara (Italy) and Universite' de Nice - Sophia Antipolis (France); G. Loffredo, Univ. degli Studi di Ferrara (Italy); V. Valsan, Univ. degli Studi di Ferrara (Italy) and Universite' de Nice - Sophia Antipolis (France); V. Carassiti, F. Evangelisti, Univ. degli Studi di Ferrara (Italy); S. Squerzanti, M. Statera, Istituto Nazionale di Fisica Nucleare (Italy)

We overview the Laue project, supported by the Italian Space Agency, for developing advanced technologies for crystal production and assembling of broad band (70-600 keV) gamma-ray lenses. In particular we will discuss the apparatus set up to assemble single crystal tiles in the lens and how we face the divergence of the source employed.

We will report results of simulations devoted to the optimization of the lens petal and the expected performance of an entire lens for space applications will also be presented.
have been proposed, where the focusing elements are made of single mosaic crystals in order to increase the diffraction efficiency with respect to perfect crystals.

Suitable crystals to be used for such application to increase the diffraction efficiency should have a sufficient density and a mosaicity ranging between 30 arcsec and 1-2 arcmin, depending on the lens focusing distance and resolution. In the past germanium and copper crystals, often employed as monochromators for neutrons, have been considered.

We have analyzed several crystalline materials of different degree of crystal perfection such as GaAs, Cu, CdTe, and CdZnTe as possible mosaic crystals for hard x-ray astronomy. They were measured by high resolution x-ray diffraction at 8 keV and diffraction at energies up to 700 keV at synchrotron. A surprising agreement was found between the mosaicity evaluated in Bragg diffraction geometry with x-ray penetration of the order of few tens micrometers and in Laue transmission geometry at synchrotron.

It was found that:

-CdTe and CdZnTe crystals exhibit low angle grain boundaries preventing the formation of a single diffracted x-ray beam;
-Cu crystals exhibit mosaicity of the order of several arcmin, however a very deep etching is needed to remove the cutting damage;
-GaAs crystals grown by LEC method show mosaicity between 15 and 30 arcsec and good diffraction efficiency up to energies of 700 keV.

Annealing and surface damage were considered as possible methods to increase the GaAs crystal mosaicity.

8147-48, Session 11

Quasi-mosaic crystals for high-resolution focusing of hard x-rays through a Laue lens

R. Camattari, V. Bellucci, V. Guidi, I. Neri, Univ. degli Studi di Ferrara (Italy)

Observation of the sky within hard x-ray domain would enable the study of many sources and violent events occurring in the Universe. However, to take full advantage of this potential, the next generation of instruments working in this energy domain will have to achieve an improvement in sensitivity by at least an order of magnitude with respect to existing telescopes. Bragg diffraction in Laue geometry is being proposed to efficiently concentrate x-ray photons. Mosaic crystals can be used, but their mosaicity (FWHM of the angular distribution of the diffraction planes) may not be adequately controlled during the growth, and diffraction efficiency is ultimately limited to 50%. On the other hand, bent crystals have no intrinsic efficiency limitation and feature a very well controlled energy bandpass. In the framework of the “Laue project”, we propose the usage of bent crystals exploiting the Quasi-Mosaicity. This latter is an effect of mechanical anisotropy in crystals that manifests itself along selected crystallographic directions. Thus, as a result of primary curvature imparted to the crystal, a secondary curvature (Quasi-Mosaic curvature) occurs. We demonstrated that a proper combination of primary and Quasi-Mosaic curvatures allows high-efficiency diffraction and high-resolution focusing of diffracted photons. As compared to traditional mosaic crystals with same size and energy passband, a Laue lens based on Quasi-Mosaic crystals would increase the signal-to-noise ratio up to two orders of magnitude. Moreover, for this latter, no mosaic defocusing would occur, making it possible measurements at very high resolution.

8147-49, Session 11

Bent crystals as high-efficiency optical elements for hard x-ray astronomy

E. Buffagni, C. Ferrari, F. Rossi, L. Marchini, A. Zappettini, Consiglio Nazionale delle Ricerche (Italy)

The focusing of hard x-rays (with energies in the 70 keV - 1 Mev range) is a crucial point for astronomy in the x- and gamma-ray energy range. The use of a Laue lens made of single crystals in the Laue diffraction configuration has been proposed to efficiently collect rays of these energies.

In order to increase the diffraction efficiency bent crystals based on SiGe alloy with composition gradients can be used as optical elements showing excellent performances. For bent crystals the diffraction range is given by the total curvature of the crystal lattice planes and the diffraction efficiency can reach values close to 100%. Unfortunately a large production of such crystals seems prevented by the difficulty in the crystal growth and the yield rate.

In this work we propose a different strategy to obtain bent crystals. The bending can be achieved by a controlled surface damaging, which introduces defects in a superficial layer of few tens nanometers in thickness undergoing a highly compressive strain.

Several silicon and mosaic gallium arsenide crystals were afterwards treated to obtain bent crystals. High resolution x-ray diffraction measurements in Bragg condition at low energy x-rays allowed to determine the local and mean curvature radius of each sample. Curvature radii between 2 and 30 m were easily obtained in wafers of different thicknesses.

Preliminary results of measurements performed at high gamma energies at synchrotron and showing high diffraction efficiency are also reported.

8147-50, Session 11

Bent crystals by superficial indentations for high-efficiency concentration of hard x-ray photons by a Laue lens

V. Guidi, R. Camattari, V. Bellucci, I. Neri, Univ. degli Studi di Ferrara (Italy); N. M. Barriere, Univ. of California, Berkeley (United States)

Curved crystals for broad-band Laue lens are very promising since they allow concentrating hard x-rays with higher diffraction efficiency than for mosaic crystals, showing a uniform distribution of the energy passband. With this regard, there has been proposed several methods, e.g., external mechanical forces, thermal or composition gradient. However, most of these methods have severe limitations for a space-borne telescope such as excessive weight and fabrication reproducibility. In the framework of the “Laue project”, we propose a technique to fabricate self-standing curved crystals by generating a permanent curvature within the crystal. This technique relies on superficial indentations on a mono-crystal by a diamond saw. Irreversible compression of the crystal beneath and beside the indentations causes deformation, resulting in a uniform curvature within the crystal. Indented Si crystals were characterized at ESRF and efficiently diffracted up to 500 keV, peaking 95% at 150 keV. Extension of the method to materials with higher atomic number, e.g., Ge, has been undertaken to provide high-efficiency diffraction up to 800 keV, this energy range being significantly wide for many applications in astrophysics. With respect to other techniques, the method of indentations is cheap, simple and reproducible, being based on mass production tools. Another important feature is that it is possible to control the energy passband of crystals by simply measuring the morphological curvature.

8147-51, Session 12

X-ray Optics for WHIMex, the Warm Hot Intergalactic Medium Explorer

W. C. Cash, Univ. of Colorado at Boulder (United States); R. L. McEnatter, Univ. of Iowa (United States); W. W. Zhang, NASA Goddard Space Flight Ctr. (United States); S. Casement, C. F. Lillie, Northrop Grumman Aerospace Systems (United States); M. L. Schattenburg, M. Bautz, Massachusetts Institute of
The soft x-ray band is a loaded with diagnostics that allow absorption line spectroscopy of hot, thin gas from the ground state. Of particular interest is the WHIM, which contains the bulk of our Universe’s baryons, mostly ionized and at high temperatures. In this paper we describe the optical design of WHIMex, an Explorer concept designed to extend ultraviolet observations, like those from Copernicus, FUSE and HST, up into the x-ray. It features a compact array of slumped thin glass paraboloid-hyperboloids with 15° quality, feeding off-plane diffraction gratings. The spectrum is dispersed onto an array of CCD’s which is placed at the 7m focus by an extendable bench. With spectral resolution of 4000 in the 0.15 to 2.0keV band, and collecting area as high as 500 square centimeters, WHIMex can open the the high temperature intergalactic medium to direct observation and explore the physics of a wide array of other high energy phenomena.

8147-53, Session 12

Development of off-plane gratings for WHIMex and IXO

R. L. McCentauffer, The Univ. of Iowa (United States); W. C. Cash, Univ. of Colorado at Boulder (United States); W. W. Zhang, NASA Goddard Space Flight Ctr. (United States); S. Casement, C. F. Lillie, Northrop Grumman Aerospace Systems (United States); M. L. Schattenburg, MIT Kavli Institute for Astrophysics and Space Research (United States); A. D. Holland, Open Univ. (United Kingdom); H. Tsunemi, Osaka Univ. (Japan); M. Bautz, MIT Kavli Institute for Astrophysics and Space Research (United States); S. L. O’Dell, NASA Marshall Space Flight Ctr. (United States)

Future x-ray astronomical missions will need to address a number of important goals such as studying the dynamics of clusters of galaxies, determining how elements are created in the explosions of massive stars, and revealing most of the “normal” matter in the universe which is currently thought to be hidden in hot filaments of gas stretching between galaxies. In order to achieve these goals, spectrometers capable of high resolution and high throughput are necessary for the lowest x-ray energies, 0.3-1.0 keV. We present recent progress in the development of off-plane reflection grating technology for use on upcoming missions. Off-plane grating spectrometers consist of an array of gratings capable of resolving photons at energies between 0.3 and 10 keV. Concepts have been made for the International X-ray Observatory X-ray Grating Spectrometer. More recently however, we have designed an Optics Module Assembly for WHIMex, an Explorer mission concept that incorporates a Wolter telescope that focuses in two dimensions. It refines the arc minute angular resolution in the other. Their positioning accuracy is the order of 1 arcsecond, and the precision required to measure positions with arc second accuracy, the precision required to test QED and General Relativity.

8147-54, Session 12

Fabrication update on critical-angle transmission gratings for soft x-ray grating spectrometers


The critical-angle x-ray transmission (CAT) grating spectrometer (CATXGS) on board the International X-Ray Observatory is an example of a design that provides high-resolution spectroscopy (FWHM E/ΔE = 3000 - 5000) with greater than 1,000 cm2 effective area over the 0.3 - 1.0 keV photon energy band for studies of the Warm-Hot Intergalactic Medium, the Interstellar Medium, warm absorption and outflows in Active Galactic Nuclei, coronal emission from stars, and other areas of strong interest to the astrophysics community. The CATXGS instrument concept consists of a lightweight grating array at maximum distance from focus, and a single linear CCD readout array. As a blazed transmission grating design it easily exceeds performance requirements with relaxed tolerances and significant resolution margins. The CAT gratings that comprise a grating array combine the traditional advantages of transmission (low mass, relaxed figure and alignment tolerances) and blazed reflection gratings (high broad-band diffraction efficiency). We have fabricated the required freestanding, ultra-high aspect-ratio grating bars from silicon-on-insulator wafers using both wet and dry etch processes. The grating bars are supported by an integrated Level 1 support mesh, and a coarser external Level 2 support mesh. We will present fabrication results on the integration of CAT gratings and the different high-throughput support mesh levels, as well as recent x-ray data analysis of 3 and 6 micron deep wet-etched prototypes.

8147-55, Session 13

The Extreme Physics Explorer and micro-channel plate optics

M. R. Garcia, M. S. Elvis, S. E. Romaine, J. Chappell, D. Patnaude, L. Brenneman, I. Evans, Harvard-Smithsonian Ctr. for Astrophysics (United States); G. Fraser, R. Willingale, Leicester Univ. (United Kingdom); E. Silver, Harvard-Smithsonian Ctr. for Astrophysics (United States)

The Extreme Physics Explorer (EPE) is a concept for a large area, moderate angular resolution x-ray timing/spectroscopy mission designed to observed bright sources to test QED and General Relativity. EPE would use ultra-lightweight microchannel plate optics (MCPO) with a long, ~30m, focal length, to provide 5m2 effective area focused to ~1 arcmin at an Explorer class mass. These optics provide a factor of 10 improvement in area to mass ratio over current state of the art. The X-rays would be focused onto an x-ray calorimeter array. By spreading the signal over the array the count-rate limitations of X-ray calorimeters are largely overcome.

We describe science drivers for such a mission, and discuss the design trade space for the large area MCPO, and the challenges of the large area MCPO design. The possibilities for including a polarimeter, which would expand the science case, are also discussed.

8147-56, Session 13

Large-angle observatory with energy resolution for synoptic x-ray studies (LOBSTER-SXS)

P. Gorenstein, Harvard-Smithsonian Ctr. for Astrophysics (United States)

The soft x-ray band hosts the largest and most diverse range of variable sources than any other region of the electromagnetic spectrum. They are stars, compact binaries, SMBH’s, as well as the X-ray components of Gamma-Ray Bursts, their soft X-ray afterglows, and recently discovered very high redshift gamma-ray bursts and soft X-ray flares from supernova. We describe a concept for a very wide field (~ 4 ster) modular focusing x-ray telescope system with high sensitivity that can measure positions with arc second accuracy, the precision required to identify fainter and increasingly more distant events. The dimensions and the materials of all the telescope modules are identical or nearly so. All but two modules are part of a cylindrical lobster-eye telescope made with flat mirrors that focus in one dimension and utilize a coded mask for angular resolution in the other. Their positioning accuracy is the order of an arc minute. The two remaining modules are orthogonal and in series along a radius of the cylinder. They are configured as a Kirkpatrick-Baez telescope that focuses in two dimensions. It refines the arc minute positions of the lobster-eye modules to an arc second and provides
larger effective area for spectral and temporal measurements. This telescope system is more powerful and versatile than either a 2D coded mask or a 2D lobster-eye telescope of similar size. Very wide field X-ray telescopes have become feasible as the ability to fabricate large area arrays of position sensitive CCD and CMOS detectors has improved. An instrument with considerably more sensitivity than current all-sky or wide field X-ray detectors would be compatible with a modest NASA Explorer mission.

8147-57, Session 13

A new x-ray interferometer

S. Kitamoto, H. Murakami, D. Takei, K. Sakata, Y. Yoshida, Rikkyo Univ. (Japan)

We report a proposal of a new X-ray interferometer for future celestial observations. An X-ray interferometer is a possible optics in order to get a diffraction limited resolution for X-rays. If the interferometer is constructed from flat mirrors, the technology might be easier than that for a “so-called” telescope with an aspheric-polished mirror, but still difficult. Especially, a very long optics-length is generally required to get a reasonable size of a fringe pattern.

We propose a new idea for an X-ray interferometer using beam splitters. By using beam splitters, we can completely align two beams, which will be superposed, with each other. Consequently its optics-length can be short and the size of the fringe pattern is determined by the alignment precision. We studied a design of an interferometer optic with the beam splitter and propose a modified type of a Mach-Zehnder interferometer.

We have started a study of this type of a simple X-ray interferometer with beam splitters. For a laboratory model, we are designing a “grazing incident” Mach-Zehnder interferometer with multi-layer flat mirrors and beam splitters. The beam splitter is designed and fabricated with Mo/Si multi-layers tuning the layer thickness to reflect O-K or C-K X-rays. We will report the design and study of the new type X-ray interferometer and the status of the laboratory experiment.

8147-58, Session 13

Toward adaptive x-ray telescopes

S. L. O’Dell, NASA Marshall Space Flight Ctr. (United States); T. W. Button, The Univ. of Birmingham (United Kingdom); V. Cotroneo, W. N. Davis, Harvard-Smithsonian Ctr. for Astrophysics (United States); P. Doel, Univ. College London (United Kingdom); C. H. Feldman, Univ. of Leicester (United Kingdom); M. D. Freeman, Harvard-Smithsonian Ctr. for Astrophysics (United States); M. V. Gubarev, J. J. Kolodziejczak, NASA Marshall Space Flight Ctr. (United States); A. G. Michette, King’s College London (United Kingdom); B. D. Ramsey, NASA Marshall Space Flight Ctr. (United States); P. B. Reid, Harvard-Smithsonian Ctr. for Astrophysics (United States); D. A. Schwartz, Harvard-Smithsonian Ctr. for Astrophysics (United States); D. A. Schwartz, Harvard-Smithsonian Ctr. for Astrophysics (United States); D. A. Schwartz, Harvard-Smithsonian Ctr. for Astrophysics (United States); D. A. Schwartz, Harvard-Smithsonian Ctr. for Astrophysics (United States); S. Troller-McKinstry, R. H. T. Wilke, The Pennsylvania State Univ. (United States); R. Willingale, Univ. of Leicester (United Kingdom); W. W. Zhang, NASA Goddard Space Flight Ctr. (United States)

Future x-ray observatories will require high-resolution (25 m^2) apertures. Even with the next generation of heavy-lift launch vehicles, launch-mass constraints and aperture-area requirements will limit the areal density of the grazing-incidence mirrors to about 1 kg/m^2 or less. Achieving sub-arcsecond x-ray imaging with such lightweight mirrors will require excellent mirror surfaces, precise and stable alignment, and exceptional stiffness or deformation compensation. Attaining and maintaining alignment and figure control will likely involve adaptive (in-space adjustable) x-ray optics. In contrast with infrared and visible astronomy, adaptive optics for x-ray astronomy is in its infancy. In the middle of the previous decade, two efforts began to advance technologies for adaptive x-ray telescopes: The Generation-X (Gen-X) concept studies in the United States, and the Smart X-ray Optics (SXO) Basic Technology project in the United Kingdom. This paper discusses relevant technological issues and summarizes progress toward adaptive x-ray telescopes.

8147-60, Session 13

Adjustable x-ray optics: correction for gravity-induced figure errors

D. A. Schwartz, V. Cotroneo, W. N. Davis, M. D. Freeman, P. B. Reid, Harvard-Smithsonian Ctr. for Astrophysics (United States)

To extend the effective collecting area for future X-ray astronomy observatories, it is necessary to use highly nested, very thin glass shells. The capability to adjust the figure of these shells on-orbit is essential in order to achieve present state-of-the-art imaging capability of order 1/2 arcsec resolution. We are pursuing concepts to carry out this adjustment using piezo-electric crystals deposited directly on the back sides of the reflectors, and divided into a pattern of discrete actuators by individually controlled electrodes. In this paper we carry out a simulation of how well gravity induced errors might be corrected by this process. We perform a finite element analysis of a conical glass piece 205mm axially by 410mm azimuthally, and with 1m radius of curvature. This gives the individual influence functions. Then we apply a 1g force axially, using various constraint conditions, and calculate the coefficients of the set of influence functions such that the adjusted shape minimizes the slope errors.
8148-01, Session 1

**A collimator for measurements of the loss cone flux of energetic eletrons**

J. D. Sullivan, Air Force Research Lab. (United States) and Boston College (United States); C. Parker, Air Force Research Lab. (United States)

An energetic electron collimator for the measurement of loss cone fluxes in the Earth's radiation belts is presented. This design addresses the problem of measuring low intensity fluxes in the presence of a large omni-directional background flux. This disc loaded collimator comprises stainless steel baffles and tungsten vanes. Electron rejection is accomplished via logarithmic baffle spacing with vanes placed more closely deep within the collimator. The collimator was fabricated. Its response was validated at the Goddard Spaceflight Center's Radiation Effects Facility. The baffled design shows an angular cutoff greater than three orders of magnitude at the geometric cutoff angle for electron energies less than 500 keV.

8148-02, Session 1

**The energetic particle telescope (EPT) performances**

M. Cyamukungu, G. Grégoire, Ctr. for Space Radiations (Belgium)

Forecasting of energetic particle fluxes on time scales of hours to weeks, at a given position in space can be achieved, based on experimentally determined particle lifetimes and real-time measurements of contamination-free spectra. These kinds of direct measurements that do not need post-processing can be provided by the Energetic Particle Telescope (EPT) developed at the Center for Space Radiations (UCL-Belgium) and which can directly acquire energy spectra of electrons (0.2 - 10 MeV), protons (4 - 300 MeV), α-particles (16 - 1000 MeV) and heavier ions (up to 300 MeV/nucleon).

This paper contains a brief description of the EPT setup and channel definition along with the calibration and validation methodology. The performances of the EPT are presented, including the particle discrimination capability, the maximum flux rate along with results of the Flight Model qualification for PROBA-V satellite.

8148-03, Session 1

**Characterization of sensitivity degradation seen from the UV to NIR by RAIDS on the International Space Station**

A. W. Stephan, U.S. Naval Research Lab. (United States); A. B. Christensen, The Aerospace Corp. (United States); S. A. Budzien, U.S. Naval Research Lab. (United States); R. L. Bishop, J. H. Hecht, The Aerospace Corp. (United States); K. R. Minschwaner, New Mexico Institute of Mining and Technology (United States)

This paper presents an analysis of the sensitivity changes experienced by four of the eight sensors that comprise the Remote Atmospheric and Ionospheric Detection System (RAIDS) after more than a year operating on board the International Space Station (ISS). These sensors include the Extreme Ultraviolet Spectrograph (EUVS) that covers 55-110 nm, the Middle Ultraviolet (MUV) and Near Ultraviolet (NUV) sensors that combine to cover 190-400 nm, and the Near Infrared Spectrometer (NIRS) that covers 722-874 nm. The scientific goal for RAIDS is comprehensive remote sensing of the temperature, composition, and structure of the lower thermosphere and ionosphere from 85-300 km. RAIDS was installed on the ISS Japanese Expansion Module External Facility (JEM-EF) in September of 2009. After initial checkout the sensors began routine operations that are only interrupted for sensor safety by occasional ISS maneuvers as well as a few days per month when the orbit imparts a risk from exposure to the Sun. This history of measurements has been used to evaluate the rate of degradation of the RAIDS sensors exposed to an environment with significant sources of particulate and molecular contamination. The RAIDS EUVS, including both contamination and detector gain sag, has shown an overall signal loss rate of 0.2% per day since the start of the mission. The MUV has shown a 30% loss with an exponential folding time of about 45 days. The NIRS has shown stability to within 1% over the first year of operations.

8148-04, Session 1

**The RAIDS experiment on the ISS: on-orbit performance**

S. A. Budzien, A. W. Stephan, U.S. Naval Research Lab. (United States); R. L. Bishop, A. B. Christensen, J. H. Hecht, The Aerospace Corp. (United States); K. R. Minschwaner, New Mexico Institute of Mining and Technology (United States)

The Remote Atmospheric and Ionospheric Detection System (RAIDS) is new NASA experiment studying the Earth’s thermosphere and ionosphere from a vantage point on the International Space Station (ISS). RAIDS along with a companion hyperspectral imaging experiment were launched in September 2009 to operate as the first US payload on the Japanese Experiment Module-Exposed Facility. The scientific objectives of the RAIDS experiment are to study the temperature of the lower thermosphere (100-200 km), to measure composition and chemistry of the lower thermosphere and ionosphere, and to measure the initial source of OI 83.4 nm emission.

The RAIDS sensor complement includes three photometers, three spectrometers, and two spectrographs which span the wavelength range 50-874 nm and scan or image the atmospheric limb 90-300 km. After installation aboard the ISS, RAIDS underwent a 30-day check-out period before entering science operations. RAIDS is serving as a pathfinder for atmospheric remote sensing from the ISS, and the experiment team gained valuable operational insights throughout the first year of the mission. We present on-orbit sensor performance and discuss the ISS as a platform for atmospheric limb measurements.

8148-05, Session 1

**Characterization of Teledyne microdosimeters for space weather applications**

C. D. Lindstrom, Air Force Research Lab. (United States); J. D. Sullivan, Boston College (United States); B. K. Dichter, F. A. Hanser, Assurance Technology Corp. (United States); D. Carssow, Air Force Research Lab. (United States) and National Research Council (United States); G. E. Galica, Assurance Technology Corp. (United States)

Ideally, a space weather nowcasting system would rely on ubiquitous coverage of the near earth space environment. However, such an approach is difficult if not impossible to achieve in practice because of the extreme cost of space access as well as the large region that needs to be covered. In recent years, this has been recognized by those working on forecasting the space particle environment. Approaches
relying on data assimilation using results of high-grade scientific instruments/missions or physics based models combined with data-limited miniature instruments have been proposed to address this. One possible limited-data sensor that has been recently developed is a single (hybrid) chip dosimeter that uses a conventional silicon detector to measure the total radiation dose. This microdosimeter (as named by the manufacturer Teledyne) offers the potential advantage of small size, low cost, and well-calibrated response (compared to radfets) that may enable easy piggybacking onto existing missions. It is, however, important that the response of this device be carefully characterized in order to use it for space particle measurements. Here the linearity with dose, angular response, and energy response of the microdosimeter for both protons and electrons will be characterized through both Monte Carlo simulations and laboratory measurements. In addition, its potential usefulness for space particle measurements as well as total dose will be briefly addressed.

8148-06, Session 2
The Fabry-Perot interferometer prototype for ADAHELI solar small mission
F. Berrilli, M. Cocciole, R. Piazzesi, D. Del Moro, L. Giovannelli, Univ. degli Studi di Roma Tor Vergata (Italy); S. Selci, Consiglio Nazionale delle Ricerche (Italy); A. Egidi, Univ. degli Studi di Roma Tor Vergata (Italy)

The spectrometric element of the narrow band unit of the Interferometer for SOlar DYnamics (ISODY) focal plane suite, on board of the ADAHELI satellite is formed by two Fabry-Perot interferometers (FPI) used in classic mount and in axial-mode, and in series with a set of narrow-band interference filters. The filters are mounted on a filter-wheel placed between the two etalons to reduce the ghosts produced by the inter-reflections. Because no large interferometers for the imager are required (50 mm in diameter) space-qualified Fabry-Perot interferometers, with a capacity servo-control for both spacing and parallelism, have been adopted. Although some industries produce space-qualified FPIs we started in optics laboratories of Physics Department of University of Rome Tor Vergata (UTOV) the design and realization of a Fabry-Perot Interferometer prototype in order to investigate low-cost solutions suitable for small missions. The proposed FPI design is discussed, giving details on the prototype realization.

8148-07, Session 2
Liquid crystals Lyot filter for solar coronagraphy
S. Fineschi, G. Capobianco, G. Massone, L. Zangrilli, INAF - Osservatorio Astronomico di Torino (Italy); T. Baur, Meadowlark Optics, Inc. (United States)

This work describes a liquid crystal Lyot tunable-filter and polarimeter (LCCTP) designed to achieve high spatial resolution imaging and two-dimensional spectrophotometry of the Fe XIV, 530.3 nm, solar coronal emission-line. The LCCTP is a bandpass filter with a full width at half maximum of 0.15 nm at a wavelength of 530.3 nm. The center wavelength of the bandpass is tunable in 0.01 nm steps from 528.64 nm to 533.38 nm. It is a four stage Lyot filter with all four stages wide-field. The free spectral range between neighboring transmission bands of the filter is more than 2.7 nm. The wavelength tuning is non-mechanical using nematic liquid crystal variable retarders (LCVRs). A separate LOVR, in tandem with the filter, is used for the polarization measurements. A prototype of the LCCTP has been built and used for coronagraphic observations during the 2010 solar eclipse. Its measured performances and potential applications for space-based coronagraphy are presented here.

8148-08, Session 2
Ground-based synoptic instrumentation for the solar observations
K. S. Balasubramaniam, Air Force Research Lab. (United States); A. Pevtsov, National Solar Observatory (United States)

We will describe the status of current ground-based solar spectroscopic and imaging instruments used in solar observations. We will describe the advantages and disadvantages of using these two classes of instruments with examples drawn from the Improved Solar Optical Observing Network (ISOON) and Synoptic Long Term Investigations of the Sun (SOLIS) Network. Besides instrumental requirements and lessons learned from existing ground-based instruments, this talk will also focus on the future needs and requirements of ground-based solar optical observations.

8148-09, Session 2
Figure testing and calibration of the ISOON Fabry-Perot etalons
B. M. Robinson, The Univ. of Alabama in Huntsville (United States); K. S. Balasubramaniam, National Solar Observatory (United States); F. Pitts, J. Justice, ARINC, Inc. (United States)

We present the methods and results for the figure testing and spectral calibration of the narrow- and wide-band etalons for the Improved Solar Optical Observing Network’s dual-etalon tunable imaging filters. The ISOON system comprises a distributed network of ground-based patrol telescopes that gather full disk data for the monitoring of solar activity and for the development of more reliable space weather models. The etalon figure testing consists mainly of testing the cavity flatness and coating uniformity of each etalon. For this testing a series of exposures is taken as the etalon is tuned through a stable spectral line and a full-aperture line profile correlation method is employed to map the variations in the effective cavity thickness. Calibration of the etalons includes absolute calibration of the cavity mean spacing change corresponding to a controller step and calibration of plate parallelism and spacing settings for each spectral region of interest. Both acceptance testing and calibration were performed in a laboratory environment using spectral sources. A calibration method that uses illumination in the telluric lines is also described. This latter method can be used to conduct calibration in the field without the use of an artificial light source.

8148-10, Session 3
The SOLAR-C mission: current status
T. Shimizu, Japan Aerospace Exploration Agency (Japan); S. Tsuneta, H. Hara, National Astronomical Observatory of Japan (Japan); K. Ichimoto, Kyoto Univ. (Japan); K. Kusano, Nagoya Univ. (Japan); T. Sekii, National Astronomical Observatory of Japan (Japan); T. Sakao, Japan Aerospace Exploration Agency (Japan); Y. Suematsu, T. Watanabe, National Astronomical Observatory of Japan (Japan)

Two mission concepts (plan A: out-of-ecliptic mission and plan B: high resolution spectroscopic mission) have been studied for the next Japanese solar mission Solar-C, which will follow the scientific success of the Hinode mission. For studies, the Solar-C working group is organized in ISAS/JAXA with participation of scientists in Japanese solar physics community and with participation of US and European scientists in sub-working group activities. The plan A mission has a focused suite of instruments designed to study the solar interior flows by helioseismology, surface magnetic fields, transition region, and extended corona from an orbit inclined at least 40 degrees to the ecliptic plane. The plan B mission has three large state-of-art advanced telescopes to...
study energy flows and fundamental physical processes governing the dynamic solar atmosphere through elementary magnetic structures with high spatial resolution, high throughput, high cadence spectroscopic and polarimetric observations seamlessly covering the entire atmosphere from photosphere and chromosphere to transition region and corona. We are in the final phase of the selection and will soon give priority to one of the mission concepts to proceed for realizing Solar-C in 2019. The evaluation of the two concepts is being done from various points of view including science, technical and programmatic issues. Solar-C will only be realized with the enthusiastic participation of the space agencies and US and European scientists in all phases. This paper will present the current state of development for both the mission concepts and discuss more details of the Solar-C mission concept in higher priority.

8148-11, Session 3

Photon-counting soft x-ray telescope for the Solar-C mission

T. Sakao, Japan Aerospace Exploration Agency (Japan); N. Narukage, M. Shimjo, S. Miyazaki, National Astronomical Observatory of Japan (Japan); K. Watanabe, S. Imada, T. Dotani, Japan Aerospace Exploration Agency (Japan); E. E. DeLuca, Harvard-Smithsonian Ctr. for Astrophysics (United States)

We report instrument outline as well as science of the photon-counting soft X-ray telescope that we have been studying as a possible scientific payload for the Japanese Solar-C mission whose projected launch around 2019. Soft X-rays (~1-10 keV) from the solar corona include rich information on (1) possible mechanism(s) for heating the bright core of active regions seen in soft X-rays (namely, the hottest portion in the non-flaring corona), (2) dynamics and magnetohydrodynamic structures associated with magnetic reconnection processes ongoing in flares, and even (3) generation of supra-thermal distributions of coronal plasma associated with flares. Nevertheless, imaging-spectroscopic investigation of the soft X-ray corona has so far remained unexplored due to difficulty in the instrumentation for achieving this aim. With the advent of recent remarkable progress in CMOS-APS detector technology, the photon-counting X-ray telescope will be capable of, in addition to conventional photon-integration type exposures, performing imaging-spectroscopic investigations on active regions and flares, thus providing, for example, detailed temperature information (beyond the so-far-utilized filter-ratio temperature) at each spatial point of the observing target. The photon-counting X-ray telescope will employ a Walter type I optics with a piece of a segmented mirror whose focal length 4 meters, combined with a focal-plane CMOS-APS detector (0.4-0.5”/pixel) whose frame read-out rate required to be as high as 1000 fps.

Expected scientific performance of the photon-counting X-ray telescope will also be discussed together with prospects for the technology development for realizing the telescope.

8148-12, Session 3

Short telescope design of 1.5-m aperture solar UV visible and IR telescope aboard Solar-C

Y. Suematsu, Y. Katsukawa, National Astronomical Observatory of Japan (Japan); T. Shimizu, Japan Aerospace Exploration Agency (Japan); K. Ichimoto, Kyoto Univ. (Japan); T. Horiuchi, Y. Matsumoto, PLANET Inc. (Japan); N. Takeyama, Genesia Corp. (Japan)

We present a basic design of one of major planned instrumental payload for SOLAR-C/Plan-B: the Solar Ultra-violet Visible and near IR observing Telescope (SUVIT). We studied a short telescope design for 1.5 m aperture solar Gregorian telescope with the compact design of off-axis three-mirror collimator unit to accommodate a launcher’s nosecone size, a wide observing wavelength coverage from UV (down to 250 nm) through near IR (up to 1100 nm), and an 0.1 arcsec resolution in the field of 200 arcsec diameter. The large aperture is essentially important to attain scientific goals of Solar-C/Plan-B, especially for accurate diagnostics of the dynamic solar chromosphere as revealed by Hinode, but make it difficult to design the telescope because of solar heat load ten times more than Hinode introduced into the telescope. Detailed study of optical and thermal design of the telescope assembly of SUVIT for diffraction-limited performance at visible wavelength is presented, which consists of an aplanatic Gregorian telescope of 2.8 m primary-secondary mirror separation, heat rejection optics at the primary focus, afocal and achromatic optics between the telescope and focal plane instruments, and an envelope shield tube which ensures the thermal control of the entire telescope.

8148-13, Session 3

Focal plane instruments for the solar UV-Vis-IR telescope aboard SOLAR-C

Y. Katsukawa, Y. Suematsu, National Astronomical Observatory of Japan (Japan); T. Shimizu, Japan Aerospace Exploration Agency (Japan); K. Ichimoto, Kyoto Univ. (Japan); N. Takeyama, Genesia Corp. (Japan)

We present a conceptual design of a focal plane instrument for the Solar UV-Vis-IR Telescope (SUVIT) aboard the next Japanese solar mission SOLAR-C. A primary purpose of the telescope is to achieve precise as well as high resolution spectroscopic and polarimetric measurements of the solar chromosphere with a big aperture of 1 - 1.5 m, which is expected to make a significant progress in understanding basic MHD processes in the solar atmosphere. The focal plane instrument consists of two packages: A filtergraph package is to get not only monochromatic images but also Dopplergrams and magnetograms using a tunable narrow-band filter and interference filters. A spectrograph package is to perform accurate spectro-polarimetric observations for measuring chromospheric magnetic fields, and is employing a Littrow type spectrograph. The most challenging aspect in the instrument design is the wide wavelength coverage from 280 nm to 1.1 um to observe multiple chromospheric lines, which is to be realized with a lens unit consisting of fluoride glasses. A high-speed camera for correlation tracking of granular motion is also implemented in one of the packages for an image stabilization system, which is essential to achieve high spatial resolution.

8148-14, Session 4

MgII observations using the MSFC solar ultraviolet magnetograph

E. A. West, J. Curtin, NASA Marshall Space Flight Ctr. (United States); K. Kobayashi, G. A. Gary, J. M. Davis, The Univ. of Alabama in Huntsville (United States)

This paper will describe the scientific goals of our sounding rocket program, the Solar Ultraviolet Magnetograph Investigation (SUMI). This paper will present a brief description of the optics that were developed to meet SUMI’s scientific goals, discuss the spectral, spatial and polarization characteristics of SUMI’s optics, describe SUMI’s flight which was launched 7/30/2010, and discuss what we have learned from that flight.
SOHO/CELIAS solar EUV monitor absolute solar EUV irradiance measurements and how they are affected by choice of reference spectrum

D. L. Judge, S. R. Wieman, L. Didkovsky, The Univ. of Southern California (United States)

The SOHO/CELIAS Solar EUV Monitor (SEM) has measured absolute EUV solar irradiance nearly continuously over a 15 year period that includes both the cycle 22/23 (1996) and cycle 23/24 (2008) solar minima. Calibration of the SEM flight instrument and verification of the data have been maintained through measurements from a series of sounding rocket calibration underflights that have included a NIST calibrated SEM clone instrument as well as a Rare Gas Ionization Cell (RGIC) absolute detector. The SOLERS 22 fixed reference solar spectrum is used to calculate absolute EUV flux values from SEM raw data. Specifically, the reference spectrum provides a set of weighting factors for determining a weighted average for the wavelength dependent SEM efficiency, and is used in the correction for second order contamination in the first order channels, and in the comparison between SEM flux measurements with broadband absolute RGIC measurements. SOHO/SEM EUV flux measurements for different levels of solar activity will be presented to show how the choice of reference spectrum affects these SEM data. Both fixed (i.e. SOLERS 22) and non-fixed (Solar Irradiance Platform/Solar 2000 and SDO/EVE/MEGS spectra) reference spectra have been included in this analysis.

Overview of chromospheric Lyman-Alpha spectropolarimeter (CLASP)

N. Narukage, S. Tsuneta, T. Bando, R. Kano, M. Kubo, H. Harra, Y. Suematsu, Y. Katsukawa, R. Ishikawa, K. Ueda, National Astronomical Observatory of Japan (Japan); H. Watanabe, K. Ichimoto, Kyoto Univ. (Japan); T. Sakao, Japan Aerospace Exploration Agency (Japan); K. Kobayashi, The Univ. of Alabama in Huntsville (United States); J. Trujillo Bueno, Instituto de Astrofísica de Canarias (Spain)

The solar chromosphere is an important boundary, through which all of the plasma, magnetic fields and energy in the corona and solar wind are supplied. Since the Zeeman splitting is typically smaller than the Doppler line broadening in the chromosphere and transition region, it is not effective to observe weak magnetic fields. However, this is not the case for the Hanle effect, when we have an instrument with high polarization sensitivity (~0.1%).

We are planning a sounding rocket experiment to be launched in 2014 summer, “Chromospheric Lyman-Alpha SpectroPolarimeter (CLASP)”, to detect linear polarization produced by the Hanle effect in Lyman-alpha line (121.6 nm) and to make the first direct measurement of magnetic fields in the upper chromosphere and lower transition region. To achieve the high sensitivity of ~0.1% within a rocket flight (5 minutes) in Lyman-alpha line, which is easily absorbed by materials, we design the optical system with high reflective surface to maximize the throughput. The CLASP consists of a classical Cassegrain telescope, a polarimeter and a spectrometer: i) The primary mirror is coated by the “cold mirror coating”, which has high reflectivity in Lyman-alpha and low reflectivity in other wavelengths to minimize the heat load and the visible light contamination. ii) The polarimeter consists of a rotating 1/2-wave plate and two reflecting polarization analyzers. One of the analyzer also works as a beam splitter to give us two orthogonal linear polarizations simultaneously. iii) Two Spherical Varied-Line-Space (SVLS) gratings for each polarization component disperse and focus spectral images on two CCD cameras separately.

LEMUR (large European module for solar ultraviolet research): the VUV imaging spectrograph for the JAXA’s Solar-C mission

L. Teriaca, Max-Planck-Institut für Sonnensystemforschung (Germany); G. A. Doschek, U.S. Naval Research Lab. (United States); L. K. Harra, Univ. College London (United Kingdom); C. M. Korendyke, U.S. Naval Research Lab. (United States); U. H. Schuehle, Max-Planck-Institut für Sonnensystemforschung (Germany); T. Shimizu, Japan Aerospace Exploration Agency (Japan)

LEMUR is a VUV imaging spectrograph with a resolution and effective area an order of magnitude higher than currently available for solar studies. It is currently proposed as ESA’s participation in the Solar-C mission. Spectroscopic observations with sufficient resolution to observe the flow and dissipation of energy from the chromosphere into the transition region and corona as well as multi-million-degree flare plasmas, are essential for understanding the physical processes heating the corona and accelerating the solar wind. The LEMUR observations directly address these questions and are critical to the scientific success of the Solar-C mission and to the advance of solar physics.

LEMUR consists of a 30-cm steerable mirror illuminating a slit assembly located 3.6 m away. The slit is imaged and dispersed by a TVLS grating that focuses the solar spectrum over the detectors. The simple two-element design provides the high throughput necessary for high spatial and temporal resolution observations. The system has no entrance filter. The mirror is coated with a suitable multilayer with B4C top-coating, providing a reflectance peak around 18.5 nm whereas the usual B4C range above 50 nm. This remarkable wavelength coverage allows the simultaneous recording of spectral lines formed at all temperatures between 0.02 MK and 20 MK. The grating is divided into two channels. One operates around 18.5 nm and the other at wavelengths above 50 nm. The system is designed to provide resolved spectra with a spatial resolution corresponding to 200 km x 200 km (0.28") projected area. A large format CCD array with an aluminum filter is foreseen for the short wavelength channel. Three intensified CCD cameras will record spectra above 50 nm.

The coronal suprathermal particle explorer (C-SPEX)

J. D. Moses, C. M. Brown, G. A. Doschek, Y. Ko, C. M. Korendyke, J. M. Laming, C. E. Rakowski, D. G. Socker, A. Tylka, U.S. Naval Research Lab. (United States); D. R. McMullin, Space Systems Research Corp. (United States); C. K. Ng, U.S. Naval Research Lab (United States) and George Mason Univ. (United States); S. R. Wossom, Utah State Univ. (United States); M. A. Lee, The Univ. of New Hampshire (United States); F. Auchère, Institut d’Astrophysique Spatiale (France); S. Fineschi, INAF - Osservatorio Astronomico di Torino (Italy)

The primary science objective of the Coronal Suprathermal Particle Explorer (C-SPEX) is to investigate the spatial and temporal variations of coronal suprathermal particle populations that are seeds for acceleration to solar energetic particles (SEPs). It is understood that such seed particle populations vary with coronal structures and can change responding to solar flare and coronal mass ejection (CME) events. Models have shown that higher densities of suprathermal protons can result in higher rates of acceleration to high energies. Understanding the variations in the suprathermal seed particle population is thus crucial for understanding the variations in SEPs. However, direct measurements are still lacking. C-SPEX will measure the variation in the suprathermal protons across...
various coronal magnetic structures, before/after the passage of CME shocks, in the post-CME current sheets, and before/after major solar flares. The measurements will not only constraining models of SEP acceleration but also constrain models of the production of suprathermal particles from processes such as magnetic reconnection at the Sun. Understanding the causes for variation in the suprathermal seed particle population and its effect on the variation in SEPs will also help build the predictive capability of SEPs that reach Earth which constitutes an important factor of space weather.

The C-SPEX measurements will be obtained from instrumentation on the International Space Station (ISS) employing well-established UV coronal spectroscopy techniques. The unique aspect of C-SPEX is a >100-fold increase of light gathering power over any previous or currently planned UV coronal spectrometer. It is demonstrated C-SPEX will thus overcome the limitations in signal to noise that have thwarted prior attempts to observe suprathermals in the corona. The ISS is an excellent platform from which to conduct these observations, contrary to popular expectations. The issues of pointing stability and contamination of UV optics are demonstrated to be manageable in the proposed program.

The present lack of a means to predict the variability of SEP intensities and the likelihood C-SPEX will help develop such predictions makes the proposed investigation directly relevant to each of the three strategic objectives of the NASA Heliophysics Research Strategic Objectives.

8148-19, Session 5

The Lyman-alpha telescope of the extreme ultraviolet imager on solar orbiter

U. H. Schuehle, Max-Planck-Institut für Sonnensystemforschung (Germany); J. Halain, Univ. de Liège (Belgium); S. Meininger, T. Teriaca, Max-Planck-Institut für Sonnensystemforschung (Germany)

On the Solar Orbiter mission, the Extreme Ultraviolet Imager (EUI) set of filtergraph-telescopes consists of two high-resolution imagers (EUI) and one dual-band full Sun imager (FSI) that will provide extreme ultraviolet and Lyman-α images of the solar atmosphere. The Lyman-α HRI is one channel of the EUI suite of telescopes that will provide imaging of the solar atmosphere at the hydrogen Lyman-α line at unprecedented high cadence at a spatial resolution of one arcsecond.

For vacuum-ultraviolet imaging of the Sun the main requirements for the instrumentation are high resolution, high cadence, and large dynamic range. We present here the novel solutions of the instrument design and show in detail the predicted performance of this telescope. We describe in detail how the high throughput and spectral purity at 121.6 nm is achieved. The technical solutions include multilayer coatings of the telescope mirrors for high reflectance at 121.6 nm, combined with interference filters and a multichannel-plate intensified CMOS active pixel camera. We make use of the design flexibilities of this camera to optimize the dynamic range in the focal plane.

8148-20, Session 5

SCORE (sounding-rocket coronagraphic experiment): pre and post-flight calibrations

S. Fineschi, INAF - Osservatorio Astronomico di Torino (Italy); M. Romoli, Univ. degli Studi di Firenze (Italy); E. Antonucci, INAF - Osservatorio Astronomico di Torino (Italy); D. Moses, J. S. Newmark, U.S. Naval Research Lab. (United States); G. Massone, G. Capobianco, D. Telloni, L. Zangrilli, INAF - Osservatorio Astronomico di Torino (Italy); F. Landini, M. Pancrazzi, M. Focardi, Univ. degli Studi di Firenze (Italy); M. G. Pelizzo, Univ. di Padova (Italy); F. Auchère, Institute d’Astrophysique Spatiale (France)

SCORE, the Sounding-rocket Coronagraphic Experiment, is part of the sub-orbital payload HERSCHEL. On September 14, 2009, SCORE successfully flew its first sub-orbital mission with HERSCHEL. SCORE is a coronagraph with an all-reflective telescope designed to obtain images of the solar coronal emission in the visible, ultraviolet and extreme ultraviolet (EUV) wavelengths. The telescope optics are coated with an innovative multilayer optimized for the EUV line HeII, 30.4 nm, and with a cap-layer that extends the optics reflectivity to the UV (100 nm) and visible (500 nm) wavelengths. Filters select the HI Lyman-alpha, 121.6 nm, line and the polarized broadband visible-light emission from the solar corona.

This presentation will describe the pre- and post-flight calibrations carried out at the US. Naval Research Laboratory, US White Sands Missile Range and the Turin Astronomical Observatory, Italy. The calibration activities included measurements of the stray-light rejection level, vignetting function, radiometric and polarimetric response.

8148-21, Session 6

SiC/Mg multilayer coatings for SCORE coronagraph: long term stability analysis

M. G. Pelizzo, Lab. for Ultraviolet and X-ray Optical Research (Italy); S. Fineschi, INAF - Osservatorio Astronomico di Torino (Italy); A. J. Corso, P. Zuppella, Lab. for Ultraviolet and X-ray Optical Research (Italy); D. L. Windt, Reflective X-Ray Optics LLC (United States); P. Nicolosi, Lab. for Ultraviolet and X-ray Optical Research (Italy)

SiC/Mg multilayers have been used as coatings of the Sounding-rocket CORonagraphic Experiment (SCORE) telescope mirrors launched during the NASA HERSCHEL program. This coating couple has been largely studied by researchers since it provides higher performances than a standard Mo/Si multilayer; the SCORE mirrors show in fact a peak reflectance of around 40% at HeII 30.4 nm. Nevertheless, long term stability of this coating is an open problem. A study on the aging and stability of this multilayer has been carried on. SiC/Mg multilayer samples characterized by different structural parameters have been deposited. They have been measured just after deposition and three years later to verify degradation based on natural aging. Experimental results and analysis are presented.

8148-22, Session 6

Development of multilayer thin film filters for the full sun imager on solar orbiter

F. Auchère, X. Zhang, Institut d’Astrophysique Spatiale (France); F. Delmotte, E. Meltchakov, Lab. Charles Fabry de l’Institut d’Optique (France)

Membranes a few hundred nanometers thick are used in EUV optics to make, for example, beams splitters or bandpass filters. Despite their necessity in numerous applications these components are, because of their thinness, extremely fragile and their implementation in space instruments is always difficult. In the frame of the Solar Orbiter mission of ESA, the authors are developing for the EUI instrument suite thin film filters of high optical efficiency (transmittance, spectral selectivity) that are more robust than traditional components. We present the optical and mechanical properties of the prototype components.

8148-23, Session 6

High-resolution solar imaging with a photon sieve

J. M. Davila, NASA Goddard Space Flight Ctr. (United States)

Dissipation in the solar corona is expected to occur in extremely thin
current sheets of order 1-100 km. Emission from these current sheets should be visible in coronal EUV emission lines. However, this spatial scale is far below the resolution of existing imaging instruments, because conventional optics cannot be easily manufactured with sufficient surface figure accuracy to obtain the required < 0.1 arcsec resolution. A photon sieve, a diffusive imaging element, can be manufactured to provide a few 10-3 arcsec resolution, with much more relaxed tolerances than conventional imaging technology.

A simple design for a sounding rocket payload is presented that obtains 80 marsec imaging with a 100 mm diameter photon sieve to image Fe XIV 334 and Fe XVI 335. These images will not only show the structure of the corona at a resolution never before obtained, they will also allow a study of the temperature structure.

8148-24, Session 6
Effect of varying heat load on lightweighted solar telescope mirror
R. K. Banyal, B. Ravindra, Indian Institute of Astrophysics (India)

The next generation large aperture telescopes will probe the solar atmosphere at unprecedented detail. From the point of thermal management alone, the lightweighted mirrors offer significant advantages over heavy monolithic mirrors. Apart from significant reduction in weight, a lightweighted mirror reaches the thermal equilibrium with surroundings rapidly, thus reducing the detrimental effect of ‘mirror seeing’ on image quality. The lightweighting structure is created by removing pockets of material from the mirror blank in the form of triangular, hexagonal or circular cores without significantly affecting the rigidity and stiffness of the mirror. The resulting structure has side walls and ribs of certain thickness that supports the reflecting face plate of the mirror. Unlike solid mirror, the core structure created by the lightweighting process leads to material inhomogeneities within the mirror blank. The most conspicuous fallout of the different cell geometries and side wall structure is the appearance of thermal footprints on the reflecting surface. In this paper, we present our finite element method studies of surface deformations arising from thermally induced stress and temperature inhomogeneities inside a 2-m class lightweighted mirror. A simple physics-based model is used as an input to account for the existing thermal conditions at the observatory site. A comparative study is also made for two commonly used mirror substrate materials for optical telescopes, namely silicon carbide and Zerodur. The insight gained from these simulations will provide a valuable input for estimating the error budget and designing an efficient and stable thermal control system for the primary mirror.

8148-25, Session 6
Fabrication and metrology of the high-resolution coronal imager (Hi-C) primary and secondary mirrors
B. M. Robinson, The Univ. of Alabama in Huntsville (United States); C. Griffith, T. J. Kester, M. R. Young, NASA Marshall Space Flight Ctr. (United States); W. Podgorski, Harvard-Smithsonian Ctr. for Astrophysics (United States); K. Kobayashi, The Univ. of Alabama in Huntsville (United States); J. Curtin, NASA Marshall Space Flight Ctr. (United States)

The High Resolution Coronal Imager (Hi-C) is a high-resolution EUV solar imaging telescope designed to achieve ~0.2 arcsec resolution (0.1 arcsec pixel size). It is currently under development for a 2012 sounding rocket flight. Its primary and secondary mirrors are being fabricated and tested by the NASA Marshall Space Flight Center ES31 Optics Team. The figure specification for each mirror is given as a slope requirement extended to spatial periods of 4 mm, while higher spatial frequencies fall in the range of the roughness and microroughness specifications. These normal incidence, EUV mirrors serve as very high quality substrates for a ~50 layer-pair EUV coating. We present the results of the mirror fabrication effort and detail some of the methods, implemented in Matlab code, to analyze the metrology data obtained for each mirror element during the fabrication process.

8148-26, Session 6
Spectral features: an overview
H. H. Van Brug, TNO Science and Industry (Netherlands)

Most earth observation satellites use an on board diffuser to perform solar calibration measurements. The diffuser leads to, due to the narrow bandpass of the spectrometer, speckle effects. Since the speckle patterns changes with about everything it is virtually impossible to calibrate out the speckle effects and they therefore limit the achievable accuracy.

In this presentation an overview of all our findings and insights in spectral features and ways to reduce them will be given. The specially designed SanDiff will be presented and the ideas behind it will be discussed. The modeling of the spectral features amplitude will be an important part of the presentation since this leads to the possibility to predict the achievable accuracy of the instruments before they are launched.

Special emphasis will be on the wavelength band where the largest problems are, the infra red band about 2.3um.

8148-27, Session 6
Atmospheric turbulence and high-precision ground-based solar polarimetry
N. Krishnappa, A. J. Feller, Max-Planck-Institut für Sonnensystemforschung (Germany); S. Ihie, H. Soltau, PNSensor GmbH (Germany)

High-precision full-Stokes polarimetry at near diffraction limited spatial resolution is important to understand numerous physical processes on the Sun. In view of the next generation of ground based solar telescopes, we have explored, through numerical simulation, how polarimetric accuracy is affected by atmospheric seeing, especially in the case of large aperture telescopes with increasing ratio between mirror diameter and Fried parameter. In this work we focus on higher-order wavefront aberrations while suppressing tip/tilt terms. The numerical generation of time-dependent turbulence phase screens is based on the well-known power spectral method and on the assumption that the temporal evolution is mainly caused by wind driven propagation of frozen-in turbulence across the telescope. To analyze the seeing induced crosstalks between the Stokes parameters we consider different polarization modulation schemes, driven at frequencies between 1 Hz and several 100 Hz.

Further, we have started the development of a new fast solar imaging polarimeter, based on prCCD detector technology from PNSensor. The first detector will have a size of 264 x 264 pixels and will work at frame rates of up to 1kHz, combined with a very low readout noise of 2-3 e-. The camera readout electronics will allow for buffering and accumulation of images corresponding to different phases of the fast polarization modulation. A high write-out rate (~ 30 frames/s) will allow for post-facto image reconstruction. We will present the concept and the expected performance of the new polarimeter, based on the above-mentioned simulations of atmospheric seeing.

8148-28, Poster Session
Ly-alpha Polarimeter design for CLASP rocket experiment
H. Watanabe, Kyoto Univ. (Japan); N. Narukage, M. Kubo, R. Ishikawa, T. Bando, R. Kano, S. Tsuneta, National Astronomical Observatory of Japan (Japan); K. Kobayashi, The Univ. of
A sounding-rocket program called the Chromospheric Lyman-Alpha Spectro-Polarimetre (CLASP) is planned to be launched in 2014 summer. CLASP will observe the solar chromosphere in Ly-alpha (1216 nm), aiming to detect the linear polarization signal produced by the Hanle effect for the first time. The polarimeter of CLASP consists of a half-waveplate, a beam splitter, and a polarization analyzer.

We use Magnesium Fluoride (MgF2) as a material for these optical components, because MgF2 exhibits birefringent property and high transparency at UV wavelength. We performed two experiments to know the optical constants of MgF2 at Ly-alpha wavelength.

The first one is the retardation measurement of a stacking waveplate made of MgF2 to derive the difference between ordinary and extraordinary refractive index. The retardation of a waveplate is determined by observing the modulated intensity come out of a rotating waveplate and a polarization analyzer. The thickness difference of a stacking waveplate needed for 180-degree retardation is 14.60 um. The second experiment is the reflectance-and-transmittance measurement against oblique incident angles for the electric vector parallel and the electric vector perpendicular light. The ordinary refractive index and extinction coefficient along ordinary and extraordinary axis are derived with a least-square fitting in such a way that the reflectance and transmittance, satisfy the Kramers-Kronig relation. The reflection at the Brewster's Angle of MgF2 plate works as a good polarization analyzer.

We developed an engineering model of CLASP polarimeter using the MgF2 half-waveplate, and polarization analyzers, and discuss the performance of this polarimeter.

**8148-29, Poster Session**

**DIMMI-2h a MOF-based instrument for ADAHELI solar small mission**

F. Berrilli, Univ. degli Studi di Roma Tor Vergata (Italy); P. F. Moretti, Consiglio Nazionale delle Ricerche (Italy); D. Del Moro, M. Stangalini, Univ. degli Studi di Roma Tor Vergata (Italy); S. M. Jefferies, Univ. of Hawaii’i (United States); G. Severino, M. Oliviero, INAF - Osservatorio Astronomico di Capodimonte (Italy)

The Doppler-Intensity-Magnetograms with a Magneto-optical filter Instrument at two heights (DIMMI-2h) is a double channel imager, using Magneto Optical Filters (MOF) in the potassium 770 nm and sodium 589 nm lines, proposed for solar small mission Advanced Astronomical HELiphysics (ADAHELI). The instrument will provide simultaneous dopplergrams (velocity fields), intensity and longitudinal magnetic flux images at two heights in the solar atmosphere corresponding to low and high photosphere.

The spatial resolution (approximately 4 arcsec) and the high temporal cadence (15 s) will permit observation of low and medium oscillating modes (from 0 to below 1000) up to approximately 32 mHz in the frequency spectrum. The acquisition of long-term simultaneous velocity, intensity and magnetic information up to these high frequencies will also permit the study of the propagation and excitation of waves with a frequency resolution never obtained before.

**8148-30, Poster Session**

**The intensity effect in magneto-optical filters**

F. Berrilli, Univ. degli Studi di Roma Tor Vergata (Italy); M. Oliviero, G. Severino, INAF - Osservatorio Astronomico di Capodimonte (Italy); P. F. Moretti, Consiglio Nazionale delle Ricerche (Italy); S. M. Jefferies, Univ. of Hawaii’i (United States)

Magneto-Optical Filters (MOF) are low-cost, low-weight instruments largely used on ground and particularly suitable for space applications. Therefore, any effort useful to improve the setup and calibration of MOFs is worthwhile.

We used a laser system for determining the bandpasses of the two vapour cells, the Magneto-Optical Filter and the Wing Selector (WS), which are the core of solar narrow-band filters based on the MOF technology. A new result, which we called the Intensity Effect, was found: the MOF and WS bandpasses depend not only on the temperature at which the cell is heated and the external magnetic field in which the cell is embedded, but also on the intensity during the window where the MOF and WS spectral transmisions.

**8148-31, Poster Session**

**OPSys: an optical payload systems facility for testing space coronagraphs**

S. Fineschi, G. Massone, G. Crescenzio, G. Capobianco, INAF - Osservatorio Astronomico di Torino (Italy); F. Anselmi, Alca Technology srl (Italy)

The Turin Astronomical Observatory recently completed construction in Altec, Turin, of a new Optical Payload System (OPSys) facility for tests of contamination sensitive optical space flight instruments. The facility is specially tailored for tests on solar instruments like coronagraphs. The solar simulator is an off-axis parabolic mirror collimating the light from the source with the solar angular divergence. This presentation will describe the SPOCC’s vacuum system and optical design, and the post-flight stray-light tests to be carried out on the Sounding-rocket Experiment (SCORE). This sub-orbital coronagraph is the prototype of the METIS coronagraph for the ESA Solar Orbital mission. Solar Orbiter closest perihelion is one-third the Sun-Earth distances. The plans will be illustrated for testing METIS simulating in SPOCC the coronagraph observing conditions from the Solar Orbiter perihelion.

**8148-32, Poster Session**

**Long term stability of optical coatings in close solar environment**

M. G. Pelizzo, A. J. Corso, P. Zuppella, Lab. for Ultraviolet and X-ray Optical Research (Italy); P. Nicolosi, Univ. degli Studi di Padova (Italy)

Observations of the solar atmosphere and surface are required in order to understand the solar activity and its influence on Earth. The ESA Solar Orbiter mission is conceived to carried on such observations at the closest distance ever reached from the Sun, being the minimum perihelion at only 0.28 AU. At these distance, the spacecraft and instruments are immersed in a very harsh environment, characterized by high temperature and high density of ions carried on by the solar wind components. The stability of the optical components in these working conditions are a crucial point for the proper instruments functioning. In this work we present a series of experiment conceived for validating the optical coatings through the investigation of the environment effects. Experimental results that show the effects of solar wind low energy particles bombardment on coatings and multilayers are presented.

**8148-33, Poster Session**

**Slitless solar spectroscopy**

J. M. Davila, NASA Goddard Space Flight Ctr. (United States); S. Jones, The Catholic Univ. of America (United States)
Spectrographs have traditionally suffered from the inability to obtain line intensities, widths, and Doppler shifts over large spatial regions of the Sun quickly because of the narrow instantaneous field of view. This has limited the spectroscopic analysis of rapidly varying solar features like, flares, CME eruptions, coronal jets, and reconnection regions. Imagers have provided high time resolution images of the full Sun with limited spectral resolution.

In this paper we present recent advances in deconvolving spectrally dispersed images obtained through broad slits. We use this new theoretical formulation to examine the effectiveness of various potential observing scenarios, spatial and spectral resolutions, signal to noise ratio, and other instrument characteristics.

This information will lay the foundation for a new generation of spectral imagers optimized for slitless spectral operation, while retaining the ability to obtain spectral information in transient solar events.

**8148-34, Poster Session**

**Earth-Affecting Solar Causes Observatory (EASCO): a mission at the Sun-Earth L5**

N. Gopalswamy, NASA Goddard Space Flight Ctr. (United States); F. Auchère, Institut d’Astrophysique Spatiale (France)

Coronal mass ejections (CMEs) corotating interaction regions (CIRs) originate from the closed and open magnetic regions on the Sun, respectively. Imaging these source regions is important because CMEs and CIRs have important space weather consequences. The current understanding of CMEs primarily comes from the SOHO and STEREO missions, but these missions lacked some key measurements: STEREO did not have a magnetograph; SOHO did not have in-situ magnetometer. From the Sun-Earth line, SOHO was not well-suited for observing Earth-directed CMEs because of the occulting disk. STEREO’s angle with the Sun-Earth line is changing constantly, so only a limited number of Earth-directed CMEs were observed in profile. In order to overcome these difficulties, we proposed a news L5 mission concept known as the Earth-Affecting Solar Causes Observatory (EASCO). The mission concept was recently studied at the Mission Design Laboratory (MDL), NASA Goddard Space Flight Center. The aim of the MDL study was to see how the scientific payload consisting of ten instruments can be accommodated in the spacecraft bus, what propulsion system can transfer the payload to the Sun-Earth L5, and what launch vehicles are appropriate. The study found that all the ten instruments can be readily accommodated and can be launched using an intermediate size vehicle such as Taurus II with enhanced fairing. The study also found that a hybrid propulsion system consisting of an ion thruster (using ~55 kg of Xenon) and hydrazine (~10 kg) is adequate to place the payload at L5. The transfer will take about 2 years and the science mission will last for 4 years around the next solar maximum in 2025. The mission can be readily extended for another solar cycle to get a solar-cycle worth of data on Earth-affecting CMEs and CIRs. This paper describes the EASCO mission, the scientific payload, and the results of the MDL study.

**8148-35, Poster Session**

**Space-qualified liquid-crystal variable retarders for wide FOV coronagraphs**

N. Uribe-Patarroyo, A. Alvarez-Herrero, P. García Parejo, J. Vargas, R. L. Heredero, R. Restrepo, Instituto Nacional de Técnica Aeroespacial (Spain); V. Martínez-Pillet, Instituto de Astrofísica de Canarias (Spain); J. C. del Toro Iniesta, A. Lopez, Instituto de Astrofísica de Andalucía (Spain); S. Fineschi, G. Capobianco, INAF - Osservatorio Astronomico di Torino (Italy); M. Georges, Centre Spatial de Liége-CSL (Belgium); M. López, Visual Display S.L.L. (Spain); G. Boer, ARCoptix S.A. (Switzerland); I. G. Manolis, European Space Research and Technology Ctr. (Netherlands)

Liquid-crystal variable retarders (LCVRs) are an emergent technology for space-based polarimeters, following its success as polarization modulators in ground-based polarimeters and ellipsometers. Although they provide many advantages to both ground- and space-based instrumentation with respect to more traditional modulators, they have some characteristics that should be taken into account and, if necessary, addressed during the instrument design. One of the more important properties of any polarization modulator is its angular acceptance. In the case of nematic LCVRs, due to the very principle in which they provide variable retardance, the angular sensitivity is variable, and is a function of the retardance state (given by applied voltage) of the LCVR. At some retardance regimes, this dependence can be large and might not be affordable by the polarimetric signal-to-noise ratio requirements.

Wide-field double nematic LCVRs were proposed to address this shortcoming (Y. Itoh et al., Jpn. J. Appl. Phys. Lett. 30, L1296 -L1299 (1991)) and used in a tunable filter (G. A. Kopp et al., Appl. Opt. 36, 291 (1997)). In the framework of the project “Validation of LCVRs for the Solar Orbiter Polarization Modulation Package” (A. Alvarez-Herrero et al., Polarization Science and Remote Sensing V, SPIE 2011 ), we designed and built wide-field LCVRs, modelled their angular acceptance and validated this technology for space environmental conditions, including a campaign studying the effects of gamma, proton irradiation, vibration and shock, thermo-vacuum and ultraviolet radiation. Additionally, we propose some improvements that could improve even further the performance of this technology in space applications.

Liquid-crystal variable retarders (LCVRs) are an emergent technology for space-based polarimeters, following its success as polarization modulators in ground-based polarimeters and ellipsometers. Wide-field double nematic LCVRs address the high angular sensitivity of nematic LCVRs at some voltage regimes. We present a work in which wide-field LCVRs were designed and built. A detailed model of their angular acceptance was made, and we validated this technology for space environmental conditions, including a campaign studying the effects of gamma, proton irradiation, vibration and shock, thermo-vacuum and ultraviolet radiation.
The race to higher contrast imaging is an ongoing theme in exoplanet imaging, both from earth and from space. Next-generation instruments such as the Gemini Planet Imager (GPI) and SPHERE are designed to achieve contrast ratios of 10^6-10^7; this requires very good wavefront correction and coronagraphic control of diffraction. GPI is a facility instrument, now in integration and test, with first light on the 8-m Gemini South telescope expected by the beginning of 2012. It combines a 1700 subaperture AO system using a MEMS deformable mirror, an apodized-pupil Lyot coronagraph, a high-accuracy IR interferometer calibration system, and a near-infrared integral field spectrograph to allow detection and characterization of self-luminous extrasolar planets at planet/star contrast ratios of 10^7. In this paper we will discuss the status of the integration and test happening at the University of Santa Cruz California.

Overview of the control strategies for the TMT alignment and phasing system

P. K. Piatrou, G. A. Chanan, Univ. of California, Irvine (United States)

In this paper we present the current status of control algorithm development for the Thirty Meter Telescope (TMT) Alignment and Phasing System (APS). We discuss ways to address the main challenges inherent in the active control of extremely large segmented telescopes: high complexity of the control problem, disentangling the aberrations on the primary, secondary and tertiary mirrors, and the tight requirements for residual errors. We also present preliminary APS performance estimates derived from simulations.

Advancements in laser tomography implementation at the 6.5m MMT telescope

E. A. Bendek, College of Optical Sciences, The Univ. of Arizona (United States); M. Hart, The Univ. of Arizona (United States)

Laser tomography capability using the Multi Laser Guide Star system is being implemented at the 6.5 m MMT telescope at Mt. Hopkins AZ. The system uses five range gated and dynamically refocused Rayleigh laser beacons to perform the tomographic sampling of the atmosphere. The correction is then applied to the wavefront using the 336-actuator adaptive secondary mirror of the telescope. Laser tomography will be attempted by means of a least squares reconstructor, which is obtained using an additional infinite conjugated natural guide star. This paper also discuss methods to find the pupil misregistration of each laser and
information about the turbulence intensity distribution Cn², which are important to optimize the system for least square tomography approach but are critical to build analytic tomographic reconstructors.

8149-08, Session 2
Wavefront control with SCExAO: concepts and first on-sky results
O. Guyon, F. Martinache, C. Clergeon, R. Russell, Subaru Telescope, National Astronomical Observatory of Japan (United States); T. Groff, Princeton Univ. (United States); V. Garrel, Subaru Telescope, National Astronomical Observatory of Japan (United States)

The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system uses advanced coronagraphic technique for high contrast imaging of exoplanets and disks as close as 1 lambda/D from the host star. In addition to unusual optics, achieving high contrast at this small angular separation requires a wavefront sensing and control architecture which is optimized for exquisite control and calibration of low order aberrations. The SCExAO system was thus designed to include the wavefront sensors required for bias-free high sensitivity and high speed wavefront measurements. Information is combined from two infrared wavefront sensors and a fast visible wavefront sensors to drive a single MEMS type deformable mirror mounted on a tip-tilt mount. The wavefront sensing and control architecture is highly integrated with the coronagraph system. We describe the architecture and show recent results obtained on sky during our recent engineering observations.

8149-09, Session 2
A sensitivity comparison between the non-linear curvature wavefront sensor and the Shack-Hartmann wavefront sensor in broadband
M. Mateen, Air Force Research Lab. (United States); O. Guyon, Subaru Telescope, National Astronomical Observatory of Japan (United States); M. Hart, The Univ. of Arizona (United States)

In this paper we present results from a side-by-side comparison of the non-linear curvature wavefront sensor (nICWFS) with the Shack-Hartmann wavefront sensor (SHWFS). The non-linear curvature technique is derived from the successful curvature wavefront sensing concept, but uses a non-linear wavefront reconstruction scheme. The nICWFS approach the theoretical sensitivity limit imposed by fundamental physics by taking advantage of wavefront spatial coherence in the pupil plane. Interference speckles formed by natural starlight encode wavefront aberrations with the sensitivity set by the telescope's diffraction limit (λ/D) rather than the seeing limit of more conventional linear WFSs. The nICWFS offers high sensitivity on reasonably bright targets mV < 15.

In our last paper we showed verification of the nICWFS technique and an initial comparison of the nICWFS with the SHWFS at monochromatic light. In this paper we extend the analysis to polychromatic light. We have designed an experiment that allows for polychromatic compensation by use of refractive optics and minimizes chromatic aberration of the diffraction-limited speckles. The current design is ready to be implemented on a telescope. We show results of a comparison of the wavefront correction preformed by the nICWFS and the SHWFS for broadband imaging. Phase Wheels are used to generate atmospheric turbulence in the lab. Our results show that the exquisite control of low order aberrations by the nICWFS delivers significant gain in sensitivity over the SHWFS.

8149-10, Session 2
Image plane phase-shifting wavefront sensor for giant telescope active and adaptive optics
F. Hénault, Univ. de Nice Sophia Antipolis (France)

Since the realization of the twin Keck telescopes of 10-meter diameter built atop the Mauna Kea in Hawaii, the technology of segmented mirrors has become a cornerstone for on-going projects of Extremely Large Telescopes (ELT). Here the individual mirror segments should actually be phased (i.e. reconstruct the surface of an ideal giant mirror) within an accuracy typically better than one tenth of the operating wavelength. This could be done using existing Wavefront Sensors (WFSs), but may also involve the development of alternative methods: herein is described a new generation WFS operating in the image plane and able to sense differential piston errors of the segments with residual errors around 10 nm by means of a phase-shifting technique. We describe the principle of the method in both monochromatic and polychromatic light and present its achievable performance in terms of limiting magnitude of the guide star in presence of various noise sources. It is emphasized that the technique is also applicable for co-phasing sparse aperture interferometers, or more generally to any Adaptive Optics (AO) system making use of image plane WFS.

8149-12, Session 3
Demonstration of 17 cm robust carbon fiber deformable mirror for adaptive optics
S. M. Ammons, Lawrence Livermore National Lab. (United States); M. Hart, The Univ. of Arizona (United States); B. Coughenour, College of Optical Sciences, The Univ. of Arizona (United States); R. Romeo, R. Martin, Composite Mirror Applications, Inc. (United States)

CFRP composites provide several advantages as a substrate for thin-shell adaptive secondary mirrors, including high stiffness to-weight ratio, robustness, and zero coefficient of thermal expansion (CTE). We use 8 and 17 cm prototype CFRP thin-shell deformable mirrors to show that residual CTE variation may be addressed with mounted actuators for a variety of mirror sizes. We present measurements of surface quality at a range of temperatures characteristic of mountaintop observatories. For the 8 cm piece, the figure error of the Al-coated reflective surface under best actuator correction is ~43 nm RMS, placing it into consideration for use in near-IR astronomy. The low surface error internal to the outer ring of actuators (17 nm RMS at 15°C and 33 nm RMS at -5°C) suggests that larger mirrors will have a similar figure quality under actuator correction on ground-based Adaptive Optics systems. Surface roughness is low (< 3 nm P-V) at a variety of temperatures. We present new figure quality measurements of the larger 17 cm piece, showing that the figure error does not scale sharply with mirror diameter. These experiments demonstrate CFRP’s potential as a lightweight, robust substrate for large, 1-m thin-shell deformable secondary mirrors.

8149-13, Session 3
Bending modes for active optics
B. W. Smith, Lowell Observatory (United States); B. Cuerden, The Univ. of Arizona (United States)

While the concept of wavefront decomposition is a foundation of active optics systems, the choice of basis functions for mirror figure control is divided. The common functions are Zernike polynomials, ubiquitously used for wavefront descriptions, and bending (also called minimum energy or vibration) modes which offer optimal performance. We present a look at the comparative performance between the two approaches, and discuss an implementation approach which seeks to combine much of the analytic and interface simplicity of Zernike polynomials with the improved performance of bending modes.
8149-20, Session 3

Linear estimation of the Giant Magellan Telescope inter-segment piston error from wave-front sensor data
M. Hart, Ctr. for Astronomical Adaptive Optics, Steward Observatory (United States)

The Giant Magellan Telescope (GMT) will place seven 8.4 m diameter primary mirror segments on a common mount to form a single co-phased aperture of 25 m. High order adaptive optics based around an adaptive secondary mirror will be used to operate the telescope at the diffraction limit in the near infrared. Critical to the performance of the telescope will be real-time correction of atmospherically-induced phase errors between the primary mirror segments. The gaps between the segments, where the aberrated wavefront is not explicitly measured by the sensors of the adaptive optics, are approximately 30 cm at their narrowest points.

In an idealized case where the atmospheric phase aberration is characterized by layers of frozen turbulence moving over the telescope pupil with their respective wind velocities, the instantaneous piston differences between the mirror segments could, despite the missing wavefront information, be well estimated by examining the immediate history of the aberration. Aberration in the gaps at any given time would be visible to the sensors in earlier data. The real value of the approach is hard to assess from simulations, which almost always model the atmosphere as layers of frozen flow and therefore can be expected to yield overly optimistic results. These considerations have led to a study of data from the first-light AO system now running on the Large Binocular Telescope (LBT), which closely mimics one of the GMT segments. The data are of very high quality and realistically capture the temporal behavior of the wavefront. I use data from two nights to show that the GMT segment piston errors may be estimated to <30 nm accuracy with a simple linear estimator, but that in fact looking back in time, at least over a period of about 10 ms, is not helpful.

8149-15, Poster Session

On numerical simulation of high-speed CCD/CMOS-based wavefront sensors in adaptive optics
M. V. Konnik, J. S. Welsh, The Univ. of Newcastle (Australia)

Wavefront sensors, which use solid-state CCD or CMOS photosensors, are sources of errors in adaptive optics systems. Inaccuracy in the detection of wavefront distortions introduce considerable errors into wavefront reconstruction and leads to overall performance degradation of adaptive optics system. The accuracy of wavefront sensors is significantly affected by photosensor noise. Thus it is crucial to formulate a high-level image sensor system model that enable adaptive optics engineers to simulate realistic effects of noise from wavefront sensors. However, the complexity of solid-state photosensors and multiple noise sources makes it difficult to formulate an adequate model of the photosensors. Moreover, the characterisation of the simulated sensor and comparison with real hardware is often incomplete due to lack of comprehensive standards and guidelines. Such circumstances lead to oversimplified models of wavefront sensors and consequently imprecise numerical simulation results.

The paper presents an approach for the modelling of noise sources for CCD and CMOS sensors that are used for wavefront sensing in adaptive optics. Both dark and light noises such as fixed pattern noise, photon shot noise, and a read noise, as well as, charge-to-voltage noises are described. Procedures for characterisation of both light and dark noises of the simulated photosensors are provided. Numerical simulation results of a photosensor for high-frame rate Shack-Hartmann wavefront sensor are presented.

8149-16, Poster Session

Influence of photosensor noise on accuracy of cost-effective Shack-Hartmann wavefront sensors
M. V. Konnik, J. S. Welsh, The Univ. of Newcastle (Australia)

A Shack-Hartmann (SH) wavefront sensor (WFS) is used in most modern adaptive optics systems where precision and robustness of centroiding are important issues. The accuracy of the SH WFS depends not only on lenslet quality but also on the measurement accuracy of centroids, especially in low-light conditions. In turn, accuracy depends on light and dark noises that are inevitably present in solid-state photosensors. Using a comprehensive mathematical model of the CMOS photosensor, the accuracy of the Shack-Hartmann wavefront sensor is assessed and analysed for each type of noise.

In this paper, new results regarding the influence of different noise sources from a CMOS photosensor on centroiding in Shack-Hartmann wavefront sensors are presented. For the numerical simulations, a comprehensive mathematical model of photosensor’s noise was formulated. The influence of light and dark noises as well as pixelisation factor have been assessed. Analysis of the wavefront sensor’s accuracy is provided. Results should be of interest for further development of high-speed wavefront sensors.

8149-17, Poster Session

Research on calibration method of LAMOST fiber robot
Z. Liu, Z. Chao, H. Hu, J. Wang, J. Chu, Univ. of Science and Technology of China (China)

Large sky area multi-object fiber spectroscopy telescope (LAMOST) is an innovative reflecting schmidt telescope. One of it’s key technology is 4000 dual rotational fiber robot located in the focal plane.
In accordance with the requirements of the star-observations and the positioning mode of the fiber robot, we confirm seven necessary precise positioning parameters and a calibration curve for each fiber robot. It is difficult to obtain these parameters rapidly in the complex field environment. We attempt to discuss the calibration problem based on CCD, due to the Camera aberration, the spherical focal plane and the high-precision positioning requirement.

We propose a fast calibration method, include of CCD camera calibration using the installation location of the fiber robot in the focal plane, spherical coordinate rotation algorithm, multi-subregion calibration and coordinate splicing based on installation location. Finally, we describes the calibration process of the LAMOST fiber robot.

8149-18, Poster Session

An automated aircraft detection system to prevent aircraft illumination from the laser guide star beacons at the MMT and LBT

K. Newman, M. Hart, The Univ. of Arizona (United States)

High powered guide star laser beams are a potential hazard for aircraft. Currently at the MMT telescope located on Mt. Hopkins in Southern Arizona, five Rayleigh guide stars create a total of 25 W of power at 532nm wavelength. The ARGOS laser guide star for the LBT located on Mt. Graham in Southern Arizona will generate six Rayleigh guide stars with a total of 108 W at 532nm. We present an automated system for use at the MMT and the LBT designed to detect aircraft and shutter the lasers when aircraft illumination is pending. The detection system at the MMT uses a single wide-angle CCD camera mounted to the optical support structure of the telescope. The LBT system employs two wide-field CCDs, and an additional bore-sighted infrared camera. The CCDs integrate frames for 2 seconds to produce streaks from anti-collision beacons required for all aircraft. Successive frames are compared using image processing software to detect streaks and movement in the field. If an aircraft is detected, the position and projected trajectory are calculated and compared to the position of the laser beams. If an aircraft illumination is suspected, the laser safety shutter is closed and a message is sent to the laser operator. As a safety precaution, a "heartbeat" signal is required to keep the laser shutter open.

8149-19, Poster Session

Status report on the large binocular telescope’s ARGOS ground-layer AO system

M. Hart, The Univ. of Arizona (United States); S. Rabien, Max-Planck-Institut für extraterrestrische Physik (Germany); L. Busoni, INAF - Osservatorio Astrofisico di Arcetri (Italy)

ARGOS, the laser-guided adaptive optics system for the Large Binocular Telescope (LBT), is now under construction at the telescope. By correcting atmospheric turbulence close to the telescope, the system is designed to deliver high resolution near infrared image quality over a field of 4 arc minute diameter. Each side of the LBT is being equipped with three Rayleigh laser guide stars derived from six 18 W pulsed green lasers and projected into two triangular constellations matching the size of the corrected field. The returning light is to be detected by wavefront sensors that are range gated within the seeing-limited depth of focus of the telescope. Wavefront correction will be introduced by the telescope’s deformable secondary mirrors driven on the basis of the average wavefront errors computed from the respective guide star constellation. Measured atmospheric turbulence profiles from the site lead us to expect that by compensating the ground-layer turbulence, ARGOS will deliver median image quality of about 0.2 arc sec across the JHK bands. This will be exploited by a pair of multi-object near-IR spectrographs, LUCIFER1 and LUCIFER2, with 4 arc minute field already operating on the telescope.
Testing and calibration of phase plates for JWST optical simulator

Q. Gong, NASA Goddard Space Flight Ctr. (United States); J. Chu, Orbital Sciences Corp. (United States); S. C. Tournois, Sigma Space Corp. (United States); W. L. Eichhorn, D. A. Kubalak, NASA Goddard Space Flight Ctr. (United States)

Three phase plates were designed to simulate the JWST segmented primary mirror wavefront at three on-orbit alignment stages: coarse phasing, intermediate phasing, and fine phasing. The purpose is to verify JWST’s on-orbit wavefront sensing capability. Amongst the three stages, coarse alignment is defined to have piston error between adjacent segments being 30 um to 300 um, intermediate being 0.4 um to 10 um, and fine is below 0.4 um. The phase plates were made of fused silica, and were assembled in JWST Optical Simulator (OSIM). The piston difference was realized by the thickness difference of two adjacent segments. This paper emphasizes the testing and calibration of the phase plates at ambient and cryo. The parameters to be calibrated are piston and wavefront errors. Dispersed Fringe Sensor (DFS) method was used for coarse and intermediate piston measurement. Point Diffraction Interferometer (PDI) was used for fine piston and wavefront error. In order to remove piston’s 2 pi uncertainty with PDI, three laser wavelengths, 640nm, 660nm, and 780nm, were used for the measurement. The same tests were performed at ambient and at cryo. The test setup, analysis algorithm and the results at ambient and cryo are presented. The phase plate design concept and its application (i.e. verifying the JWST on-orbit alignment algorithm) are described. The layout of JWST OSIM and the function of phase plates in OSIM are also addressed briefly.

Development of four-color simultaneous imager for efficient and reliable color measurements in the era of large-scale surveys

D. Kinoshita, C. Wu, T. Chen, R. Huang, P. Shen, National Central Univ. (Taiwan)

A four-color simultaneous imager is now being developed as a first generation astronomical instrument for 2-m telescope which is being built at Lulin observatory in Taiwan. The aim of this instrument is to conduct immediate and intensive follow-up observations of newly identified objects detected by Pan-STARRS PS1 sky surveys. A set of dichroic mirrors split the light from the telescope, and the images are recorded by four CCD imagers. A fully depleted CCD is used for y-band camera to enhance the sensitivity, and three deep depleted CCDs are used for r', i', and z'-band cameras. A simultaneous imager is useful to provide reliable color measurements of transient objects and moving objects even under relatively poor sky conditions. It also improves the observing efficiency. We report the scientific objectives, overall design, development strategy, current status of the development, and characterization of unit cameras under the CCD temperature of -100 deg C.

A panchromatic imaging Fourier transform spectrometer for the NASA Geostationary Coastal and Air Pollution Events Mission

J. Wu, R. W. Key, J. Blavier, S. P. Sander, Jet Propulsion Lab. (United States)

This paper summarizes the design and development of the Panchromatic Imaging Fourier Transform Spectrometer (PanFTS) for the NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) Mission. The PanFTS instrument will advance the understanding of the global climate and atmospheric chemistry by measuring specrally resolved outgoing thermal and reflected solar radiation. With continuous spectral coverage from the near- ultraviolet through the thermal infrared, this instrument is designed to measure pollutants, greenhouse gases, and aerosols as called for by the NASA GEO-CAPE mission. The PanFTS instrument is a hybrid based on spectrometers like the Tropospheric Emissions Spectrometer (TES) that measures thermal emission, and those like the Orbiting Carbon Observatory (OCO), and the Ozone Monitoring Instrument (OMI) that measure scattered solar radiation. Simultaneous measurements over the broad spectral range from UV to IR are accomplished by a two sided interferometer with separate optical trains and detectors for the UV-visible and IR spectral domains. This allows the instrument design to be independently optimized for both spectral domains. The overall design is compact because the two sides share a single common interferometer optical path difference mechanism (OPDM) and metrology laser as well as a number of other instrument systems, including the line-of-sight pointing mirror, the data management system, thermal control system, electrical system, and the mechanical structure. The PanFTS breadboard instrument has been tested in the laboratory and demonstrated the basic functionality for simultaneous measurements in the visible and IR. It is now operating in the field measuring the atmospheric chemistry across the Los Angeles basin.

Emittance properties of multiwalled carbon nanotubes coatings in the infrared spectral region

M. A. Quijada, J. G. Hagopian, S. A. Getty, E. J. Wollack, NASA Goddard Space Flight Ctr. (United States)

Recent visible wavelength observations of Multiwalled Carbon Nanotubes (MWCNT) coatings have revealed that they represent the blackest materials known in nature with a Total Hemispherical Reflectance (THR) less than 0.25%. This makes them as exceptionally good absorbers, with the potential to provide order-of-magnitude improvement in stray-light suppression over current black surface treatments when used in an optical system. Here we extend the characterization of this class of materials into the infrared spectral region to further evaluate their potential for use on instrument baffles for stray-light suppression and to manage spacecraft thermal properties to dissipate heat through radiant heat transfer process. These characterizations will include the wavelength-dependent Total Hemispherical Reflectance properties in the mid-IR and far-infrared spectral regions (2- to 100 µm). Determination of the temperature-dependent emittance will be investigated in the temperature range of 20- to 300 K. These results will be compared against other more conventional black coatings such as Z-306 or Acktar black coatings among others. We will also provide numerical electromagnetic model calculations for tuning the MWCNT growth geometry to further enhance performance in the infrared spectral region.
8150-02, Session 1

A novel approach to tribological measurements at harsh conditions

E. Weltevreden, E. van der Heide, TNO Science and Industry (Netherlands)

When dealing with high-tech equipment, accurate positioning is of the utmost importance to ensure durability and a productive lifetime. Unexpected high friction or wear of positioning mechanisms can lead to unnecessary down-time or products that are not up to specification.

To ensure a sufficient lifetime, it is necessary to know beforehand how the sliding and rolling contacts will behave over time. This demand becomes more stringent when the machine operates at extreme conditions, e.g., vacuum or extremely low temperatures. Traditional greases and mineral oil based lubricants do not perform adequately in such extreme environments, since they either contaminate the vacuum or do not provide sufficient film thickness. TNO recently developed an unique measuring application, the TNO cryotribometer, in order to measure friction and wear of position mechanisms at harsh conditions. The centre of the tribometer consists of a rotating disk, which can be actuated by means of a stepper motor using a feedthrough. Because of the temperature (120 K to 420 K) and the pressure (1 bar to 10-6 mbar) in the vacuum chamber, the feedthrough had to be isolated to ensure a proper measurement. Measurements were conducted using a spherical shaped surface which was placed against the test disk by means of dead-weight. The results show that the contact pressure and the sliding velocity influenced the friction level greatly. This set-up is currently used to find and analyse different material combinations, which demonstrate a constant friction level under cryogenic vacuum conditions. Only when the friction level is constant accurate positioning can be guaranteed.

8150-03, Session 1

Cryogenic half-wave plate polarimeter using a superconducting magnetic bearing

J. M. Klein, Univ. of Minnesota, Twin Cities (United States)

We present an implementation of a superconducting magnetic bearing (SMB) for use as a rotation mechanism for half-wave plate (HWP) polarimetry and discuss the integration of this system into a millimeter-wave balloon-borne polarimeter. In this implementation the 24 cm diameter HWP is enclosed by NdFeB ring magnets, which forms the stator of the SMB. The stator is made of YBCO high temperature superconductor and is heat sunk to a liquid helium bath. At temperatures above the superconducting transition of YBCO, a warm support mechanism suspends the rotor relative to the stator and provides sufficient thermal conductance to cool the 5.6 kg rotor to 77 K in less than 20 hours. The rotor is belt-driven by a pulley that is connected to a motor outside the cryostat. A rotor-mounted chopper wheel, in combination with a cryogenic laser and diode detector, provide angular encoding for the HWP. We demonstrate robust, remote operation of this system with the EBEX balloon-borne payload. Rotation speed was 2 Hz, RMS angular encoding accuracy during the flight was 0.01 degrees and RMS rotation speed variation was 0.2 %. We discuss sources of power dissipation and rotation speed variations. We characterize the resonant frequencies and time constants of the system. We find that the radial resonance frequency is r(2) that of the axial one, consistent with predictions for an SMB. The implementation is a candidate for low noise space applications because of the absence of stick-slip friction and low wear.

8150-04, Session 1

A flux-pinning mechanism for segment assembly and alignment

J. A. Gersh-Range, M. A. Peck, Cornell Univ. (United States); H. P. Stahl, Marshall Space Flight Ctr. (United States)

Currently, the most compelling astrophysics questions include how planets and the first stars formed and whether there are protostellar disks that contain large organic molecules. Although answering these questions will require space telescopes with apertures of at least 10 meters, it is challenging to construct such large space telescopes by scaling up previous designs; the limited capacity of a launch vehicle places an upper bound on the diameter of a monolithic primary, and beyond a certain size, deployable telescopes cannot fit in any current launch vehicle fairing. One potential solution is to connect the primary mirror segments edgewise using flux-pinning mechanisms. A type of interaction between a magnet and a type II superconductor, flux pinning is analogous to a damped spring force.

In the baseline design, a flux-pinning mechanism consists of a magnet and a superconductor separated by a predetermined gap, with the amount of damping adjusted by placing aluminum near the interface. Since flux pinning is possible only when the superconductor is cooled below a critical temperature, flux-pinning mechanisms are uniquely suited for cryogenic space telescopes. These non-contact mechanisms operate best at low temperatures, unlike mechanical mechanisms, which can have problems with lubrication, CTE matching, and thermal snap. By placing these mechanisms along the edges of the mirror segments, a primary can be built up over time. Since flux pinning requires no mechanical deployments, the assembly process can be robotic or use some other non-contacting scheme. Advantages of this approach include scalability and passive stability.

8150-05, Session 1

Space and air-borne sensor testing in a cryogenic test environment at Arnold Engineering Development Center


Performance testing of space imaging systems is crucial to meeting the requirements of such systems for all types of space applications. The use of infrared scene projection systems in the cryo-vacuum ground test environment is essential to this testing and is a challenging task. Experiences from the space test facilities at Arnold Engineering Development Center (AEDC) can offer lessons learned from its experience in projection technologies, optical system design, optical material characteristics and measurement (including cryodeposition), positioning systems, and pertinent analytical tools involved in performing ground testing of a sensor system under flight conditions. For over 30 years, the space chambers at AEDC have performed space sensor characterization, calibration, and mission simulation testing on space-based, interceptor, and air-borne sensors. This paper describes recent work at AEDC in the utilization and proposed enhancement of this cryo-vacuum test capability.

8150-06, Session 2

James Webb space telescope system cryogenic optical test plans

L. D. Feinberg, NASA Goddard Space Flight Ctr. (United States); M. Waldman, Sigma Space Corp. (United States); A. A. Barto, Ball Aerospace & Technologies Corp. (United States); T. L. Whitman, ITT Corp. Geospatial Systems (United States)

The James Webb Space Telescope Optical Telescope Element (OTE) and Optical Telescope Element/Integrated Science Instrument Module (OTIS) will be tested at the same time in the final and only cryogenic optical test of the full observatory. Due to the size and temperature of JWST, this is a complex test which has undergone changes in the last year aimed at reducing test execution risk. We will summarize the test plan changes, architecture changes, and predicted timeline changes for this test. We will also explain the checkout plans for assuring the test will go smoothly.
Cryogenic performance of the JWST primary mirror segment engineering development unit

D. M. Chaney, Ball Aerospace & Technologies Corp. (United States); J. B. Hadaway, The Univ. of Alabama in Huntsville (United States); J. A. Lewis, B. B. Gallagher, R. J. Brown, Ball Aerospace & Technologies Corp. (United States)

The JWST (James Webb Space Telescope) primary mirror consists of 18 hexagonal mirror segments each approximately 1.5 meters point to point. The mirror segments are constructed from a lightweight beryllium substrate with both a radius-of-curvature actuation system and a six degree-of-freedom hexapod actuation system. The manufacturing process for each individual mirror assembly takes approximately six years due to limitations dealing with the number of segments and manufacturing & test facilities. In order to catch any manufacturing or technology roadblocks, as well as to streamline specific processes, an Engineering Development Unit (EDU) was built to lead the mirror manufacturing flow. This development unit has all of the same requirements as the flight units and is actually considered to be one of the flight spare mirrors. The EDU was manufactured with a lead time of approximately six months over the other mirrors to assure adequate time to optimize each step in the manufacturing process. Manufacturing and test occurred at six locations across the U.S. with multiple trips between each. The EDU recently completed this arduous process with the final cryogenic performance test of the mirror assembly taking place at Marshall Space Flight Center’s (MSFC) X-Ray & Cryogenic Facility (XRCF). Testing included survivability tests to 25 Kelvin, hexapod & radius-of-curvature actuation systems testing, and cryogenic figure & prescription testing. Presented here is a summary of the tests performed along with the results of that testing.

Cryogenic thermal distortion performance characterization for the JWST ISIM structure


The James Webb Space Telescope (JWST) Integrated Science Instrument Module (ISIM) Structure is a precision optical metering structure for the JWST science instruments. Optomechanical performance requirements place stringent limits on the allowable thermal distortion of the metering structure. A significant effort was completed to develop capabilities to predict and metrologize cryogenic thermal distortion of the ISIM Structure. This paper focuses on thermal distortion finite element modeling, analysis, and model validation for the flight structure. Extensive thermal distortion analysis was completed during the design phase for the ISIM Structure to demonstrate that thermal distortion requirements were achieved. Recently completed cryogenic performance testing has verified that the ISIM Structure meets optomechanical performance requirements related to cooldown from ambient to cryogenic operating temperatures (~35 K). The extensive metrology dataset generated during performance testing has been used to validate predictions from the thermal distortion model. Comparison of test measurements and model predictions demonstrate the adequacy of thermal distortion modeling uncertainty factors adopted during the design phase, and provide a bound on the accuracy of the model predictions. This paper will provide an overview of the test configuration and results, describe the thermal distortion model of the test, and provide a comparison of test results and analytical predictions from the model.

The wavelength calibration of the JWST near infrared spectrograph (NIRSpec)

S. M. Birkmann, T. Böker, P. Ferruit, G. Giardino, P. Jakobsen, G. de Marchi, M. Sirianni, M. B. J. te Plate, J. Savignol, European Space Research and Technology Ctr. (Netherlands); X. Gnata, T. Wettmann, EADS Astrium GmbH (Germany); B. Dorner, Observatoire de Lyon (France); G. Cresci, INAF - Osservatorio Astrofisico di Arcetri (Italy); F. Rosales-Ortega, Univ. Autonoma de Madrid (Spain); M. Stuhlinger, European Space Astronomy Ctr. (Spain); R. E. Cole, J. A. Tandy, C. Brockley-Blatt, Univ. College London (United Kingdom)

The Near Infrared Spectrograph (NIRSpec) is one of four science instruments aboard the James Webb Space Telescope (JWST) that is to be launched later this decade. NIRSpec is sensitive in the wavelength range from ~0.6 to 5.0 micron and operates at temperatures ≤ 40 K. It offers multi-object, fixed slit, and integral field spectroscopy with seven selectable dispersers. The on-ground spectrophotometric calibration of the instrument is performed by means of continuum and line emission lamps. NIRSpec also contains an internal calibration assembly (CAA) that will provide the wavelength and radiometric calibration in orbit. Due to thermal constrains, the CAA features low power tungsten filament lamps in combination with long-pass and Fabry-Perot like interference filters, which need to be calibrated at instrument level. We will report on the wavelength calibration of the NIRSpec flight model and the CAA, carried out during the first cryogenic performance testing. Emphasis will be put on the challenges that can be expected when using temperature dependent, resolved lines with asymmetrical profiles for wavelength calibration.
8150-12, Session 3

Calibrating the position of images and spectra in the NIRSpec instrument

G. de Marchi, S. M. Birkmann, T. Böker, P. Ferruit, G. Giardino, P. Jakobsen, M. Siranini, M. B. J. te Plate, J. Savgnol, European Space Research and Technology Ctr. (Netherlands); X. Gnata, R. Barho, M. Kosse, P. Mosner, EADS Astrium GmbH (Germany); B. Dorner, Observatoire de Lyon (France); G. Cresci, INAF - Osservatorio Astrofisico di Arcetri (Italy); F. Rosales-Ortega, Univ. Autónoma de Madrid (Spain); M. Stuhlinger, European Space Astronomy Ctr. (Spain); T. Gross, T. Leikert, Carl Zeiss Optronics GmbH (Germany)

The Near Infrared Spectrograph (NIRSpec) is one of four science instruments aboard the James Webb Space Telescope (JWST). NIRSpec offers multi-object, fixed slit, and integral field spectroscopy in the wavelength range from -0.6 to 5.0 micron. There are eight user selectable optical elements in NIRSpec, six gratings, a double-pass prism, and a mirror. All these elements are mounted on the grating wheel assembly (GWA). The precise knowledge of the position and tilt of the mirror is critical for target acquisition, and that of the dispersers essential for an accurate extraction of science data. Therefore, the GWA is equipped with magneto-resistive position-sensing sensors. We will present the first results concerning the stability and repeatability of the GWA, obtained during the NIRSpec flight model ground test campaign, and the performance of the sensors and their calibration.

8150-13, Session 4

JWST NIRCam flight mirror assemblies

P. V. Mammini, H. C. Holmes, L. W. Huff, F. P. Lopez, M. S. Jacoby, Lockheed Martin Space Systems Co. (United States)

The Near Infrared Camera (NIRCam) instrument for NASA’s James Webb Space Telescope (JWST) has an optical prescription which includes numerous fold mirror assemblies. The instrument will operate at 37K after experiencing launch loads at ~293K and the optic mounts must accommodate all associated thermal and mechanical stresses, plus maintain an exceptional wavefront during operation. Lockheed Martin Space Systems Company (LMSSC) conceived, designed, assembled, tested, and integrated the mirror assemblies for the NIRCam instrument.

This paper covers the design, assembly, and test of two of the instruments key fold mirrors; First Fold Mirror Assembly and Shortwave Fold Mirror Assembly.

8150-14, Session 4

NIRCam coronagraphic Lyot stop: design, fabrication, and testing

Y. Mao, T. S. Kubo, T. B. Andersen, M. Virgen, H. M. Chan, G. S. Feller, L. W. Huff, S. F. Sommerstein, E. H. Smith, Lockheed Martin Space Systems Co. (United States); S. D. Horner, NASA Ames Research Ctr. (United States); J. E. Krist, C. A. Beichman, Jet Propulsion Lab. (United States); C. Barone, R. Schmidt, D. Levin, S. Seymour, Max Levy Autograph, Inc. (United States); D. M. Kelly, M. J. Rieke, The Univ. of Arizona (United States)

The NIRCam instrument on the James Webb Space Telescope (JWST) will provide coronagraphic image capability to search for extrasolar planets in the wavelength range 2 - 5 microns. This capability is realized by a set of Lyot pupil stops with patterns matching the occulting mask located in the JWST intermediate focus plane in the NIRCam optical system. The complex patterns with transparent apertures are made by photolithographic process with metal coating in the opaque region. The optical density needs to be high for the opaque region, and transmission needs to be high at the aperture. The Lyot stop needs to be operated at cryogenic conditions. We will report the Lyot stop design, fabrication and testing in this paper. This work was performed and funded by NASA Goddard Space Flight Center under Prime Contract NASS-02105.

8150-15, Session 4

Flight build of the collimator and shortwave camera optics for the NIRCam instrument

E. T. Kvamme, H. C. Holmes, Lockheed Martin Space Systems Co. (United States)

The Near Infrared Camera (NIRCam) instrument for NASA’s James Webb Space Telescope (JWST) has an optical prescription which employs six triplet lens cells. The instrument will operate at 37K after experiencing launch loads at ~293K and the optic mounts must accommodate all associated thermal and mechanical stresses, plus maintain an exceptional wavefront during operation. The Lockheed Martin Advanced Technology Center (LMATC) has built and tested the collimator and camera optics for use on the NIRCam flight instrument. This paper presents an overview of the driving requirements, a brief overview of the changes in the opto-mechanical design since our last presentation, a discussion of the collimator and shortwave camera triplet assembly processes, and finally the mechanical and optical test results as they relate to mechanical and optical performance.

8150-16, Session 4

Design, build, and test of the NIRCam focal plane array housing

D. R. Little, M. S. Jacoby, E. R. Casco, Lockheed Martin Space Systems Co. (United States)

The Near Infrared Camera (NIRCam) instrument for NASA’s James Webb Space Telescope (JWST) has an optical prescription which terminates at two focal plane arrays for each module. The instrument will operate at 37K after experiencing launch loads at ~293K and the focal plane array housings must accommodate all associated thermal and mechanical stresses, while keeping the FPAs aligned. The main purpose of the FPAH is to provide a stray light, contamination, and radiation shield to the Focal Plane Assemblies. The design includes a fold mirror used to direct incoming light up to the detectors and mechanical support for the Application Specific Integrated Circuits (ASIC). A six degree of freedom shim is used to align the Focal Plane Assembly at the operating temperature of 37 Kelvin. This paper will provide an overview of the FPAH design including an update to the Fold Mirror design described in previous papers. Analysis and test results of the ambient temperature optical and vibration testing will be presented.

8150-17, Session 5

Tracking the surface figure error of the pick off mirror throughout build and environmental testing of the focus and alignment mechanism qualification unit of the near infrared camera of JWST

B. Witherspoon, Lockheed Martin Space Systems Co. (United States)

The Pick Off Mirror (POM) sits at the end of the Focus and Alignment Mechanism (FAM) of NIRCam. The POM takes the light delivered by the
telescope and steers it into the NIRCam instrument. At strategic points during the build and test of the Pick Off Mirror and its mechanism (the FAM) the surface figure error (SFE) of the mirror was monitored. This metric was used to track the health of the mirror throughout this testing regime. For example, the team ran an SFE test before and after Vibration testing the FAM. In this paper, we will provide an overview of the testing regime and the results of these periodic SFE tests. These results lead to the qualification of the POM and FAM designs for flight on the James Webb Space Telescope.

8150-18, Session 5
Qualifying the flight design of the focus and alignment mechanism of the near infrared camera on the James Webb space telescope
B. Witherspoon, Lockheed Martin Space Systems Co. (United States)

The Focus and Alignment Mechanism (FAM) is the opto-mechanical, cryogenic mechanism that positions the Pick Off Mirror (POM) for the Near Infrared Camera of the James Webb Space Telescope. The POM is used to direct the light collected by the telescope into the Near Infrared Camera. This paper is a follow on to SPIE Paper 7439C-49. In this paper, we will summarize the design and role of this opto-mechanical mechanism and present the results of the environmental testing of the Qualification Unit. The testing consisted of 7 thermal cycles from ambient temperature to 26 Kelvin, as well as a 2 X Mechanism Life test at this cryogenic temperature plateau. These results lead to the qualification of the POM and FAM designs for flight on the James Webb Space Telescope.

8150-19, Session 5
Redesign and test of cryogenic mechanism for improved stiffness
C. S. Clark, M. S. Jacoby, P. V. Mammini, H. C. Holmes, Lockheed Martin Space Systems Co. (United States)

The Near Infrared Camera (NIRCam) instrument for NASA is one of the four science instruments installed into the Integrated Science Instrument Module (ISIM) of the James Webb Space Telescope (JWST) intended to conduct scientific observations over a five year mission lifetime. The NIRCam instrument will have a Pupil Imaging Lens actuator assembly (PIL) to provide a means of imaging the primary mirror for ground testing, instrument commissioning, and diagnostics which must operate at from 293K to 37K and be in support of the usual launch environments.

More refined optic prescriptions and initial PIL vibration test data lead to the re-design of the PIL. This paper discusses the re-design of the lens mounts to accommodate a new optic prescription. This paper also details the analysis of vibration test data that lead to the re-design of a stiffer bearing mount for the PIL flight mechanism that would ultimately be tested to show appropriate margins for meeting program vibration test requirements.

8150-20, Session 5
Fret wear mediation of NIRCam filter wheel assembly
B. I. Privari, Lockheed Martin Space Systems Co. (United States)

We will discuss a fret wear solution developed for the James Webb Space Telescope NIRCam filter wheel assembly by implementation of a hard coating. With mechanisms and structures designed for space flight application, titanium is often selected as the choice material of construction. Titanium offers a low-density high strength material that is good for use with many optical instruments due to its' favorable thermal properties. An important factor to consider with titanium mechanisms and structures are component fits and the vibration environment that must be survived during launch. In many instances, small (slip) fits between titanium components can cause fret wear during launch induced vibration. Titanium is particularly susceptible to fret wear, although other materials also demonstrate the fret wear. A discussion of several coating alternatives and associated wear testing will be presented along with the selection of an optimal solution.

8150-22, Session 5
Top lessons learned during the development of components for NIRCam
A. A. Nordt, Lockheed Martin Martin Space Systems Co. (United States)

No abstract available
Laboratory demonstration of high-contrast imaging at inner working angles better than 2 I/D

R. Belikov, E. Pluzhnik, F. C. Witteborn, D. H. Lynch, T. P. Greene, P. T. Zell, NASA Ames Research Ctr. (United States); O. Guyon, The Univ. of Arizona (United States)

Coronagraph technology is advancing and promises to directly image and spectrally characterize extrasolar Earth-like planets in the foreseeable future (such as the 2020 decade) with a telescope as small as 1.5m. A small Explorer-sized telescope can also be launched in the 2010 decade capable of seeing debris disks as dim as tens of zodis and potential planets. The Phase Induced Amplitude Apodization (PIAA) coronagraph makes such aggressive performance possible, providing high throughput and high contrast close to the diffraction limit. We report on the latest results from a testbed at NASA Ames that is focused on developing and testing the PIAA coronagraph. This laboratory facility was built in 2008 and is designed to be flexible, operated in an actively thermally stabilized environment, and to complement collaborative efforts at NASA JPL’s High Contrast Imaging Testbed. For our wavefront control we are using small Micro-Electro-Mechanical-System deformable mirrors (MEMS DMs), which promise to reduce the size of the beam and overall instrument, a consideration that becomes very important for small telescopes. We describe our lab progress and results, which include (as of February 2010): the demonstration of 5.4e-8 average raw contrast in a dark zone from 2.0 - 5.2 I/D and of 3.6e-6 contrast from 1.5-2.5 I/D (in monochromatic light); the testing of the next-generation reflective PIAA mirror set built by Tinsley and designed for broadband; and finally, the testing of a slightly modified PIAA coronagraph that is capable of achieving 1e-6 contrasts at 1 I/D.

Influence of surface errors on the design of PIAA mirrors using numerical and semi-analytical propagation models.

A. Carlotti, Princeton Univ. (United States); L. Pueyo, The Johns Hopkins Univ. (United States)

A ray-optics designed PIAA pair of mirrors cannot provide the contrast levels necessary to the direct detection of exo-earth. Apodizing the edges of the incoming beam before it reaches the first mirror can increase this contrast. Since the pre-apodizer only attenuates the diffraction effects due to the propagation from the first mirror to the second one, its benefits can be cancelled if the surface quality of the mirrors is too low. As the pre-apodizer limits the throughput of the system, estimating its actual ability to increase the contrast is crucial. In order to estimate the influence of the surface errors on the usefulness of the pre-apodizer, we compute the propagated electric field using two different tools: the semi-analytical model developed by Pueyo and a purely numerical model based on the Huygens integral. Random cosines aberrations are introduced through the mapping function in the first case and directly on the mirrors surfaces in the second. A statistical analysis is then made and the results are compared and discussed. It appears that there is a limit to the maximum contrast that PIAA mirrors can provide. This limit is set by the surface quality and cannot be reached by increasing the strength of the pre-apodizer but with a higher deformation of the mirrors and a smaller distance between them. Finally, as an adaptive optics system must be used to attenuate the optical aberrations created outside of the PIAA, it can also be used to increase the final contrast.

Low-cost diamond turned high-precision PIAA optics: laboratory results and novel high-throughput designs

K. Balasubramanian, E. J. Cady, Jet Propulsion Lab. (United States); L. Pueyo, The Johns Hopkins Univ. (United States); S. B. Shaklan, X. An, Jet Propulsion Lab. (United States); R. Belikov, NASA Ames Research Ctr. (United States); O. Guyon, The Univ. of Arizona (United States)

Of-axis, high-sag PIAA optics for high contrast imaging present challenges in manufacturing and testing. With smaller form factors and consequently smaller surface deformations (<30 microns), diamond turned fabrication of these mirrors becomes feasible. Though such a design reduces the system throughput, it still provides 2/D inner working angle. We report on the design, fabrication, measurements, and initial assessment of the novel PIAA optics in a coronagraph testbed. We also describe a four mirror PIAA coronagraph that relaxes apodizer requirements and significantly improves throughput while preserving the low-cost benefits.

Studies of the effects of optical system errors on the HCIT contrast performance

E. Sidick, S. B. Shaklan, A. Give’on, B. D. Kern, Jet Propulsion Lab. (United States)

The High Contrast Imaging Testbed (HCIT) at the Jet Propulsion Laboratory employs a broadband wavefront correction algorithm called Electric Field Conjugation (EFC) to obtain the required 10-10 contrast. This algorithm works with one or multiple deformable mirrors (DM’s) to create a “dark hole” in a predefined region of the image plane where terrestrial planets would be found. It achieves the desired high contrast level in two stages. The first is the reconstruction stage. In this stage, the algorithm provides an estimate of the aberrated complex electric field in the image plane based on pairs of images taken at the final image plane using different DM configurations. The second is the correction or the electric field conjugation stage. In this stage the algorithm generates a correction based on the electric field estimated in the first stage. The correction is then applied to the DM actuators to null the image electric
field in the predefined dark-hole region.

We have investigated the effects of DM actuator errors and the optic position errors on the efficiency of the EFC algorithm in a Lyot coronagraph configuration. Considered cases include dead actuators, lateral and longitudinal movement of the occluding mask, and the lateral movement of a flat optical surface. The structural design of the optical system as well as the parameters of various optical elements used in the analysis are drawn from those of the HCIT system that have been implemented with one DM. The simulation takes into account the surface errors of various optics. The optical simulation algorithm uses MACOS (Modeling and Analysis for Controlled Optical Systems) as its analytic tool. Hence it is capable of performing full three-dimensional near-field diffraction analysis on HCIT’s optical model. Results of some of these studies have been verified by actual measurements.

8151-06, Session 1

Exosystem modeling with multiple data sources
D. Savransky, N. J. Kasdin, Princeton Univ. (United States)

We present a unified description of exosystem data gathered by various means (including astrometry, doppler spectroscopy, transit photometry and imaging) as partial observations of a Markov process defined by a single parameter set. Using dynamic filtering and sequential parameter estimation, this description allows us to systematically update existing exosystem models with new observations and derive estimates of the fit parameter errors. We present multiple examples of potential applications for various combinations of detection methods and discuss the utility of known distributions of exosystem parameters to initialization of all forms of orbit fitting.

8151-07, Session 1

Taking the vector vortex coronagraph to the next level for ground- and space-based exoplanet imaging instruments: review of technology developments in the USA, Japan, and Europe
D. P. Mawet, European Southern Observatory (ESO) (Chile) and Jet Propulsion Lab. (United States); N. Murakami, Hokkaido Univ. (Japan); C. Delacroix, O. Absil, Univ. de Liège (Belgium); N. Baba, Hokkaido Univ. (Japan); J. Baudrand, A. Boccaletti, Observatoire de Paris à Meudon (France); R. Burruss, Jet Propulsion Lab. (United States); R. A. Chipman, College of Optical Sciences, The Univ. of Arizona (United States); S. Habraken, Univ. de Liège (Belgium); S. Hamaguchi, Hokkaido Univ. (Japan); C. Hanot, Univ. de Liège (Belgium); A. Ise, Hokkaido Univ. (Japan); M. Karlsson, Uppsala Univ. (Sweden); B. D. Kern, J. E. Krist, A. C. Kuhnert, B. P. Mennesson, D. Moody, Jet Propulsion Lab. (United States); H. Murakami, Japan Aerospace Exploration Agency (Japan); A. F. Niessner, Jet Propulsion Lab. (United States); J. Nishikawa, National Astronomical Observatory of Japan (Japan); N. O’Brien, JDSU (United States); K. Oka, Hokkaido Univ. (Japan); P. Park, Jet Propulsion Lab. (United States); P. Piron, Univ. de Liège (Belgium); L. Pueyo, The Johns Hopkins Univ. (United States); P. Riaud, Univ. de Liège (Belgium); M. Sakamoto, Hokkaido Univ. (Japan); E. Serabyn, Jet Propulsion Lab. (United States); M. Tamura, National Astronomical Observatory of Japan (Japan); J. T. Trauger, Jet Propulsion Lab. (United States); D. Shemo, JDSU (United States); J. Surdej, Univ. de Liège (Belgium); N. Tabirian, BEAM Engineering for Advanced Measurements Co. (United States); W. Traub, J. K. Wallace, Jet Propulsion Lab. (United States); K. Yokochi, Tokyo Univ. of Agriculture and Technology (Japan)

The Vector Vortex Coronagraph (VVC) is one of the most promising next generation coronagraphs for future ground- and space-based exoplanet imaging/characterization instruments, as recently demonstrated on sky and in the lab. It provides small inner working angle, high throughput, simplicity of implementation. It has recently demonstrated high contrasts (these proceedings).

Manufacturing technologies for devices covering wavelength ranges from the optical to the mid-IR, are maturing quickly. We will review the current status of technology developments supported by NASA in the USA (Jet Propulsion Laboratory, University of Arizona, JDSU and Beam Co), Europe (University of Liege, Observatoire de Paris-Meudon, University of Uppsala) and Japan (Hokkaido University, and Photonic lattice), using liquid crystal polymers, subwavelength gratings, and photonic crystals, respectively.

We will then focus on concrete perspectives for the use of the VVC on upcoming extreme adaptive optics facilities, extremely large ground-based telescopes, and space-based internal coronagraphs.

8151-08, Session 1

Stability error budget for an aggressive coronagraph on a 3.8-m telescope
S. B. Shaklan, L. F. Marchen, J. E. Krist, M. Rud, Jet Propulsion Lab. (United States)

We evaluate in detail the stability requirements for a band-limited coronagraph with an inner working angle as small as 2 lambda/D coupled to an off-axis, 3.8-m diameter telescope. We have updated our methodologies since presenting similar work for the Terrestrial Planet Finder Coronagraph mission that worked at 4 lambda/D and employed an 8th-order mask to reduce aberration sensitivities. In the previous work, we determine the tolerances relative to the total light leaking through the coronagraph. Now, we separate the light into a radial component, which is readily separable from a planet signal, and an azimuthal component, which is easily confused with a planet signal. In the current study, throughout consideration results in a 4th-order coronagraph. This, combined with the more aggressive working angle, places extraordinarily tight requirements on wavefront and opto-mechanical stability. We find that the stability requirements are driven mainly by coma that leaks around the coronagraph mask and mimics the localized signal of a planet, and focus that scatters light into the background, decreasing SNR. We also show how the requirements would be relaxed if a low-order aberration detection system could be employed.

8151-09, Session 1

Imaging power of fibered nulling telescopes for extra-solar planets characterization
F. Hénault, Univ. de Nice Sophia Antipolis (France)

We discuss the imaging properties of monolithic pupil, nulling telescopes equipped with a focal plane waveguide array, which could be envisaged as a precursor space mission for future nulling interferometer arrays searching for habitable planets outside of our solar system. Three different concepts of nulling telescopes are reviewed, namely the unmasked Sheared-Pupil Telescope (SPT), a variant of the SPT where the exit pupil is limited by a Lyot stop, and a Super-Resolving Telescope (SRT) having multiple, non-overlapping exit sub-apertures. For each case simple theoretical relationships allowing to estimate the nulling rate, Signal-to-Noise Ratio (SNR) and Inner Working Angle (IWA) of the telescopes are established or recalled, and numerical simulations are conducted. The results of this preliminary study show that the most promising designs should either be the masked SPT having reduced entrance sub-pupils, or a SRT associated with an adequate...
leakage calibration procedure, depending whether deep nulling or high radiometric efficiency are preferred.

8151-10, Session 1

Current results of the PERSEE testbench: the cophasing control and the polychromatic null rate

J. Lozi, ONERA (France) and Ctr. National d’Études Spatiales (France) and Partenariat Haute resolution Angulaire Sol Espace (France); F. Cassaing, ONERA (France) and Partenariat Haute resolution Angulaire Sol Espace (France); J. Le Duigou, Ctr. National d’Études Spatiales (France); B. Sorrente, J. Montri, ONERA (France) and Partenariat Haute resolution Angulaire Sol Espace (France); J. Reess, E. Lhome, J. M. Buey, Observatoire de Paris à Meudon (France) and Partenariat Haute resolution Angulaire Sol Espace (France); F. Hénault, A. Marcotto, P. Girard, Observatoire de la Côte d’Azur (France); M. Bariliot, Thales Alenia Space (France); M. Ollivier, Univ. Paris-Sud 11 (France); V. Couédé du Foresto, Observatoire de Paris à Meudon (France) and Partenariat Haute resolution Angulaire Sol Espace (France)

Stabilizing a nulling interferometer at a nanometric level is the key issue to obtain deep null depths. The PERSEE breadboard has been designed to study both cophasing and typical null rate, in the most realistic disturbing environment of a space mission. This presentation focuses on the current results of the PERSEE bench. In terms of metrology, we cophased at 0.33 nm rms for the piston and 60 mas rms for the tip/tilt. A Linear Quadratic Gaussian (LQG) control coupled with an unsupervised vibration identification allows us to maintain that level of correction, even with characteristic vibrations of nulling interferometry space missions. Those performance, with an accurate design and alignment of the bench, currently lead to a polychromatic unpolarised null depth of 1.6e-5 stabilized at 2e-7 on the [1.65-2.4] um spectral band (38% bandwidth). This recent null depth can be improve by optimizing the calibration scheme. With those significant results, we give the first more general lessons we have already learned from this experiment, both at system and component levels for a future space mission.

8151-11, Session 1

The possibility of application of polarization-holographic elements for the discovery and characterization of exoplanets

G. A. Kakauridze, B. N. Kilosanidze, Institute of Cybernetics (Georgia)

The information on the state and degree of polarization of light scattered by the atmosphere of the exoplanets and reflected from their surface can give the possibility of their detection and characterization. A polarimetric method provides an additional channel of information by finding polarization signal against a background of a unpolarized starlight. Polarization- holographic element with complex distribution of anisotropy and gyrotropy in the band is suggested for detection and characterization of exoplanets by means of real time analysis of the state and degree of polarization of light that went into the entrance pupil of the telescope and also determination of the dispersion of this state. The main advantage of such an element is its extraordinary simplicity and compactness, which is especially important for its installation on the space telescopes. Unlike currently used astropolariometers the polarimeter on the basis of such an element will not contain any mechanically moving or electronically tunable components, and will not introduce any distortion in the polarization state of light, as there will be no reflections from any internal surfaces which causes its accuracy. The element decomposes the light incident on it into the orthogonal circular and linear basis forming diffraction orders. The element has an angular dispersion and decomposes each diffraction order into four Stokes parameters to be determined and the dispersion of this state. The possibility of the creation of suitable high effective element and its application for main goal is discussed.

8151-12, Session 2

TPF-Interferometer: a decade of development in exoplanet detection technology


The last decade has seen great advances in interferometric nulling technology, propelled at first by the SIM and KECK nulling programs and then by the Terrestrial Planet Finder Interferometer. In the infrared at N-band (using a CO2 laser at 10.6 micron wavelength) the first million to one nulls were reported on a KECK testbed in 2003. For TPF-I, nulls needed to be both deep and broadband, and a suite of testbeds was designed and built to study all aspects of achromatic nulling and system implementation, including formation flying technology. Also, observational designs were drawn up and studied against performance models. Models revealed that natural variations in the alignment and control of the optical system produced an “instability noise” signal and this realization led to a redesign of the preferred layout (at least on this side of the Atlantic) to a rectangular formation. The complexity of the early TPF-I spacecraft design was mitigated by the infusion of ideas from Europe and produced the current X-Array design which utilizes simple reflectors to form the apertures together with a stretched three dimensional formation geometry. This paper summarizes the main achievements of the infrared nulling technology program including the development of adaptive nulling for broadband performance and the demonstration of starlight suppression by 100 million to one.

8151-13, Session 2

Assessing the performance limits of internal coronagraphs through end-to-end modeling: a NASA TDEM study

J. E. Krist, D. P. Mawet, Jet Propulsion Lab. (United States); R. Belikov, NASA Ames Research Ctr. (United States); L. Pueyo, The Johns Hopkins Univ. (United States); D. Moody, J. T. Trauger, S. B. Shaklan, Jet Propulsion Lab. (United States)

We are conducting a study of three internal coronagraphs (PIAA, vector vortex, hybrid bandlimited) to understand their behaviors in realistically-aberrated systems with wavefront control (deformable mirrors). This study consists of two milestones: (1) develop wavefront propagation codes appropriate for each coronagraph that are accurate to 1% or better (compared to a reference algorithm) but are also time and memory efficient, and (2) use these codes to determine the wavefront control limits of each architecture. We discuss the results from the study so far, with emphasis on representing the PIAA and vector vortex coronagraphs and the wavefront control behaviors of those systems. This study is funded by the NASA ROSES Technology Demonstrations for Exoplanet Missions (TDEM) program.

8151-14, Session 2

Vacuum nuller testbed performance, characterization and null control

Technologies Corp. (United States); M. A. Helmbrecht, Iris AO, Inc. (United States)

The Visible Nulling Coronagraph (VNC) can detect and characterize exoplanets with filled, segmented and sparse aperture telescopes, thereby spanning the choice of future internal coronagraph exoplanet missions. NASA/Goddard Space Flight Center (GSPC) has developed a Vacuum Nuller Testbed (VNT) to advance this approach, and assess and advance technologies needed to realize a VNC as a flight instrument. The VNT is an ultra-stable testbed operating at 15 Hz in vacuum. It consists of a Mach-Zehnder nulling interferometer; modified with a "W" configuration to accommodate a hex-packed MEMS based deformable mirror (DM), coherent fiber bundle and achronatic phase shifters. The 2-output channels are imaged with a vacuum photon counting camera and conventional CCD. Error-sensing and feedback to DM and delay line with control algorithms are implemented in a real-time architecture. The inherent advantage of the VNC is that it is its own interferometer and directly control its errors by exploiting images from bright and dark channels simultaneously. Conservation of energy requires the sum total of the photon counts be conserved independent of the VNC state. Thus sensing and control bandwidth is limited by the target stars throughput, with the net effect that the higher bandwidth offloads stressing stability tolerances within the telescope.

We report our recent progress with the VNT towards achieving an incremental sequence of contrast milestones of 10^-8, 10^-9 and 10^-10 respectively at inner working angles approaching 2l/D. Discussed will be the optics, lab results, technologies, and null control. Shown will be evidence that the milestones have been achieved.

8151-15, Session 2

A hybrid Lyot coronagraph for the direct imaging and spectroscopy of exoplanet systems


We report the design, fabrication, and performance of a hybrid focal-plane occulter for Lyot coronagraphy. It is composed of thickness-profiled metallic and dielectric thin films, vacuum deposited on a fused silica substrate. Band-limited in both the real and imaginary parts of the complex attenuation pattern, it provides the theoretical basis for mathematically perfect angular suppression. Together with a deformable mirror for control of wavefront phase, the hybrid Lyot coronagraph potentially exceeds billion-to-one contrast over dark fields extending to within 3 lambda/D of the central star, over spectral bandwidths of 20% or more, and with throughput efficiencies up to 60%.

The science capabilities of the hybrid Lyot coronagraph are described in the context of the ACCESS mission, a representative exoplanet space telescope concept study for the direct imaging and spectroscopy of exoplanet systems. This work has been supported by NASA's Technology Development for Exoplanet Missions (TDEM) program.

8151-16, Session 2

Phase-induced amplitude apodization (PIAA) coronagraphy: recent results and future prospects

O. Guyon, The Univ. of Arizona (United States) and Subaru Telescope, National Astronomical Observatory of Japan (United States); R. Belikov, NASA Ames Research Ctr. (United States); B. D. Kern, A. C. Kuhnert, A. Give'on, S. B. Shaklan, Jet Propulsion Lab. (United States)

The Phase Induced Amplitude Apodization (PIAA) concept uses aspheric optics to apodize a telescope beam for high contrast imaging. The lossless apodization, achieved through geometrical redistribution of the light (beam shaping) allows designs of high performance coronagraphs, ideally suited for direct imaging of exoplanets similar to Earth around nearby stars. The PIAA coronagraph concept has evolved since its original formulation to mitigate manufacturing challenges and improve performance. Our group is currently aiming at demonstrating PIAA coronography in the laboratory to 1e-9 raw contrast at 2 lambda/D separation. Recent results from the High Contrast Imaging Testbed (HCIT) at NASA JPL demonstrate contrasts about one order of magnitude from this goal at 2 lambda/D.

In parallel with our high contrast demonstration at 2 lambda/D, we are developing and testing new designs at a complementary testbed at NASA Ames, and solving associated technical challenges. Some of these new PIAA designs have been tested that can further mitigate PIAA manufacturing challenges while providing theoretically total starlight extinction and offering 50% throughput at less than 1 lambda/D. Recent tests demonstrated on the order of 1e-6 contrast close to 1 l/D (while maintaining 5e-8 contrast at 2 l/D).

8151-17, Session 2

Advanced speckle sensing for internal coronagraphs

M. C. Noecker, Ball Aerospace & Technologies Corp. (United States); S. B. Shaklan, J. K. Wallace, Jet Propulsion Lab. (United States); R. Belikov, NASA Ames Research Ctr. (United States); N. J. Kasdin, Princeton Univ. (United States)

A 4-8m telescope carrying a coronagraph instrument is a leading candidate for an anticipated flagship mission to detect and characterize Earth-size exoplanets in the 2020s. The telescope and instrument will need exquisite stability and precise control of the incoming wavefront to enable detection of faint companions (1e-10 of the star) at an angular separation of 2-4 Airy radii. In particular, wavefront errors cause speckles in the image, and variations in those speckles can confound the exoplanet detection. This challenge is compounded by the background light from zodiacal dust around our Sun and the target star, which limits the speed with which we can estimate and correct the speckles. We are working on developing coherent speckle detection techniques that will allow rapid calibration of speckles on the science detector, allowing subtraction in post-processing or correction with deformable mirrors. The expected speed improvement allows a much quicker timeline for measurement & calibration, which reduces the required telescope stability requirement and eases both the flight system design and the challenge of ground testing. We will describe the experiments and summarize progress to date.

8151-18, Session 2

Design, tolerancing, and prototyping of starshades for exoplanet detection and characterization

N. J. Kasdin, D. N. Spergel, Princeton Univ. (United States); D. Lisman, S. B. Shaklan, M. W. Thomson, L. F. Marchen, P. J. Dumont, Jet Propulsion Lab. (United States); D. J. Tenerelli, Lockheed Martin Space Systems Co. (United States); B. A. Macintosh, R. E. Rudd III, Lawrence Livermore National Lab. (United States); J. Mikula, NASA Ames Research Ctr. (United States)

Starshades provide the starlight suppression needed for detecting and characterizing exoplanets with a much simpler telescope and instrument than is required for the equivalent performing coronagraph. In this paper we describe progress on our Technology Development for Exoplanet Missions project to design, manufacture, and measure a prototype occulter petal. We focus on the key requirement of manufacturing a
8151-19, Session 2  
**A photon-counting detector for exoplanet missions**

D. F. Figer, J. Y. Lee, D. J. Stauffer, B. J. Hanold, Rochester Institute of Technology (United States)

This paper summarizes progress of a project to develop photon-counting detectors for NASA exoplanet missions through a radiation testing program. The project, funded by NASA ROSES TDEM, uses a 256x256 pixel silicon Geiger-Mode Avalanche Photodiode (GM-APD) per pixel, each individually bump-bonded to a silicon readout circuit. Each pixel independently registers the arrival of a photon and can be reset and ready for another photon within 100 ns. The pixel has built-in circuitry for independently counting photo-generated events. The readout circuit is multiplexed to read out the photon arrival events. The signal chain is inherently digital, allowing for noiseless transmission over long distances. The detector always operates in photon counting mode and is thus not susceptible to excess noise factor that afflicts other technologies. It continues operating with shot-noise limited performance up to extremely high flux levels, >10^6 photons/second/pixel, and delivers signal-to-noise ratios on the order of thousands for higher fluxes. Its performance is expected to be maintained at a high level throughout mission lifetime in the presence of the expected radiation dose.

8151-20, Session 3  
**The exoplanet microlensing survey by the proposed WFIRST Observatory**

J. Kruk, D. Bennett, E. Cheng, S. Gaudi, N. A. Gehrels, NASA Goddard Space Flight Ctr. (United States); A. M. Tanner, Georgia State Univ. (United States); T. Sumi, Osaka Univ. (Japan); R. K. Barry, NASA Goddard Space Flight Ctr. (United States); W. Traub, J. H. Catanzarite, Jet Propulsion Lab. (United States); S. Kane, California Institute of Technology (United States); J. Anderson, Space Telescope Science Institute (United States); J. Beaulieu, Institut d’Astrophysique (France)

The New Worlds, New Horizons report released by the Astronomy and Astrophysics Decadal Survey Board in 2010 listed the Wide Field Infrared Survey Telescope (WFIRST) as the highest-priority large space mission for the coming decade. This observatory provides wide-field imaging for the coming decade. This observatory provides wide-field imaging and slitless spectroscopy at near infrared wavelengths. The scientific goals are to obtain a statistical census of exoplanets using gravitational microlensing, measure cosmic acceleration by multiple methods, and perform other astronomical surveys to be selected through a guest observer program.

A Science Definition Team has been established to assist NASA in the development of a Design Reference Mission that accomplishes this diverse array of science programs with a single observatory. In this paper we will present the current WFIRST payload concept and the expected capabilities for planet detection.

8151-21, Session 4  
**The performance of SPHERE in the integration lab**

F. P. Wildi, Observatoire de Genève (Switzerland); K. Dohlen, L. Le Mignant, Observatoire Astronomique de Marseille-Provence (France); J. Charton, A. Costille, S. Rochat, D. Mouillet, J. L. Beuzit, Lab. d’Astrophysique de l’Observatoire de Grenoble (France); M. Feldt, Max-Planck-Institut für Astronomie (Germany); P. Puget, Lab. d’Astrophysique de l’Observatoire de Grenoble (France); A. Baruffolo, INAF - Osservatorio Astronomico di Padova (Italy); A. Boccaletti, Observatoire de Paris à Meudon (France); R. U. Claudi, INAF - Osservatorio Astronomico di Padova (Italy); P. Feautrier, Lab. d’Astrophysique de l’Observatoire de Grenoble (France); T. Fusco, ONERA (France); R. G. Gratton, INAF - Osservatorio Astronomico di Padova (Italy); M. Kasper, European Southern Observatory (Germany); M. P. Langlois, Ctr. de Recherche Astronomique de Lyon (France); A. Pavlov, Max-Planck-Institut für Astronomie (Germany); C. Petit, ONERA (France); J. H. Pragt, ASTRON (Netherlands); P. Rabou, Lab. d’Astrophysique de l’Observatoire de Grenoble (France); R. Roelfsema, ASTRON (Netherlands); J. Sauvage, ONERA (France); H. M. Schmid, ETH Zurich (Switzerland)

SPHERE, the extra-solar planet imager for the Very Large Telescope is a program that has been running since 2006. The instrument is now nearing completion and it is in the final integration stage in 2011. The 3 science instruments of SPHERE have now been completed and have passed the internal acceptance, while the complex common path with the extreme Adaptive optics system, the coronographs and the calibration module is aggressively progressing.

This presentation will review the performance of the three focal instruments of SPHERE at the time of their internal acceptance (The dual band imager, the integral field spectrograph and the imaging polarimeter) as they were measured in their integration facilities, using an entrance optical beam simulating a perfect AO system.

In addition, we will present the performance of the AO system which is integrated separately from the rest of the system.

Last but not least, we will also disclose the very first results obtained on the fully integrated system.

8151-22, Session 4  
**The ZIMPOL high-contrast imaging polarimeter for SPHERE: sub-system test results**

R. Roelfsema, ASTRON (Netherlands); D. Gisler, ETH Zurich (Switzerland); J. H. Pragt, ASTRON (Netherlands); H. M. Schmid, A. Bazzoni, ETH Zurich (Switzerland); C. Dominik, Univ. van Amsterdam (Netherlands); A. Baruffolo, INAF - Osservatorio Astronomico di Padova (Italy); J. Beuzit, J. Charton, Lab. d’Astrophysique de l’Observatoire de Grenoble (France); K. Dohlen, Observatoire Astronomique de Marseille-Provence (France); M. Downing, European Southern Observatory (Germany); E. Elswijk, ASTRON (Netherlands); M. Feldt, Max-Planck-Institut für Astronomie (Germany); M. de Haan, ASTRON (Netherlands); N. Hubin, M. Kasper, European Southern Observatory (Germany); C. U. Keller, Utrecht Univ. (Netherlands); J. Lizon, European Southern Observatory (Germany); D. Mouillet, Lab. d’Astrophysique de l’Observatoire de Grenoble (France); A. Pavlov, Max-Planck-Institut für Astronomie (Germany); P. Puget,
8151-23, Session 4

Near infrared interferometric spectroscopy with TEDI

J. Edelstein, Univ. of California, Berkeley (United States); D. J. Erskine, Lawrence Berkeley National Lab. (United States); P. S. Muirhead, K. R. Covey, Cornell Univ. (United States); M. W. Muterspaugh, Tennessee State Univ. (United States); P. M. Andelson, D. Kimber, D. Mondo, A. Vanderburg, M. M. Sirk, Univ. of California, Berkeley (United States); J. P. Lloyd, Cornell Univ. (United States)

The TripleSpec - Exoplanet Discovery Instrument (TEDI) interferometric spectrometer, a hybrid of an interferometer and a moderate resolution echelle spectrograph (TripleSpec, R=2,700), performs radial velocity and spectral synthesis at infrared wavelengths (0.9 - 2.4 µm) from the Cassegrain focus of the Palomar 200" telescope. Here we present results from on-sky observations of standard and science targets following an instrumental upgrade development. Velocity precision stability of < 30 m/s and six-fold spectral resolution boosting has been achieved.

8151-24, Session 4

First light results for the fibered imager for single telescope (FIRST) on the Lick 3m-Shane telescope

E. Huby, G. S. Perrin, Observatoire de Paris à Meudon (France); F. Marchis, Univ. of California, Berkeley (United States); S. Lacour, Observatoire de Paris à Meudon (France); T. Kotani, Japan Aerospace Exploration Agency (Japan); E. L. Gates, Lick Observatory (United States); E. Choquet, Observatoire de Paris à Meudon (France); G. Duchene, Univ. of California, Berkeley (United States); J. M. Wolville, W. M. Keck Observatory (United States)

We present the first on-sky results obtained with the Fibered Imager for Single Telescope (FIRST). Observations have been made in July (7 nights) and October (5 nights) 2010 at Lick Observatory with the 3m-Shane Telescope and using its Adaptive Optics system optimized in the near-infrared.

The FIRST instrument combines both techniques of single mode fibers interferometry and pupil remapping. The pupil of the telescope is divided into several sub-pupils. The flux corresponding to each sub-pupil is injected into single mode fibers such that the spatial phase fluctuations are removed (only atmospheric piston terms remain). The fiber outputs are rearranged according to a non redundant configuration in order to measure the visibilities and phases for each baseline independently. The principle is the same as for the technique of aperture masking but in our case we can use the entire pupil and thus increase the sensitivity.

Simulations predict a dynamic range up to 10^6 close to the central star (~0") at visible to near-infrared wavelengths (corresponding to a few tens of milliarcseconds at 600nm with an 8m-telescope). Laboratory experiments successfully demonstrated the cogency of the concept. We have recently set up a 9fibers-prototype on the 3m-Shane telescope and the first on-sky observations confirmed it as well : the first measured closure phases on a non resolved star (Vega) are biased (11°) but stable (4° rms).

8151-25, Session 4

The Subaru coronagraphic extreme AO project

F. Martinache, O. Guyon, V. Garrel, C. Clergeon, Subaru Telescope, National Astronomical Observatory of Japan (United States); T. D. Groff, Princeton Univ. (United States); P. Stewart, The Univ. of Sydney (Australia); R. Russell, Subaru Telescope, National Astronomical Observatory of Japan (United States); C. Blain, Univ. of Victoria (Canada)

In 2009 our group started the integration of the SCExAO project, a highly flexible, open platform for high contrast imaging at the highest angular resolution, inserted between the coronagraphic imaging camera HICIAO and the 188-actuator AO system of Subaru. In its first version, SCExAO combines a MEMS-based wavefront control system feeding a high performance PIAA-based coronagraph, that apodizes the telescope pupil while preserving throughput and angular resolution. It also includes a coronagraphic low-order wavefront sensor, a non-redundant aperture mask and a visible imaging mode with fast low readout detector, all of them designed to take full advantage of the angular resolution (40 mas in the H-band) that an 8-meter telescope has to offer. We present the first on-sky results acquired during SCExAO’s spring 2011 engineering campaign and discuss the lessons learned from them.

8151-26, Session 4

The Subaru coronagraphic extreme AO (SCExAO) system: fast visible imager

V. Garrel, O. Guyon, Subaru Telescope, National Astronomical Observatory of Japan (United States); P. Baudoz, Observatoire de Paris à Meudon (France); F. Martinache, Subaru Telescope, National Astronomical Observatory of Japan (United States); P. Stewart, The Univ. of Sydney (Australia); J. Lozi, ONERA (France); T. D. Groff, Princeton Univ. (United States)

The Subaru Coronagraphic Extreme Adaptive Optics (SCExAO) system is an instrument designed to be inserted between the Subaru AO188
We are developing a diffractive pupil concept for space-based states). E. A. Bendek, O. Guyon, The Univ. of Arizona (United States); R. A. Shaklan, M. Shao, Jet Propulsion Lab. (United States); R. A. Woodruff, Lockheed Martin Space Systems Co. (United States)

A concept for high precision astrometry with a conventional wide field telescope is presented, enabling a space telescope to perform simultaneously coronagraphic imaging of exoplanets, astrometric measurement of their orbits and masses, and deep wide field imaging for a wide range of astroophysical investigations.

Our concept uses a diffractive telescope pupil (primary mirror), obtained by placing a regular grid of small submillimeter spots on the primary mirror coating. When the telescope is pointed at a bright star, the wide field image contains both a large number of background stars used for astrometric referencing, and faint diffraction spikes created by the grid of dots on the primary mirror. The diffraction spikes encode instrumental astrometric distortions due to optics or the detector, allowing precise measurement of the central star against a large number of faint background stars.

With up to a few percent of the primary mirror area covered by the dots, the fraction of the central starlight located in the diffraction spikes is kept sufficiently small to allow full sensitivity deep imaging over the telescope’s field of view. Since the dots are regularly spaced, they do not diffract light at small angular separations, and therefore allow full coronagraphic imaging capability. We show that combining simultaneous astrometric and coronagraphic measurements allows improved detection and characterization of exoplanets by constraining the planet(s) characteristics with both measurements. Our preliminary astrometric accuracy error budget shows that sub-microarcsecond astrometry can be achieved with a ~1.5 m diameter telescope, and that astrometric accuracy improves rapidly with telescope diameter.

**8151-27, Session 5**

**Diffractive pupil telescope for high-precision space astrometry**

O. Guyon, The Univ. of Arizona (United States) and Subaru Telescope (United States); E. A. Bendek, College of Optical Sciences, The Univ. of Arizona (United States); S. M. Ammons, Lawrence Livermore National Lab. (United States); T. D. Milster, College of Optical Sciences, The Univ. of Arizona (United States); R. Beilokov, NASA Ames Research Ctr. (United States); S. B. Shaklan, M. Shao, Jet Propulsion Lab. (United States); R. A. Woodruff, Lockheed Martin Space Systems Co. (United States)

We describe applications of this concept to ground-based uncrowded astrometry using a transmissive pupil mask and a wide-field camera to image ~100 background reference stars (30’x30’). Final relative astrometric precision is limited by differential tip/tilt jitter caused by high altitude layers of turbulence. A small telescope (< 2 m) equipped with a transmissive pupil mask would achieve single-axis precision of 70 microarcseconds per epoch in 1 hour on bright stars (V < 12) and a large telescope (6-10 m) could achieve as low as 10 microarcseconds, an order of magnitude better than space-based facilities available today. Permitting the sky to naturally roll and averaging signals over many thousands of pixels helps to mitigate the effects of detector imperfections. We present a proposed design to test the concept with a 20” diffractive pupil mask on a small telescope in Arizona.

**8151-29, Session 5**

**Dynamic distortion calibration using a diffracting pupil: high-precision astrometry laboratory demonstration for exoplanet detection**

E. A. Bendek, College of Optical Sciences, The Univ. of Arizona (United States); S. M. Ammons, Lawrence Livermore National Lab. (United States); T. D. Milster, College of Optical Sciences, The Univ. of Arizona (United States); O. Guyon, The Univ. of Arizona (United States)

Detection of earth-size exoplanets using the astrometric signal of the host star requires sub microarcsecond measurement precision. One major challenge in achieving this precision using a medium-size (<2-m) space telescope is the calibration of dynamic distortions. We propose a diffractive pupil technique, which uses an array of approximately 50μm dots on the primary mirror that generate polychromatic diffraction spikes in the focal plane. The diffraction spikes encode optical distortions in the optical system and may be used to calibrate astrometric measurements. This concept can be used simultaneously with coronagraphy for exhaustive characterization of exoplanets (mass, spectra, orbit). At University of Arizona a high precision astrometry laboratory is being developed to demonstrate the capabilities of this diffractive pupil concept. We aim to achieve 10 μas single-axis precision in the laboratory, simulating 0.14 μas precision on a 1.4 m space telescope. Here we describe this laboratory and present the data and results obtained so far. We consider a plan to test a diffractive pupil with a high contrast PIAA coronograph to demonstrate that the diffraction spikes do not affect the coronagraph performance, as they diffract light only at large angular separations, well outside the coronagraph field of view.
stellar images to 1e-5 pixels, and for this to happen we have to know where the pixels are at 1e-5 pixels as well as the OEx(x,y) within each pixel. This paper describes the mission concept as proposed to ESA as an M class mission.

The mission could search 75–100 nearby stars for planets as small as the Earth in a 1 AU orbit.

The telescope is a single long focus off axis parabola.

8151-31, Session 5

Micropixel-level image position sensing testbed
B. Nemati, M. Shao, C. Zhai, H. Erlig, R. Goulioud, X. Wang, Jet Propulsion Lab. (United States)

Image position sensing at the few micro-pixels level would enable technology for a wide range of astronomical goals, from search for exoplanets to dark energy. Monitoring the position of an image to this level of accuracy requires metrology of the pixel positions, knowledge of the intra-pixel quantum efficiency variation, as well as a linearized image position algorithm. JPL’s Micropixel Centroiding Testbed (MCT) uses a low-expansion bench to stabilize the locations of fiber tips which illuminate a CCD with a set of ‘stars’ as well as heterodyne metrology fringes. In this paper we describe the test and present the first results.

8151-32, Session 6

Designing an optimal estimator for more efficient wavefront correction
T. D. Groff, N. J. Kasdin, Princeton Univ. (United States)

Space-based coronagraphs for future earth-like planet detection will require focal plane wavefront control techniques to achieve the necessary contrast levels. These correction algorithms are iterative and the control methods require an estimate of the electric field at the science camera, which requires nearly all of the images taken for the correction. In order to maximize science time the amount of time required for correction must be minimized which means reducing the number of exposures required for correction. This drives reducing both the number of iterations and the number of exposures per iteration required to achieve a targeted contrast. Given the large number of images required for estimation, the ideal choice is to use fewer exposures to estimate the electric field. Here we demonstrate an optimal estimator that uses prior knowledge to create the estimate of the electric field. In this way we can optimally estimate the electric field by minimizing the number of exposures required to estimate under an error constraint. The performance of this method is compared to a pairwise estimator which is designed to give the least-squares minimal error. This allows us to evaluate the number of images necessary to achieve a contrast target and is the first step towards generating an adaptive algorithm which combines estimation and control to optimize the entire correction problem.

8151-33, Session 6

Unified coronagraph and wavefront control design
N. J. Kasdin, A. Carlotti, T. Groff, R. J. Vanderbei, Princeton Univ. (United States)

Numerous coronagraph designs for high-contrast have been proposed over the last decade with a number of them in advanced stages of technology development. These coronagraph designs are differentiated by various performance metrics, such as throughput, inner working angle, bandwidth, ease of implementation (a surrogate for cost), sensitivity, and robustness. Some are being considered for very high-contrast (greater than 10^11) and small inner working angles to enable imaging of terrestrial planets in the habitable zone of nearby stars. In this paper we show that every coronagraph works on the same principal—to modify the amplitude of the electric field across the exit pupil in order to create a final high-contrast image. This may be done through apodization, phase plates, remapping, or phase and amplitude adjustment at intermediate image planes. Unfortunately, phase and amplitude errors in the telescope limit the achievable contrast.

All practical systems must include the capability for both amplitude and phase control of the wavefront. We demonstrate that whatever coronagraph is chosen, it need only be designed to achieve contrast to the level at which amplitude errors dominate. The remaining contrast will be achieved via the wavefront control system; the final inner working angle is determined by the deformable mirrors. We present a number of designs using shaped pupils and multiple deformable mirrors and discuss the design trade-offs.

8151-34, Session 6

Optimizing broadband wavefront control to correct amplitude and phase aberrations
T. D. Groff, N. J. Kasdin, A. Carlotti, Princeton Univ. (United States)

The Stroke Minimization algorithm developed at the Princeton High Contrast Imaging Laboratory has proven symmetric dark hole generation using minimal stroke on two deformable mirrors (DM) in series. We extend the concept of minimizing DM actuation to achieve symmetric dark holes in broadband light. This requires simultaneously correcting both amplitude and phase aberrations over the bandwidth. Here we address the relationship of amplitude and phase aberrations with wavelength and the implication for wavefront control and design tolerances. This drives the number of deformable mirrors, their locations in the optical path, and design constraints on the deformable mirrors. Broadband suppression is achieved experimentally by using three wavelengths to define the bandwidth of correction in the optimization problem. This windowed approach to Stroke Minimization makes the optimization in wavelength tractable and allows for estimation only at a single wavelength which reduces the number of exposures required for correction. The output of the estimation algorithm is extended to the higher and lower wavelengths by establishing a functional relationship of the image plane electric field in wavelength. The accuracy of the functional relationship will ultimately bound the achievable bandwidth, therefore as a metric these results are also compared to estimating each wavelength separately.

8151-35, Session 6

Pair-wise, image plane-based electric field estimation for high-contrast coronagraphy
A. Give’on, B. D. Kern, S. B. Shaklan, Jet Propulsion Lab. (United States)

In this paper we describe the estimation methodology for image plane-based electric field measurements for high contrast coronagraphic imaging. A deformable mirror (DM) shape is modified to create diversity in the image plane of the science camera where the intensity of the light is measured. The DM is adjusted to create complementary pairs of intensity patterns from which the complex field is estimated. Along with the Electric Field Conjugation correction algorithm, this estimation method has been used in various high contrast imaging testbeds to achieve the broadest contrasts to date. We demonstrate the effectiveness of this method through laboratory experiments for both narrow-band light (2%) and broadband light (10%).
8151-36, Session 6

**Kernel-phases for high-contrast detection beyond the resolution limit**

F. Martinache, Subaru Telescope, National Astronomical Observatory of Japan (United States)

The detection of high contrast companions at small angular separation appears feasible in conventional direct images using the self-calibration properties of interferometric observable quantities. In the high-Strehl regime, soon to be available thanks to the coming generation of extreme Adaptive Optics systems on ground based telescopes, and already available from space, quantities comparable to the closure-phase are used with great success in non-redundant masking interferometry, can be extracted from direct images, even taken with a redundant aperture. These new phase-noise immune observable quantities, called kernel-phases, are determined a-priori from the knowledge of the geometry of the pupil only. Analysis of HST/NICMOS archive and other ground based AO images, using this new kernel-phase algorithm, demonstrates the power of the method, and its ability to detect companions at the resolution limit and beyond.

---

8151-37, Session 7

**Nondimensional representations for occulter design and performance evaluation**

E. J. Cady, S. B. Shaklan, Jet Propulsion Lab. (United States)

An occulter is a spacecraft with a precisely-shaped optical edges which flies in formation with a telescope, blocking light from a star while leaving light from nearby planets unaffected. Using linear optimization, occulters can be designed for use with telescopes over a wide range of telescope aperture sizes, science bands, and starlight suppression levels. It can be shown that this optimization depends primarily on a small number of independent nondimensional parameters, which correspond to Fresnel numbers and physical scales and enter the optimization only as constraints. We show how these can be used to span the parameter space of possible optimized occulters; this data set can then be mined to determine occulter sizes for various mission scenarios and sets of engineering constraints. This also may be used to compare performance for missions of different scales and bandpasses, and we use this to discuss some point designs applicable to future telescopes.

---

8151-38, Session 7

**A starshade petal error budget for exo-earth detection and characterization**

S. B. Shaklan, L. F. Marchen, D. Lisman, E. J. Cady, S. R. Martin, Jet Propulsion Lab. (United States); N. J. Kasdin, Princeton Univ. (United States); P. J. Dumont, Jet Propulsion Lab. (United States)

We have looked in detail at the shape requirements on starshade petals and have found several factors that significantly relax the requirements compared to our earlier work. First, by adopting an observational scenario where the occulter spins about its axis on timescales short relative to the zodi-limited integration time, typically several hours, scatter from localized petal errors is smoothed into annuli around the center of the image plane. This results in a large reduction in the background flux variation. It also reduces thermal gradients. Second, after completing development of a prototype petal and planning a second one, several manufacturing errors were found to be negligible, allowing us to allocate a larger fraction of the error budget to the more challenging aspects. Finally, a more thorough Monte-Carlo analysis of random errors allowed us to relax requirements compared to several ‘worst case’ scenarios reported earlier. We compare the requirements for four cases: we assume telescope of 1.5 and 4 m diameter, and inner working angles of 75 and 90 mas.

---

8151-39, Session 7

**Position sensing and control at the Princeton occulter testbed**

D. Sirbu, Princeton Univ. (United States); E. J. Cady, Jet Propulsion Lab. (United States); N. J. Kasdin, R. J. Vanderbei, M. Carr, M. Galvin, E. Kao, M. McLlwain, J. A. Spechler, Princeton Univ. (United States)

Direct imaging of planets around other solar systems requires starlight suppression. One space-based mission concept involves the usage of an external occulter, a second spacecraft specially shaped to create a deep shadow on the space telescope. At the Princeton Occulter Testbed, a subscale experiment was designed to test long-distance beam propagation and verify the numerical diffraction propagation. We present a scheme for inferring relative position of the occulter and telescope from diffraction leakage outside of the suppression passband. In this experiment, the optical mask consists of an inner portion which represents the scaled occulter mask and an outer ring that minimizes diffraction effects at the dark hole. A new optical mask was designed with the inner mask operating over a suppression band covering the visible wavelengths and an outer ring that minimizes diffraction effects over the camera’s sensitivity wavelengths. The testbed was also outfitted with two-degrees of freedom control at the observation plane that allows a position sensing experiment to determine sensitivity localization sensitivity.

---

8151-40, Poster Session

**Higher-precision radial velocity measurements with the SOPHIE spectrograph using octagonal-section fibers**

S. Perruchot, Observatoire de Haute-Provence (France); F. Bouchy, Institut d’Astrophysique de Paris (France) and Observatoire de Haute-Provence (France); I. Boisse, Institut d’Astrophysique de Paris (France); R. F. Díaz, G. Hébrard, Institut d’Astrophysique de Paris (France) and Observatoire de Haute-Provence (France); A. Santerne, Observatoire Astronomique de Marseille-Provence (France); B. Chazelas, F. A. Pepe, Observatoire de Genève (Switzerland); G. Moreaux, Observatoire Astronomique de Marseille-Provence (France); K. Arnaud, D. Tézier, Ctr. de Physique des Particules de Marseille (France); G. Avila, European Southern Observatory (Germany)

High-precision spectrographs play a key role in exoplanet searches using the radial velocity techniques. But at the accuracy level of 1 m/s, required for super-Earth characterization, stability of spectrograph performance is crucial considering variable observing conditions such as seeing, guiding errors, telescope vignetting and ambient temperature.

In fiber-fed spectrographs such as HARPS or SOPHIE, the fiber link scrambling properties are one of the main issues. Both the stability of the fiber near-field uniformity at the spectrograph entrance and of the far-field illumination on the echelle grating (pupil) are critical for high-precision radial velocity measurements because of the spectrograph geometrical field and aperture aberrations. We conducted tests on the SOPHIE spectrograph at the 1.93-m OHP telescope to measure the instrument sensitivity to the fiber link light feeding conditions: star decentering, telescope vignetting by the dome, defocussing.

To significantly improve on current precision, we studied a fiber link modification considering the spectrograph operational constraints. We have thus developed a new link which includes a piece of octagonal-section fiber, having good scrambling properties, lying inside the former circular-section one, and we tested the concept on a bench to characterize near-field and far-field scrambling properties.

This modification has been implemented in Spring 2011 on all four links of the SOPHIE spectrograph and tested for the first time directly on
the sky to demonstrate the gain compared to the previous fiber link. Scientific validation for exoplanet search and characterization has been achieved by observing standard stars and known low-mass exoplanets.

8151-41, Poster Session
Design of a star, planet and exo-zodiacal cloud simulator for the nulling testbench PERSEE
F. Hénault, P. Girard, A. Marcotto, N. Mauclet, Univ. de Nice Sophia Antipolis (France); J. Le Duigou, Ctr. National d’Études Spatiales (France)

On-going developments on the PERSEE nulling testbench include the realization of a focal plane simulator featuring one central star, an extra-solar planet orbiting around it, and Exo-Zodiacal Clouds (EZC) surrounding the observed stellar systems. PERSEE (Pégase Experiment for Research and Stabilization of Extreme Extinction) is a laboratory testbench jointly developed by a Consortium of six French institutes and companies, incorporating Observatoire de la Côte d’Azur (OCA) who is in charge of the manufacturing and procurement of the future Star and Planet Simulator (SPS). In this communication is presented a complete description of the SPS, including general requirements, techniques employed for simulating the observed planet and EZC, opto-mechanical design and expected performance. Current status of the activities is summarized in the conclusion.

8151-42, Poster Session
Debris sightings in the Kepler field
F. C. Witteborn, J. Van Cleve, W. J. Borucki, NASA Ames Research Ctr. (United States); V. S. Argabright, Ball Aerospace & Technologies Corp. (United States); P. Hascall, Orbital Network Engineering Inc. (United States)

A small fraction of Kepler telescope exposures are rejected because of transient, excess background in the field. The patterns of illumination vary from broad streaks to diffuse patches, sometimes filling the focal plane. Examination of such images and their temporal variation shows that they can be attributed to nearby particles crossing the field-of-view of the telescope. Most of the particles appear to be receding. The visual appearance and frequency are consistent with the “debris storms” reported by STEREO SECCHI observers and which they found to be coincident with meteoroid impacts. In addition, a few events, lasting several hours each, appear to be caused by more distant, extended sources. The tracking cameras, located at the opposite end from the telescope’s entrance, and pointed at roughly right angles to its line-of-sight, also detected moving light sources. Their behavior was consistent with the main telescope sightings. Future missions requiring precise, uninterrupted photometry and pointing may benefit from understanding this phenomenon and mitigating it by design and data analysis.

8151-44, Poster Session
Relaxing the sensitivity of nuller coronagraphs to finite stellar diameters using apodization
A. Carlotti, Princeton Univ. (United States); C. J. Aime, Univ. de Nice Sophia Antipolis (France); Y. Rabia, Observatoire de la Côte d’Azur (France)

Nuller coronagraphs such as the Achromatic-Interfero-Coronagraph can perfectly cancel the starlight by destructively interfering it with itself, if the star is unresolved and exactly on-axis. Small pointing errors as well as the finite stellar diameter of the targeted star can however ruin the performances of this type of coronagraph. Observed at 600nm with an AIC behind a 10m telescope, the Sun at 10pc would present an apparent angular diameter of 1 mas that would induce a star-leakage of 10^-6 at 0.1°. The expected flux ratio between a Sun-like star and an Earth-like planet is however much higher (10^-10 in the visible). We show through an analytical formalism that an apodized nuller coronagraph (ANC) can achieve planet detections with much higher contrasts. We use for demonstrative purposes specific apodization profiles such as Sonine profiles, concentric ring profiles or cosine profiles. Expressions of the local contrast ratio and of the signal-to-noise ratio are derived. The possibility to estimate the performances of other types of apodizations such as spheroidal prolate apodizations through numerical simulations is considered, although the additional integration over the stellar disk is computationally challenging.

8151-45, Poster Session
Pressure and temperature stabilisation of an existing Échelle spectrograph II
F. U. Grupp, Max-Planck-Institut für extraterrestrische Physik (Germany) and Univ.-Sternwarte München (Germany); A. Brucalassi, Max-Planck-Institut für extraterrestrische Physik (Germany); F. Lang, Univ.-Sternwarte München (Germany); S. M. Hu, Shandong Univ. (China); R. Holzwarth, Max-Planck-Institut für Quantenoptik (Germany) and Menlo Systems GmbH (Germany); T. Udem, Max-Planck-Institut für Quantenoptik (Germany); U. Hopp, Univ.-Sternwarte München (Germany); R. Bender, Max-Planck-Institut für extraterrestrische Physik (Germany)

First results from the pressure stabilization and extended temperature stabilization of the existing FOCES high resolution Échelle spectrograph are presented with this paper. A pressure stabilize environment slightly above the environmental weather dependant pressure is created for FOCES. In addition a two layer onion shell like temperature stabilization is applied to keep the instrument stable with respect to environmental conditions. Detailed analysis of the level of stability for both temperature and pressure are performed. First results of the instrument stability are being evaluated in this stabilized environment.

8151-46, Poster Session
Speckle identification to assist the direct detection of exoplanets
E. Young, N. J. Kasdin, A. Carlotti, M. G. Littman, Princeton Univ. (United States); M. C. Noecker, Ball Aerospace & Technologies Corp. (United States)

One of the major limitations to detecting exoplanets in high-contrast images is confusion with residual quasi-static speckles, formed due to aberrations in the optical system. Speckles look like the image of a planet, therefore threatening the planet detection. However, we can take advantage of their different behavior and optical coherence by using interference to distinguish speckles from the image of a planet. Princeton is designing and building a testbed suitable for coherent speckle detection studies. Our technique adds deliberate perturbations to a deformable mirror (DM) to create a reference field from the starlight on the image plane detector. Large variations in intensity on the detector are therefore caused due to the interference between the prior residual speckle field and the reference field. We study specific functions on the DM to see the new reference field created and to capture an image. We then analyze the series of images (as we change the known function placed on the DM) to estimate the amplitude and phase of the speckles. The interference term allows us to distinguish speckles from the incoherent planet signals. This generic technique works with any type of
Wide-field telescope design for the KMTNet project

S. Kim, B. Park, C. Lee, Korea Astronomy and Space Science Institute (Korea, Republic of); L. G. Kappler, N. Kappler, TBR Construction & Engineering (United States); W. M. Poteet, H. Cauthen, D. R. Blanco, CP Systems, Inc. (United States); J. U. Lee, Cheongju Univ. (Korea, Republic of); M. K. Cho, National Optical Astronomy Observatory (United States); I. Yuk, M. Chun, Korea Astronomy and Space Science Institute (Korea, Republic of); H. Jin, Kyung Hee Univ. (Korea, Republic of); J. U. Teran, S. Freestone, M3 Engineering & Technology Corp. (United States); S. Cha, Korea Astronomy and Space Science Institute (Korea, Republic of)

The Korea Astronomy and Space Science Institute (KASI) will develop three 1.6m optical telescopes for the Korea Micro-lensing Telescope Network (KMTNet) project.

These will be installed at three southern observatories with different time zones by early 2014 to monitor dense star fields like the Galactic bulge and Large Magellanic Cloud. The primary scientific goal of the project is to discover numerous extra-solar planets using the gravitational microlensing technique.

We have completed the final design of the telescope. The most critical design issue was wide-field optics. The project science requires the Delivered Image Quality (DIQ) of less than 1.0 arcsec FWHM within 1.2 degree radius FOV, under atmospheric seeing of 0.75 arcsec.

We chose the prime-focus configuration and realized the DIQ requirement by using four corrector lenses with all spherical surfaces.

We will also present the design details such as the optical alignment, focus system with three linear actuators on the top ring, and friction drive system.

Achieving high-precision ground-based photometry for transiting exoplanets

O. Guyon, Subaru Telescope, National Astronomical Observatory of Japan (United States)

An analysis of the sources of error affecting ground-based transit photometric accuracy is presented. The terms other than photon noise can be dramatically reduced by hardware choices and data processing algorithms. In particular, the effect of scintillation can be reduced by apodization of the pupil, proper time weighting of the measurements, and simultaneous multi-color photometry. Differential extinction can be calibrated by a combination of PSF modeling, multi-color photometry, and analysis of spatial and temporal correlations in a wide field image. Conventional imaging systems are thus usually poorly suited for high precision photometry.

A low cost camera system was recently deployed on the Mauna Loa observatory to increase our understanding of the effects limiting photometric precision and test some of the improvements achieved by hardware and data reduction techniques optimized for transit photometry. The system offers a 150 sq deg field with a 70mm entrance aperture, and a 3-band simultaneous photometry at a 0.01 Hz sampling. The detector is a low-cost commercial 3-color CMOS array, and is an attractive cost-effective choice for high precision transit photometry. The design of the system and early results are presented.

8151-49, Poster Session

Recent results of the second generation of vector vortex coronagraphs on the high-contrast imaging testbed at JPL


Coronagraphy is necessary to image and characterize extra-solar planets. The vortex coronagraph is one solution amongst many others. It presents many advantages (simplicity, small inner working angle, high throughput) and so it has been developed by NASA for the past 3 years. Here we report on the results of an experiment conducted on the high contrast imaging testbed at JPL. New contrast records have been established, which make this coronagraph more attractive than ever.

8151-50, Poster Session

Zodiac II: debris disk science from a balloon

G. Bryden, W. Traub, L. C. Roberts, Jr., R. Bruno, Jet Propulsion Lab. (United States); S. Chakrabarti, Boston Univ. (United States); P. Chen, Jet Propulsion Lab. (United States); L. Hillenbrand, California Institute of Technology (United States); J. Krist, Jet Propulsion Lab. (United States); C. F. Lillie, Northrop Grumman Aerospace Systems (United States); B. A. Macintosh, Lawrence Livermore National Lab. (United States); D. P. Mawet, B. P. Mennesson, D. Moody, K. R. Stapelfeldt, Jet Propulsion Lab. (United States); D. Stuchlik, NASA Goddard Space Flight Ctr. (United States); J. T. Trauger, G. Vaischt, S. C. Unwin, Jet Propulsion Lab. (United States)

Zodiac II is a proposed balloon-borne science investigation of debris disks around nearby stars. Debris disks are analogs of the Asteroid Belt (mainly rocky) and Kuiper Belt (mainly icy) in our Solar System.

We will measure the size, shape, brightness, and color of each disk. These measurements will enable us to answer these fundamental questions: what do debris disks tell us about the evolution of planetary systems; how are debris disks produced; how are debris disks shaped by planets; what materials are debris disks made of; how much dust do debris disks make as they grind down; and how long do debris disks live?

In addition, Zodiac II will observe hot, young exoplanets, as targets of opportunity.

The Zodiac II instrument is a 1.1-m diameter SiC telescope and an imaging coronagraph on a gondola carried by a stratospheric balloon. Four mid-latitude flights will be operated: two overnight flights in the US, and two half-global flights in the Southern Hemisphere, totaling about 123 hours of observing time.

The data from Zodiac II is a set of four-color images of each debris disk, in broad bands, at visible wavelengths. Zodiac II will answer its science questions by making accurate, multi-wavelength images of the debris disks around about 25 of the available 104 known targets.

On these targets, it will be 100 times more sensitive than HST with ACS; no existing telescope can match the Zodiac II contrast and resolution performance. A second objective of Zodiac II is to use the near-space environment to raise the Technology Readiness Level (TRL) of SiC mirrors, internal coronagraphs, deformable mirrors, and wavefront sensing and control, all potentially needed for a future space-based telescope for high-contrast exoplanet imaging.
8151-51, Poster Session

The performance of the new Fabry-Perot calibration system of HARPS

F. A. Pepe, F. P. Wildi, B. Chazelas, Observatoire de Genève (Switzerland)

ESO’s radial velocity spectrograph HARPS is arguably the most successful ground based extra-solar planet hunting instrument today. It has been shown recently that one of the largest contributor of this instrument’s error budget is the wavelength calibration error. Three years ago we have started a program to upgrade HARPS with a new calibrator system in the form of a Fabry-Perot etalon. In the mean time, this system has been installed, tested and improved on-site. It has now passed the science commissioning phase and is offered to the community as an observation mode of HARPS. It’s performance is essentially photon limited, which in the present configuration means that a calibration noise of 0.1m/s is achieved. Our presentation will review the system design, the lessons learned and show the details of the performance.

8151-52, Poster Session

Deep UV to NIR Space Telescopes and Exoplanet Coronagraphs: a trade study on throughput, polarization, mirror coating options and requirements

K. Balasubramanian, S. B. Shaklan, A. Give’on, L. F. Marchen, Jet Propulsion Lab. (United States)

The NASA Exoplanet program and the Cosmic Origins program are exploring technical options to combine the visible to NIR performance requirements of a space coronagraph with the general astrophysics requirements of a space telescope covering the deep UV spectrum. Are there compatible options in terms of mirror coatings and telescope architecture to satisfy both goals? In this paper, we address some of the main concerns, particularly relating to polarization in the visible and throughput in the UV. On-axis and off-axis telescope architectures employing coating options compatible with current technology are considered in this trade study.
Searching for a second sample of life on Earth: the lesson of arsenic

P. C. W. Davies, Arizona State Univ. (United States)

In the absence of a known mechanism for life to emerge from non-living precursors, it is impossible to meaningfully assign a probability to the emergence of life on an earthlike planet. Life on Earth may be a freak phenomenon, unique in the observable universe, or alternatively just one example of an almost inevitable progression from matter to life in a universe teeming with biology. Since the biogenesis mechanism is unlikely to be definitively identified in the foreseeable future, it makes sense to focus instead on empirical methods. If life is probable on earthlike planets then it should have arisen many times on Earth. If that were the case, then there may be extant terrestrial micro-organisms belonging to a separate tree from standard life, and intermingled with it. I shall describe a program of research aimed at discovering a “shadow biosphere” of weird life, using the recent excitement concerning arsenic life as a proof of concept.

Investigations of microfossils in carbonaceous meteorites and ancient terrestrial rocks at the A. A. Borisyak Paleontological Institute (RAS)

A. Y. Rozanov, Paleontological Institute (Russian Federation)

Bacterial Paleontology studies carried out at the A. A. Borisyak Paleontological Institute of the Russian Academy of Sciences have shown that pseudomorphoses of filamentous and coccolidal bacteria are present in many carbonaceous meteorites, although they are absent in other meteorites studied. In this paper we review the studies of the forms detected in various carbonaceous meteorites and compare them with microfossils found in phosphorites and other ancient terrestrial rocks.

Filamentous trichomic prokaryotes in carbonaceous meteorites: indigenous microfossils, minerals, or modern bio-contaminants?

R. B. Hoover, NASA Marshall Space Flight Ctr. (United States); A. Y. Rozanov, Paleontological Institute (Russian Federation)

Large complex filaments have been detected in freshly fractured interior surfaces of a variety of carbonaceous meteorites. Many exhibit the detailed morphological and morphometric characteristics of known filamentous trichomic prokaryotic microorganisms. In this paper we review prior studies of filamentous microstructures encountered in the meteorites along with the elemental compositions and characteristics of the, fibrous evaporite minerals and filamentous cyanobacteria and homologous trichomic sulfur bacteria. The meteorite images and elemental compositions will compared with data obtained with the same instruments for abiotic microstructures and living and fossil microorganisms in order to evaluate the relative merits of the alternate hypotheses that have been advanced to explain the nature and characteristics of the meteorite filaments. The possibility that the filaments found in the meteorites may be comprise modern bio-contaminants will be evaluated in light of their observed elemental compositions and data by other researchers on the detection of indigenous complex organic biosignatures, and extraterrestrial amino acids and nucleobases found in the Murchison CM2 and the Orgueil C1 carbonaceous meteorites.

Multicellular algae from lower proterozoic (2.45 Ga) weathering crusts of Kola Peninsula

M. M. Astafieva, Paleontological Institute (Russian Federation); A. Y. Rozanov, Paleontological Institute (United States); R. B. Hoover, NASA Marshall Space Flight Ctr. (United States)

New interesting data were received from the ancient weathering crusts aged ca.2.45 Ga from the hole bored under the direction of our Norwegian colleagues V. Melezhik and A. Lepland while working on the International Continental Drilling Program (ICDP). The hole is situated in the Monchegorsk Region of Kola Peninsula.

Weathering crusts are indicators of continental sedimentation conditions. The question of bacterial colonization of land is interesting by itself. Investigations in this field are rather fruitful. Active role of bacteria in the formation of the most ancient weathering crusts has already proven and supposition concerning bacterial colonization of land from the very beginning of sedimentary rocks formation, i.e. from the very beginning of geological annals, has been made.

What is the principle interest of the last find? Fossil remains of the highly organized for that time forms were found. These forms here and there merge with the rock matrix, here and there they submerge or penetrate into the rock. That is why it is possible to suggest that these forms were buried in situ, but not a later contamination. Judging by morphology, the found structures probably refer to green or red algae. However the exact systematic position of these finds is not very important. The main thing is that they referred to eucaryots, and moreover - to multicellular eucariots. So high level of organization of forms with the age more than 2.4 Ga is the evidence of the fact that the level of atmosphere oxygenation was much higher than it was ancient weathering crusts has already proven (the latest reconstruction needs modification) and that middle surface temperatures could not differ from recent temperatures more than 15-20o.

The study was executed within the framework of the complex program of basic research of the Presidium of the Russian Academy of Sciences “Origin of Biosphere and Evolution of Geo-biological Systems” (subprogram II) and was supported by the Russian Foundation for Basic Research, projects 08-04-00484 and SS-65493.2010.4. The samples were received due to International Continental Drilling Program (ICDP).

Nonbiogenic amino acids in natural bitumens and problem of genetic identification of geo- and astro-problematics

N. P. Yushkin, A. Lysiuk, Institute of Geology (Russian Federation)

Nucleotides, proteins and their components - amino acids, often referred to as biologic, have long been known to be present in various geological objects of both biogenic and non-biogenic origin. Amino acids were also found in the organic matter of many cosmic bodies and various geological objects of different genetic nature. Our studies of mechanisms of crystallization and supermolecular ordering in natural solid hydrocarbons aimed to analyze peculiarities of amino acids contents in bitumens of various types and in highly carbonaceous
substances (shungite), to reveal their relation to the structural genetic nature of the hydrocarbons and to obtain the information to gain an insight into amino acids genesis.

Amino acids from natural solid hydrocarbons, like other organic compounds, have essentially abiogenetic origin. This fact suggests polymerization and self-organization of monomers bringing about multi-functional structures, homologous to biopolymeric ones.

Experiments on the thermal and radiation influence on natural bitumens testified about abiogenetic intensive synthesis of amino acids, including also His, Lys, Arg, Phe, considered to be reliable biomarkers by many researchers. The radiosynthesis resulted in the increasing concentration of predominantly left modifications Gly, l-Ala, L-Ala, L-Ile, L-Val, L-Leu, L-Pro, L-Ser, L-Ala. The same phenomenon was observed in phitofulgurites resulted from lightning impacts into accumulations of dry vegetation.

Hence, the reliable identification of biomorphic structures requires additional criteria apart from biochemical ones. Thus, our investigations showed the presence of amino acids in all genetic and structural types of natural solid carbonaceous substances, revealed the typomorphism of amino acids content in their different types, presented regular increasing amino acids content with increasing temperature of formation and ordering of the substances, revealed possibility of abiogenetic synthesis of amino acids and established its optimal conditions.

8152-06, Session 3

Biomimic microstructures in ferromanganese nodules: evidence of the biological and abigenous origin

G. Lysyuk, Institute of Geology (Russian Federation)

Manganese oxide is one of the most widespread and practically important objects, in formation and transformation of which microorganisms play an active role, Manganese oxide is characterized by the joint presence of both well crystallize modifications, and fine phases with the lowest order strength (with the contents of rohentgenamorphous component till 50 - 60% at significant concentration of ore component). This fact will now has no enough strict scientific explanation. We examined formation of rohentgenamorphous nano-dimensional manganese oxide from positions of biogenic mineral formation. Objects of our researches were nano-dimensional phases of the iron-mangsnous nodules and manganese residual soil.

Electronic-microscopic investigations showed a great expansion of mineralized biofilms on the studied samples. The content of the bacterial mass make (%): MnO - 28.34; Fe2O3 - 17.14; SiO2 - 7.11; CaO - 2.41; TiO2 - 1.90; Na2O - 1.74; Al2O3 - 1.73; MgO - 1.30; P2O5 - 1.25; SO3 - 1.25; CoO - 0.68; CuO - 0.54; NIO - 0.53; K2O - 0.50.

Another development of a bacteria factor during formation of manganous oxide is occurrence of fossilized cyanobacterial mat with the content (%): MnO - 48.35; Fe2O3 - 6.23; MgO - 8.76; Al2O3 - 5.05; SiO2 - 4.45; NIO - 3.63; Na2O - 2.30; CuO - 2.15; CaO - 1.31; K2O - 0.68. The use atomic-force microscopy method allows determining size of some cells of cyanobacteria with the 200nm at length and about 70nm across diameter. Electronic- microscopic investigations showed that the phase data is a mineralized glycocalix, composed of nanodimensional flakes of todorokite.

8152-07, Session 4

Pre-biotic organic synthesis: laboratory simulation experiments and their significance for the origin of life in the solar system

M. H. Engel, D. H. Engel, The Univ. of Oklahoma (United States)

It is commonly assumed that the origin of life on Earth and perhaps elsewhere in the solar system was preceded by the synthesis and accumulation of organic compounds essential for life as we know it (e.g. amino acids, sugars, purines, pyrimidines, etc.) by non-biological processes. Over the past century, laboratory simulation experiments using a variety of inorganic precursors and energy sources have resulted in the synthesis of some, but not all of the compounds required for life. More importantly, the mechanisms by which these simple organic compounds initially combined to form the more complex structures (proteins, nucleic acids, etc.) upon which all life is based remain elusive. Here we report a summary of the progress to date concerning pathways for the pre-biotic synthesis of organic matter and their significance for the origin of life in the solar system.

8152-08, Session 4

Potential exoplanet pseudo-biosignatures

G. A. Konesky, K-Plasma Ltd. (United States)

Current exoplanet detection techniques are biased toward large, massive planets in very close orbits to their host star, so-called “hot Jupiters.” Since they are far from the habitable zone around that host star, any potential biosignature, such as methane, would likely have an abiotic origin. Similarly, other biogenic gases, including oxygen (and resulting ozone), nitrogen, carbon dioxide, carbon monoxide, methane, nitrogen dioxide, ammonia, nitrous oxide, sulfur dioxide, hydrogen sulfide, carbonyl sulfide, dimethyl sulfide, and various non-methane hydrocarbons, have alternate abiotic sources. We consider both biotic and abiotic sources for these gases.

Given the great distances these potential exoplanet biosignature gases would need to be spectroscopically detected, we primarily concentrate on potential biogenic gases that would be abundant, especially oxygen and ozone. In general, there are few abiotic geochemical processes that would produce free oxygen in any significant quantity, although volcanic hydrogen has been considered as a reducing agent to “soak up” oxygen on the early Earth. The history of the rise of oxygen on Earth, and the “Great Oxidation Event” might then be taken as the archetype of exoplanet biosignatures.

There is evidence that water was once abundant on Venus, as indicated by high deuterium/hydrogen atmospheric ratios, and on Mars, by its observed water-based surface mineralogy. While some water remains on Mars on its poles and likely underground, both planets lost considerable quantities through photodissociation, with the liberation of hydrogen to space, and the retention of oxygen. If similarly observed on distant exoplanets, it could be mistaken as a pseudo-biosignature.

8152-09, Session 4

Developing an astrobiological search protocol through the Taphonomic window

R. S. Shapiro, California State Univ., Chico (United States)

It is generally agreed by the astrobiological community that any fossil or extant life forms to be found outside of Earth would likely be archaea or bacteria or their near analogue. Paleontologists and geochemists are developing a library of evidence from ancient Earth sediments as well as active extreme environments. Yet, while there has been much research addressing the challenges in modeling the processes to create an extraterrestrial fossil record, less attention has been focused on establishing the taphonomic parameters in preserving the record.

Taphonomy encompasses the study of the processes involved in creating and later modifying the fossil record. Specific to astrobiological missions is an understanding of how near-surface weathering and rock alteration might change the mineralogical and morphological character of any fossil structures. The most likely causes of alteration would come from: heat and pressure due to bolide impact, igneous intrusion, and chemical changes due to interaction with reducing or oxidizing fluids.

Modeling these alteration pathways and the resulting deposits is extremely challenging. As of yet, there is little agreement on what the
original conditions might encompass on another planet or satellite. Tectonic activity is quite diverse in our solar system and the resulting deformation structures would have very different consequences for any fossil-bearing strata. Most critically, the ancient gas and fluid compositions of the various planets and satellites specifically the timing of potential liquid water—is still being unraveled. Generic models can be developed from Earth-analogues as a starting point for delineating key questions for future missions.

8152-10, Session 4

The changes of spectroscopic characteristics of sulfur-reducing bacteria: desulfituromonas acetoxidans under the influence of different metal ions

O. M. Vasylyv, O. I. Bilyy, V. B. Getman, I. V. Kushkevych, S. O. Hnatush, Ivan Franko National Univ. of L'viv (Ukraine)

The Earth was settled only by the microorganisms during more than 80% of organic evolution. They were prevalent in the biosphere more than 0.5 billion years ago. There were methanogens, sulfate-, iron- and sulfur-reducing bacteria which belonged to such genuses as Methanobacterium, Desulfovibrio, Rhuminococcus, Desulfuromonas and others that made an overwhelming contribution into the formation of different minerals of the Earth's crust. Desulfuromonas acetoxidans, which is regarded to the oldest microorganisms, are uncoloured gram-negative obligatory anaerobic bacteria that have an ability to reduce sulfur to hydrogen sulfide. Sulfurbacteria have a great effect on the biogeochemistry of the aquatic environments because of their ability to reduce and precipitate of toxic metal ions. Using strains of these bacteria, which have a high heavy metals' resistance, allow to neutralize the toxicity of hydrogen sulfide, which is the final product of dissimilation sulfurreduction, and these metals as the result of their particular binding and forming the unsoluble precipitations. In this study the interaction between bacteria Desulfuromonas acetoxidans and such heavy metal ions as copper, lead, zinc and cadmium has been investigated. The light scattering properties’ changes of bacterial cells D. acetoxidans on the base of their size distribution and relative content under the influence of investigated metal ions have been observed by the new method of measurement. It includes sounding of flow suspended bacterial cells by monochromatic coherent light, registration of signals of co-operation of sounding radiation with the explored microbiological objects by detects amplitudes and durations of scattered light impulses.

8152-11, Session 5

Ramifications of a sterile Mars

G. V. Levin, Arizona State Univ. (United States)

The seldom considered ramifications of a sterile Mars are explored. The Martian environment has been extensively defined by analyses performed by 22 successful missions, composed of eight landers and 14 flybys and orbiters, and by countless Earth-based observations, plus the detailed examination of Martian meteorites. The individual and collective parameters that could preclude life are examined. No single or combination of these measurements precludes the ability of Mars to support even a wide number of terrestrial microbial species, let alone possible alien life forms. Some yet unknown factor or combination of factors would have to be responsible for Mars' failure to generate life or to successfully harbor viable forms received from space. Since Mars is so Earth-like, the red planet's sterility would constitute a severe blow to the concept of a cosmic biologic imperative, and would raise the daunting prospect that Earth is a unique or very rare habitat.

8152-12, Session 5

Io and its role in the Jupiter system

R. Lopes, Jet Propulsion Lab. (United States)

Jupiter’s moon Io is the solar system’s most volcanically active body and the only place other than Earth where large-scale silicate volcanism has been observed. Io’s volcanic activity significantly affects the Jovian system, including causing aurorae on Jupiter, forming the Io torus and neutral cloud, and causing sulfur to be transported by Jupiter’s magnetosphere and implanted into Europa’s ice. Although Io is not considered a target of interest from an astrobiology point of view due to its lack of water, it is important in this context for several reasons. (1) Io’s high heat flow and prodigious rate of volcanism make it is unique among the silicate bodies, providing insight into processes that operated very early in the histories of the terrestrial planets, including Earth, (2) Io’s geologic activity is the result heat transfer from the tidally-flexed interior to the surface, Io is the best target for the study of tidal heating, a process of fundamental importance to the evolution of planetary satellite systems, and one that may greatly expand the habitability zone for extraterrestrial life. (3) Io’s exotic chemistry is unique in the solar system. Io’s surface is dominated by SO2 frost, sulfur allotropes, and silicates, but unidentified materials remain. Unlike its neighbors Europa, Ganymede, and Callisto, Io has no water, though a 3.15 micron feature in its spectra could arise from the OH stretch transition in a hydroxide (Carlson et al., 1997, Geophys. Res. Let. 24). (4) Io’s volcanic plumes transport volatiles into space, and from Io to Europa. Understanding Io’s sources and sinks of volatiles is therefore key to understanding the Jupiter system as a whole, including the icy satellites where conditions may exist suitable for life. Our knowledge of Io has been substantially expanded by planetary missions such as Galileo and New Horizons, but many questions remain. The study of Io is considered a major objective in future missions to the Jovian system.

8152-13, Session 5

Does Saturn’s Titan have an active surface: could indications of surface activity be consistent with a pre-biotic environment?

R. M. Nelson, Jet Propulsion Lab. (United States)

The surface of Saturn’s moon Titan has been reported to change over time. During the Cassini spacecraft’s seven year orbital tour of the Saturnian system the Visual and Infrared Mapping Spectrometer (VIMS) reported spectrophotometric changes at a region called Hotel Reggio (a.k.a. Hotel Arcus) near 26S,78W [1,2]. This variation is consistent with the deposition, followed by coverage or dissipation, of ammonia frost. Cassini RADAR images found that Hotel Reggio, has lobate “flow” forms, suggesting a volcanic terrain there[3] and at other locations on Titan including Sotra Facula, a 60 km subcircular feature near 40W 15S [4]. It has not escaped our attention that ammonia, in association with methane and nitrogen, the principal species of Titan’s atmosphere, may replicate the environment at the time that life first emerged on earth. If Titan is currently active then these results raise the following questions: What is the full extent of current geologic activity? What are the ongoing processes? Are Titan’s chemical processes today supporting a prebiotic environment similar to that under which life evolved on Earth?

1. Nelson et al. LPSC abs. 2158 2007
3. Wall et al. GRL VOL, 36, L04203, 2009
High-sensitivity biomarker imaging using surface enhanced Raman spectroscopy (SERS)

Z. Tanaka, NASA Ames Research Ctr. (United States) and Univ. of California, Santa Cruz (United States); B. Chen, NASA Ames Research Ctr. (United States)

The detection of various biological agents, in general, and bacterial pathogens, in particular, has garnered much recent attention in the field of diagnostic microbiology and astrobiology studies. Surface Enhanced Raman Spectroscopy (SERS) has been successfully applied to the detection of field samples in various environments. Emergent to SERS is the possibility for imaging. In particular, our SERS imaging technique is capable of simultaneously demonstrating high spatial resolution as well as composition sensitivity for biomolecules and bacteria/viruses due to its potential advantage of molecular specificity. Raman or SERS imaging can provide high throughput chemical information with, spatial distributions of analytes with resolution in the micrometer range. Facile and reproducible SERS signals from Shewanella oneidensis were obtained utilizing silver nanoparticles (AgNPs) and silver nanowires (AgNWs). Additionally, SERS images identify the distribution of SERS hot-spots. One important observation is the synergistically enhanced SERS signal when AgNPs and AgNWs are used in conjunction, due to constructively enhanced electromagnetic field. The talk will further this technique for future field deployment in the context of fiber optical instrument development in our lab. For an example, a custom-built 1064nm near-infrared (NIR) fiber-Raman spectrometer that has been lab tested to characterize organic carbon content in 1.7Byr old stromatolite mineral samples obtained from Mars-analog environments. Compared to visible excitations, the NIR Raman has profoundly less background fluorescence and is suited to be deployed autonomously on Mars "test" rovers.

The brines of the Phoenix landing site, the potential for life to adapt to them, and the implications for life elsewhere

N. O. Rennó, H. Elliott, G. Martinez Martinez, D. Halleaux, B. Block, G. Dick, J. Hoffman, Univ. of Michigan (United States); S. B. Joye, The Univ. of Georgia (United States); C. P. McKay, NASA Ames Research Ctr. (United States); O. Prieto-Ballesteros, F. Gomez Gomez, E. Mateo-Marti, M. Paz Zorzano, Ctr. de Astrobiología (Spain)

Rennó et al. [2009] presented physical and thermodynamical evidence that liquid brines were observed at the Phoenix landing site on Mars’ Arctic. Then, Zorzano et al. [2009] showed experimentally that liquid brines could form by deliquescence at the Phoenix landing site. Rennó et al. [2009] shows that the thermodynamics of freeze-thaw cycles could produce brine pockets almost anywhere on Mars, where ground ice is present near the surface. The presence of liquid brines on Mars has important implications for its habitability because many terrestrial microbes thrive in brines [Boetius and Joye, 2009].

We are analyzing the Phoenix mass spectrometer and atmospheric science data with focus on the understanding of the formation and stability of liquid brines on Mars’ Arctic. In parallel, we are conducting laboratory experiments to study the range of environmental conditions that can support the presence of liquid brines on Mars. The ‘Centro de Astrobiología’ group is conducting studies of the habitability of liquid brines to give insights on “Planetary Conditions for Life.” Our study has the potential to shed light on the capability of microbial life to adapt to the environmental conditions of the Phoenix landing site, and its implications for life elsewhere. Here we describe our laboratory experiments and present preliminary results.
Aerospaciales (Spain); F. Rull, Univ. de Valladolid (Spain); I. Hutchinson, R. Ingleby, Univ. of Leicester (United Kingdom); C. Tato, SENER Ingeniería y Sistemas S.A. (Spain)

The Raman Laser Spectrometer (RLS) is one of the Pasteur Payload instruments, within the ESA’s Aurora Exploration Programme, ExoMars mission.

The RLS Instrument will perform Raman spectroscopy on crushed powdered samples deposited on a small container after crushing the cores obtained by the Rover’s drill system.

The RLS Instrument is composed by the following units: SPU (Spectrometer Unit): a combined spectrometer unit with a thermally controlled CCD detection.

iOH: Internal Optical Head): an optical unit which focus the laser excitation light over the sample, and filters the scattered Raman signal for its processing at the SPU. The iOH also provides an autofocus mechanism.

ICEU (Instrument Control and Excitation Unit): within this unit it is housed the laser source and the FEE for signal processing; it also contains the power and processor modules.

Other instrument units are EH (Electrical Harness), OH (Optical Harness) and SW.

During last 2010 and beginning of 2011, an instrument BB programme has been developed, by RLS AIV Team to achieve the Technology Readiness level 5 (TRL5) for delta PDR in response to ESA requirements.

RLS BB concept has been designed as modular as possible in order to be able to upgrade the breadboard in a step by step process. In this way the complete RLS chain can be validated as a whole, but component by component if necessary. As far as possible, RLS baseline optical critical parameters, interfaces and functionalities has been kept (but for the nominal environment).

It is planned to have a fully operative breadboard, conformed from different unit and sub-units breadboards that would demonstrate the end-to-end performance of the flight representative units by 2011 Q3.

8152-19, Session 6

Raman Laser Spectrometer for ExoMars

C. Pérez Canora, Instituto Nacional de Técnica Aeroespacial (Spain)

The Raman Laser Spectrometer (RLS) is one of the Pasteur Payload instruments, within the ESA’s Aurora Exploration Programme, ExoMars mission.

ExoMars 2018 main Scientific objective is “Searching for evidence of past and present life on Mars”. Particularly, the RLS scientific objectives within ExoMars Mission are as follows:

- identify organic compound and search for life
- identify the mineral products and indicators of biologic activities
- characterize mineral phases produced by water-related processes
- characterize igneous minerals and their alteration products
- characterise water/geochemical environment as a function of depth in the shallow subsurface

Raman Spectroscopy is used to analyse the vibrational modes of a substance either in the solid, liquid or gas state. It relies on the inelastic scattering (Raman Scattering) of monochromatic light produced by atoms and molecules. The radiation-matter interaction results in the energy of the exciting photons to be shifted up or down. The shift in energy appears as a spectral distribution and therefore provides an unique fingerprint by which the substances can be identified and structurally analyzed.

RLS expected main characteristics are as follows:

- Laser excitation wavelength: 532 nm
- Irradiance on sample: 0.6 - 1.2 kW/cm²
- Spectral range: 150-3800 cm⁻¹
- Spectral resolution: 6 cm⁻¹ lower spectral wavenumbers; 8 cm⁻¹ long spectral wavenumbers
- Spectral accuracy: < 1 cm⁻¹
- Spot size: 50 microns

Instrument performances are being evaluated by means of simulation tools and development of a BB campaign currently on going.

8152-20, Session 6

A new spectrometer concept for Mars exploration

M. Colombo, T. Belenguer, M. Fernández, Instituto Nacional de Técnica Aeroespacial (Spain)

The Raman Laser Spectrometer (RLS) instrument is included in the ExoMars program Pasteur payload and it is focused on the analytical analysis of the geochemistry content and elemental composition of the observed crushed samples obtained by the Rover.

One of the most critical Units of the RLS instrument is the Spectrometer unit (SPU) that performs Raman spectroscopy technique and operates in a very demanding environment (radiation, temperature, dust, etc.) with very restrictive design constraints (mass, power, schedule). It is a very small optical instrument capable to cope with 0.09 nm/pixel of resolution and withstand with the Martian environment (operative temperature conditions: from -40 oC to 6 oC). The selected solution is based on a single transmissive holographic grating especially designed to actuate as the dispersion element.

At this stage of the project SPU Team is improving and optimizing the SPU FM design and Delta RLS PDR will take place on July 2011. SPU PDR is expected on Autumn 2011.

In parallel, a set of activities have been already started by RLS SPU Team in order to achieve the TRL 5 for RLS Delta PDR:

- Grating validation test campaign: first results have been very successful.
- SPU breadboard which main AIT objectives are to:
  - Determine concepts feasibility and demonstrate the technical principles of immediate interest.
  - Ensure manufacturing tolerance and optical compensators.
  - Verification of the optical analytical models.
  - Validate RLS SPU radiometric model.
  - Verification of the susceptibility to thermal gradient in axis and some critical tolerances.

8152-21, Session 7

Biosignatures for detecting unicellular and multicellular organisms in extreme environments

J. Seckbach, The Hebrew Univ. of Jerusalem (Israel); J. Chela-Flores, The Abdus Salam International Ctr. for Theoretical Physics (Italy)

With respect of our anthropocentric point of view most organisms dwell in what we consider to be “normal” environments, while others, which are called extremophiles, may thrive in harsher conditions. These living organisms are mainly of unicellular (both prokaryotes and, to a lesser extent, there are some eukaryotes). But the extremophiles also include multicellular organisms, including protozoa, algae, worms, insects and crustaceans. In their evolution both unicellulars and multicellulars have adapted to their corresponding niches. In this presentation we will survey specific extremophiles in some detail. We have selected one example of a unicellular red alga Cyanidium caldarium (with its cohorts), and
Archaea were separated from Eubacteria after discovery of their specific cell outer membrane that usually not affected by common antibiotics. Phylogenetic analyses introduced by Karl Wöese supported this separation. Presently, only two phyla Crenarchaeota and Euryarchaeota include the valid representatives. Another three phyla that were proposed based on sequence analyses of environmental samples, do not contain validly published species, and for this reason could not be included in the subject consideration.

In this article, we are providing the update and comparative analyses for this domain, discussing unique features of this group and Evolution, estimating their physiology in the matrix of physic-chemical factors, and outlining future perspectives in their study.

Archaeal surface appendages: their function and the critical role of N-linked glycosylation in their assembly

K. F. Jarrell, D. B. Nair, G. M. Jones, Queen’s Univ. (Canada); S. M. Logan, E. Vinogradov, J. F. Kelly, National Research Council Canada (Canada)

Many cultivated archaea are extremophiles and as such various archaea inhabit some of the most inhospitable niches on the planet in terms of temperatures, pH, salinity and anaerobiosis. Different archaeal species have been shown to produce a number of unusual and sometimes unique surface structures. The best studied of these are flagella which are fundamentally different from bacterial flagella and instead bear numerous similarities to bacterial type IV pili in their structure and likely assembly. The major structural proteins, flagellins, are made as preproteins with type IV pilin-like signal peptides processed by a specific signal peptidase. In addition, the flagellins are glycoproteins with attached N-linked glycans. These posttranslational modifications have been studied in the archaean, Methanococcus maripaludis, which also possesses another surface appendage, an unusual version of type IV pilin, of which the major constituent is also a glycoprotein. Analysis of mutants unable to make either or both flagella and pili demonstrated that both structures are essential for attachment to surfaces. Mutants defective in the assembly and biosynthesis of the tetrasaccharide N-linked to the flagellins have been isolated. Investigations of these mutants by electron microscopy, mass spectrometry and motility assays have demonstrated that flagellins possessing no attached glycan or a glycan truncated to a single sugar cannot assemble flagella on their surface. Mutants which can attach a glycan of 2 or 3 sugars to flagellins assemble flagella but they are impaired in their swimming compared with wildtype cells which attach the tetrasaccharide to their flagellins.

Deep subsurface biodiversity: remarkable novelty and flexibility despite proposed geochemical constraints

E. Van Heerden, Univ. of the Free State (South Africa); G. Borgonie, Univ. Gent (Belgium); A. Jugdave, Univ. of the Free State (South Africa); A. Garcia-Moyano, Univ. of Bergen (Norway); D. Litthauer, Univ. of the Free State (South Africa); T. Onstott, Univ. of Bergen (Norway)

Microbial populations in the deep subsurface extend to depths below where nutritional and environmental parameters limit the ability of microbes to survive. Highly diverse microorganisms occur in expanses where carbon sources are not evident. The studies of the deep subsurface exposed valuable information of the ecology of microbes, the chemical and geological factors associated with these thriving and diverse microbial populations and more insight were gained into their metabolism using genomic and proteomic tools.

Low cell mass samples were concentrated by either massive or tangential flow filtration systems. Complete biodiversity studies were done using 16S and 18S rRNA gene clone libraries, operational taxonomic units (OTU) were calculated using distance based and richness parameters (DOTUR). Microbial isolations were attempted using selective media followed by pyrosequencing and annotation analyses. Proteome analyses, including expression and kinetic, were completed on various proteins from subsurface microbes. Each geological setting provides new insight into its particular associated geochemistry and how it influences the biodiversity. With increasing depth and temperature lower diversity is recovered, however several sites reveal surprisingly high interspecies diversity, even for eukaryotes.

Here we even report species of the phylum Nematoda that have been detected in or recovered from fracture water at 0.9-3.6 km depth in South Africa, and includes a new species Halicephalobus mephisto that tolerates high temperature, reproduces asexually and preferentially feeds upon subsurface bacteria. Twenty-two water samples were collected from 6 boreholes ranging in depth from 0.5 to 3.6 km in 5 different South African mines. Beatrix Au Mine borehole water yielded a new species, Halicephalobus mephisto sp. n., 18x500 m in size.

We extend the current knowledge on subsurface cycling by comparing of anaerobic and chemolithotrophic metabolic reactions to indicate that SO42-reduction is the dominant metabolic process at high and low salinities and that matrix diffusion can sustain planktonic fracture microbial concentrations of ~108 cells mL-1. Methanogenesis becomes more dominant with declining salinities. Neither acetogenesis nor syntrophic degradation of abiogenic hydrocarbons appears to be the source of the observed carboxylic acids, but regardless respiration leads to direct in situ carbonation within the fractures.

High-density 16S microarray and clone library-based bacterial and archean diversity of Icelandic hot springs

P. A. Vaishampayan, Jet Propulsion Lab. (United States); A.
It is beyond any doubt that the search for life on other planets should be microbial in nature. As the extraordinary ability of microorganisms to overcome the challenges posed by these "extreme" environments prove testament to life's resolve, and compelled us to believe that life could persist almost anywhere on Earth, and possibly beyond.

We present here a comprehensive microbial diversity study of samples from Icelandic hot springs. Sampling was performed in a vegetated hot springs system of Hveragerdi area (Iceland), that was about 20 m long and could be divided into three interconnected hot spring pools (P1, P2 and P3) and one opening or mud hot spring at the beginning of the system with no surface connection with others. The temperature was at the range of 57° to 100°C and the pH from 2.9 to 3.8. Additionally, samples were collected from two geographically distinct hot springs of Leirgerdur (L1) with high acidic pH (2.0) and Hrila spring (HS1) with neutral pH (7.0).

Though numerous studies have described the microbial populations of hot springs using cloning based and other molecular approaches, this is the first investigation to study a comprehensive microbial diversity using High-Density 16S Microarray. We have observed diverse bacterial and archael OTUs in samples for which cloning approach fail to detect any OTUs. Effect of abiotic forces in shaping microbial community structure and comparative diversity was also studied in detail.

8152-26, Session 8
The Dry Valley Lakes, Antarctica: a key to evolutionary biomarkers on Europa and elsewhere

J. Chela-Flores, The Abdus Salam International Ctr. for Theoretical Physics (Italy) and Instituto de Estudios Avanzados, Caracas (Venezuela); J. Seckbach, The Hebrew Univ. of Jerusalem (Israel)

In a new approach to the search for biomarkers on Europa we first discuss the main geochemical motivations and concepts. We continue with the specifications of the relevant instrumental techniques. In doing so, we have kept the molecular and evolutionary background to a minimum. We must underline that so far there is a surprising lack of literature on the search with available instrumentation of biomarkers for eukaryotic or for simple metazoa in likely environments of the Solar System. We discuss whether sulfur traces on Jupiter’s moon Europa could be of microbial origin and whether further stages of evolution can be identified. The chemical elements and compounds detected by the Galileo Mission have been conjectured to be endogenic, most likely of cryovolcanic origin, due to their non-uniform distribution in patches. The Galileo space probe first detected the sulfur compounds, as well as revealing that this moon almost certainly has a volcanically heated and potentially habitable ocean hiding beneath a surface layer of ice. There are options for sorting out the source of the surficial sulfur in future exploration of Europa. Returning to Europa is being planned with the Europa Jupiter System Mission, EJSM (Grassett et al., 2009). What is most relevant, oceans may be present on other Galilean moons, but so far we are only aware of a single Jovian moon- Europa- that has its ocean in direct contact with its silicate mantle, unlike the case of Ganymede. However, if terrestrial microbes can thrive in extreme environments, similar microorganisms might also be extant on some of the icy Galilean satellites. Furthermore, since extremophiles have not only succeeded in establishing themselves in the most unlikely ecosystems, but also they have thrived by chemosynthesis of a stunning suite of elements, why would they not thrive as well on the some of the oceans of the Galilean satellites? (Seckbach and Chela-Flores, 2011). The question of habitability by the identification of reliable bioindicators is a major priority for astrobiology. We discuss the present objectives of the future mission to Europa, the EJSM. We consider especially the options for approaching the challenge of selecting the right instrumentation for the identification of a potential biota on Europa. In other words, we raise the following question: What are the challenges facing current technology with miniaturised instruments compatible with realistic payload budgets for identifying prokaryotic microorganisms? This is a question relevant in biogeochemistry. More importantly, we ask what are the challenges yet to overcome with only minor alterations in the payload mass constraints for deciding whether the same available instrumentation can be used for the identification of eukaryotes and simple metazoa? This is a question to be answered in the context of molecular biology.

8152-27, Session 8
Diverse nucleotide compositions and sequence fluctuation in rubisco protein genes

T. Holden, S. Dehipawala, E. Cheung, R. Bienaime, G. Tremberger, Jr., P. Schneider, D. Lieberman, T. D. Cheung, Queensborough Community College (United States)

The rubisco protein is arguably the most abundance protein on Earth and it is notoriously inefficient in its enzyme action in the Calvin cycle. X-ray studies show that the tertiary structure is necessary for the required conformational folding while circular dichromism studies on its associated unfolding sates demonstrate the necessary secondary structure for its enzyme function. The biology dogma of transcription and translation necessitates the study of the rubisco gene in various species. Genome studies via BLAST reveal diverse composition in the associated nucleotide sequences among species. Pre-plant rubisco-like protein study shows similar results. The threshold requirement for functional photosynthesis could be satisfied by selection of diverse nucleotide sequences indicative of multiple evolutionary pathways. Whether the pathways contain an extra-terrestrial source could be speculative but interesting, Shannon entropy of the nucleotide composition and fractal dimension of the nucleotide sequence in terms of its atomic number fluctuation suggest relatively less experienced evolutionary pressure as compared to radiation resistant sequences. The nucleotide interaction would appear to pose very little additional constraints on rubisco production. Similar photosynthesis process that could utilize host star radiation would not compete with radiation resistant process from the biology dogma perspective in environments such as Mars and exoplanets just off the habitable zone.

8152-28, Session 8
Technologically important extremophile 16S rRNA sequence Shannon entropy and fractal property comparison with long term dormant microbes

T. Holden, N. Gadura, S. Dehipawala, E. Cheung, M. Tuffour, P. Schneider, G. Tremberger, Jr., D. Lieberman, T. D. Cheung, Queensborough Community College (United States)

Technologically important extremophiles including oil eating microbes, uranium and rocket fuel perchlorate reduction microbes, electron producing microbes and electrode electrons feeding microbes were studied in terms of their 16S rRNA sequences, a standard practice in comparative phylogeny studies. Microbes that were reported to have survived a prolonged dormant duration were also studied. Examples included the recently discovered microbe that survives after 34,000 years in a salty environment while feeding off organic compounds from other trapped dead microbes. Shannon entropy of the 16S rRNA nucleotide composition and fractal dimension of the nucleotide sequence in terms of its atomic number fluctuation analyses suggest a selected range for these extremophiles as compared to other microbes; consistent with the experience of relatively mild evolutionary pressure. However, most of the microbes that have been reported to survive in prolonged dormant duration carry sequences with fractal dimension between 2 and 2.01 (N =10 out of 12). Similar results are observed for halophiles, red-shifted chlorophyl and high radiation resistant microbes. The results suggest that prolonged dormant duration, in analogous to high salty or radiation...
environment, would select high fractual 16S rRNA sequences. Candidate choices for high fractual 16S rRNA microbes could offer protection for prolonged spaceflights. BioBrick gene network manipulation could include extremophile 16S rRNA sequences in synthetic biology and shed more light on exobiology and future colonization in shielded spaceflights. Whether the high fractual 16S rRNA sequences contain an asteroid-like extra-terrestrial source could be speculative but interesting.

8152-29, Session 8

Anaerobic cultures from preserved tissues of baby mammoth

E. V. Pikuta, National Space Science and Technology Ctr. (United States); D. Fisher, Univ. of Michigan (United States); R. B. Hoover, NASA Marshall Space Flight Ctr. (United States)

Microbiological analysis of several cold-preserved tissue samples from the Siberian baby mammoth known as Lyuba revealed a number of culturable bacterial strains that were grown on anaerobic media at 4 oC. Lactic acid produced by LAB (lactic acid bacteria) group, usually by members of the genera Carnobacterium and Lactobacillus, appears to be a wonderful preservative that prevents other bacteria from over-dominating a system. Permafrost and lactic acid preserved the body of this one-month old baby mammoth and kept it in exceptionally good condition, resulting in this mammoth being the most complete such specimen ever recovered.

The diversity of novel anaerobic isolates was expressed on morphological, physiological and phylogenetic levels. Here we discuss the specifics of the isolation of new strains, differentiation from trivial contamination, and preliminary results for the characterization of cultures.

8152-30, Session 8

The nature of water within bacterial spores: protecting life in extreme environments

C. V. Rice, The Univ. of Oklahoma (United States)

The bacterial spore is a formidable container of life, protecting the vital contents from chemical attack, antimicrobial agents, heat damage, UV light degradation, and water dehydration. The exact role of the spore components remains in dispute. Nevertheless, water molecules are important in each of these processes. The physical state of water within the bacterial spore has been investigated since the early 1930’s. The water is found two states, free or bound, in two different areas, core and non-core. It is established that free water is accessible to diffuse and exchange with deuterated water and that the diffusible water can access all areas of the spore. The presence of bound water has come under recent scrutiny and has been suggested the water within the core is mobile, rather than bound, based on the analysis of deuterium relaxation rates. Using an alternate method, deuterium quadrupole-echo spectroscopy, we are able to distinguish between mobile and immobile water molecules. In the absence of rapid motion, the deuterium spectrum of D2O is dominated by a broad line, whose line shape is used as a characteristic descriptor of molecular motion. The deuterium spectrum of bacterial spores reveals three distinct features: the broad peak of immobilized water, a narrow line of water in rapid motion, and a signal of intermediate width. This third signal is assigned this peak from partially deuterated proteins with the spore in which N-H groups have undergone exchange with water deuterons to form N-D species. Likewise, desiccation changes intensity of the rapid water signal while the signals for immobilized water and deuterated proteins remain unchanged. As a result of these observations, the nature of water within the spore requires additional explanation to understand how the spore and its water preserve life.

8152-31, Session 8

Future outlook for SETI

S. Bowyer, Univ. of California, Berkeley (United States)

Initially, the Search for Extra-Terrestrial Intelligence emphasized the radio band, but soon searches were carried out in other bands. No signals have yet been detected. New searches and research efforts will dominate the future SETI landscape. The detection of planetary systems suggests there will be far more planets than expected, but many with unstable orbits. Unfortunately, water, a necessity for the development of life, may be the result of an odd set of unlikely circumstances. On the positive side, recent laboratory work on the origin of life suggest that life forms may be easily produced. Interesting times for SETI!! The idea that a credible search for Extra-Terrestrial Intelligence could be carried out evolved beginning in the middle of the last century. Initial work emphasized searches in the radio band but soon searches were developed investigating other bands of the electromagnetic spectrum. No signals have been detected. However, by 2010 several radio searches were close to starting that would have provided a huge increase in detection capabilities. In addition, a major discovery was the detection of a surprising number of planetary systems. This increases the potential locations for extraterrestrial intelligence. However, the systems that have been discovered show that the formation of planetary systems results in many systems that are unstable. In a worst case scenario, there will be far more stars with planetary systems but few planets with stable orbits. An additional complexity is the requirement, based on very general grounds, that water is a necessity for the development of life.

But the origin of water on Earth appears to be the result of an odd set of circumstances which might be unlikely. Despite these uncertainties most workers in the field continue to be optimistic regarding the likelihood of eventually detecting an alien signal. Tragically, the extremely sensitive search with the Allen Telescope at Hat Creek has been cancelled for funding reasons. Nonetheless, work continues on developing even more sensitive searches. A brief summary of work carried out to date, and a description of some of the innovative new ideas now being developed, will be provided.

8152-32, Session 9

The origins of the translation machinery may provide insight to the emergence of the last universal common ancestor

G. E. Fox, Q. Tran, M. R. Tirumalai, Univ. of Houston (United States)

Efforts to understand the last universal common ancestor, LUCA, have largely focused on the nature of that ancestor, whether genote or progenote, and the genes that were likely present. Also of interest is the issue of why LUCA emerged when it did, rather than at an earlier or later stage. In order to gain insight to early events in the emergence of living systems, we are studying the evolutionary history of the translation machinery. Many ribosome components are universal in all Domains of life, and hence likely were present before LUCA while other aspects differ and hence were likely added after LUCA. Using timing events such as the order of addition of components during ribosome assembly, it is possible to infer the relative age of various components. The ribosome is thought to fundamentally be a Brownian motor, the modern version is a dynamic machine with key coordinated movements occurring during each synthesis cycle. These include ratcheting of the 30S subunit, opening and closing of the L1 stalk and movement of the tRNAs through the decoding center as a result of GTP cleavage by elongation factor G. These movements are associated with ribosomal components that appear to have been incorporated at approximately the time of LUCA. For example, SS ribosomal RNA, which is thought to play a role in coordinating the various movements by transmitting signals between the peptidyl transferase center and the decoding site, exhibits modest structure differences in the three Domains of life. This suggests that it was present in almost final form at the time of LUCA. It is hypothesized here that dramatic improvements in the efficiency of protein synthesis...
had a global impact on emerging biological systems resulting in the
emergence of LUCA.

8152-33, Session 9
Ribosomal paleontology and resurrection:
molecular fossils from before coded protein
L. D. Williams, C. Hsiao, J. C. Bowman, C. R. Bernier, J. Peters,
D. M. Schneider, E. O’Neill, Georgia Institute of Technology
(United States)

The translational machinery is life’s most ancient assembly. The origins
and early development of the translation machinery remain imprinted
in the extant ribosome, in sequences, folding, and function. To mine
the information contained within the ribosome, we are developing new
methods of molecular paleontology. We will recapitulate fundamental
steps in the origin and evolution of the ribosome, and will determine
the relative ages of ribosomal components. We are biochemically
resurrecting working models of ancestral ribosomes. We are developing
timelines for critical steps in the evolutionary history of the ribosome.
The results of these studies will help provide keys to understanding
the origin of proteins and RNA, and the origin of life. We use structure-
and sequence-based comparisons of the Large Subunits (LSUs) of Haloarcula
marismortui and Thermus thermophilus. Using an onion analogy, we have
sectioned the superimposed bacterial and archaeal LSUs into concentric
shells, using the sites of peptidyl transfer as the centers. This spherical
approximation allows shell-by-shell dissections and comparisons that
clearly capture significant information along the evolutionary timeline. The
results support the notion that ever-older molecular fossils are revealed
as one bores toward the center of the LSU onion. The conformations and
interactions of both RNA and proteins change over time. The frequency
with which macromolecules assume regular secondary structural
elements, such as A-form helices containing Watson-Crick base pairs
(RNA) and α-helices and β-sheets (protein), increases with time. The
conformations of the oldest ribosomal protein components suggest they
are molecular fossils of the non-coded peptide ancestors of ribosomal
proteins.

8152-36, Session 9
Comets as parent bodies of CI1
carbonaceous meteorites and possible
habitats of ice-microbiota
N. C. Wickramasinghe, Cardiff Univ. (United Kingdom); R. B.
Hoover, NASA Marshall Space Flight Ctr. (United States); A. Y.
Rozanov, Paleontological Institute (Russian Federation); J. Wallis,
Cardiff Univ. (United Kingdom)

Recent studies of comets and cometary dust have confirmed the
presence of biologically relevant organic molecules along with clay
minerals and water ice. It is also now well established by deuterium/
hydrogen ratios that the CI1 carbonaceous meteorites contain
indigenous extraterrestrial water. The evidence of extensive aqueous
alteration of the minerals in these meteorites led to the hypothesis that
water-bearing asteroids or comets represent the parent bodies of the
CI1 and perhaps CM2 carbonaceous meteorites. These meteorites
have also been shown to possess a diverse array of complex organics
and chiral and morphological biomarkers. Stable isotope studies by
numerous independent investigators have conclusively established that
the complex organics found in these meteorites are both indigenous
and extraterrestrial in nature. Although the origin of these organics is
still unknown, some researchers have suggested that they originated by
unknown abiotic mechanisms and may have played a role in the delivery
of chiral biomolecules and the origin of life on Early Earth.

In this paper we review these results and investigate the thermal history
of comets. We show that permanent as well as transient domains of
liquid water can be maintained on a comet under a plausible set of
assumptions. With each perihelion passage of a comet volatiles are
preferentially released, and during millions of such passages the comet
could shed crustal debris that may survive transit through the Earth’s
atmosphere as a carbonaceous meteorite. We review the current state
of knowledge of comets and carbonaceous meteorites. We also present
the results of recent studies on the long-term viability of terrestrial ice-
microbiota encased in ancient glacial ice and permafrost. We suggest
that the conditions which have been observed to prevail on many comets
do not preclude either survivability (or even the active metabolism
and growth) of many types of eukaryotic and prokaryotic microbial
extremophiles—including algae, cyanobacteria, bacteria and archaea.
It is argued that the chemical and morphological biomarkers detected
on comets and carbonaceous meteorites can be explained by ancient
microbial activity without the need to invoke unknown abiotic production
mechanisms.

8152-37, Session 9
The biological big bang: the first oceans of
primordial planets at 2-8 million years explain
Hoyle/Wickramasinghe cometary panspermia
C. H. Gibson, Univ. of California, San Diego (United States)

Hydrogravitational dynamics of cosmology of Gibson/Schild 1996 predicts
all of the primordial hydrogen-helium gas produced by the big bang
fragments into proto-globular-star-cluster clumps of a trillion earth-

mass planets at 300 Kyr. The first stars formed promptly from these
hot gas planets. The first chemicals created by supernovae seeded the
planets so oceans of water at critical temperature 647 K could host
organic chemistry and the first life, distributed to the 10^80 planets of
the big bang by comets produced in star formation. The biological big
bang time is between 2 Myr when oceans first condensed and 8 Myr
when they froze. A flood of new information from new space telescopes
supports the HGD cosmology scenario, which predicts thirty million
planets per star in million solar mass clumps comprise the dark matter
of galaxies. The biological big bang scenario explains the Hoyle/
Wickramasinghe concept of cometary panspermia by providing a hot,
nourishing, cosmical primordial soup and the means for transmitting
the resulting life forms widely throughout the big bang universe. A solid
astrophysical basis is provided for astrobiology.

8152-38, Session 9
Genesis of oil and hydrocarbon gases within
Mars, other planets and moons within our solar system:
organic origin (source rocks or
direct biogenic sink?)
P. K. Mukhopadhyay, Global Geoenergy Research Ltd. (Canada)

No abstract available

8152-39, Session 10
Status of the UC-Berkeley SETI efforts
E. J. Korpela, Univ. of California, Berkeley (United States)

For nearly three decades, a group of researchers at the University
of California have been involved in progressively more sophisticated
searches for signals due to extraterrestrial civilizations. The initial
searches were in the radio portion of the spectrum and looked for narrow
band signals. Recent searches have expanded the parameter space to
include signals that are narrow band in accelerated reference frames and
short duration pulsed signals that have been dispersed by interstellar
matter. Similarly the searches have expanded to the visible and, soon,
infrared portions of the spectrum. These searches include searches for
both nanosecond scale pulses, and narrow emission lines from lasers.
We report the status of these ongoing searches.
Threshold effects in assembling the genome of a primitive cell in a young planet

D. J. Mullan, Univ. of Delaware (United States)

The pre-biotic era of a planet’s development extends over a time interval which may be as long as gigayears or may be much shorter, possibly a few Myr. During this time interval, molecules in the oceans of a planet in the habitable zone undergo a finite number of collisions $N_c$. The value of $N_c$ is well constrained in regards to velocity and cross-section, and it depends on the total number $N_m$ of relevant monomers. When expressed in terms of the nucleotides which can be generated abiotically (such as demonstrated by Powner et al. 2009), the occurrence of $N_c$ collisions allows for a certain sampling of genomic phase space for an organism with RNA genetic material. From considerations of the large degree of “neutrality” which accompanies the replacement of monomers in many biomolecules, there can be a vast reduction (factor $Q>>1$) in the size of the relevant phase space compared to cases where all monomers are invariant. Given the size of the reduced RNA phase space for a grouping of $p$ genes, we ask: how densely could this phase space have been sampled by reactions in aequous solution on a young planet during the pre-biotic era? Formally, if $Q$ is large enough ($Q>>Q_{\min}$), the RNA phase space can in principle be sampled densely during the prebiotic era.

However, the formal solution $Q>>Q_{\min}$ is of no practical interest if $Q_{\min}$ exceeds a well-defined upper limit $Q_{\max}$ which is controlled by the need to retain some specificity in the operations of biomolecules. For genetics based on doublet codons, $Q_{\min}$ can be less than $Q_{\max}$ in the pre-biotic era of Earth as long as $p \leq 10-15$. Such an RNA phase space could have been sampled densely in the pre-biotic era provided that $N_m$ is larger than a critical value. This sets a threshold for the assembly of the genome of a primitive cell: if the monomers can reach a concentration of $10^{-7}$ molar, we estimate that the presence of a few tons of monomers would suffice to allow emergence of a primitive genome in ~10 Myr.

The cometary biosphere and the origin of life

R. B. Sheldon, Consultant (United States)

It is commonly asserted that panspermia merely dislocates the origin of life (OOL) from a place we know a lot about (Earth) to a place we know very little about (extra-terrestrial), so that it is more of an excuse for not being able to solve OOL than for courageously facing the Earth-based challenge. We argue that pansozoonia—the theory that the biosphere is mostly on comets rather than on rocky planets—is a superior theory to panspermia, moving the OOL problem from warm ponds to cold comets. This changes the nature of the OOL problem from a focus on change (evolution) to a focus on transport. Physically, we use the trivial example of horizontal gene transport from comets versus the warm pond evolution to illustrate the difference between addition and multiplication of information. If we invert the OOL problem into an information theoretic problem, this refocus on transport makes OOL a question of distributed information, where the network contains as much or more information as the nodes. We model this as a conservation of Shannon information in spacetime + its Fourier transform, where we calculate the way in which pansozoonia can approach the information densities of life—i.e. OOL. While this doesn’t provide a detailed mechanism for OOL, it does make tremendous progress increasing the probability of OOL due to distributed information.

ExoMars Raman laser spectrometer breadboard: detector design and performance

I. Hutchinson, R. Ingle, Univ. of Leicester (United Kingdom); H. G. M. Edwards, Univ. of Leicester (United Kingdom) and Univ. of Bradford (United Kingdom); A. G. Moral, E. Diaz, G. Ramos, O. Barcos, C. Perez Canora, Instituto Nacional de Tecnica Aeroespacial (Spain); F. Rull, Unidad Asociada CSIC-CAB (Spain); C. Tato, SENER Ingeniería y Sistemas S.A. (Spain); P. Pool, e2v technologies plc (United Kingdom)

The Raman Laser Spectrometer is scheduled for launch on board the ESA Exomars mission in 2018. Its purpose is to perform analysis of the Raman signal scattered from crushed core samples retrieved from up to 2m below the Martian surface. In support of this activity an RLS breadboard instrument has been assembled at INTA (Instituto Nacional de Tecnica Aeroespacial, Madrid) whose focal plane incorporates an inverted mode CCD cooled to between -10°C and -40°C. The thermal, mechanical and detector design of this elegant breadboard instrument focal plane is described, and the system performance is evaluated in terms of the noise performance, signal to noise ratios and dynamic range for key detector operating modes. The predicted performance of the flight model focal plane is also described, which includes an analysis of the effects caused by the radiation environment.

The design and development of a detector assembly for a portable Raman/LIBS spectrometer

I. Hutchinson, R. Ingle, Univ. of Leicester (United Kingdom); H. G. M. Edwards, Univ. of Leicester (United Kingdom) and Univ. of Bradford (United Kingdom); B. Ahlers, TNO Science and Industry (Netherlands); F. Rull, Unidad Asociada CSIC-CAB (Spain); M. Sovago, TNO Science and Industry (Netherlands); G. R. Davies, R. Motamed, Vrije Univ. Amsterdam (Netherlands); P. Pool, e2v technologies plc (United Kingdom)

This paper describes the design, operation and performance of a detector assembly specifically developed for a combined Raman/LIBS (Laser Induced Breakdown Spectroscopy) spectrometer. The portable (low mass, low power, small volume), analytical instrument was built by TNO Space (under contract to ESA) for the ExoMars programme and was designed to be used for the in-situ analysis of samples from planetary surfaces or the moon. The trade-offs associated with selecting a detector that is appropriate for performing both Raman and LIBS spectroscopy are identified and the operating modes adopted for optimum instrument performance are described. Data obtained with the detector assembly (from both the Raman & LIBS channels of the instrument) are presented for a variety of sample types (selected based on their relevance to planetary surface studies). The performance levels of the instrument are assessed in terms of the signal to noise achieved for each sample type across a range of detector operating temperatures.
Science highlights and lessons learned from the Atmospheric Infrared Sounder (AIRS)

T. S. Pagano, Jet Propulsion Lab. (United States)

The Atmospheric Infrared Sounder (AIRS) on the Aqua spacecraft measures the hyperspectral infrared spectrum (3.7-15.4 microns) of the atmosphere with nearly twice global daily coverage. National Weather Prediction (NWP) centers worldwide assimilate the AIRS spectra at its native resolution of 13.5 km, however the majority of the data are rejected due to cloud "contamination". The spectra are also used to retrieve cloud cleared radiances and atmospheric temperature and water vapor profiles with high accuracy and product resolutions approaching 50 km per retrieval. Assimilation of these products into the forecast models has shown considerably higher impact, however, this methodology has not yet become operational at the NWP centers. Additional products including cloud properties and trace gases including carbon monoxide, methane, carbon dioxide, and sulfur dioxide are also retrieved from AIRS and used in a wide variety of scientific investigations. These investigations include atmospheric transport and global circulation, atmospheric chemistry, climate processes and anthropogenic impacts to Earth’s atmosphere. While the AIRS has been very successful in its meeting the mission objectives, there is much we have learned over the years that would need to fold into the requirements of future systems. These lessons include requirements on the instrument measurement itself, such as coregistration and higher spatial and spectral resolution. Results from the NASA Science Community Workshop in IR and MW Sounders relating to AIRS requirements and concerns are covered. Also lessons related to the instrument design and calibration are identified and put into context of how to reduce instrument artifacts when attempting to meet a new and more challenging set of requirements. This paper looks back at what was achieved and forwards towards what needs to be done in the future to meet the growing needs of the scientific community.

Sensitivity of AIRS and IASI radiometric calibration to scene temperature

D. A. Elliott, H. H. Aumann, Jet Propulsion Lab. (United States)

High radiometric accuracy under all conditions (such as scene temperature and scan angle) is critical for establishing a climate-quality data record. In this study we compare radiances of both AIRS and IASI using the difference each instrument sees between the brightness temperature at 1231 cm⁻¹ and that at 961 cm⁻¹. We collected spectra at 17 different sites distributed around the world in tropical, temperate, desert, and arctic climates. For perfectly calibrated instruments, the brightness temperature differences should closely agree, since diurnal differences caused by the differing orbits cancel to first order. We examine observed differences (indicative of calibration artifacts) as functions of scene temperature, time of day, and scan angle. AIRS is a cooled grating array spectrometer with 2378 spectral channels in the wavelength range from 3.7 to 15.4 microns. AIRS began routine operations in September 2002. IASI is a Fourier Transform spectrometer covering the range 3.6 to 15.5 microns in three bands. The spectral resolutions of AIRS and IASI are similar. IASI data have been available since July 2007.

Evaluation of deep convective clouds as stable references for climate research using AIRS data

H. H. Aumann, Y. Jiang, D. A. Elliott, Jet Propulsion Lab. (United States)

Changes due to global warming are expected to be the order of 100 mK/decade in temperatures and 1%/decade in cloud amounts. The detection of such small changes are facilitated by observations covering many decades. They also require a very accurate absolute calibration. We use Deep Convective Clouds (DCC) in the tropical zone as a reference for the evaluation of the absolute calibration accuracy and stability of infrared radiometers. Since DCC cover about 1% of the tropical zone, thousands of DCC can be seen every day. We illustrate the method with Atmospheric Infrared Sounder (AIRS) data and apply it to data from the Infrared Interferometric Spectrometer (IRIS). The method is general and can be applied retrospectively to any infrared radiometer like AIRS, AVHRR and GOES. AIRS is on the EOS Aqua satellite, which was launched into a 1:30 PM ascending node polar sun-synchronous orbit in May 2002 and is expected to continue to produce high quality data until 2015 or longer. Two copies of the IRIS flew on Nimbus satellites between April 1970 and January 1971.

Performance and operations impact of the spaceborne environment on the Atmospheric Infrared Sounder

S. E. Broberg, H. H. Aumann, D. A. Elliott, Jet Propulsion Lab. (United States); K. R. Overoye, BAE Systems (United States); M. H. Weiler, ATK Space Systems (United States)

NASA is increasingly considering instrumentation in space with longer and longer lifetimes, 5 years or more. The validity of the ground based calibration is potentially compromised by exposure of the instrument to space radiation environment, as well as mechanical relaxation/fatigue effects. We use 9 years of on-orbit data from the Atmospheric InfraRed Sounder (AIRS) to examine the impact of such environments, both expected and unexpected.

Improved surface and tropospheric temperatures determined using only shortwave channels: The AIRS Science Team Version-6 retrieval algorithm

J. Susskind, NASA Goddard Space Flight Ctr. (United States); J. M. Blaisdell, L. Iredell, SAIC (United States)

The Goddard DISC has been analyzing AIRS/AMSU data from September 2002 to the present using the AIRS Science Team Version 5 retrieval algorithm. This talk will describe, and show results using, the AIRS Science Team Version-6 retrieval algorithm which contains significant improvements in retrieval methodology compared to Version-5. The most significant improvement in retrieval methodology compared to Version-5 is the use of only shortwave channels in the physical retrieval of land and ocean surface skin temperatures, which are determined simultaneously with shortwave surface spectral emissivity and bi-directional reflectance. As in Version-5, the physical retrieval uses only shortwave CO2 channels in the determination of tropospheric temperatures, with longwave CO2 channels being used primarily to determine cloud cleared radiances for all channels. Significant improvements have also been made in QC methodology, allowing for high quality retrievals under most cloud conditions which are optimized separately for data assimilation purposes and for climate monitoring. This approach, which also allows for the generation of very accurate "AIRS Only" retrievals under most cloud cover conditions that make no use of AMSU observations, is possible using AIRS observations because AIRS has very low noise channels extending to 2660 cm⁻¹. These findings imply that accurate soundings can be generated from geostationary orbit with a high spectral resolution.
IR sounder, without being accompanied by a microwave sounder, as long as the IR sounder has very low noise in the shortwave spectral region.

8153-06, Session 2

The improved MODIS solar diffuser screen vignetting function calculation and its implementation in RSB calibration

Z. Wang, Sigma Space Corp. (United States); X. Xiong, NASA Goddard Space Flight Ctr. (United States); W. L. Barnes, Univ. of Maryland, Baltimore County (United States)

The MODIS high-gain ocean color bands (B8-B16) are calibrated with its solar diffuser screen (SDS) closed so that the vignetting function (VF) of SDS is necessary for the calculation of their calibration coefficients. Since there was no pre-launch system level characterization of the SDS VF, a series of yaw maneuvers were carried out at the mission beginning for each MODIS to enable its on-orbit characterization. Current VF was derived from the low-gain bands (B1-B7 & B17-B19) data and applied to high-gain ocean color bands, with the assumption that all bands and detectors should share the same VF. As expected, errors in VF characterization will be carried over into the calibration coefficients for the bands that use the SDS for their on-orbit calibration. In this paper, an improved VF calculation method, still using the yaw data as input, is presented. The new method considers the frame-level mismatch of the detector footprint on the solar diffuser (SD) so that a proper SD image frame adjustment is needed when the VF of the low-gain bands is transferred to high-gain bands. A set of band-and-detector dependent VFs can be derived using this approach. The implementation of the new VFs has effectively reduced seasonal oscillations from up to 1.0% to 0.2% in Aqua MODIS high gain band calibration coefficients.

8153-07, Session 2

Adjustments to the MODIS Terra radiometric calibration and polarization sensitivity in the 2010 reprocessing

G. Meister, B. A. Franz, NASA Goddard Space Flight Ctr. (United States)

There are two units of the Moderate Resolution Imaging Spectroradiometer (MODIS) orbiting the earth. The first was launched in December 1999 on NASA’s Earth Observing System (EOS) Terra satellite, the second on the Aqua satellite in May 2002. Both MODIS instruments are calibrated using on-board calibrators and lunar irradiances. For MODIS Aqua, these calibration sources have been sufficient to produce high quality ocean color products up to 2007. For MODIS Terra, this has not been the case. The Ocean Biology Production Group at NASA has derived radiometric corrections using SeaWiFS ocean color products as truth fields. The assumption was made that the NIR bands (bands 15 and 16) do not require any adjustments. In the 2010 reprocessing of MODIS Terra ocean color data, these corrections have been applied to the whole mission life span of 10 years. This paper presents the corrections to the radiometric gains and to the instrument polarization sensitivity, demonstrates the improvement to the Terra ocean color products, and discusses issues that need further improvement.

The largest corrections are needed for the short wavelength bands (bands 8 and 9). In addition to significant radiometric gain corrections as a function of scan angle (up to 10% for large incidence angles on the scan mirror), the polarization sensitivity at the end of scan has increased dramatically for large incidence angles on the MODIS scan mirror, up to about 50%. The magnitude of the corrections decreases strongly with wavelength, to the extent that the corrections needed for the red bands (bands 13 and 14) is on the order of only 1% or less. The small magnitude of the corrections required for the longer wavelengths gives support to the assumption that the NIR bands do not require any modifications. Applying the corrections to the MODIS Terra data leads to ocean color products with similar global trends as for MODIS Aqua, but with greater radiometric uncertainty due to the additional corrections.

8153-08, Session 2

MODIS on-orbit calibration uncertainty assessment

X. Xiong, NASA Goddard Space Flight Ctr. (United States); K. Chiang, J. Sun, A. Wu, Sigma Space Corp. (United States)

MODIS has 20 reflective solar bands (RSB) and 16 thermal emissive bands (TEB). Compared to its heritage sensors, MODIS was developed with very stringent calibration uncertainty requirements. As a result, MODIS was designed and built with a set of on-board calibrators (OBC), which allow key sensor performance parameters and on-orbit calibration coefficients to be monitored and updated. In terms of its calibration traceability, MODIS RSB calibration is reflectance based using an on-board solar diffuser (SD) and the TEB calibration is radiance based using an on-board blackbody (BB). In addition to on-orbit calibration coefficients derived from its OBC, calibration parameters determined from sensor pre-launch calibration and characterization are used in both the RSB and TEB calibration and retrieval algorithms. This paper provides a brief description of MODIS calibration methodologies and an in-depth analysis of its on-orbit calibration uncertainties. Also discussed in this paper are uncertainty contributions from individual components and differences due to Terra and Aqua MODIS instrument characteristics and on-orbit performance.

8153-09, Session 2

MODIS cloud optical property retrieval uncertainties derived from pixel-level VNIR/ SWIR radiometric uncertainties

S. E. Platnick, NASA Goddard Space Flight Ctr. (United States); G. Wind, Science Systems and Applications, Inc. (United States); X. Xiong, NASA Goddard Space Flight Ctr. (United States)

Moderate Resolution Imaging Spectroradiometer (MODIS) retrievals of optically thick and effective particle radius for liquid water and ice phase clouds employ a well-known VNIR/SWIR solar reflectance technique. For this type of algorithm, we evaluate the quantitative uncertainty in simultaneous retrievals of these two cloud parameters to pixel-level radiometric calibration estimates and other fundamental (and tractable) error sources.

The technique, first implemented in MOD06 Collection 5 processing, uses sensitivity calculations derived from pre-computed cloud reflectance look-up tables coupled with estimates for the effect of various error sources on cloud-top reflectance. An important error source is instrument radiometric calibration (other tractable sources included in Collection 5 are surface spectral albedo and atmospheric corrections). We will show cloud retrieval uncertainties derived from new MODIS L1B VNIR and SWIR band pixel-level uncertainty estimates that will be used in Collection 6 processing. Because of the nature of the approach, results will deal exclusively with pixel-level uncertainties associated with plane-parallel clouds; real-world radiative departures from a plane-parallel model are an additional consideration. While we demonstrate the uncertainty technique with operational 1 km MODIS retrievals from the Terra and Aqua satellite platforms, the technique is applicable to any reflectance-based satellite or air-borne sensor retrieval using similar spectral channels.
Uncertainty assessment of the SeaWiFS on-orbit calibration

R. E. Eplee, Jr., SAIC (United States); G. Meister, NASA Goddard Space Flight Ctr. (United States); F. S. Patt, SAIC (United States); B. A. Franz, C. R. McClain, NASA Goddard Space Flight Ctr. (United States)

Ocean color climate data records require water-leaving radiances with 5% absolute and 1% relative accuracies as input. Because of the amplification of any sensor calibration errors by the atmospheric correction, the 1% relative accuracy requirement translates into a 0.1% long-term radiometric stability requirement for top-of-the-atmosphere radiances. Monthly observations of the Moon provide the primary monitor of the on-orbit instrument response for SeaWiFS. The rigorous on-orbit calibration program developed and implemented for SeaWiFS by the NASA Ocean Biology Processing Group (OBPG) Calibration and Validation Team (CVT) has allowed the CVT to maintain the stability of the radiometric calibration of SeaWiFS at 0.13% or better over the mission. The uncertainties in the resulting calibrated top-of-the-atmosphere (TOA) radiances can be addressed in terms of accuracy (biases in the measurements), precision (scatter in the measurements), and stability (repeatability of the measurements). Comparison of the residuals of the lunar observations from the USGS Robotic Lunar Observatory (ROLO) photometric model of the Moon with gains derived from the vicarious calibration of SeaWiFS against the Marine Optical Buoy (MOBY) show that the calibration biases for SeaWiFS are 2-3%. The solar diffuser-derived on-orbit signal-to-noise analysis and the lunar residual analysis show that the precision of the SeaWiFS TOA radiances is 0.12%. The combined uncertainties for the SeaWiFS TOA radiances are 2-3%, with a long-term stability of 0.13%. These results allow the OBPG to produce climate data records from the SeaWiFS ocean color data.

Landsat 8 on-orbit characterization and calibration system

E. Micijevic, R. Morfitt, M. Choate, U.S. Geological Survey (United States)

The Landsat Data Continuity Mission (LDCM) is planning to launch the Landsat 8 satellite in December 2012, which continues an uninterrupted record of consistently calibrated globally acquired multispectral images of the Earth started in 1972. The satellite will carry two imaging sensors: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI will provide visible, near-infrared and short-wave infrared data in nine bands while the TIRS will acquire thermal infrared data in two bands. Both sensors have a pushbroom design and consequently, each has a very large number of detectors to be characterized. Image and calibration data downlinked from the satellite will be processed by the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center using the Landsat 8 Image Assessment System (IAS), a component of the Ground System. In addition to extracting statistics from all normal Earth images acquired, the IAS will process and trend results from analysis of special calibration acquisitions, such as solar diffuser, lunar, shutter, night, lamp and blackbody data, and preselected calibration sites. The trended data will be systematically processed and analyzed, and calibration and characterization parameters will be updated using both automatic and customized manual tools. This paper describes the analysis tools and the system developed to monitor and characterize on-orbit performance and calibrate the Landsat 8 sensors and image data products.

Modeling the image performance of the Landsat Data Continuity Mission sensors

J. R. Schott, S. D. Brown, M. G. Gartley, A. D. Gerace, Rochester Institute of Technology (United States)

The LDCM will carry two new pushbroom imagers. The nine band Operational Land Imager (OLI) and the two band Thermal Infrared Sensor (TIRS) represent significant changes in Landsat Sensor Technology, as does the plan to generate a common data product from two sensors (registered 11 band data). This effort is designed to generate synthetic images that will predict the LDCM performance pre-launch, will support trouble shooting of instrument behavior during initialization and operation, and perhaps most importantly, can support Landsat remote sensing science activities throughout the mission. This paper reports on the initial results, which focused on geometric issues associated with orbital dynamics, sensor focal plane design specifics, scene geometry, and the impact of jitter on image quality and radiometric issues which included; the impact of TIRS spectral response variation on banding and approaches to simulate detector-to-detector and array-to-array non-uniformities (gain and bias) and non-linearities. The approach involves modifying the DIRSIG image simulation model to allow detailed modeling of the Landsat orbit and LDCM sensors parameters and generation of the reflective 30-meter and panchromatic 15-meter EMT+ bands plus bands at 443 nm and 1375 nm. The TIRS has two 100-meter bands that spectrally split the EMT+ thermal band. OLI has completed performance testing, though analysis is still in progress. Radiometric analyses completed to date indicate: Polarization sensitivity: 1-2%; Signal-to-Noise Ratio: at signal levels about 5-10% of full scale, between 6-12 times better than ETM+, e.g., 250 versus 30; radiometric stability over 16 days: better than 0.5% (2-sigma); coherent noise: not visible; detector operability: 100% (no dead or inoperable detectors). Linearity, uniformity, absolute calibration, spatial response, spectral response and other analyses are continuing. TIRS commenced performance testing in February 2011 with initial focus testing to confirm that the focus is within requirements. Radiometric tests will be upcoming in March 2011.
274

Results from solar reflective band end-to-end testing for VIIRS F1 sensor using T-SIRCUS

J. McIntire, Sigma Space Corp. (United States); D. I. Moyer, The Aerospace Corp. (United States); J. K. McCarthy, Northrop Grumman Aerospace Systems (United States); F. DeLucia, The Aerospace Corp. (United States); X. Xiong, J. J. Butler, NASA Goddard Space Flight Ctr. (United States); B. W. Guenther, National Oceanic and Atmospheric Administration (United States)

Verification of the Visible Infrared Imager Radiometer Suite (VIIRS) End-to-End (E2E) sensor calibration is highly recommended before launch, to identify any anomalies and to improve our understanding of the sensor on-orbit calibration performance. E2E testing of the Reflective Solar Bands (RSB) calibration cycle was performed pre-launch for the VIIRS Fight 1 (F1) sensor at the Ball Aerospace facility in Boulder CO in March 2010. VIIRS reflective band calibration cycle is very similar to heritage sensor MODIS in that solar illumination, via a diffuser, is used to correct for temporal variations in the instrument responsivity. Monochromatic light from the NIST T-SIRCUS was used to illuminate both the Earth View (EV), via an integrating sphere, and the Solar Diffuser (SD) view, through a collimator. The collimator illumination was cycled through a series of angles intended to simulate the range of possible angles for which solar radiation will be incident on-orbit. Ideally, the measured instrument responsivity should be the same whether the EV or SD view is illuminated. Monitors were present on both the integrating sphere and collimator, allowing for real-time tracking of the responsivities over data collections roughly equivalent to an on-orbit calibration cycle. The ratio of the measured responsivities was determined at each collimator angle and wavelength. In addition, the Solar Diffuser Stability Monitor (SDSM), a radioing radiometer designed to track the temporal variation in the SD BRF by direct comparison to solar radiation, was illuminated by the collimator. The measured SDSM ratio was compared to the predicted ratio.

A maximum likelihood approach to determine sensor radiometric response coefficients

N. Lei, Sigma Space Corp. (United States)

Optical sensors aboard Earth orbiting satellites such as the Moderate Resolution Imaging Spectroradiometer (MODIS) and the next generation Visible/Infrared Imager Radiometer Suite (VIIRS) assume that the sensors’ radiometric response in the Reflective Solar Bands (RSB) may be described by a quadratic polynomial, in relating the spectral radiance to the digital number readout. For the case of VIIRS, the coefficients are to be determined before launch through an attenuation method, although the linear coefficient will be further determined on-orbit through observing the Solar Diffuser. In determining the quadratic polynomial coefficients through the attenuation method, a Maximum Likelihood (ML) approach is applied in carrying out the least-square procedure. Crucial to the ML least-square procedure is the computation of the weight. The weight not only has a contribution from the noise of the sensor’s digital count, but also has an important contribution from the error in digitization of the count. In addition, the mathematical expression used in the least-square procedure has a crucial role in the weight calculation due to the fact that both the independent and the dependent variables contain random noises. We shall show the details in calculating the weight. Furthermore, we shall show the impact of the fitting residuals in the attenuator’s transmittance on the coefficients’ uncertainties (for VIIRS). We compute the values as well as the uncertainties for the coefficients and compare the results obtained from the traditional method.
VIIRS F1 “best estimate” relative spectral response characterization by the government team

C. C. Moeller, Univ. of Wisconsin-Madison (United States); J. McIntire, T. Schwarting, Sigma Space Corp. (United States); D. I. Moyer, The Aerospace Corp. (United States)

The VIIRS Flight 1 (F1) instrument completed sensor level testing at the Raytheon El Segundo, CA facility in 2009 and is moving forward towards a launch on the NPP platform late in 2011. The sensor level testing, consisting of ambient and thermal vacuum (TVAC) phases, was designed to provide characterization for all elements of sensor performance, populating the Sensor Data Record (SDR) algorithm lookup tables (LUTS) and establishing compliance on performance metrics. As part of its oversight on this project, the VIIRS government team, consisting of NASA, Aerospace Corp., and MIT/Lincoln Lab participation has been tasked to perform an independent (from industry) data analysis and review of the VIIRS F1 sensor level test data, producing estimates of key performance and LUT essentials.

One of the key factors of the VIIRS sensor performance is the relative spectral response (RSR) characterization. Test data to derive RSR for all VIIRS spectral bands was collected in the TVAC environment using the Spectral Measurement Assembly (SpMA), a dual monochromator system with tungsten bulb and ceramic glow bar sources. Spectrally contiguous measurements were made, including the inband (IB) and out-of-band (OIB) spectral regions of each band. These measurements were analyzed by the government team to produce a complete IB+OIB RSR for 22 of the 23 VIIRS bands (exception of the Day-Night Band, DNB). This paper will provide insight on key aspects and findings of the RSR data analysis, including detector to detector variation and OOB features, as well as present the government team “best estimate” RSR (released into the public domain in fall, 2010) to the community. A review of RSR performance metric results (center wavelength, bandpass, extended bandpass, integrated out-of-band) will also be presented.

Comparison of VIIRS prelaunch RVS among independent studies

A. Wu, J. McIntire, Sigma Space Corp. (United States); X. Xiong, NASA Goddard Space Flight Ctr. (United States); F. J. De Lucchia, The Aerospace Corp. (United States); J. A. Cronkhite, Sigma Space Corp. (United States)

VIIRS is a key sensor carried on the NPOESS, developed recently from predecessor instruments including AVHRR, OLS, MODIS, and SeaWiFS. The VIIRS response versus scan angle (RVS) was characterized prelaunch in lab ambient conditions and will be used on-orbit to characterize the response for scan angles. This document provides three RVS results obtained from NICST, Raytheon and Aerospace. A comparison of the RVS results is conducted for each band, detector and half angle mirror (HAM) side. The associated RVS uncertainties are examined and compared with the relative differences found between independent studies. Results show that the agreement is within 0.1% for all bands except for RSB band M9, where a difference of 0.2% results from the application of the atmospheric water vapor correction for laboratory conditions during the test by Raytheon. NICST has slightly larger RSB RVS uncertainties but still well within the 0.3% total uncertainty allowed for the RVS characterization.
bore-sighted with the IR line-scanner, and includes an active source for monitoring calibration stability.

eMAS is intended to support future satellite missions including the Hyperspectral Infrared Imager (HypsIRI), the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) and the follow-on Joint Polar Satellite System (JPSS.)

8153-23, Session 5

Development of a low-cost student-built multispectral sensor for the International Space Station

D. R. Olsen, H. J. Kim, J. Ranganathan, S. Laguette, The Univ. of North Dakota (United States)

Built by students and faculty at the University of North Dakota (UND), the International Space Station (ISS) Agricultural Camera (ISSAC) is a multispectral Earth-imaging sensor currently onboard the ISS. Capabilities include three spectral bands (green, red, near-infrared), moderate (20-30 m) spatial resolution, and off-nadir pointing (+/-30 degrees) for episodic rapid-response imaging. We describe the low-cost electro-optical design approach, which relies on modified commercial components operating within a passive vibration isolation mounting, installed inside the Window Observational Research Facility and viewing the Earth through the US Laboratory Science Window. Interfaces, safety, and other factors unique to the human-rated operational environment of the ISS are outlined. Limitations of the student-centric development environment and constraints of operating from the ISS are addressed, as well as the benefits and opportunities of such. Pre-launch sensor characterization results, including spatial distortion and radiometric measurements, indicate Earth remote sensing using such a sensor is a viable approach for demonstrative operational missions. An element of the ISS National Laboratory, ISSAC was launched on HTV-2 in January 2011. Plans are presented for sensor operations, now set to commence in summer 2011. Student operators at UND will receive sensor tasking requests from public end users, upload commands, process telemetry, and deliver imagery; all as part of a broader applied research initiative known as the Upper Midwest Aerospace Consortium (UMAC). The mission of UMAC is to develop, support, and enable adoption of innovative Earth science applications, such that informed decision making can improve both environmental sustainability and societal economics.

8153-24, Session 5

SENTINEL-2 level 1 image processing and performances

S. J. Baillarin, A. Meygret, Ctr. National d’Études Spatiales (France); P. Martimort, European Space Research and Technology Ctr. (Netherlands); C. Dechoz, B. Petrucci, Ctr. National d’Études Spatiales (France); F. Spoto, European Space Research and Technology Ctr. (Netherlands); P. J. Henry, Ctr. National d’Études Spatiales (France); O. Colin, ESRIN (Italy); C. Isola, European Space Research and Technology Ctr. (Netherlands)

In partnership with the European Commission and in the frame of the Global Monitoring for Environment and Security (GMES) program, the European Space Agency (ESA) is developing the Sentinel-2 optical imaging mission devoted to the operational monitoring of land and coastal areas.

The Sentinel-2 mission is based on a satellites constellation deployed in polar sun-synchronous orbit. While ensuring data continuity of former SPOT and LANDSAT multi-spectral missions, Sentinel-2 will also offer a wide range of improvements such as a global coverage, a large field of view (290km), a high revisit capability (5 days with two satellites), a high resolution (10m, 20m and 60m) and multi-spectral imagery (13 spectral bands).

In this context, the Centre National d’Études Spatiales (CNES) supports ESA to define the system image products and to prototype the relevant image processing techniques.

First, this paper presents the Sentinel-2 system and the image products that will be delivered: starting from raw decompressed images up to accurate ortho-images in Top of Atmosphere reflectances. The stringent image quality requirements are also described, in particular the very accurate target geo-location.

Then, the prototyped image processing techniques will be addressed. Both radiometric and geometric processing will be described with a special focus on the automatic enhancement of the geometric physical model involving a global set of reference data.

Finally, the very promising results obtained by the prototype will be presented and discussed. The radiometric and geometric performances will be provided as well as the associated computing time spent on the target platform.

8153-25, Session 5

SPnPS: a Space Plug-n-Play Spectrometer for constellation CubeSat applications

S. R. Watchorn, Scientific Solutions, Inc. (United States); R. Doe, K. Leveque, SRI International (United States); J. Noto, Scientific Solutions, Inc. (United States)

The CubeSat initiative envisions inexpensive, easily reproducible satellite packages for Earth-viewing remote sensing applications, such as space weather modeling (including winds and temperatures) and spectral probes of vegetation canopies, among other applications. A constellation of CubeSat payloads could provide worldwide coverage for measuring these and similar phenomena. Such payloads require lightweight, robust, standardized components. For remote sensing payloads, one of the most difficult components to standardize and make robust for high-resolution applications (such as wind measurements in space weather) is the spectrometer itself.

The Space Plug-and-Play Spectrometer (SPnPS) is an answer to that problem. Using a monolithic Spatial Heterodyne Spectrometer (requiring no moving parts for high resolution sensing) at its heart, the SPnPS system allows for standardized spectrometer insertion into an optical train. Coupled with standard avionics developed according to the Space Plug-and-Play Avionics (SPA) initiative, SPnPS allows for easily reproducible and re-taskable spectrometer packages for CubeSat-based applications.

This presentation will talk about the very early stages of SPnPS development, including modeling its “tradespace:” the resolution, sensitivity, and field of view attainable within the CubeSat size, weight, and power constraints; the preliminary optical design of the system; and a breadboard (brassboard) avionics mock-up to simulate the final-version SPnPS payload.

8153-26, Session 5

Preliminary error budget for the reflected solar instrument for the Climate Absolute Radiance and Refractivity Observatory

K. J. Thome, NASA Goddard Space Flight Ctr. (United States); T. Gubbels, Sigma Space Corp. (United States); R. A. Barnes, Science Applications International Corp. (United States)

The Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission addresses the need to observe high-accuracy, long-term climate change trends and to use decadal change observations as the most critical method to determine the accuracy of climate change. The CLARREO Project will implement a spaceborne earth observation mission designed to provide rigorous SI-traceable observations (i.e.,
radiance, reflectance, and refractivity) that are sensitive to a wide range of key decadal change variables. The instrument suite includes emitted infrared spectrometers, global navigation receivers for radio occultation, and reflected solar spectrometers. The measurements will be acquired for a period of five years and will enable follow-on missions to extend the climate record over the decades needed to understand climate change. This work describes a preliminary error budget for the RS sensor. The RS sensor will retrieve at-sensor reflectance over the spectral range from 320 to 2300 nm with 500-m GIFOV and a 100-km swath width. The current design is based on an Offner spectrometer with two separate focal planes each with its own entrance aperture and grating covering spectral ranges of 320-640, 600-2300 nm. Reflectance is obtained from the ratio of measurements of radiance while viewing the earth’s surface to measurements of irradiance while viewing the sun. The requirement for the RS instrument is that the reflectance must be traceable to SI standards at an absolute uncertainty <0.3%. The calibration approach to achieve the ambitious 0.3% absolute calibration uncertainty is predicated on a reliance on heritage hardware, reduction of sensor complexity, and adherence to detector-based calibration standards. The design above has been used to develop a preliminary error budget that meets the 0.3% absolute requirement. Key components in the error budget are geometry differences between the solar and earth views, knowledge of attenuator behavior when viewing the sun, and sensor behavior such as detector linearity and noise behavior. Methods for demonstrating this error budget are also presented.

8153-29, Session 6

ORCA’s depolarizer

E. Waluschka, M. E. Wilson, M. A. Quijada, B. McAndrew, L. Ding, NASA Goddard Space Flight Ctr. (United States)

The Ocean Radiometer for Car bon Assesment (ORCA), currently being developed at Goddard, is a hyper spectral instrument with a spectral range extending from 350nm to 880nm. Its radiometric measurement accuracy will depend, in part, on the extent to which it is insensitive to linearly polarized light. A wedge type depolarizer is used to reduce ORCA’s polarization sensitivity over its entire spectral range. The choice for this approach is driven by the large spectral range and to a certain extent is also influenced by the currently orbiting SeaWIFS instrument’s use of a wedge depolarizer and its low polarization sensitivity. The wedge depolarizer’s design, its modeled and measured depolarization characteristics are presented.

8153-30, Session 6

Characteristics of a new type of Mie scattering volume diffuser and its use as a spectral albedo calibration standard for the solar reflective wavelength region

D. F. Heath, Ball Aerospace & Technologies Corp. (United States)

Emerging instrumental requirements for remotely sensing tropospheric trace species have led to a rethinking by some of the paradigm for SI traceability of the spectral irradiance and radiance radiometric calibrations to spectral albedo which has units of sr^-1 which is not a SI unit. In the solar reflective wavelength region the spectral albedo calibrations of space instruments are tied often to the either the spectral albedo of a solar diffuser or the Moon. This new type of Mie scattering diffuser (MSD) is non-porous, capable of withstanding high temperatures, and is more Lambertian than PTFE a.k.a. Spectralon. It has the potential of covering the solar reflective wavelength region from the UV through the SWIR. Laboratory measurements have shown that the specular reflectance component is negligible from 200 nm through 3600 nm. A 3.0 mm thick MSD has a typical diffuse reflectance ~ 70% and a diffuse transmittance ~20% from 250 nm to 2500 nm. The sum of the diffuse reflectance and the diffuse transmittance is ~ 90 % which indicates that internal absorption by multiple scattering is small. This MSD, a true volume diffuser, exhibits a high degree of radiometric stability which suggests that measurements of its spectral albedo at the NIST STAR II facility could provide a NIST traceable spectral albedo standard. Measurements are currently in progress on its radiometric stability under a simulated space environment of high energy ionizing and UV solar radiation for its eventual use in space as a solar diffuser.

8153-31, Session 6

RF-excited plasma lamps for use as sources in OGSE integrating spheres

A. V. Arecchi, G. A. McKee, C. N. Durell, Labsphere, Inc. (United States)

Integrating spheres for optical calibration of remote sensing cameras have traditionally been made with Quartz Tungsten Halogen (OTH) lamps because of their stability. However, OTH lamps have the spectrum of a blackbody at approximately 3000K, while remote sensing cameras...
are designed to view a sun-illuminated scene. This presents a severe significant mismatch in the blue end of the spectrum. Attempts to compensate for this spectral mismatch have primarily used Xenon lamps to augment the QTH lamps. However, Xenon lamps suffer from temporal instability that is not desirable in many applications. This paper investigates the possibility of using RF-excited plasma lamps to augment QTH lamps. These plasma lamps promise to be more stable than Xenon and have a smoother spectrum. The paper presents measurements of spectra and stability. The spectrum is measured from 320 nm to 2500 nm and the temporal stability from DC to 10 MHz. The RF-excited plasma lamps are quite small, less than 10mm in diameter and about 15 mm in length. This makes them quite suitable for designing reasonably sized reflective optics for directing their light into a small port on an integrating sphere. The paper reports on the design and testing of such an optic.

8153-32, Session 6

Using a hyperspectral image projector to test remote sensing instruments

J. P. Rice, National Institute of Standards and Technology (United States)

NIST is developing, along with several collaborators, a Hyperspectral Image Projector (HIP) for system-level performance testing of multispectral sensors. The HIP is capable of projecting realistic spatial scenes with high-fidelity spectral content into sensors. The current HIP prototype has a spatial resolution of 1024 x 768 pixels and a spectral range of 450 nm to 2400 nm, with spectral resolution from 2 nm in the visible to 5 nm in the short-wave infrared. The HIP can simulate top-of-the-atmosphere spectral radiance over a 10 mm x 14 mm, f/3 image, and this can be collimated to stimulate remote sensing instruments. Also, the spectral radiance of the projected scenes can be measured with a NIST-calibrated spectroradiometer, such that the spectral radiance projected into each pixel of the sensor under test can be accurately known. We describe the experimental characterization of the HIP, and the use of the HIP in testing remote sensing instruments.

8153-33, Session 6

Thermal stability of a 4 meter primary reflector for the Scanning Microwave Limb Sounder

R. E. Cofield IV, Jet Propulsion Lab. (United States); E. P. Kasl, DR Technologies Inc. (United States)

We describe the fabrication and thermal-stability analysis and test of a composite demonstration model of the Scanning Microwave Limb Sounder (SMLS) primary reflector, having full 4 m height and 1/3 the width planned for flight. SMLS is a space-borne heterodyne radiometer which will measure pressure, temperature and atmospheric constituents from thermal emission between 180 and 660 GHz. Current MLS instruments in low Earth orbit scan pencil-beam antennas (sized to resolve about one scale height) vertically over the atmospheric limb. SMLS, planned for the Global Atmospheric Composition Mission of the NRC Decadal Survey, adds azimuthal scanning for better horizontal and temporal resolution and coverage than typical orbit spacing provides. SMLS combines the wide scan range of the parabolic torus with unblocked offset Cassegrain optics. The resulting system is diffraction-limited in the vertical plane but highly astigmatic in the horizontal, having a beam aspect ratio ~1:20. Symmetry about the nadir axis ensures that beam shape is nearly invariant over +/-65 degrees of azimuth. The antenna feeds a low-noise SIS receiver whose FOV is swept over the reflector system by a small scanning mirror. Using finite-element models of antenna reflectors and structure, we evaluate thermal deformations and the resulting optical performance for 4 orbital environments and isothermal soak. We compare deformations with photogrammetric measurements made during wide-range (ambient:[-97, +75]degrees C) thermal soak tests of the primary in a chamber. This range exceeds predicted orbital soak ranges by large factors, implying in-orbit thermal stability of 0.21 micron rms/degree C, which meets SMLS requirements.

8153-34, Session 7

NEON ground validation capabilities for airborne and space-based imagers

J. T. McCorkel, M. A. Kuester, T. U. Kampe, National Ecological Observatory Network, Inc. (United States)

Airborne remote sensing measurements provide the capability to quantitatively measure biochemical and biophysical properties of vegetation at regional scales, therefore complementing surface and satellite measurements. The National Ecological Observatory Network (NEON) will build three airborne systems to allow for routine coverage of NEON sites (60 sites nationally) and the capacity to respond to investigator requests for specific projects. Each airborne system will consist of an imaging spectrometer, waveform lidar and high-resolution digital camera. Remote sensing data gathered with this instrumentation needs to be quantitative and accurate in order to derive meaningful information about ecosystem properties and processes. Also, comprehensive and long-term ecological studies require these data need to be comparable over time, between coexisting sensors and between generations of follow-on sensors. NEON’s calibration plan for the airborne instrument suite relies on intensive laboratory, on-board, ground-based characterization as well as inter-sensor comparisons. As part of these efforts, NEON organized a pathfinder mission in September 2010 to test prototype techniques and procedures for field sampling and sensor validation. Imaging spectroscopy data from AVIRIS and waveform lidar data were acquired in addition to ecological field sampling at the Ordway-Swisher Biological Station near Gainesville, Florida. This paper presents NEON’s capabilities for validation of at-sensor radiance of airborne and space-based sensors and shows results from the September 2010 pathfinder mission.

8153-35, Session 7

Comparison of diffuse sky irradiance calculation methods and effect on surface reflectance retrieval from an automated radiometric calibration test site

N. P. Leisso, J. S. Czapla-Myers, College of Optical Sciences, The Univ. of Arizona (United States)

The Remote Sensing Group at the University of Arizona is currently refining an automated system for the absolute radiometric calibration of earth-observing sensors. The Radiometric Calibration Test Site (RadCaTS) relies on semi-permanent instrumentation at the Railroad Valley test site to collect data from which surface reflectance and an atmospheric characterization is determined. Multispectral surface reflectance is determined from calibrated ground viewing radiometers and assimilated to determine the hyperspectral reflectance used in radiative transfer calculations. The reflectance retrieval algorithm relies on an accurate determination of the diffuse sky irradiance for the time of interest. Currently, diffuse sky irradiance is modeled using the atmospheric characterization as input into MODTRAN. This work investigates the accuracy of the diffuse sky modeling by comparing modeled results to measurements made at the test site. Diffuse sky irradiance from several alternative methods are also presented. Surface reflectance is computed for each method and compared to in-situ measurements taken with a portable spectroradiometer. Top-of-atmosphere spectral radiance results are computed for MODIS using modeled and in-situ measurements and a comparison of results is presented.
ROSAS: a ROBotic Station for Atmosphere and Surface characterization dedicated to on-orbit calibration

A. Meygret, Ctr. National d’Études Spatiales (France); R. P. Santer, Univ. du Littoral Côte d’Opale (France); B. Berthelot, VEGA Technologies SAS (France)

La Crau test site is used by CNES since 1987 for vicarious calibration of SPOT cameras. The former calibration activities were conducted during field campaigns devoted to the characterization of the atmosphere and the site reflectances. Since 1997, automatic photometric station (ROSAS) was set up on the site on a 10m height pole. This station measures at different wavelengths, the solar extinction and the sky radiances to fully characterize the optical properties of the atmosphere. It also measures the upwelling radiances over the ground to fully characterize the surface reflectance properties. The photometer samples the spectrum from 380nm to 1600nm with 9 narrow bands. Every non cloudy day the photometer measures the radiances sequentially and in parallel before and after its measurements. Data are transmitted by GSM (Global System for Mobile communications) to CNES and processed. The photometer is calibrated in situ over the sun for irradiance and cross-band calibration, and over the Rayleigh scattering for the short wavelengths radiance calibration. The data are processed by an operational software which calibrates the photometer, estimates the atmosphere properties, computes the bidirectional reflectance distribution function of the site, then simulates the top of atmosphere radiance seen by any sensor over-passing the site and calibrates it.

This paper describes the instrument, its measurement protocol and its calibration principle. Calibration results are discussed and an error budget is presented. It details the surface reflectance characterisation and presents SPOT4 and SPOT5 calibration results deduced from the estimated TOA radiance. The results are compared to these sensors official calibration.

Radiometric quality of the MODIS bands at 667 and 678nm

G. Meister, B. A. Franz, NASA Goddard Space Flight Ctr. (United States)

The MODIS instruments on Terra and Aqua were designed to allow the retrieval of fluorescence effects over ocean. The high radiometric accuracy needed to retrieve the small fluorescence signal lead to a dual gain design for the 667 and 678nm bands. This paper discusses the benefit obtained from this design choice and provides justification for the use of only one set of gains for global processing. Furthermore, other radiometric artifacts and algorithm issues impacting the fluorescence products are evaluated as well, especially instrument straylight contamination. The straylight contamination is evaluated in case studies at ocean/cloud boundaries. The performance of the two units on Terra and Aqua is compared. Some seasonal dependent responses in the MODIS Terra red bands has been tied to the MODIS Aqua red bands by NASA’s Ocean Biology Processing Group, the focus of this paper is on the MODIS Aqua products.

Using the moon for Terra MODIS MTF characterization

Z. Wang, T. J. Choi, Sigma Space Corp. (United States); X. Xiong, NASA Goddard Space Flight Ctr. (United States)

The on-orbit MTF of MODIS instrument can be accurately measured by its on-board SpectroRadiometric Calibration Assembly (SRCA). For other earth-observing instruments without calibrators similar to SRCA, the sharp edge of the moon can provide a reasonable high-contrast target for their on-orbit MTF characterization. In this paper, we propose a method to characterize MODIS MTF using its lunar observations and present the results for Terra MODIS over its entire mission. For each lunar calibration event, the images of the moon from multiple scans are taken and traced across the right edge to form an edge spread function (ESF). The ESF is used to calculate the line spread function (LSF) through differentiation. The MTF in along-scan direction is then derived through the Fourier Transform of LSF. We will show that the long-term trending of lunar MTF generally agrees with that derived from the SRCA. As expected, lunar MTF results show relatively large variations. This is mainly because of the lunar surface non-uniformity and the sensor’s low spatial resolution, making it difficult to accurately locate the lunar edge in a sub-pixel level. Improvements to the current method are also discussed in this paper.

Characterization of MODIS mirror-side dependent response in the reflective solar spectral region

X. Geng, Sigma Space Corp. (United States); A. Angal, Science Systems and Applications, Inc. (United States); J. Sun, A. Wu, T. J. Choi, Sigma Space Corp. (United States); X. Xiong, NASA Goddard Space Flight Ctr. (United States)

The MODIS instruments onboard the Terra and Aqua spacecrafts, launched in December 1999 and May 2002, respectively, have successfully operated through the present time. MODIS collects the earth view (EV) data via a two-sided paddle wheel scan mirror at angles of incidence (AOI) from 10.5 to 65.5 degrees. This paper describes the methodology used to characterize MODIS reflective solar bands (RSB) EV mirror-side dependent responses and calculate on-orbit changes in their relative responses versus scan angle (RVS). It evaluates the long-term trends of response differences between two mirror sides using different EV targets. Results show that the on-orbit changes in the properties of the scan mirror are wavelength and AOI dependent with large changes seen at shorter wavelengths and larger AOI. Starting from 2005, the mirror-side dependent responses have gradually exhibited some seasonal dependent features in a few Terra MODIS visible spectral bands, which are mainly due to changes in the scan mirror’s polarization properties. In addition to fully characterizing on-orbit changes of MODIS scan mirror properties, results and discussions provided in this paper will help understand their impact on the Level 1B data products and support our future effort to maintain MODIS data quality.

The VIIRS ocean data simulator enhancements and results

W. D. Robinson, F. S. Patt, SAIC (United States) and NASA Goddard Space Flight Ctr. (United States); B. A. Franz, NASA Goddard Space Flight Ctr. (United States); K. R. Turpie, SAIC (United States) and NASA Goddard Space Flight Ctr. (United States); C. R. McClain, NASA Goddard Space Flight Ctr. (United States)

The VIIRS Ocean Science Team (VOST) has been developing a VIIRS Ocean Data Simulator to create realistic VIIRS SDR datasets based on MODIS water-leaving radiances. The simulator is helping to assess instrument performance and scientific processing algorithms. Several changes were made in the last two years to complete the simulator and broaden its usefulness. The simulator is now fully functional and includes all sensor characteristics measured during prelaunch testing including electronic and optical crosstalk influences, polarization sensitivity, and relative
spectral response. Also included is the simulation of cloud and land radiances to make more realistic data sets and to understand their important influence on ocean color data when combined with instrument artifacts. The tables used in the processing including aerosol and Rayleigh radiances have been modeled using VIIRS relative spectral responses.

The capabilities of the simulator were expanded to work in an unaggregated sample mode and to produce scans with additional samples beyond the standard scan. Both these features improve the capability to realistically simulate artifacts which act on individual instrument samples and which may originate from beyond the actual scan boundaries. The simulator was expanded to simulate all 16 M bands and the EDR processing was improved to use these bands to make an SST product.

The simulator is being used to generate global VIIRS data from and in parallel with the MODIS Aqua data stream. Instrument artifact impact studies have also been conducted using the simulator. This paper discusses the simulator improvements and results from the global processing and artifact impact studies.

8153-64, Poster Session

Remote monitoring systems

F. Mkrtchyan, Institute of Radio Engineering and Electronics (Russian Federation)

Now wide development in the world is received by multichannel monitoring systems of remote basing. Such systems allow to receive the operative information on an environment condition in different scales. These systems the important place is occupied with the systems focused on studying of water systems. The technique of detection offered in given work and identification of the abnormal phenomena in the water environment (microwave and optical) combines presence with application of possibilities of remote measurements algorithmic and the software, allowing to solve measurement and detection problems in real time. The effective decision of these problems is impossible without wide introduction in practice of researches of the automated systems of gathering, storage and data processing on the basis of modern computer systems with application of technology of open systems.

Already created methods and algorithms possess ability to overcome such difficulties, as scantiness and not stationarity information, presence small statistically non-uniform samples.

It is obvious that complex research of the given land and remote measurements can raise reliability of estimations of parameters of natural systems and solve a problem of planning of these measurements. Application of means of remote monitoring in many cases is connected with acceptance of the statistical decision on presence on a surveyed part of studied space of this or that phenomenon. One of features of conditions of gathering of the information for such decision is the impossibility of reception statistical samples great volumes. Therefore working out and research of optimum algorithms of distinction of the casual signals characterized by samples of the limited volume, in the conditions of parametrical aprioristic indefinite necessary.

8153-65, Poster Session

Results of MODIS band-to-band registration characterization using on-orbit lunar observations

X. Xiong, NASA Goddard Space Flight Ctr. (United States); J. Sun, Sigma Space Corp. (United States); A. Angal, Science Systems and Applications, Inc. (United States)

Since launch, lunar observations have been made regularly by both Terra and Aqua MODIS and used for a number of sensor calibration and characterization related applications, including radiometric stability monitoring, spatial characterization, optical leak and electronic cross-talk characterization, and calibration inter-comparison. MODIS has 36 spectral bands with a total of 490 individual detectors. They are located on four focal plane assemblies (FPA). This paper focuses on the use of MODIS lunar observations to characterize its band-to-band registration (BBR). In addition to BBR, the approach developed by the MODIS Characterization Support Team (MCST) can be used to characterize MODIS detector-to-detector registration (DDR). Long-term BBR results developed from this approach are presented and compared with that derived from a unique on-board calibrator (OBC). Results show that on-orbit changes of BBR have been very small for both Terra and Aqua MODIS and this approach can be applied to other remote sensing instruments.

8153-66, Poster Session

Enabling radiometric validation and on-orbit calibration: flight software of the CERES scanning radiometer

K. K. Teague, G. L. Smith, Science Systems and Applications, Inc. (United States); K. J. Priestley, NASA Langley Research Ctr. (United States)

Five CERES scanning radiometers have been flown to date. The Proto-Flight Model flew aboard the Tropical Rainfall Measuring Mission spacecraft in November 1997. Two CERES instruments, Flight Models (FM) 1 and 2, are aboard the Terra spacecraft, which was launched in December 1999. Two more CERES instruments, FM-3 and FM-4, are on the Aqua spacecraft, which was placed in orbit in May 2002. These instruments continue to operate after providing over a decade of Earth Radiation Budget data. FM-5 has been integrated to the NPP spacecraft, scheduled for launch this year. Another CERES instrument, FM-6, is being built for use on the JPSS C-1 spacecraft and a successor to these CERES instruments is presently in the definition stage. This paper describes the evolving role of flight software in the operation of these instruments to accomplish the Science objectives of the mission and also to enable execution of supplemental tasks. The CERES software interface was designed to allow for on-orbit modification, and as such, constantly evolves to meet changing needs.

The CERES flight software was originally written in the early 1990's by Walter Mallory of the Space Division of TRW, now Northrop-Grumman, using C code. There are two sets of software in each CERES instrument, each running on an Intel 80C186 processor. The Data Acquisition Processor (DAP) controls the elevation scanning mechanism, the contamination covers, internal calibrations, and the thermal control subsystem. The Instrument Control Processor controls the azimuth scanning assembly, internal sequences, and is responsible for the spacecraft and DAP interfaces.

8153-67, Poster Session

The measured point response functions of the CERES Flight Model 5 instrument

J. L. Daniels, G. L. Smith, Science Systems and Applications, Inc. (United States); K. J. Priestley, NASA Langley Research Ctr. (United States); H. Bitting, Northrop Grumman Corp. (United States)

The Clouds and Earth Radiant Energy System (CERES) Flight Model 5 instrument is scheduled to be placed in orbit aboard the NPP spacecraft in order to continue the Climate Data Record for Earth radiation budget. The CERES instrument is a three channel radiometer and measures solar radiation reflected by the Earth, radiation emitted by the Earth and radiation in the 8 to 12 micron window of the atmosphere. CERES data will be used together with measurements from the VIIRS (Visible Infra-red Imager Radiometer Suite), also on the NPP, to compute cloud information for each CERES pixel. The VIIRS pixels are an order of magnitude
smaller than those of CERES, so it is necessary to know the response of the instrument to a point within the CERES field of view as it scans. This effect is denoted the point response function (PRF). Knowledge of the PRF is also needed to validate accurately the geo-location of the CERES measurements. The Radiative Calibration Facility of the Space Division of Northrup-Grumman, the designer and builder of the CERES instruments, includes the PRF Source, which is an optical devise for measuring the PRF. The PRF Source provides a suitable light beam which is measured by the CERES instrument as it scans in vacuum. This paper presents the analysis of these tests and the resulting PRF for each of the three channels and compares the measured PRFs to that predicted theoretically.

8153-69, Poster Session

Initial operation results of in-orbit radiometric calibration for geostationary ocean color imager

S. Cho, S. Lee, E. Oh, H. Han, Y. Ahn, J. Ryu, Korea Ocean Research & Development Institute (Korea, Republic of)

As the world's 1st ocean color observation satellite in geostationary orbit, Geostationary Ocean Color Imager(GOCI) was successfully co-developed by Korea Aerospace Research Institute (KARI) and EADS Astrium in France by the request and supervision of the Korea Ocean Research & Development Institute (KORDI). GOCI was successfully launched at Kourou Space Center in French Guiana by Ariane 5 ECA Launch Vehicle in 27 June 2010(KST). After the successful launch, GOCI in-orbit test campaign was operated for sensor validation during six months. From the first half of 2011, nominal operation and data distribution service of GOCI is planned under the responsibility of the Korea Ocean Satellite Center(KOSC) in KORDI. During the in-orbit test campaign, GOCI functional test for the performance check of GOCI sub-systems. GOCI radiometric tests was followed after the success of GOCI functional test. GOCI radiometric model, the reference internal radiative transfer function of GOCI H/W, was characterized by the GOCI Solar calibration image acquisition. GOCI radiometric linears gains calculated from initial in-orbit solar calibration varies about 5% comparing with the ground test results. For the GOCI in-orbit radiometric calibration, Solar Diffuser and Diffuser Aging Monitoring Device(DAMD) are implemented into shutter wheel of GOCI. Diffuser aging monitoring is operated from GOCI in-orbit radiometric test. In-orbit measured GOCI diffuser aging factor for six months during GOCl in-orbit tests is about 3%. In this paper, we present the initial operation results of preliminary characterization result of GOCI in-orbit solar calibration operated at in-orbit test period.

8153-70, Poster Session

NPP VIIRS geometric performance status

G. Lin, INNOVIM (United States); R. E. Wolfe, NASA Goddard Space Flight Ctr. (United States); M. Nishihama, Sigma Space Corp. (United States)

Visible Infrared Imager Radiometer Suite (VIIRS) instrument on-board the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project (NPP) satellite is scheduled for launch in October, 2011. The instrument geometric performance includes sensor (detector) spatial response, band-to-band co-registration (BBR) and pointing stability. They have been calibrated and characterized through ground testing under ambient and thermal vacuum conditions, numerical modeling and analysis. This paper summarizes the results, along with anomaly investigations, and describes paths forward for characterizing on-orbit BBR and spatial response, and for improving instrument on-orbit performance in pointing and geolocation.

VIIRS sensor spatial response is measured by line spread functions (LSFs) in the scan and track directions for every detector. We parameterize the LSFs by: 1) dynamic field of view (DFOV) in the scan direction and instantaneous FOV (IFOV) in the track direction; 2) modulation transfer function (MTF) for the 17 moderate resolution bands (M-bands); and 3) horizontal spatial resolution (HSR) for the five imagery bands (I-bands). We define VIIRS BBR for M-bands and I-bands as the overlapped fractional area of angular pixel sizes from the corresponding detectors in a band pair, including nested I-bands with M-bands. The ground tests result in static BBR matrices. VIIRS pointing stability includes scan plane tilt, scan rate and scan start position variations, and thermally induced pointing variations with respect to orbital position. These will be tracked or corrected.

8153-71, Poster Session

High-temperature fixed points for pre-launch calibration of Earth observing sensors

Y. Yamada, J. Ishii, National Institute of Advanced Industrial Science and Technology (Japan)

Radiometric pre-launch calibration of earth observing multispectral sensors such as ASTER was performed traceable to defining fixed-point blackbodies of the International Temperature Scale of 1990. The highest temperature of these is the copper point at 1357.77 K, which was sufficient for the calibration of the shortest band at around 560 nm. However, with the next generation hyperspectral sensors with the spectral band extending down to 400 nm, the copper point blackbody radiance drops rapidly and decreases by two orders of magnitude from that at 560 nm. Therefore, a fixed-point of higher temperature, possibly around 2000 K, is desired.

The authors have proposed high-temperature fixed points of metal-carbon systems for temperature standards use, which have now become a part of the high-temperature traceability system in Japan as well as in other countries. Application of these fixed points to hyperspectral sensor calibration is of high interest.

In this presentation, a fixed-point cell of Co-C eutectic (1597 K) for remote sensor calibration application is described. To enable alignment of the radiance comparator utilizing a grating monochromator, an enlarged aperture design is employed for the fixed-point cell while at the same time retaining the outer dimension to fit in existing fixed-point furnaces. Extension of the technique to Pt-C eutectic (2011 K) or Gr3C2-C peritectic (2100 K) systems is envisaged.

8153-73, Poster Session

Effects of geometric misregistration on cross-calibration of sensors

G. Chander, R. Rengarajan, U.S. Geological Survey (United States); A. Shrestha, Science Systems and Applications, Inc. (United States); D. L. Helder, South Dakota State Univ. (United States)

The appearance of the ground areas in images captured by sensors may vary due to differences in sensor type, sensor altitudes, imaging, and viewing geometry. This can make image registration extremely difficult for data acquired even on the same-day within a few minutes apart. The effect of viewing geometry on the appearance of images is even more pronounced in sensors with a large view angle. Image registration plays a significant role in providing accurate cross-calibration results and can be a major source of error when cross-calibration is performed using the region of interest (ROI) from image pairs. In general, to minimize the effect of misregistration and spatial non-uniformity, large homogeneous regions are preferred for cross-calibration. However, the uncertainty caused by image misregistration needs to be investigated for better understanding of cross-calibration uncertainty among various imaging platforms. This paper presents the results of the sensitivity study to determine the effect of misregistration of the ROI in several images. Five representative land cover types (desert, rangeland, grassland, deciduous forest, and coniferous forest) were selected for the study. Several cloud-free images acquired over the lifetime of the Landsat 5 Thematic Mapper (TM) sensor
were selected from each site, and a moving window technique was used to model potential misregistration within standard image products.

8153-74, Poster Session

Calibration of the AVHRR near-infrared (0.86 µm) channel at the Dome C site
S. Upadhyay, C. Cao, National Oceanic and Atmospheric Administration (United States)

AVHRR is a heritage polar instrument with more than 30 years of global earth observation. Due to absence of onboard calibrator for VNIR channels, AVHRR sensors relies on desert sites for relative calibration with uncertainties primarily due to lack of rigorous site characterization and atmospheric effects. This study aims at quantifying the long term degradation of near-infrared channel (0.86 µm) of AVHRR using Antarctic Dome C site which has very small atmospheric effects. All afternoon-orbit NOAA series AVHRR instruments are considered for this study. Though the TOA reflectance data exists only during auroral summer for Dome C, the degradation estimated using TOA reflectance time series for the respective instruments is comparable to those from the previous studies. The degradation estimation suggests that NOAA-7 and -9 have largest drift (more than -3% per year) compared to the other instruments which have less than -1.5% drift per year. The AVHRR channel 2 (0.86 µm) calibration using desert sites has always been challenging due to high uncertainty mainly introduced by the presence of water vapor absorption wavelength. The study shows that, due to extremely cold and dry climate of Dome C, the water vapor absorption effect is negligible and thus it is possible to calibrate near-infrared (0.86 µm) channel with calibration uncertainty less than 1%

8153-76, Poster Session

Evaluation of climate change in 40 years by using AIRS and IRIS hyperspectral infrared measurements
Y. Jiang, H. H. Aumann, Jet Propulsion Lab. (United States); M. Lau, Y. Yung, California Institute of Technology (United States)

Outgoing longwave radiation (OLR) measurements over a long period from satellites provide valuable information for the climate change research. Due to the different coverage, spectral resolution and instrument sensitivities, the data comparisons between different satellites could be problematic and possible artifacts could be easily introduced. We have analyzed the data taken by IRIS in 1970 and by AIRS from 2002 to 2010. We used the spectra between 650 cm-1 and 1350 cm-1 for nadir view footprints in order to match the IRIS’s measurements. Most of the possible sources of error or biases have been carefully handled, these include the errors from the data editing, spatial coverage, missing data (spatial gap), and spectral resolution, spectra frequency shift due to the fields of view, sea surface temperature fluctuations, clear sky determination, and spectra response function symmetry. It is extremely important when comparing spectra in the high slope spectra regions where possible large artifacts could be introduced.

8153-77, Poster Session

A comparison of ice cloud and dust aerosol physical characteristics in Taklimakan desert
Y. Ma, W. Gong, Wuhan Univ. (China)

Classification is an indispensable step in spaceborne lidar data processing. The depolarization signal is achieved from the perpendicular channel divided by the parallel channel at 532 nm. It is a very helpful parameter; and makes a description of the particle’s shape. In general, common aerosol is spherical and dust aerosol is crystalline and non-spherical, but the relationship also exists between ice cloud and water cloud. If we directly add the depolarization ratio to classifier as a higher dimension scheme, this just makes the ice cloud and dust aerosol more confusable, and it becomes more difficult to discriminate the ice cloud and dust aerosol, the precision of aerosol retrieval cannot be further improved.

We try to improve the performance of classifier, so the physical characteristics of cloud/dust layer are the important reference for future study. In this paper, the Aqua-MODIS remote sensing image is introduced, though these data the dust and cloud is easy classified by eyes. Then select the synchronous observations from CALIPSO, after finding the layers altitude and calculating their physical characteristics (depolarization ratio, attenuated backscattering and so on). By choosing a dust storm happened in Taklimakan deserts, 2007, we can find some different exist between them. For example, the cloud exist at N: 40°-41° and N: 44°-44.5° is altocumulus, and the clouds top exceed 10km and 5km respectively, the depolarization ratio of clouds is higher then aerosol, the average value are 0.436 and 0.384 respectively. Compared with dust aerosol, the non-spherical characteristic of ice cloud expressed more obviously. Clouds and aerosol yield large color ratio value, but compare these two clouds, the color ratio are 1.03999 and 1.16094 respectively. This means the size of ice particles in the higher altitude are smaller then the lower altitude.

8153-78, Poster Session

Angular variation of GOES imager scan mirror reflectance
X. Wu, National Oceanic and Atmospheric Administration (United States); D. Ryan-Howard, Massachusetts Institute of Technology (United States); T. C. Stone, U.S. Geological Survey (United States); G. Sindic-Rancic, F. Yu, National Oceanic and Atmospheric Administration (United States); M. Weinreb, Riverside Technology Inc. (United States); M. Grotenhuis, National Oceanic and Atmospheric Administration (United States)

As the GOES Imager scans along the east-west direction, the angle of light incident upon the Imager’s scan mirror varies from approximately 40° to 50°. The scan mirror emissivity in the infrared spectrum varies slightly with incidence angle. This variation has been quantified before launch with measurements on witness samples in the laboratory and after launch with measurements of space scans, and the observations have been properly corrected on orbit to ensure data quality (Weinreb et al. 1997). It has long been hypothesized that the Imager scan mirror reflectance in the visible spectrum may also vary with incidence angle. Recent advances in laboratory measurement and vicarious calibration using the Moon make it possible to examine this hypothesis, both in laboratory and on orbit, in a similar way as for the infrared channels. The research is on-going and will be reported at the conference.

8153-79, Poster Session

Topographic mapping experiment with Chinese airborne SARMapper
J. Zhang, Chinese Academy of Surveying and Mapping (China); Z. Zhao, Wuhan Univ. (China); G. Huang, Chinese Academy of Surveying and Mapping (China)

Aiming for steep terrain relief and complex geomorphic types, the practical airborne SAR mapping system of China developed by a group led by CASM was constructed. Some factors limit the application of airborne SAR mapping such as geometric and radiometric distortion, shadow, difficult field work etc. In order to cope with these shortcomings, some new methods and mapping technical flow were proposed according to difficult terrain area covered by cloud, fog, ice, and snow perennially, lush vegetation and diverse species, steep terrain etc. Face to challenges how to get precise DEM, Digital Orthophoto Map
(DOM), and Digital Line Graphic map (DLG), several key technologies and solutions were studies, such as DEM extraction through refined interferometry, stereogrammetry, and DEM fusion, DOM generation with single/multi-polarization or single/quadr-polarization SAR images acquired from multi-direction, DLG generation under stereo-environment. Based on these technologies, SAR mapping workstation is used to map in such a large area of difficult terrains. It can be used to process airborne and spaceborne SAR images to produce DOM, DEM and DLG. And then the comprehensive experiment in Qinling Mountain Area was carried on. Firstly, interferometric parameters were calibration by angle reflector. Secondly, different resolution of X band interferometric SAR and P band polarimetric SAR data were acquired by the integrated airborne SAR data acquisition system. Finally, mapping experiments in scale of 1:10000 and 1:50000 were carried on these areas, and mapping production was generated by the SAR mapping workstation. Experimental results have proved that the system works well. The production could satisfy the mapping accuracy of 1:10000 and 1:50000.

8153-80, Poster Session

A ground-based hyperspectral sensor system: field imaging spectrometer system (FISS)

J. Wang, Institute of Remote Sensing Applications (China); L. Zhang, J. Yan, Institute of Remote sensing Applications (China); Q. Tong, Institute of Remote Sensing Applications (China)

Recently, to stimulate the development of the field imaging spectrometry in China, we have developed a new ground-based hyperspectral sensor system: Field Imaging Spectrometer System (FISS). This paper describes the main performance and preliminary applications of the China's first field imaging spectrometer system, including its imaging principle, structural design, main technology parameters, and its latest field applications. Before the specific applications, the FISS was accurately spectrally, radiometrically and spatially calibrated in the laboratory, which largely ensured its afterwards quantitative applications reliable. Laboratory calibration results provided a profound understanding of the FISS system. The FISS covers a VIS/NIR spectral range of 437-902 nm, which is split into 344 spectral channels. The spectral resolution of each channel was precisely calibrated better than 5 nm; meanwhile absolute radiometric calibration of the FISS with less than 5% calibration error for each band was achieved using a well calibrated integrating sphere. There are 215 channels with signal to noise ratios (SNRs) greater than 500 (62.5% of the bands). In addition, through spatial calibration in the laboratory, the spatial resolution of the FISS nearly reaches its theoretical level with the instantaneous field of view (IFOV) of 1 mrad. The high performance levels in spectral, radiometric and spatial responses achieved by the FISS implicated its potential applications in various fields, including geography, food science, agriculture, forestry, and urban research. Fortunately our recent applications in crop-weed discrimination, offshore marine environment monitoring, milk discrimination, and estimation of vegetation biochemical information using the FISS have Preliminary confirmed the perfect ability in its field measurements and applications.

8153-81, Poster Session

Atmospheric correction of HJ-1 A/B CCD over land

Q. Fu, Institute of Remote Sensing Applications (China) and China Ctr. for Resource Satellite Data and Applications (China); X. Min, China Ctr. for Resource Satellite Data and Applications (China); L. Sun, Shandong Univ. of Science and Technology (China)

Atmosphere is a large uncertainty factor in the surface reflectance measurement, when examining the Earth’s surface from a satellite platform. Atmospheric correction is one of the key elements to obtain accurate Geographical and biophysical products for earth observation purposes. The algorithms of atmospheric correction continue to be refined and improved in these years.

HJ-1 A/B CCD is one of the key instruments operating on HJ-1 A/B satellites, launched on September 6, 2008 by China, with a spatial resolution of 30 meters. HJ-1 A/B CCD has three visible bands and one near-IR band. The combination of two CCD cameras can get a swath width of 700 km and revisit per 48-hour. However, for lacking of shortwave infrared band, especially bands near 2.1 um, atmospheric correction of HJ-1 A/B CCD over land is very hard. To facilitate the operational atmospheric correction of HJ-1 A/B CCD datasets, a new algorithm of HJ-1 A/B CCD AOD retrieval is developed by introducing MODIS surface reflectance products (MOD09) as base-knowledge. HJ-1/CCD blue band surface reflectance was retrieved through MOD09 blue band surface reflectance by band matching of the two sensors, and aerosol optical thickness was retrieved based on it.

In this paper, On the basis of sensitivity analysis on atmospheric condition and the geometry, the look-up table (LUT) of atmospheric correction coefficient is created using 6S. The calculated reflectance of HJ-1 A/B CCD was compared with the in-situ measurement reflectance and the MODIS surface reflectance outputs (MOD09), results indicated that this proposed atmospheric correction method has a preferable precision.

8153-37, Session 8

CERES FM-5 on the NPP Observatory: predicted performance and early orbit validation plans

K. J. Priestley, NASA Langley Research Ctr. (United States); G. L. Smith, S. Thomas, Science Systems and Applications, Inc. (United States)

To understand our climate, it's necessary to understand energy flows which govern movements and temperatures of the atmosphere and oceans. Solar radiation absorbed by the Earth and its emission as outgoing longwave radiation (OLR) are the heat source and heat sink for this heat engine. The Clouds and Earth Radiant Energy System (CERES) Flight Model FM-1 and FM-2 sensors aboard Terra and the FM-3 and FM-4 sensors aboard the Aqua spacecraft have provided the first CERES observed decadal Earth Radiation Climate Data Record (CDR). To assure continuity of this CDR the CERES FM-5 sensor will fly on the NPP spacecraft, scheduled for launch in October 2011.

In late 2006, FM-5 was removed from storage and completed abbreviated radiometric characterization tests to verify performance. In 2008, the sensor was re-manifested on the NPP mission, removed from storage, the interfaces modified, and again subjected to the full pre-launch radiometric characterization campaign. Integration on the NPP spacecraft occurred in 2008 with environmental and performance testing executed at the observatory level.

NPP's orbit will have the same inclination but higher altitude than Aqua. The Early Orbit Validation & Calibration campaign will consist of exercising all operational modes of the sensor, characterizing scan angle dependent offsets, observing the onboard calibration sources to establish traceability to the pre-launch radiometric scale, as well as initiate the intercalibration opportunities with other CERES sensors which are operating on NASA's Terra and Aqua missions.

8153-38, Session 8

Pre-launch sensor characterization of the CERES Flight Model 5 (FM5) instrument on NPP mission

S. Thomas, Science Systems and Applications, Inc. (United States); K. J. Priestley, NASA Langley Research Ctr. (United States)
States); M. Shankar, N. P. Smith, M. G. Timcoe, Science Systems and Applications, Inc. (United States)

Clouds and the Earth’s Radiant Energy System (CERES) instrument was designed to measure broadband radiances in reflected shortwave and emitted outgoing longwave energy. The 3-sensor CERES instrument measure radiances in 0.3 to 5.0 micron region with Shortwave sensor, 0.3 to >100 microns with Total sensor and 8 to 12 micron region with Window sensor. Flight Model 5, the sixth of the CERES instruments is scheduled to launch aboard the NPP spacecraft on October 2011. An accurate determination of the radiometric gains and spectral responsivity of CERES FMS sensors was accomplished through rigorous calibrations at Northrop Grumman Aerospace Systems’ (NGAS) Radiometric Calibration Facility (RCF). The longwave calibration of the total and window sensors are achieved using the Narrow Field-of-View Blackbody (NFB) source which is tied to International Scale of 1990 (ITS ’90). A Shortwave Reference Source (SWRS) along with the Transfer Active Cavity radiometer (TACR) which acts as the transfer standard of NFB source, is used to determine the radiometric responsivity and spectral response estimates of the SW sensor and shortwave portion of the Total sensor. The spectral responsivity in longwave region is determined using a Fourier Transform Spectrometer (FTS) system. CERES instrument also perform calibrations using on-board sources during pre-launch testing which serve as a traceability standard to carry the ground determined sensor radiometric gains to orbit. This paper covers the calibration philosophy and the results from ground calibration testing of FM5 sensors conducted in 2008. The sensor radiometric gain responses calculated using primary sources and performance of the sensors using on-board sources will be discussed.

8153-39, Session 8

On-orbit solar calibration contamination/degradation effects on the Clouds and Earth’s Radiant Energy System (CERES) in-flight calibration system

R. S. Wilson, Science Systems and Applications, Inc. (United States); K. J. Priestley, NASA Langley Research Ctr. (United States); S. Thomas, P. C. Hess, Science Systems and Applications, Inc. (United States)

The Clouds and Earth’s Radiant Energy System (CERES) scanning thermistor bolometers measure earth-reflected solar and earth-emitted long-wave radiances. The bolometers measure the earth radiances in the (0.3-5.0 microns), (0.3->100 microns) (8->12) microns spectral bands. December 1999, the second and third set of CERES sensors were launched on the Terra spacecraft. May 2003, the fourth and fifth set of bolometers was launched on the Aqua spacecraft. The mirror attenuator mosaic (MAM), a solar diffuser plate, was built into the CERES instrument package calibration system in order to define in-orbit shifts or drifts in the sensor responses. The MAM diffuser reflecting type surface consists of an array of spherical aluminum mirror segments, which are separated by a Merck Black A absorbing surface. In their first year of operation the Terra and Aqua MAMs showed shifts in their calibrations larger than 10% of their nature have been seen in other Solar viewing instruments in the past. A possible explanation has attributed change to pre-orbit or on-orbit contamination/degradation combined with solar ultraviolet/atomic oxygen induced chemical changes to the diffuser plate or contaminant during solar exposure. The synergistic effect of these elements can affect the optical properties of the spherical mirror segments and the black absorbing mask. In this paper, the results of a literature search and lab experiments to zero in on possible physical and chemical mechanisms which can explain the observed elements of the CERES solar calibration time-series will be presented. Comparisons are also made between the TRMM, Terra and the Aqua CERES instruments during their MAM solar calibrations.

8153-40, Session 8

Infrared sensitivity study of the Clouds and Earth’s Radiant Energy System (CERES) Instrument Sensors

M. Shankar, S. Thomas, Science Systems and Applications, Inc. (United States); K. J. Priestley, NASA Langley Research Ctr. (United States); D. R. Walikainen, Science Systems and Applications, Inc. (United States)

The Clouds and Earth’s Radiant Energy System (CERES) mission currently employs four instruments onboard two spacecraft to measure the earth’s reflected shortwave energy and the earth emitted thermal energy that represent the two components of the earth’s energy budget. These measurements are made through three sensors that measure different spectral regions- a Shortwave channel that measures the 0.3 to 5 microns wavelength band, a Total channel that measures all the incident energy (0.3 to 200 microns) and a Window channel that measures the 8 to 12 micron wavelength band. The radiances measured in each channel (filtered radiances) are used to estimate the incident (unfiltered) shortwave and longwave radiances using knowledge of the response functions of each of the measurement channels as well as theoretical knowledge of the energy spectrum of the particular earth scene being measured. For longer wavelengths particularly in the far infrared, both the earth scene spectra as well as the instrument spectral response functions are not very well characterized because of the difficulties in obtaining models for the earth scene spectra as well as the limitations in the capabilities to measure the spectral responses over a very large spectral range. This results in errors in obtaining estimates of the unfiltered radiances. This paper will focus on studying the sensitivity of the CERES sensors to these inaccuracies and its impact on the errors in estimation. In addition, those spectral regions in the longwave infrared where the CERES instruments are most sensitive will be identified.

8153-41, Session 8

The CERES calibration strategy of the geostationary visible channels for CERES cloud and flux products

D. Morstad, Science Systems and Applications, Inc. (United States); D. R. Doelling, NASA Langley Research Ctr. (United States); B. R. Scarino, R. Bhatt, Science Systems and Applications, Inc. (United States)

The Clouds and Earth’s Radiant Energy System (CERES) project has greatly improved the understanding of the role of clouds and energy cycles in global climate studies. CERES flux and cloud properties rely on not only CERES broadband fluxes and MODIS cloud properties but also relies on operational geostationary (GOES, METEOSAT, MTSAT) derived fluxes and clouds in between CERES measurements to properly account for the diurnal cycle. The high quality of the CERES products relies on a consistent radiometric calibration of the un-calibrated geostationary visible sensors and MODIS. To achieve this consistency, the calibration of a reference sensor must be transferred to the other instruments. Historically, Terra-MODIS and Aqua-MODIS, both of which employ solar diffusers, have been regarded as having a well-calibrated visible channel (650 nm). Recent analysis has revealed that the Aqua-MODIS instrument to be more stable than the MODIS instrument onboard the Terra satellite. For this reason, Aqua-MODIS has been chosen as the reference sensor with Terra-MODIS adjustments can be used to put it on the same radiometric scale as Aqua-MODIS. The ray-matching technique can be used to transfer the calibration of the well-calibrated MODIS instrument to the un-calibrated GEO sensors. Additionally, empirically derived BRDF models for pseudo-invariant test sites and deep convective clouds (DCC) have been developed and applied for monitoring and validating the GEO calibration. Latest results include GEO calibration updates for the 2000-2010
time period where Aqua/Terra-MODIS cross calibration trends are in agreement with calibration trends obtained from pseudo-invariant test sites and DCC. These results are in preparation for CERES Edition4 products, which will include updated geostationary calibration coefficients and cloud retrieval improvements.

8153-42, Session 9

Using MODIS to calibrate NOAA series AVHRR reflective solar channels

A. Wu, Sigma Space Corp. (United States); A. Angal, Science Systems and Applications, Inc. (United States); X. Xiong, NASA Goddard Space Flight Ctr. (United States)

Nearly 30 years of continuous observations made by a series of AVHRR sensors have offered a great potential for studies of global environment and climate change. In order to achieve this objective, each sensor must be accurately and consistently calibrated. This is not an easy task as there is no onboard calibrator for AVHRR solar reflective channels and vicarious calibration often needs to accumulate enough observations to derive useful trends. In this study, we select CEOS (the Committee on Earth Observation Satellites) endorsed Cal/Val desert sites to track the long-term stability of reflective solar channels of NOAA-17 AVHRR (launched on June 24, 2002) and re-calibrate them using well-calibrated MODIS as reference. A site-specific Bi-directional Reflectance Distribution Function (BRDF) developed based on observations made by MODIS is used to normalize AVHRR observed reflectances. Impacts of atmospheric water vapor on AVHRR to MODIS reflectance ratios are corrected with the total water vapor content derived from the split-window temperature difference technique. Finally, MODIS-based AVHRR calibration coefficients on top of its prelaunch values are provided in time-dependent look-up tables (LUT). A further validation is performed using MODIS and AVHRR observations obtained over Antarctic Dome C site where impact due to atmospheric water vapor is negligibly small.

8153-43, Session 9

Long-term cross-calibration of the Terra ASTER and MODIS over the CEOS calibration sites

H. Yamamoto, A. Kamei, R. Nakamura, S. Tsuchida, National Institute of Advanced Industrial Science and Technology (Japan)

Remotely sensed optical satellite data can provide spatial and temporal information for various research field on global monitoring. Many recent researches have used this technology as an attractive tool, and recent studies have provided information for the integration of various satellite data and products. The accuracy of higher-level satellite products depend on the radiometric accuracy. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and the Moderate Resolution Imaging Spectroradiometer (MODIS), which are onboard the Terra platform, have contributed to the global research with both fine and coarse spatial resolution. Both of ASTER and MODIS sensor have been operated more than 10 years, and it is very useful for cross-calibration because of their simultaneous observations mostly without BRDF effect. This cross-calibration will contribute to the understanding of relative accuracy each other. Although this kind of research needs the homogeneous, large, and flat test site(s), the CEOS IVOS subgroup arranges the pseudo-invariant standard test sites for cross-calibration, which are able to evaluate the long-term stability among multiple sensors. This paper shows the TOA reflectance comparison between ASTER and MODIS sensor over the CEOS pseudo-invariant standard test sites.

8153-45, Session 9

Verification of GSICS GEO-LEO correction products using GEO-GEO inter-calibration

F. Yu, Earth Resources Technology, Inc. (United States); X. Wu, National Oceanic and Atmospheric Administration (United States); G. Sindic-Rancic, Joint Ctr. for Satellite Data Assimilation (United States)

The Global Space-based Inter-Calibration System (GSICS) was developed aiming to improve the calibration accuracy of operational satellite instruments through inter-calibration between different instruments. Over the past few years, NOAA has been routinely providing the GSICS correction products for the Geostationary Operational Environmental Satellite (GOES) Imager and Sounder radiance by inter-calibrating GEO radiometers to the well-calibrated hyper-spectral instruments on-board Low Earth orbit (LEO) satellites. The inter-calibration between instruments on two GEO satellites over the overlapped area, developed to monitor instrument performance and to detect potential calibration anomaly, can also be used to verify the GSICS GEO-LEO correction products when the differences of spectral response functions (SRF) and viewing condition can be compensated for. In this study, the collocated pixel pairs between GOES-11 and -12/13 are identified when two GEO instruments coincidently view the same pixel at similar viewing zenith angle. The double difference between GSICS corrected observation and simulated radiance with Community Radiative Simulation Model (CARTM) at the collocated pixels is then used to evaluate the correction accuracy. To compensate for the bias introduced from different SRFs, the observed and calculated spectra of each instrument are convolved with SRF of the other. Results of this study will be presented in the coming meeting.

8153-46, Session 9

Cross-calibration of HIRS aboard NOAA satellites using MetOp IASI

R. Chen, I. M. Systems Group, Inc. (United States); C. Cao, National Oceanic and Atmospheric Administration (United States)

The 30 years of observations from High-Resolution Infrared Radiation Sounder (HIRS) aboard NOAA series of satellites have been widely used in numerical weather prediction and climate studies. However, there are significant discrepancies in the HIRS measurements between different satellites. The HIRS data from NOAA satellites series need to be recalibrated to establish an accurate and consistent temporal series before it can be used for climate changing detection. In this study, the HIRS radiance measurements from NOAA satellites (NOAA-6–19) are recalibrated using the hyper-spectral IASI radiance measurements from MetOp satellite as reference. For the satellites after NOAA 15, the HIRS measurements from the NOAA satellites are compared with the matched IASI measurements at Simultaneous-Nadir-Overpass (SNO) locations. For the satellites before NOAA 15, the HIRS measurements are compared with the recalibrated HIRS measurements from the successive NOAA satellite at SNO locations. A detailed analysis of the biases is performed to quantify the root causes of the biases, including both spectral and radiometric causes. By removing these biases, our analysis shows that the HIRS measurements from the NOAA series of satellites can be recalibrated and made traceable to IASI measurements with improved radiometric and spectral calibration.
Impact of near-cloud boundaries on radiometric performance of imaging sounders: an examination of FTS and dispersive spectrometer error sources
T. Ramond, Ball Aerospace & Technologies Corp. (United States); A. B. Newbury, DigitalGlobe, Inc. (United States); M. Stephens, Ball Aerospace & Technologies Corp. (United States)

Meteorological sounding data provided by atmospheric imaging sounders have applications in weather forecasting, atmospheric chemistry, and climate monitoring. Realistic scenes for these instruments vary in both spatial and spectral content and such variations can impact their radiometric performance. As sounders are developed to provide climate records with demanding long-term radiometric accuracy requirements, it becomes increasingly important to understand the effect of scene variations on the performance of these instruments.

We have examined the noise performance and radiometric accuracy of two geostationary sounder architectures in cloudy scenes: a Fourier Transform Spectrometer (FTS) and a dispersive spectrometer. Factors such as stray light, ghosting, scattering, and line-of-sight jitter in the presence of scene inhomogeneities are considered. Quantitative estimates of the radiometric errors associated with sounding in cloudy scenes are made for each architecture. We find that in a dispersive system the dominant error in a cloudy scene originates from ghosting within the instrument, while in an FTS the dominant error originates from scene modulation created by line-of-sight jitter in a partially cloudy scene coupling into signal modulation over the scale of the changing optical path length of the interferometer. In this paper we describe the assumptions made and the modeling performed. We also describe how each factor influences the radiometric performance for that architecture.

Virtual green band for GOES-R
I. Gladkova, M. D. Grossberg, F. Shahrir, The City College of New York (United States)

The ABI on GOES-R will provide imagery in two narrow visible bands (red, cyan), which is not sufficient to directly produce color (RGB) images. In this paper we present a method to estimate a 550 nm green band from a simulated ABI multi-spectral image. To address this problem we propose to use statistical learning methods to train and update functions that implement an estimator, using data from MODIS imager. The need to combine many parameters from multiple bands rules out the straightforward use of traditional look-up tables because the number of entries in look-up tables grows exponentially with the number of parameters. Other basic approaches such as simple linear regression will not produce satisfactory results due to the underlying non-linearity of the data. The relationship among different spectra for cloud footprints will be radically different from that of desert or forest. The approach we propose is to use piecewise polynomial regressions on the multi-spectral input. Our predictor consists of a classifier, which assigns an ABI pixel to a class based on the array of values from all the simulated ABI bands at that pixel. To each class is associated a set of coefficients for a multi-variable polynomial predictor for the 550 nm green band to be predicted. Thus the parameters of the predictor consist of parameters of the classifier, as well as coefficients of the multi-variable polynomial for each class. To determine these classifiers we will use methods based on K-means clustering, as well as standard multi-variable polynomial regression.

WEB recourse to perform the atmospheric correction of satellite data
M. V. Engel, V.E. Zuev Institute of Atmospheric Optics (Russian Federation); S. V. Afonin, V. V. Belov, V.E. Zuev Institute of Atmospheric Optics (Russian Federation) and Tomsk State Univ. (Russian Federation)

At present, the importance of the atmospheric correction (AC) of data of remote surface temperature measurements is well recognized. The AC capabilities are provided practically by all most widespread software products (such as ERDAS and ENVI). Nevertheless, in some cases the AC is totally ignored or performed with accuracy insufficient to solve a particular thematic problem. AC tasks, in particular, necessitate the use of large volume of accurate a priori information on the optical-meteorological state of the atmosphere.

The current development level of information and telecommunication networks allows research to be performed on the basis of the spatially distributed information and calculation resources. Such an approach is used as a basis for a WEB resource to perform the atmospheric correction of remote measurement data, which is currently being developed at Institute of Atmospheric Optics SB RAS (IAO SB RAS). The AC algorithm is based on the optical models of the atmosphere and data of satellite measurements (such as thematic products of MODIS spectroradiometer), stored both in remote databases and in databases inside the WEB resource. The use of the data from the distributed sources provides the necessary a priori optical-meteorological information.

The calculational capabilities of the WEB resource are implemented on the basis of well-known programs for simulating the optical radiative transfer through the atmosphere (e.g., MODTRAN, 6S). This work is also based on the algorithms and methods of AC of remote measurement data, developed at IAO SB RAS, and on local software tools, developed on the basis of these methods.

South Atlantic anomaly filter for satellite UV observation
J. Niu, L. E. Flynn, National Oceanic and Atmospheric Administration (United States)

A South Atlantic Anomaly (SAA) filter has been developed to filter out large amounts of noise caused by high energy protons hitting onto the optical instrument focal plane when the satellite passes through the SAA region. The filter is based on the Empirical Orthogonal Function (EOF) analysis. The EOF vectors derived from an orbit outside of the SAA region were used to represent the observations coming from the noisy SAA region. Then using the clear EOF vectors, the observations within SAA region are rebuilt with just the first five to ten principle components. The filter works well for wavelength shorter than 310 nm. In this region signals are contributed primarily from the upper atmosphere where the cloud effects are small. Tests on L1B data from Ozone Monitoring Instrument (OMI) and Global Ozone Monitoring Experiment-2 (GOME2) have been conducted. It is expected that this filter can help to improve the measurements and retrievals for the OMPS nadir profiler in the SAA region.

Graphyte software for integrated remote sensing research using HPCC
M. D. Grossberg, I. Gladkova, J. K. Gabaldon, P. K. Alabi, J. K. Neiman, The City College of New York (United States)
Graphyte is software for distributed research collaboration and prototyping. Rather than impose a new system structure, our goal is to integrate tools, interfaces, and data that scientists are already using. In addition, we incorporate some of the best practices from modern software engineering: distributed version control, grid and cloud computation, data management, and advanced analysis and visualization tools with multiple clients—including a web based interface. The first prototype of Graphyte provided a web interface for editing python scripts to read, statistically analyze, and visualize NOAA's remote sensing data. Based on user feedback, we have completely restructured the system to better accommodate NOAA's current workflow. The system now handles other coding languages, including Fortran, IDL, and C/C++, besides python. Execution is managed by a sophisticated job system that is able to use grid and cloud HPCC resources.

Another important aspect of the next generation version of Graphyte is that it provides fine-grained user and group permissions. This allows researchers to control the access of files and results. This is a critical pre-requisite for any practical adoption in a research context. In addition to the wide, and deep functionality provided through installed open-source libraries—such as for GIS, economic analysis, machine learning, statistics, image processing, physics, and visualization of data—we provide wrappers for data readers to provide convenient access to NOAA and NASA remote sensing data.

8153-51, Session 11

**Latest decade's spatial-temporal properties of aerosols over China**


Aerosols are one of the most important parameters affecting the Earth's energy balance and hydrological cycle[1]. They can have uncertainties effects on climates. With the development of economic activities, the cities of China are unfortunately exposed to high concentrations of aerosol particles, which often are immediately evident as a dense haze over the city. To narrow the uncertainties associated with the direct and indirect aerosol effects on climates, the spatial-temporal properties of aerosol is investigated over China. The study use the Aerosol Optical Depth (AOD) derived from the radiance measurements performed by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on board the Terra and Aqua satellites from 2002 to 2010.

The most prominent changed regions are the North China and East China. The high AOD values occur in 2004, 2006 and 2007, respectively. The tendencies of AOD are in good agreement with the variations of population and economic activities. The Terra- and Aqua- MODIS data was used to monitor aerosol loading. During the Beijing Olympic Games, due to the strict ensuring good air quality for Beijing Olympic Games, a series of measures for improving air quality were carried out in Beijing and its surrounding areas. 300,000 high emission vehicles were prohibited on roads, 2,000,000 cars were restricted on roads by the policy "odd days for odd number cars, even days for even number cars". A large number of plants and factories were temporarily closed or limited in producing capability, or works after meeting the emission standard. Satellite observational data were used to monitoring the air quality over northern China during this period. The Aura-OMI data was used to monitor O3 and tropospheric NO2 column amount. The Terra- and Aqua- MODIS data was used to monitor aerosol loading. During the Beijing Olympic Games, due to the strict ensuring measures for good air quality, more than 40% reduction in NO2 column was found from satellite observation. On the same time, the ground-based standard CE-318 sunphotometer data was used to validate the retrieval data of MODIS, and the MAXDOAS measurement to validate the retrieval data of Aura-OMI. Also the lidar monitoring for aerosol vertical distribution and tower measurements for gas pollutants and their layer distribution were conducted.

8153-52, Session 11

**Satellite observation of air pollutants over northern China**

P. Wang, H. Yu, G. Wang, X. Zong, Institute of Atmospheric Physics (China)

Much attention has been paid to northern China region because of the fast economic growth and also fast developing air pollution. Satellite observation could be most efficient to monitor the regional air quality, including suspended particles and concentrations of trace gases such as NO2, SO2, O3. During the Beijing Olympic Games, in order to ensure good air quality for Beijing Olympic Games, a series of measures for improving air quality were carried out in Beijing and its surrounding areas. 300,000 high emission vehicles were prohibited on roads, 2,000,000 cars were restricted on roads by the policy "odd days for odd number cars, even days for even number cars". A large number of plants and factories were temporarily closed or limited in producing capability, or works after meeting the emission standard. Satellite observational data were used to monitoring the air quality over northern China during this period. The Aura-OMI data was used to monitor O3 and tropospheric NO2 column amount. The Terra- and Aqua- MODIS data was used to monitor aerosol loading. During the Beijing Olympic Games, due to the strict ensuring measures for good air quality, more than 40% reduction in NO2 column was found from satellite observation. On the same time, the ground-based standard CE-318 sunphotometer data was used to validate the retrieval data of MODIS, and the MAXDOAS measurement to validate the retrieval data of Aura-OMI. Also the lidar monitoring for aerosol vertical distribution and tower measurements for gas pollutants and their layer distribution were conducted.

8153-53, Session 11

**McIDAS-V: a tool for developing and evaluating science applications for weather and climate data**

T. H. Achtor, T. D. Rink, Univ. of Wisconsin-Madison (United States)

The fifth generation of the Man-computer Interactive Data Access System (McIDAS-V) is a java-based, open-source, freely available system that provides powerful data manipulation and visualization capabilities. The unique capabilities of the McIDAS-V software support development of innovative techniques for creating and evaluating algorithms, visualizing data and products in 4 dimensions, and validating results. The GEO/ GESS program seeks to make the global network of weather monitoring observations, databases and forecasting model output available to the international user community. Thus, McIDAS-V can be a very valuable tool for researchers and operational users within the GEO/GEOSS domain. As McIDAS-V has moved from the development stage to a mature software package, new development is focusing on adding functionality and expanding access to new data types. This paper will present results from several research projects involving current and future environmental satellites, demonstrating how the McIDAS-V software can be used to acquire satellite and ancillary data, create imagery and products using both scripting and interactive data manipulation tools, and evaluate output through on-board validation techniques.

8153-54, Session 11

**McIDAS-V: a data analysis and visualization application for GEOSS**

T. D. Rink, Univ. of Wisconsin-Madison (United States)

McIDAS-V, the next-generation McIDAS, is entirely new code-base being built on top a modern, cross-platform software framework which supports development of 4-D interactive displays and integration of
wide-array of geophysical data. As the replacement of McIDAS, the development emphasis is on future satellite observation platforms such as JPSS and GOES-R. Data interrogation, analysis and visualization capabilities have been developed for multi- and hyper-spectral instruments like MODIS, AIRS and IASI, and are being extended for application to VIIRS and CrIS. Compatibility with current geostationary platforms, and GOES-R ABI baseline and AWG Framework products has been demonstrated. The abstract data model, which can internalize most any geophysical data, and Python based user defined computation tools, opens up new possibilities for data fusion techniques, for example, polar and geostationary, (LEO/GEO), synergy, cross-instrument product synthesis and inter-calibration and validation. Data access is local, or remote via OpenDAP/THREDDS, and ADDE. McIDAS-V follows an object-oriented design model, using the Java programming language, allowing specialized extensions for new sources of data, novel displays and interactive behavior. The distributed reference application, can be customized, and the system has a persistence mechanism allowing sharing of the application state across the internet. McIDAS-V is open-source, and free to the public.

8153-55, Session 12

Geometric/radiometric calibration from ordinary images for high-resolution satellite systems

C. Latry, Ctr. National d’Études Spatiales (France)

For high resolution systems, radiometric and geometric calibration and performance assessment are very important matters. They are usually based upon dedicated acquisitions: uniform landscapes for noise performance, knife edge target for Modulation Transfer Function assessment, specific landscapes with well known Ground Control Points for geometric characterization.

This induces heavy programming constraints when adding the cloudiness contingency.

However, thanks to image processing techniques, both radiometric and geometric accurate information may be retrieved from a standard image. This paper aims to present two techniques respectively devoted to noise and geometric characteristics assessment from standard images.

The noise computation technique is based upon the assumption that high spatial frequencies are sufficiently weakened by MTF so that only noise remains near Nyquist frequency. The mathematical tool may be Fourier Transform or wavelet packet decomposition. The output is a noise assessment over the full radiance range, while the classical method using a uniform landscape only gives noise information for one radiance value. It is particularly well suited to high resolution systems with low MTF values at Nyquist.

The second technique is based upon matching processing between spectral bands assuming the imaging system focal plane has staggered arrays. Averaging the disparity images issued from the dense matching process yields very accurate information on focal plane layout as well as high frequency attitude perturbances.

Results obtained on simulated images as well as Worldview-2 real products are detailed.

8153-58, Session 12

SAR data for subsurface saline lacustrine deposit detection and primary interpretation on the evolution of the vanished Lop Nur Lake

Y. Shao, H. Gong, Institute of Remote Sensing Applications (China)

Lop Nur is a huge vanished lake located at the east end of Tarim Basin, northwest of China and finally dried up before 70’s. With the advantage of penetration capability and sensitivity to moist saline materials, SAR revealed the subsurface lacustrine deposits and delineated partially the buried shorelines and made a complete picture of Lop Nur Lake that leads to three important scientific findings in this study. Based on scattering mechanism interpretation of polarimetric and multiple frequency SAR data, field investigation and sample analysis it is found the total area of the vanished Lop Nur lake is more than 10,000 km² which is much larger than 5335 km² as reported. The relative younger West Lake is superposed on the top of the lacustrine deposit of East Lake so the west part of the shoreline was buried and not visible in optical remote sensing images, which made the well known “Ear” feature of Lop Nur; Therefore the Lop Nur Lake actually has nearly circular, closed shoreline. The drying-up process of East Lop Nur Lake went through six phases according to the shorelines interpreted from multiple SAR data. The shrinking phases of Lop Nur Lake indicate the climate changes between dry and wet environment conditions.
8154-01, Session 1

A field-widened spectrometer-interferometer: back from the past to measure ionospheric-thermospheric energetics

S. J. Wellard, Space Dynamics Lab. (United States)

Recent broadband observations by the SABER sensor aboard the TIMED satellite hint at intriguing new vibration-rotation excitation and loss processes that occur in the energy dissipation of the ionosphere-thermosphere as it responds to solar storms. To address the questions exposed by the SABER data, SDL's field-widened interferometer has been brought back after three decades to again fly into or above aurorally disturbed atmosphere to gain the data needed to better understand the different processes of ionosphere-thermosphere energetics. The paper discusses the evaluation and design phases (laboratory evaluation, a rocket flight, and a satellite flight) needed to prepare this elegant and unique interferometer to reach its goal of making high resolution (0.5 cm-1) and wide bandwidth (1300-8000 cm-1) measurements of the ionosphere-thermosphere world-wide. Design details of interferometer will be presented along with comparisons between a standard Michelson interferometer and the field-widened sensor to illustrate just how the Bouchareine and Connes field-widened form provides the enhanced performance needed for the new missions. The paper also describes how the improved Interferometer design will leverage advances in modern electronics, detectors, bearing design and software to gain significant improvements in the performance of the upgraded field-widened interferometer-spectrometer when compared with the heritage instrument.

8154-02, Session 1

Testing of highly accurate blackbodies

H. Latvakoski, M. Watson, S. Topham, D. K. Scott, Space Dynamics Lab. (United States)

Many organizations, including Space Dynamics Laboratory, have built blackbodies with calculated emissivities of 0.995 to 0.9999 and estimated radiance temperature uncertainties of a few hundred mK or less. However, the calculated performance has generally not been demonstrated through testing or comparison with other high-performance blackbodies. Intercomparison is valuable, historically, when equipment or experimental results have been intercompared they are often found to disagree by more than the claimed uncertainties. Blackbody testing has been limited because testing at the required accuracy (0.1% or better in radianc) is a significant expense. Such testing becomes essential when proven, SI-traceable, absolute accuracy is required, such as for the CLARREO mission which has an absolute accuracy requirement of 0.1 K (3 sigma) at 220 K over most of the thermal infrared and needs high-performance blackbodies to support this requirement. Properly testing blackbodies requires direct measurement of emissivity and accurate measurement of radiances or comparison of radiances from two blackbodies. This presentation will discuss these testing needs, currently available test equipment, and testing and test results for a CLARREO prototype blackbody.

8154-03, Session 1

Advancements in understanding auroral ionosphere-thermosphere coupling from infrared remote sensing

C. J. Mertens, NASA Langley Research Ctr. (United States); X. Xu, Science Systems and Applications, Inc. (United States); S. J. Wellard, Space Dynamics Lab. (United States)

Recent discoveries from analysis of measurements made by the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on the Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED) satellite have shown that NO(v) 5.3 um emission is the primary mechanism of dissipating solar-geomagnetic storm energy in the thermosphere. Further insight into the ionosphere-thermosphere (IT) storm-time response emerged from observations and analysis of the SABER 4.3 um channel radiances, which showed that nighttime 4.3 um emission is dominated by NO+(v) during geomagnetically disturbed conditions. Analysis of SABER NO+(v) 4.3 um emission led to major advances in the understanding of E-region ion-neutral chemistry and kinetics, such as the identification of a new source of auroral 4.3 um emission, which also provides a new context for understanding auroral infrared emission from O2(1-Delta). Surprisingly, NO+(v) 4.3 um emission is the second largest contribution to solar-geomagnetic infrared radiative response and provides a non-negligible contribution to the "natural thermostat" thought to be solely due to NO(1) 5.3 um emission. Despite these major advances, a fully physics-based understanding of the two largest sources of storm-time energy dissipation in the IT system from NO(v) and NO+(v) is lacking because of the limited information content contained in SABER's broadband infrared channel measurements. On the other hand, detailed information on the chemical-radiative excitation and loss processes for NO(v), NO+(v), and O2(1-Delta) emission is encoded in the infrared spectrum, of which SABER only provides an integral constraint. Consequently, a prototype infrared field-wide Michelson interferometer (FWMI) is currently under development to advance our understanding of IT storm-time energetics beyond the current state of knowledge. In the near term, the prototype FWMI will be transitioned to a rocket-borne payload for a science campaign dedicated to the study of auroral ion-neutral coupling within the IT system. It is anticipated that progress in the developments of the FWMI technology, along with advancements in a physics-based understanding of the fundamental chemical-radiative mechanisms responsible for IT infrared emission, will play an integral role in the future planning of a satellite-based E-region science mission. In this presentation, a survey of recent SABER discoveries in IT ion-neutral coupling will be given, open questions in a physics-based understanding of chemical-radiative vibration-rotation excitation and loss from important IT infrared emitters will be identified, and the FWMI and other instrument requirements necessary to address these open science questions will be presented.

8154-04, Session 1

Laser technology development for future NASA spaceborne laser missions

M. A. Stephen, A. W. Yu, M. A. Krainak, S. X. Li, NASA Goddard Space Flight Ctr. (United States)

At NASA's Goddard Space Flight Center, we have been doing in-house research and working with several industry partners to develop laser technology for the 2nd Ice Cloud and Land Elevation Satellite (ICESat-2) mission, scheduled to launch in 2016. ICESat-2 will fly a single instrument, the Advanced Technology Laser Altimeter System (ATLAS), which will use the time-of-flight of laser pulses to make topographic measurements of the Earth's surface. The ATLAS laser will be a 1064 nm MOPA (master oscillator power amplifier) system that is frequency-doubled to the green. We have been focusing on advancing the technology readiness of these technologies for a space environment. The 1064 nm MOPA technology developed is quite versatile and can be used for several future infrared NASA laser missions including LIST and ASCENDS. In this paper, we will discuss the laser technology developed thus far for ICESat-2 and how this technology can be
applied to meet future needs. The ATLAS laser technology that is being advanced differs from conventional laser altimeter systems in which high repetition rate of tens of kHz, pulse energies of hundreds of microwatts and sub-nanosecond pulses are used for the science measurements. This represents a new era in space-based instrument for the space agency. We will discuss scientific goals and likely instrument requirements for these missions.

8154-05, Session 1

Latest developments for low-power infrared laser-based trace gas sensors for sensor networks

S. So, Sentinel Photonics (United States) and Princeton Univ. (United States); D. Thomazy, Sentinel Photonics (United States); W. Wang, Princeton Univ. (United States); O. Marchat, Princeton Univ. (United States) and ETH Zurich (Switzerland); G. Wysocki, Princeton Univ. (United States)

Scientific and industrial researchers are beginning to require ultra-low power, compact laser based sensor systems for the most demanding environmental and space-borne applications. The latest in developments for such sensors have demonstrated proof-of-concept sensors which can provide near-IR to mid-IR based semiconductor laser sensors which dissipate between 0.3-5 W and fit in the palm of a hand. Three novel innovations have greatly improved the potential size, compactness, and cost of these sensors: 1) a novel quasi-Lissajous multipass cell, 2) more efficient mid-IR quantum cascade laser based sources which operate at around room temperature, and 3) power efficient, fully integrated, and compact laser controllers, detector electronics, and data acquisition systems. Additionally, for paramagnetic molecules, Faraday rotation spectroscopy also provides extremely compact, robust sensor systems which consume minimal power. Such FRS based sensor architectures can eventually enable high precision NO2 wireless sensor networks, a critical technology for future air quality assessments.

The latest results from 4 projects will be described: 1) an ultra compact CO2 sensor using QCLs which consumes less than 5W, 2) a high dynamic range Faraday rotation spectrometer for O2 using a multipass cell and balanced detection, 3) a fully ruggedized compact laser spectrometer at 2.7 microns for outdoor wireless sensor networks, and 4) a novel multipass cell using spherical mirrors which provide high number of passes similar to an astigmatic Lissajous beam spot pattern. These results will be described in detail, with a projection for performance of future sensors based on this technology.

8154-06, Session 1

Temperature sensor for scanning thermal microscopy based on photoluminescence of microcrystal

A. Sayoud, N. Trannoy, J. Jouart, P. Grossel, Univ. de Reims Champagne-Ardenne (France); M. Diaf, Univ. Badji Mokhtar (Algeria); T. Duvaut, Univ. de Reims Champagne-Ardenne (France)

A new sensor is developed for measurement of local temperature and its imagery at sub-micrometric scale. This sensor is based on a thermal-resistive probe and on photoluminescence of crystal. The final purpose is to develop a new device calibrated in temperature and capable of acquiring images of local temperature. Indeed, the temperature of the sensor can be obtained from two distinct ways: one from the parameters of thermal probe and the other from the green photoluminescence generated in the anti-Stokes mode by the Er ions directly excited by a red laser. The thermal probe is a thermal-resistive probe in Wollaston wire whose thermal-resistive element is in Platinum/Rhodium. This probe is usually used in scanning thermal microscopy. An electrical current is used to induce a Joule effect heating. Its temperature is estimated from the probe electrical characteristics and a modelling. A transparent microcrystal of Cd0.75Sr0.3F2: Er3+(4%)-Yb3+(6%) of 5µm in diameter is glued at the end of the probe. This luminescent material has the particularity to give an emission spectrum with intensities sensitive to small temperature variations.

A first temperature calibration using a heater allows the evaluation of the crystal temperature from the intensity measurements at 522, 540 and 549 nm by taking advantage of particular optical properties due to the crystalline nature of Cd0.75Sr0.3F2: Er3++Yb3+. The temperature of probe microcrystal is then assessed as a function of electric current by applying the Boltzmann’s equations linking the intensities of emission lines to the temperature. The first results will be presented and discussed.

8154-08, Session 2

Mid-infrared chirped laser dispersion spectrometer for remote detection of trace chemicals

G. Wysocki, M. Nikodem, Princeton Univ. (United States); D. Weidmann, Rutherford Appleton Lab. (United Kingdom)

Remote trace gas detection plays an important role in numerous applications including environmental sensing, industrial monitoring and security. Sensitive chemical detection by means of optical absorption requires measurements of small optical power changes in presence of a large background (the total photodetected light intensity). Detection of refractive index change, which is inherent to molecular absorption, provides theoretically baseline-free measurement. Recently a chirped laser dispersion spectroscopy (CLaDS) was introduced (Wysocki and Weidmann, OE18, p26123, 2010). CLaDS enables fast and quantitative trace-gas detection with large immunity to optical power fluctuations. This feature makes the CLaDS technique well suited for remote sensing. In this paper we will present performance of a CLaDS system designed specifically for long-range remote sensing applications. The system is based on a mid-infrared quantum cascade laser operating at 4.52µm (2210cm-1) and targets the most intense, fundamental ro vibrational band of nitrous oxide (N2O). CLaDS is based on two-color dynamic interferometric heterodyne detection. The optical signal collected by a telescope is focused onto a fast room-temperature photodetector. A RF spectrum analyzer acquires and demodulates the photodetected RF heterodyne beatnote. As the laser is chirped across a molecular transition, the dispersion produces a frequency modulation of the heterodyne beatnote. The RF analyzer performs frequency demodulation to recover information of the refractive index change. Based on preliminary experiments we estimate the detection limit for N2O to be of <1ppbv for path-lengths of ~100m and 1s integration time. In this paper a detailed system configuration, performance tests and future directions will be discussed.

8154-09, Session 2

Precision spectroscopy with frequency combs at 3.4 µm

E. Baumann, F. R. Giorgetta, I. Coddington, W. C. Swann, N. R. Newbury, National Institute of Standards and Technology (United States)

We discuss precision spectroscopy with a fiber comb-based spectrometer at 3.4 µm. Our goal is to explore comb-based spectroscopy as an alternative to high-resolution FTS or swept laser systems for rapid, high-resolution, high-accuracy measurements of gas line shapes. The spectrometer uses dual femtosecond fiber laser combs at 1.5 µm with slightly different repetition rates. The output of each femtosecond fiber laser comb is down converted via difference frequency generation (DFG) against a cw 1-µm fiber laser in a PPLN crystal to create two frequency
In order to guarantee the continuity in atmospheric trace gases retrieval spectrometer operating in the UV, VIS, NIR and SWIR wavelength ranges. TROPOMI is an advanced non-scanning imaging absorption M. Esposito, cosine Research B.V. (Netherlands)

8154-49, Session 2

A pulsed quantum cascade laser-based wavelength modulation spectroscopy for open-path gas sensing

J. Manne, A. Lim, W. Jäger, J. Tulip, Univ. of Alberta (Canada)

Quantum cascade (QC) lasers have been extensively used in closed path configurations for gas sensing applications.[1-3] The biggest challenge in utilizing these lasers (either pulsed or cw) for open-path spectroscopy lies in obtaining a proper background subtraction to retrieve absorption information. Open path spectroscopy is important since it can provide integrated absorption measurements over long distance and consequently can be used for atmospheric monitoring of different molecules. Here, we report the results of wavelength modulation spectroscopy (WMS) with a pulsed QC laser which can open new avenues for sensitive open-path gas sensing. Pulsed WMS has many advantages over its continuous wave (cw) counterpart. The pulsed QC laser is much easier to fabricate than the cw QC laser. Pulsed QC lasers are typically used with 1-2% duty cycle so the power consumed is a small fraction of that in a cw device. Moreover, high frequency pulses of light with relatively higher intensity are much easier to detect than modulated cw light.[4] Additionally, this technique is independent of laser characteristics. The implementation of such new mid-infrared laser technologies into industrial trace gas analyzers holds great promise.

A pulsed QC laser operating at 957 cm-1 was used which provides an output power of ~5mW at 2% duty cycle. The laser is excited with short current pulses at a repetition rate of 500 kHz. First, the QC laser was characterized and operating parameters were optimized for gas sensing applications. CO2 or water vapour spectral lines were used for all these measurements. A linear sub-threshold current ramp at 20Hz was added to the excitation pulse train which resulted in a ~2.5 cm-1 frequency scan. We utilized demodulation approach to catch the envelope of the pulses and thus avoiding high speed electronics. We then combine the ramp with a sine modulation at 10kHz, and detect the second harmonic signal using a in-house designed and built phase locked loop (PLL) detection circuit.

8154-10, Session 3

The TROPOMI instrument performance and their impact

M. Esposito, cosine Research B.V. (Netherlands)

TROPOMI is an advanced non-scanning imaging absorption spectrometer operating in the UV, VIS, NIR and SWIR wavelength ranges. TROPOMI is being developed by a joint venture of Dutch parties and builds on the success of the SCHIAMACHY, GOME and OMI instruments. It will be launched as part of the ESA’s Sentinel-5 precursor mission now planned for 2014.

In order to guarantee the continuity in atmospheric trace gases retrieval and the consequent understanding of climate change, TROPOMI will fill the gap between the current SCHIAMACHY instrument, onboard the ESA’s ENVISAT satellite, and OMI instrument, onboard the NASA’s AURA mission both coming to an end, and the Sentinel-5 satellite now planned for launch around 2020.

Simulations of the instrument’s channels are taking place to evaluate the impact of instrument performance on retrieved data products. They will be shown and discussed.

8154-11, Session 3

The calibration of the multispectral imager on board the EarthCARE spacecraft

A. Perez-Albinana, R. V. Gelsthorne, A. Lefebvre, European Space Research and Technology Ctr. (Netherlands); M. Sauer, K. Kruse, R. Münzenmayer, EADS Astrium GmbH (Germany); G. C. Baister, M. Chang, Surrey Satellite Technology Ltd. (United Kingdom)

The European Space Agency (ESA) is currently developing, in cooperation with the Japan Aerospace Exploration Agency (JAXA) the EarthCARE satellite mission with the basic objective of improving the understanding of the cloud-aerosols-radiation interactions within the Earth’s atmosphere.

As part of the EarthCARE payload, the MSI instrument will provide images of the earth in 7 spectral bands in the visible and infrared parts of the spectrum, with a spatial ground resolution of 500 m and an image width on the ground of 150 km.

The radiometric accuracy of the MSI instrument is of paramount importance to accurately retrieve the physical properties of clouds and aerosols from the radiometric measurements in the different MSI spectral channels. The pre-launch calibration campaign together with the in-flight calibration facilities that the MSI instrument incorporates, ensure the fulfilment of the radiometric requirements of the mission.

The overall calibration approach for the MSI instrument is described in this paper, including the pre-launch and in-flight calibration activities.

8154-12, Session 3

Development of tunable polarimetric optical scattering instrument from 4.3-9.7 microns

J. C. Vap, S. E. Nauyoks, T. M. Fitzgerald, M. A. Marciniak, Air Force Institute of Technology (United States)

To examine the polarimetric Bidirectional Scatter Distribution Function (BSDF) of samples in the mid-wave infrared (MWIR) and long-wave infrared (LWIR), a full Stokes polarimetric optical scatter instrument has been developed which is tunable from 4.3-9.7 microns. Six tunable external-cavity quantum-cascade lasers (EC-QCL, 4.3-4.6, 4.8-5.2, 5.2-5.7, 5.6-6.5, 7.4-8.2 and 8.1-9.7 microns) were introduced into the instrument, taking it from four discrete wavelengths (544 and 632 nm, and 3.39 and 10.6 microns) to a nearly continuous waveband of 4.3-9.7 microns. The polarimeter is realized through a dual-rotating-retarder configuration, which allows full Mueller-matrix extraction over the tunable wavelengths since the retarders are much less than one-half-wave at any wavelength in the band. Optical characterization of the polarimeter components was conducted to establish performance baselines for the system. While the dynamic range of the system at the previous discrete wavelengths ranged from 15 orders of magnitude at 544 nm to 12 at 3.39 microns, the dynamic range with the tunable QCL is 9 orders of magnitude. Polarimetric BSDF measurements on IR standard samples are underway and being analyzed using existing BSDF models. Measurements on novel optical materials, such as nanostructured materials, are also underway, but may require the development of new BSDF models to fully interpret the results.
Quantum electro-optical interface in nanowire devices

M. E. Reimer, G. Bulgari, M. Hocevar, Technische Univ. Delft (Netherlands); E. Bakkers, Technische Univ. Delft (Netherlands) and Technische Univ. Eindhoven (Netherlands); L. P. Kouwenhoven, V. Zwiller, Technische Univ. Delft (Netherlands)

The unique electronic and optical properties of one-dimensional nanowires are advantageous in the combination of both transport and optics. The merging of these two research fields promises an electro-optical interface between ‘stationary’ qubits [1] and ‘flying’ qubits [2]. The ultimate aim of this interface is to coherently convert an electron spin into a photon and vice-versa for the long-distance transfer of quantum information.

In this work, we study the electro-optical interface consisting of individual InAsP quantum dots embedded in one-dimensional InP nanowire devices. We first demonstrate a high emission count rate, exhibiting single photon emission from the excited ground state by exploiting the nanowire geometry to achieve a wave-guide effect. Next, we show charge control and that we can isolate a single electron in the quantum dot either by depleting the nanowire with an electrostatic back-gate or through tunneling with an applied electric field along the nanowire growth axis [3]. Utilizing an on-chip micro-pGm, we extract the spin information of a lying nanowire device. Promising for entangled photon generation in the presence of an asymmetric dot shape, we show that the binding energy of the biexciton can be removed in a lateral electric field [4]. Finally, by embedding the quantum dot within the depletion region of a nanowire p-n junction, remarkably, we observe an efficient conversion of light into an electrical signal that is more than two orders of magnitude more efficient than the current state-of-the-art quantum dot photodetector [5].

References:

New interface control of type II superlattice photo detectors for high performance infrared applications

A. Moy, SVT Associates, Inc. (United States)

IR photo detectors are in high demand for various military and civilian applications, such as airborne surveillance, remote sensing, environmental monitoring, and spectrometry. Since the type II InAs/GaSb superlattice (T2SL) was first proposed for IR detection in 1987, the performance of T2SL photo detectors has improved considerably and is currently comparable to that of state-of-the-art HgCdTe photo diodes. Here we report the advancement of T2SL photo diodes through a novel design with enhanced interface control. A modified T2SL structure with thick InSb interlayer and GaAs layer was introduced to extend the cutoff wavelength and enhance quantum efficiency (QE). Besides forming the boundary at the InAs-GaSb interface our theoretical analysis shows that InSb plays another more important role in T2SL structure, especially for LWIR T2SLs. Namely, the cutoff wavelength of the T2SL device can be adjusted more effectively by intentionally changing the InSb thickness. Additionally, the thicker InSb layer and GaAs layer will improve the overlap of the wave functions of electrons and holes in the T2SL, which will lead to higher QE. Applying this new design, resistance-area product
The role of InAs thickness on the material properties of InAs/GaSb superlattices

H. J. Haugan, G. J. Brown, F. Szmulowicz, Air Force Research Lab. (United States); S. Elhamri, Univ. of Dayton (United States); B. Olson, T. F. Boggess, The Univ. of Iowa (United States)

The epitaxial growth parameters optimized for mid wavelength infrared (MWIR) InAs/GaSb superlattices (SL) growth are not directly applicable for long wavelength infrared (LWIR) SL growth. We have observed a two orders of magnitude spectral intensity drop in photoconductivity as the InAs layer thickness increases from 7 monolayers (MLs) to 16 MLs with a fixed GaSb layer thickness of 7 MLs, while the theoretical absorption strength indicates only a decrease of about a factor of three. Since the measured Hall properties of MWIR and LWIR SLs were very different - majority carriers in MWIR (LWIR) SLs were holes (electrons), material factors likely account for the discrepancy between measured signal and predicted optical strength. Since a key factor in infrared detector performance is dark-current related noise, especially in active region of photodiodes, we studied the number of charge carriers and the mobility and their recombination dynamics in this series of samples. We adjusted several growth parameters to keep low background carrier concentrations and improve carrier lifetimes in LWIR SLs using temperature dependent Hall effect and pump-probe measurements.

Growth and performance of superlattice-based detectors


The type-II InAs/GaSb strained layer superlattice (SLS) system has been investigated as a promising system for infrared (IR) detection ever since it was proposed by Smith and Mailhiot [1] over three decades ago. The type-II InAs/GaInSb superlattices have been theoretically shown to have reduced Auger recombination and suppressed band-to-band tunneling. Suppressed tunneling in turn allows for higher doping in the absorber, which has led to reduced diffusion dark current. The versatility of the antimonide material system, with the availability of three different types of band offsets, provides great flexibility in device design. Heterostructure designs that make effective use of unipolar barriers have demonstrated strong reduction of G-R dark current. As a result, the dark current performance of antimonide superlattice based single element LWIR detectors is now approaching that of the state-of-the-art MCT detector. To date, the antimonide superlattices still have relatively short carrier lifetimes; this issue needs to be resolved before type-II superlattice infrared detectors can achieve their true potential. The antimonide material system has relatively good mechanical robustness when compared to II-VI materials; therefore FPAs based on type-II superlattices have potential advantages in manufacturability. Improvements in substrate quality and size, and reliable surface leakage current suppression methods, such as those based on robust surface passivation or effective use of unipolar barriers, could lead to high-performance large-format LWIR focal plane arrays.

Performance optimization and first astronomical observations of the Stratospheric Observatory for Infrared Astronomy (SOFIA)

J. Wolf, NASA Ames Research Ctr. (United States); D. Backman, SOFIA / USRA (United States); U. Lampater, Univ. Stuttgart (Germany); P. M. Marcum, NASA Ames Research Ctr. (United States); E. Pfitzler, A. Reinacher, H. Roeser, M. Wiedemann, Univ. Stuttgart (Germany); E. T. Young, SOFIA / USRA (United States)

The Stratospheric Observatory for Infrared Astronomy, SOFIA, is a modified Boeing 747SP aircraft that carries a 2.7 meter infrared telescope to flight altitudes of up to 13.7 km (45,000ft) to conduct astrophysical measurements in the wavelength range of 0.3 to 1600 µm. Observations at infrared wavelengths, where SOFIA's performance is optimized, target objects in the universe that are too cold to radiate at visible wavelengths, regions of the universe that are hidden at shorter wavelengths by the absorption of interstellar dust, and astrophysically significant spectral features that provide unique characterization of interstellar gas conditions and composition. The observatory has accomplished significant milestones in 2010/2011. Test flights with the open telescope port have established the safety and reliability of the modified aircraft. The in-flight pointing stability of the telescope and its chopping secondary mirror have been measured and fine tuned using images of one of SOFIA's science instruments (FORCAST) and of a dedicated Fast Diagnostic Camera (FDC). The first science targets observed include the star forming region M42 in Orion and the starburst galaxy M82. Images were taken at wavelengths out to 37 µm, a wavelength that cannot be accessed by any telescope on the ground due to absorption in the Earth's atmosphere. In the summer of 2011, guest investigators who were selected through an open and competed call for proposals will use SOFIA to acquire their proposed data.
The evolution of the performance of the AVHRR, HIRS and AMSU-A instruments on board MetOp-A after over four years in orbit

D. R. Battles, Raytheon Co. (Germany); R. W. Lambeck, Perot Systems Government Service (United States); A. Perez-Albinana, European Space Research and Technology Ctr. (Netherlands); R. V. R. Mundakkara Kovilakom, I. M. Systems Group, Inc. (United States); X. Wu, C. Cao, National Oceanic and Atmospheric Administration (United States); H. Bauch, VEGA Deutschland GmbH (Germany); F. Montagner, European Organisation for the Exploitation of Meteorological Satellites (Germany)

The MetOp series of satellites constitute the space segment for the EUMETSAT Polar System (EPS), the European contribution to the Initial Joint Polar System, being developed in co-operation with the National Oceanic and Atmospheric Administration (NOAA) of the USA, to provide meteorological data from the polar orbit.

The first MetOp satellite was launched on 19 October 2006 on a Soyuz launcher from the Baikonur Cosmodrome in Kazakhstan. Following the successful completion of the commissioning campaign, the MetOp-A satellite and its ground segment were declared operational by both agencies, NOAA and EUMETSAT, during the summer of 2007. Now approaching its mission lifetime goal of five years in service, the performance trends presented in this paper take on special significance.

The Advanced Very High Resolution Radiometer (AVHRR), the High-resolution Infrared Radiation Sounder (HIRS) and the Advanced Microwave Sounding Unit-A (AMSU-A) instruments constitute the operational meteorological payload provided by NOAA that, in addition to the EUMETSAT provided Microwave Humidity Sounder (MHS), is flown on both the NOAA Polar Orbiting Satellites (POES) and the EUMETSAT MetOp satellites.

It is well known that the varying geometrical relationships between the Sun and the Earth throughout the year affect to some degree the performance of the instruments onboard Earth orbiting satellites. Following the commissioning of MetOp-A, EUMETSAT and NOAA have continued monitoring the long term trends in in-orbit performance of AVHRR, HIRS and AMSU-A. The data acquired since the launch of the satellite has allowed studying how the yearly seasonal variations, as well as aging, have affected the instrument performance. This paper presents the evolution of the performance of the AVHRR, HIRS and AMSU-A for more than four years since the launch of the Metop-A satellite.

HIRDLS radiance corrections and improved atmospheric products

M. Belmonte Rivas, J. C. Gille, National Ctr. for Atmospheric Research (United States)

This paper details the updated radiance correction algorithms for the HIRDLS infrared limb-scanning radiometer on board the EOS Aqua satellite. The need for radiance corrections arise from the partial blocking of the radiometer field of view, both into the target atmosphere and the calibration loads, by an object whose emission appears to be driven by the thermal environment of the host platform and mechanically coupled to the motion of the scan mirror - most likely a detached sheet of insulating Kapton. This work provides a description of the steps involved in the radiance correction algorithms, from the characterization of the blockage emission (including mechanically coupled oscillations) for later subtraction, to radiance recalibration using selected atmospheric standards. Improving our understanding and effective removal of the systematic errors brought along by the blocking radiance has allowed for ever weaker trace gas signals to emerge from the instrumental noise floor. Sample new and improved HIRDLS atmospheric products will be shown.
Extinction ratios. This paper shows analysis indicating the importance of NEDOLP and signatures that are better than existing non-polarimetric Infrared sensors. To gain acceptance polarimetric sensors must provide intelligence (NEDOLP) cutoff reducing the Noise Equivalent Degree of Linear Polarization. For polarization and spectral phenomenology. In addition the 3-7 um band another band between 3 and 7 um improves the capability of the sensor. While single band 9-11 um LWIR polarimetry has advantages adding 3-7 um bands helps to approach giga-pixel format detector arrays with a seamless 10cm x 10cm continuous image plane size possible. Onto this substrate it is straightforward growth path to an 5k×5k µm pitch 25 Mega-pixel infrared focal plane array (FPA) with smaller pitches allowing even greater format along the 10cm die length. This paper describes arrays 1.5 to 4 Mega-pixel infrared HgCdTe developed by RVS for demanding higher performance applications. Performance data for both the detector and ROIC for typical SWIR and MWIR FPAs operating at 85K will be presented. This paper will provide FPA performance capability for small pitch large format HgCdTe/Sl detector arrays fabricated at RVS and manufacturing readiness low cost Mega-pixel infrared FPAs for current and future wide FOV high-resolution systems.

Large-format high-operability low-cost infrared focal plane array performance and capabilities

J. W. Bangs, D. Lindsay, J. L. Vampola, F. B. Jaworski, C. L. Mears, R. Wyles, J. F. Asbicro, E. Norton, M. Reddy, K. Rybnicek, A. Levy, Raytheon Co. (United States)

Large format detector arrays responsive uniformly over spectral 1-5µm wavelength range are available with RVS’ high quality HgCdTe detector epitaxial layers on large area 15 cm diameter wafers. Large wafers enable both low cost HD staring FPAs much as 30cm silicon wafers are helping competitiveness of commercial IC foundries, as well as ability to approach giga-pixel format detector arrays with a seamless 10cm x 10cm continuous image plane size possible. Onto this substrate it is straightforward growth path to an 5k×5k µm pitch 25 Mega-pixel infrared focal plane array (FPA) with smaller pitches allowing even greater format along the 10cm die length. This paper describes arrays 1.5 to 4 Mega-pixel infrared HgCdTe developed by RVS for demanding higher performance applications. Performance data for both the detector and ROIC for typical SWIR and MWIR FPAs operating at 85K will be presented. This paper will provide FPA performance capability for small pitch large format HgCdTe/Sl detector arrays fabricated at RVS and manufacturing readiness low cost Mega-pixel infrared FPAs for current and future wide FOV high-resolution systems.

Staring MWIR, LWIR and 2-color and scanning LWIR polarimetry technology

N. R. Malone, Raytheon Co. (United States)

Polarimetry sensor development has been in work for some time to determine the best use of polarimetry to differentiate between manmade objects and objects made by nature. Both MWIR and LWIR and 2-color staring Focal Plane Arrays (FPAs) and LWIR scanning FPAs have been built at Raytheon Vision Systems each with exceedingly higher performance. This paper presents polarimetric performance comparisons between staring 2562 MWIR, 2562 LWIR, 5122 LWIR/LWIR staring FPAs and scanning LWIR FPAs.

LWIR polarimetry has the largest polarimetric signal level and a larger emissive polarimetric signature than MWIR which makes LWIR less dependent on sun angles. Polished angled glass and metal objects are easily detected using LWIR polarimetry. While single band 9-11 um LWIR polarimetry has advantages adding another band between 3 and 7 um improves the capability of the sensor for polarization and spectral phenomenology. In addition the 3-7 um band has improved NEDT over the 9-11 um band due to the shorter detector cutoff reducing the Noise Equivalent Degree of Linear Polarization. (NEEDLP)

To gain acceptance polarimetric sensors must provide intelligence signatures that are better than existing non-polarimetric Infrared sensors. This paper shows analysis indicating the importance of NEEDLP and Extinction ratios.

Historical advancements in UV/Vis/NIR SiPIN focal plane technology

N. R. Malone, Raytheon Co. (United States)

Landsat, MODIS, NPOESS VIIRS and Bepi Columbo are a few of the well know space programs that have been part of the evolution of SiPIN focal plane technology. Pixels have become smaller, power has been reduced, Quantum efficiency has increased beyond 400-900 nm. The ability to tune the FPA to the customer’s desired wavelength is available. The ability to hybridize large format FPAs with operability exceeding 99.9% is now routine. Focal planes are now digital allowing the elimination of the size weight and power required to support external Analog to Digital Converters.

Advancements in large-format SiPIN hybrid focal plane technology

N. R. Malone, Raytheon Co. (United States)

Silicon PIN (P-type, Intrinsic, N-type) hybrid focal planes can be produced in significantly larger sizes, use significantly lower power and eliminate the need for a mechanical shutter significantly reducing cost and weight of a similar CCD (Charge-Coupled Device) design. Programmable gain and simultaneous broad dynamic range capability have also been recently incorporated into Silicon PIN hybrid focal-planes. Operability of > 99.996 has been achieved on a 26 Mega-pixel array. A read noise floor of less than 10 electrons and dark current less than 1 e-/s have also been achieved. Broadband quantum efficiency (QE) greater than 90% between 450-900 nm is typical. In addition MTF approaches theoretical performance and bias levels have been reduced from greater than 100V to as little as 5 Volts.

Venus atmospheric and surface studies from VIRTIS on Venus Express

G. E. Arnold, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); P. Drossart, Observatoire de Paris à Meudon (France); G. Piccioni, INAF - IASF Roma (Italy)

The Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) on Venus Express, after more than five years in Venusians’ orbit, provided an enormous amount of new data including a three-dimensional view of Venus atmosphere and global surface properties of the planet. VIRTIS is a complex imaging spectrometer that combines three unique data channels in one compact instrument. Two of the channels are committed to spectral mapping (VIRTIS-M) and a third one to high spectral resolution studies (VIRTIS-H). The paper gives an overview about the experiment goals, the instrument performance, and discusses some selected scientific results achieved by VIRTIS on board Venus Express. These include studies of the surface from night emission in the NIR atmospheric window of Venus, results of the structure and properties of the lower, middle and upper atmosphere, including dynamics, polar vortex, nightglows, and NLT effects.
8154-32, Session 7

A new perspective on Mercury’s surface composition and temperatures: Mercury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS)

G. E. Arnold, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); H. Hiesinger, Westfälische Wilhelms Univ. (Germany); J. Helbert, G. Peter, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

MERTIS (MErcury Radiometer and Thermal Infrared Spectrometer), scheduled for launch on board the BepiColombo Mercury Orbiter, will be the first mid-infrared imaging spectrometer to explore the innermost planet of the Solar System from orbit. The instrument is an advanced IR technology designed to study the surface composition, and surface temperature variations of planet Mercury. High resolution and global mid-IR spectral and temperature data obtained by MERTIS will contribute to a better understanding of Mercury’s genesis and evolution. MERTIS uses an uncooled microbolometer detector array. It combines a push-broom IR grating spectrometer (TIS) with a radiometer (TIR) sharing the same optics, instrument electronics, and in-flight calibration components for a wavelength range of 7-14 and 7-40 µm, respectively. The paper summarizes the scientific objectives, observational goals, and introduces the technical overview and actual instrument development status of the experiment.

8154-33, Session 7

Deep space instrument design for thermal infrared imaging with MERTIS

I. Walter, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); T. Zeh, Kayser-Threde GmbH (Germany); J. Helbert, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); H. Hiesinger, Westfaelische Wilhelms Univ. (Germany); A. Gebhardt, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); H. Hirsch, Astro- und Feinwerktechnik Adlershof GmbH (Germany); J. Knollenberg, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); E. Kessler, Institut für Photonische Technologien e.V. (Germany); M. Rajat, Space Research Ctr. (Poland); J. Habermeier, ECM GmbH (Germany); G. Peter, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

MERTIS is a miniaturized thermal infrared imaging spectrometer onboard of ESA's cornerstone mission BepiColombo to Mercury. It shall provide measurements in the spectral range from 7-14 µm with a spatial resolution of maximal 300 m and 80 spectral channels in combination with radiometric measurements in the spectral range from 7-40 µm. The instrument concept therefore integrates two detector systems sharing a common optical path consisting of mirror entrance optics and reflective Offner spectrometer. Uncooled micro-bolometer and thermopile radiometer technology are implemented for lowest power consumption. Subsequent viewing of different targets including on-board calibration sources will provide the desired performance. Special attention is spent on the fully passive thermal design in the harsh environment around Mercury.

The article will provide an overview of the 3 kg - instrument design and highlight the concept of the subsystems and technologies used. The status of the development process will be reported.

8154-34, Session 7

Laboratory activity in support for MERTIS on BepiColombo

A. Maturilli, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

MERTIS onboard the ESA BepiColombo mission will measure thermal infrared spectra emitted from the surface of Mercury. To analyze this unique and new dataset, an appropriate spectral library of analogue materials, measured in conditions as close as possible to Mercurian, is strongly needed. In the Planetary Emissivity Laboratory (PEL) at the German Aerospace Center (DLR) in Berlin we can perform emissivity measurements at high temperatures and under vacuum conditions. The PEL is equipped with a Bruker Vertex 80V FT-IR spectrometer, coupled to an evacuable high temperatures emissivity chamber, and can acquire spectra in the entire 1 to 100 µm spectral range. The innovative heating system, based on induction properties, allows heating the samples to temperatures of up to 700K permitting measurements under realistic conditions for the surface of Mercury. As a complementary tool, the same instrument can measure bi-directional reflectance spectra of samples, with variable incoming and outgoing angles between 13° and 85°, or even transmission spectra of thin slabs of material, optical filters, optical window materials, etc., in the complete 1 to 100 µm spectral range. With a similar but older purged Bruker IFS 88 instrument we can measure bi-directional reflectance spectra of samples, with variable incoming and outgoing angles between 5° and 85° in the extended spectral range from 0.4 to 16 µm, providing us the opportunity to support the MASCS camera on NASA MESSENGER mission.

8154-35, Session 7

Observing the surface of Venus after VIRTIS on VEX: new concepts and laboratory work

J. Helbert, A. Maturilli, M. D’Amore, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); N. T. Müller, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany) and Westfälische Wilhelms Univ. (Germany); R. Nadalin, Active Space Technologies GmbH (Germany)

The VIRTIS (Venus Infrared Topography and Imaging Spectrometer) is a 5 kg instrument to routinely map the surface of Venus using the near infrared windows from orbit. The instrument is the flight spare of the VIRTIS instrument on the ESA Rosetta comet encounter mission. Originally designed to observe a very cold target far from the Sun, it was adapted to work in the Venus environment. The instruments main purpose on VEX was to study the structure, dynamics and composition of the atmosphere in 3 dimensions. The idea of surface studies were introduced very late in the mission planning and VIRTIS was never specifically adapted for this purpose. For example the wavelength coverage was not optimal and only the long wavelength flank of the main atmospheric window at 1.02µm could be imaged. Despite these issues VIRTIS was an excellent proof-of-concept and far exceeded our expectations. It provided significant new scientific results and could show for example that Venus had volcanic activity in the very recent geological past.

After the very successful proof-of-concept it is now time to assess in more details what can be done with NIR observations of Venus. To support this we have been setting up the Planetary Emissivity Laboratory in Berlin which allows taking emissivity measurements in the spectral range of the atmospheric windows at sample temperatures of 500°C.

This would provide a unique and rarely found reference data set, which can be used to improve and test future Venus missions, which we will outline.
8154-36, Session 7

MERTIS: configuration of measurement sequences for a maximized image SNR
T. Säuberlich, C. Paproth, M. Bauer, H. Jörn, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

MERTIS (MERcury Thermal infrared Imaging Spectrometer) is an advanced thermal infrared remote sensing instrument that is part of the ESA mission BepiColombo to planet Mercury. Since the instrument is designed to work in the thermal infrared range detecting radiation using an uncooled micro-bolometer matrix it is necessary to pay special attention on the development of proper scene signal extraction methods, which eliminate undesired signal portions from the measurement data. In order to evaluate the signal data proper measures for the signal and noise strengths have to be defined being compatible with the different measurement sequences the instrument can be driven with.

Shown here is a theoretical model reflecting the periodic measurements of MERTIS during orbit operation using a shutter device. The model includes the noisy characteristics of the instrument's analog channel which is used for the image acquisition. Although the analog channel itself is not explicitly modeled in detail, a precise noise strength prediction can be achieved. The prediction results depend both on the specific shutter open/close measurement sequence used and a system specific temporal autocovariance function which can be easily estimated from simple image data cubes. The predictions become very precise if a proper pre-processing of the image datasets removing the most strong disturbing signal portions is done before. Being able to predict the noise strength for arbitrary measurement sequences and giving respect to the system’s physical limits - e.g. shutter speed - an optimal measurement sequence can be found giving a maximized SNR of the images of MERTIS.

8154-37, Session 7

MERTIS: identifiability of spectral mineralogical features in dependence of the signal to noise ratio
C. Paproth, T. Säuberlich, J. Helbert, Deutsches Zentrum für Luft-und Raumfahrt e.V. (Germany)

The ESA deep-space mission BepiColombo to planet Mercury will contain the advanced infrared remote sensing instrument MERTIS (MERcury Radiometer and Thermal infrared Imaging Spectrometer). The mission has the goal to explore the planets inner and surface structure and its environment. With MERTIS investigations of Mercury’s surface layer within a spectral range of 7-14µm shall be conducted to specify and map Mercury’s mineralogical composition with a spatial resolution of 500m. Due to the limited mass and power budget the used micro-bolometer detector array will only have a temperature-stabilization and will not be cooled.

The performance of the instrument is estimated by the theoretical description of the signal to noise ratio and the optics including the Offner spectrometer. The expected signal to noise ratio will be in the order of 100 and is mainly dependent of the surface temperature and the wavelength. The derived theoretical models are used to execute simulations to compute the passage of the infrared radiation of a hypothetical mineralogical surface composition and surface temperature through the optical system of MERTIS. The resulting noisy spectra are used to determine spectral features of the minerals. So it is possible to evaluate the conditions which are necessary to achieve the scientific goals of MERTIS. The intent is to estimate the spectral positions of mineralogical features like the Christiansen feature which will be difficult because of the low signal to noise ratio and the low contrast of real mineral spectra.

8154-38, Session 7

MERTIS: geometrical calibration of thermal infrared optical system by applying diffusive optical elements
M. Bauer, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany)

Geometrical sensor calibration is essential for space applications based on high accuracy optical measurements, in this case for the thermal infrared push-broom imaging spectrometer MERTIS. The goal is the determination of the interior sensor orientation. A conventional method is to measure the line of sight for a subset of pixels by single pixel illumination with collimated light. To adjust angles which define the line of sight of a pixel a manipulator construction is used. A new method for geometrical sensor calibration is using diffusive optical elements (DOE) in connection with laser beam equipment. Diffusive optical elements (DOE) are optical microstructures which are used to split an incoming laser beam with dedicated wavelength into a number of beams with well-known propagation directions. As the virtual sources of the diffracted beams are points at infinity which gives an image invariant against translation. This particular feature allows a complete geometrical sensor calibration with one image avoiding complex adjustment procedures which means a significant reduction of calibration effort.

A new thermal infrared (TIR) suited DOE calibration facility is designed and implemented with customized TIR-DOE for geometrical TIR optical system calibration. We present a new method for geometrical calibration of thermal infrared optical systems. The fundamentals of this new technology and results of a TIR infrared optical system calibration by applying the new thermal infrared (TIR) calibration facility are shown.

8154-39, Poster Session

Self-compensating Faraday current sensor
J. L. Flores-Nuñez, H. C. Beltrán, Univ. de Guadalajara (Mexico); J. A. Ferrari, Univ. de la República (Uruguay); G. García-Torales, J. Cabrera, Univ. de Guadalajara (Mexico)

In recent decades, considerable effort has been devoted to develop new transducers for monitoring current on electric power systems. Optical current devices have many advantages with respect to conventional current transducers e.g., Rogowski coils; they have simple insulation structure, immunity to electromagnetic interference, wide dynamic range and bandwidth, accurate transient response, and show no saturation or hysteresis effects. Therefore, these optical devices are considered to be an optimum interface between high-voltage lines and electronic equipment expected to monitor on power systems.

We present a optical current sensor architecture, which is based on a polarimetric configuration and utilizes a control system for self-compensating the Faraday effect. In the proposed setup, the sensing element -a TGG crystal- is placed near the conductor carrying the current to be measured. Linearly polarized light passes through the sensor head, which rotates the polarization plane an angle proportional to the electrical current in the conductor. Afterwards the light travels in the free space, reaching a Faraday modulator placed some distance away from the conductor carrying the current. This device is used to compensate the rotation of the plane of polarization induced by electrical current at sensor head. The control system is operated in a closed-loop mode using a magneto-optical feedback through a simple current-driven solenoid to maintain constant optical output from the polarimeter. Considering that some of the optical and electrical parameters of the sensor head and the Faraday modulator are known, the electrical current carried by the conductor can be measured. Validation experiments are presented.
8154-40, Poster Session
Vectorial shearing interferometer applied in the faint sources detection
J. Sanchez Preciado, G. Garcia-Torales, J. L. Flores-Nuñez, Univ. de Guadalajara (Mexico)
Into space, stars are the most common source of light. Planets, comets and other types of rocks reflect the incoming light from near stars. It’s said that a planet is hidden when the light from the star is brighter than the reflected light from the planet. Vectorial Shearing Interferometer (VSI) is able to distinguish between the light coming from the planet and the light coming from the star, obtaining information about size and form of the planet. We present a method to detect faint sources in the way of bright sources using a VSI. We implement an algorithm based into the estimation of the wavefront from multiple directional derivatives in order to detect the presence of an object. Experimental results are shown.

8154-42, Poster Session
Designing of an intelligent flight instrumentation unit using embedded RTOS
R. Estrada-Marmolejo, G. Garcia-Torales, J. L. Flores-Nuñez, H. H. Torres-Ortega, Univ. de Guadalajara (Mexico)
Micro Unmanned Aerial Vehicles (MUAV) must know its spatial position in order to control its flight control, which is done by Inertial Measurement Units (IMUs). Some inertial sensors like MEMS have made it possible to reduce the size and power consumption of such units. Commonly the flight instrumentation operates independently of the main processor. This work presents a design which is able of reducing size and power consumption of the complete system of a MUAV. This is done by coupling the inertial sensors to the main processor leaving any intermediate level of processing aside. Using Real Time Operating Systems reduces the number of intermediate components, increasing MUAV reliability. One advantage is the possibility to control several different sensors with a single communication bus. This feature of the MEMS sensors makes a smaller and a less complex MUAV design possible.

8154-43, Poster Session
Characterization of narrow-band near-IR diodes arranged in array patterns
A. Ortega, G. Paez, M. Strojnik, Ctr. de Investigaciones en Óptica, A.C. (Mexico)
We examined old, not-well documented paintings before the process of restoration for presence of any invisible signatures and dates, as well as original line drawings and possible painted-over or hidden images. With the availability of the LEDs in the IR, emitting only in the invisible portion of the EM spectrum, we connected them in various two-dimensional array distribution to allow us to sample the surface of the art work with approximately uniform illumination, but different peak wavelength. We describe the extended area infrared LED illumination sources as to their geometrical arrangement, and their resulting spectral, spatial, and power output characteristics. With the especially designed LED based light sources, we were able to make visible the history of the painting and we observed the back-up material in detail.

8154-44, Poster Session
Updated level-1 processing after two-years operation of TANSO-FTS
H. Suto, A. Kuze, K. Shiomi, M. Nakajima, Japan Aerospace Exploration Agency (Japan)
Instrument self-emission and nonlinear response play important roles in analyzing satellite thermal infrared radiometers, and can affect the accuracy of Earth scene radiance retrieval if uncorrected. This paper presents a simplified self-emission model for infrared radiometers and analyzes the interrelationships between the instrument self-emission, detector nonlinearity, and calibration intercept and slope variations using MetOp/HIRS prelaunch characterization data. HIRS is a traditional cross-track line scanning radiometer in the infrared and visible spectrum, including 12 long wave infrared channels (669-1529cm⁻¹), 7 short wave infrared channels (2188-2657cm⁻¹), and 1 visible channel, with beam splitters and a rotating filter wheel assembly consisting of 20 spectral filters separates individual channels. The warm filters and other in-path components generate self-emission which becomes the majority of the total radiance falling on the detector. The pre-launch TV data allow us to evaluate the self-emission using the simplified model. It was found that the self-emission contributions at the detectors are in the range of 95% to 97%. The self-emission fluctuates with the instrument temperature and causes the variation in instrument response, including the variations of intercept and the instrument gain. The quantification of these variations provides guideline for on-orbit calibration algorithm improvement. The self-emission model is improved and its impact on MetOp/HIRS on-orbit calibration and Earth scene retrieval are also assessed. Potential applications of this model to other infrared radiometers and sounders are also discussed.
To monitor the global column concentration of carbon dioxide (CO2) and methane (CH4) from space, the Greenhouse gases Observing Satellite (GOSAT) was launched on January 23, 2009, and has started the operational observation. Thermal and Near Infrared Sensor for Carbon Observation- Fourier Transform Spectrometer (TANSO-FTS) has been continuously measuring CO2 and CH4 distributions globally every three days, and data distribution to the public started from Feb. 16, 2010. During two years operational periods, the radiometric, geometric and spectroscopic characterizations of TANSO have been continuously conducted with updating the Level-1 processing algorithm. To make a precise spectroscopic observation, correction algorithms were newly developed, demonstrated and installed on operational processing. Two major corrections are discussed. One is correction of the scan-speed instability caused by micro-vibration from satellite. Through the on-orbit data analysis, degrading spectroscopic accuracy caused by periodically micro-vibrations was found, and these distortion effects were compensated with applying the re-sampling technique for interferogram. The other is non-linearity correction in the electronics. In this presentation, the detail of on-orbit characteristics and the current status of TANSO will be discussed.

8154-47, Poster Session

Characterization and measurements collected from Infrared Grazing Angle Reflectometer

M. R. Benson, M. A. Marciniak, Air Force Institute of Technology (United States); J. Burks, Air Force Research Lab. (United States)

Recently, the Air Force Institute of Technology acquired a piece of equipment known as the Infrared Grazing Angle Reflectometer, or IGAR. IGAR is used for measuring the Directional Hemispherical Reflectance, or DHR, of samples at infrared wavelengths and incidence angles close to grazing. DHR is a ratio of power reflected into the entire hemisphere above a planar surface to incident power, and is of great interest to the photonic community and the Air Force. IGAR's DHR data can be compared with the Bidirectional Reflectance Distribution Function, or BRDF, measurements taken by our scatterometer. While other devices typically measure DHR at or near normal incidence, IGAR is novel as it allows us to make measurements with the angle of incidence ranging from 30 to 85 degrees, giving us a very unique data set. In addition, IGAR is equipped with a tunable laser source, allowing us to measure DHR at wavelengths ranging from 9.2 to 10.7 microns. Additional lasers can be easily added, and future plans include integrating our tunable quantum cascade lasers, extending our wavelength range from 4.3 to 9.7 microns, IGAR utilizes a hemi-elliptical mirror and a five-sided pyroelectric detector to measure DHR. By using this setup, IGAR can make low noise measurements while still capturing all of the reflected light. Our future sample set includes infrared material standards such as infragold, carbon nanotubes, nanostructured devices, and various layered media.

8154-48, Poster Session

Cost effective method to measure strain independent of temperature using a half etched fiber Bragg grating

M. Kondiparthi, Indian Institute of Science (India)

A novel approach for the measurement of strain independent of temperature is proposed. This approach is based on the fact that an applied strain on a half etched fiber Bragg grating leads to a change in spectral area of FBG reflection. Previously, relative shift in the two peaks of the FBG reflection of half-etched FBG is used as a signature to measure strain, which demands costly Optical spectrum analyzer. An FBG written in a fiber optic cable, which has two different clad diameters over its length, is considered for analysis. The clad diameter changes at half the FBG length. When such FBG is illuminated with a broadband source, strain applied on the same can be estimated by measuring the reflected radiation using an optical power meter (photodiode), hence, replacing the necessity of an optical spectrum analyzer. Temperature changes leads to a shift in the entire reflection, keeping the spectral area unaltered, hence allowing one to measure strain independent of temperature.

For an applied strain on an initially uniform half etched FBG, along with a peak split in the reflection spectrum, there will be an increase in the spectral area, which can be detected by measuring the optical power reflected back from the FBG. These variations are predominant for specific length strength combinations. For different length strength combinations, plots between the spectral area and applied strain were obtained using Transfer matrix approach. As an eg, from simulated plots, a 'spectral area-strain' monotonic range of 5nm can be obtained for a 1cm long grating.
Simultaneous 1310/1550 dual-band optical frequency domain imaging for spectroscopic investigations

Y. Mao, S. Chang, E. Murdock, C. Flueraru, National Research Council Canada (Canada)

High-speed swept-source has received much attention in recent years for applications in optical frequency domain imaging (OFDI). The swept sources published so far produce sweeping in only one single wavelength band for both polygonal mirror filter based and piezo-tunable Fabry-Perot (FP) filter based swept source, based on our knowledge. We report a novel simultaneous high-speed 1310/1550 swept laser source for spectroscopic OFDI with low computation cost. Synchronized dual-wavelength tuning is performed by using two cavities and narrow-band wavelength-filters with a single dual-window polygonal scanner. Measured average output powers of 60 mW and 27 mW have been achieved for 1310 and 1550 nm bands, respectively, while the two wavelengths were swept simultaneously from 1227 nm to 1387 nm for 1310 nm band and from 1519 nm to 1550 nm band at an A-scan rate of 65 kHz. A broadband wavelength-division multiplexing is used for coupling two wavelengths into a common-path single-mode GRIN-lensed fiber probe to form a dual-band common-path OFDI. Simultaneous imaging at 1310 and 1550 nm is achieved. This technique allows potentially for in vivo endoscopic high-speed functional OFDI with high quality spectroscopic contrast.

Electrical passivation of anti-reflective microstructures in mercury cadmium telluride

J. Pattison, P. S. Wijewarnasuriya, U.S. Army Research Lab. (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States)

Inductively coupled plasma etching was applied to create anti-reflective structures in HgCdTe. Conformal deposition of passivating materials was accomplished through atomic layer deposition of Al2O3 and SiO2 layers. Scanning electron microscopy was used to characterize the microstructures after ICP etch and again after ALD. Infrared reflectance and transmission measurements were performed on as-grown, ICP etched, and ALD passivated samples to demonstrate an increase in absorbance due to the AR structures. Planar sister samples of MCT were exposed to similar ICP etch conditions and passivated by ALD. The electrical passivation of the planar samples was studied through photoconductive decay measurements in order to compare the minority carrier lifetime of as-grown, etched, and passivated material. Planar sample served as proxies for the etched material, as the required electric field of the PCD experiment does not pass through the anti-reflective microstructure layer.

Design of readout integrated circuit with enhanced capacitance mechanism for dual-band infrared detector

Y. Lu, T. Sun, Y. Liu, S. Shiu, H. Shieh, National Chi Nan Univ. (Taiwan); S. Tang, W. Lin, Chung Shan Institute of Science and Technology (Taiwan)

This thesis will propose a solution to solve over dark current by sharing capacitor, avoiding output signal distortion because of integration voltage saturation. The integration capacitance can change by adding switch in pixel circuit; it will increase two times than original capacitance. This circuit also provide the function of output either single-band or dual-band by switching different sensor. This readout integrated circuit design has adopted TSMC 0.35um 2P4M CMOS 5V process, worked by 5V power supply and operated at 3MHz clock rate. The dual-band pixel circuit uses interface structure, the pixel circuit area of two wavelengths are both 30um x 30um. The mid-wave and long-wave sense current are from 1nA to 2nA and 6nA to 8nA, respectively. The output swing is 2.8V. There are four major contributions in this paper. First, we introduce the design of dual-band infrared focal plane array, and provide analog and digital control circuit blocks. Then we introduce inner circuit design, including pixel circuit column select circuit and output buffer stage circuit. Second, we explain the sharing capacitor module in pixel circuit, and then we design the interface readout integrated circuit by 40x16 array size. Third, we provide the simulation result. Finally, we discuss the trend of circuit application.
Enabling NIR imaging at room temperature based on quantum dots
S. Le Calvez, H. Bourvon, C. Philippot, H. Kanaan, S. Meunier-Della-Gatta, P. Reiss, Commissariat à l’Énergie Atomique (France)

If imaging in visible light is now a well-mastered technology, imaging in near infrared at room temperature remains a challenge. In our everyday life, many applications appeared for imaging in near infra-red like sensing, night vision and biological diagnostics. However, if silicon based detectors are very performing in visible, they become inefficient over 1000nm. Others as microbolometers or InGaAs detectors are not mature enough or too expensive to be efficient in this wavelength range. That’s why colloidal quantum dots materials are interesting as they have the appealing property to absorb at a tunable wavelength determined by their nature and diameter and also because their processibility in solution make them a key solution for low cost applications on either solid or flexible substrates. Then, we can assume that imagers may be made from processing near infra-red quantum dots solutions on top of active matrix backplane.

We will present, a way to synthesize PbS quantum dots with a stabilizing CdSe/ZnS double-shell. The nanocrystal core presents a 6nm core that makes it absorb around 1450nm. This quantum dot was then incorporated in a stack to prepare a device. Pixels smaller than 50µm were obtained with a detectivity higher than 10^9 Jones. We will report at the conference a comparison of the different wet deposition process used like non patternable coating as spin coating or patternable ones as inkjet printing or stamping. We will focus on the optimized parameters and the successful performances of our devices.

Long-wave infrared InAs/GaSb strain layered superlattice barrier heterostructure detectors
S. A. Myers, N. Gautam, E. Plis, M. N. Kutty, B. Klein, T. Schuler-Sandy, S. Krishna, Ctr. for High Technology Materials (United States)

Long-wave infrared (LWIR) detector technologies with the ability to operate at or near room temperature are very important for many civil and military applications including chemical identification, surveillance, defense and medical diagnostics. Eliminating the need for cryogenics in a detector system can reduce cost, weight and power consumption; simplify the detection system design and allow for widespread usage. In recent years, infrared (IR) detectors based on uni-polar barrier designs have gained interest for their ability to lower dark current and increase a detector's operating temperature.

Our group is currently investigating nBn and pBp detectors with InAs/GaSb strain layer superlattice (SLS) absorbers (n) and contacts (n), and AlGaSb and InAs/AlSb superlattice electron and hole barriers (B) respectively. For the case of the nBn structure, the wide-band-gap barrier material (AlGaSb) exhibits a large conduction band offset and a small valence band offset with the narrow-band-gap absorber material. For the pBp structure (InAs/AlSb superlattice barrier), the converse is true with a large valence band offset between the barrier and absorber and a small or zero conduction band offset. Like the built-in barrier in a p-n junction, the heterojunction barrier blocks the majority carriers allowing free movement of photogenerated minority carriers. However, the barrier in an nBn or pBp detector, in contrast with a p-n junction depletion layer, does not contribute to generation-recombination (G-R) current.

In this report we aim to investigate and contrast the performance characteristics of an SLS nBn detector with that of and SLS pBp detector.

Addressing surface leakage in type-II InAs/GaSb superlattice materials using novel approaches to surface passivation
E. A. DeCuir, Jr., J. W. Little, U.S. Army Research Lab. (United States); N. Baril, U.S. Army Night Vision & Electronic Sensors Directorate (United States); P. Ye, Purdue Univ. (United States)

Poor surface stability of InAs/GaSb SL photodetectors continues to be a major hurdle to the realization of high performance devices in this material system. While there has been continual improvement in material quality over the years, surface instability is still a major limiting factor in long-wavelength infrared detectors which ultimately hampers detector performance. This study focuses on a two step approach towards the successful passivation of long-wavelength InAs/GaSb superlattice structures. This entails various initial chemical passivation of the surface to remove surface oxides and satisfy dangling bonds followed by a robust dielectric treatment via plasma-enhanced chemical vapor deposition of SiO2 on the mesa sidewalls. Alternatively, an atomic layer deposition process of Al2O3 or HfO2 was also used to treat the mesa sidewalls in an effort to mitigate the effects of rapidly formed native oxides during device processing.

The variable area diode analysis technique employing diodes of variable diameter (20-400um) enabled the investigation of surface resistivity as a result of different passivation treatments. Temperature dependent studies of the dark current enabled an understanding of the dominating current mechanism, while temperature dependent capacitance-transient measurements were used on select diodes to gauge the presence and activation energy of defects that may be contributing to excessive dark currents in these diodes.

Avalanche photodiodes for high-resolution UV imaging applications
A. K. Sood, Magnolia Optical Technologies, Inc. (United States); R. D. Dupuis, Georgia Institute of Technology (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States); R. S. Balcerak, System Planning Corp. (United States)

High resolution imaging in UV band has a lot of applications in Defense and commercial applications. The shortest wavelength is desired for spatial resolution which allows for small pixels and large formats. UVAPD’s have been demonstrated as discrete devices demonstrating gain. The next frontier is to develop UV APD arrays with high gain to demonstrate high resolution imaging.

We will discuss model that can predict sensor performance in the UV band using APD’s with various gain and other parameters for a desired UV band of interest. SNR’s can be modeled from illuminated targets at various distances with high resolution under standard atmospheres in the UV band and the solar blind region using detector arrays with unity gain and with high gain APD’s.

We will present recent data on the GaN based APD’s for their gain, detector response, dark current noise and the 1/f noise. We will present various approaches and device designs that are being evaluated for developing APD’s in wide band gap semiconductors. The paper will also discuss state of the art in UV APD and the future directions for small unit cell size and gain in the APD’s.

Visible-blind ultraviolet photodetector fabricated on double heterojunction of n-ZnO/LAO/p-Si
D. Tsai, H. Wang, C. Kang, J. He, National Taiwan Univ. (Taiwan)

High resolution imaging in UV band has a lot of applications in Defense and military applications including chemical identification, surveillance, defense and commercial applications. The shortest wavelength is desired for spatial resolution which allows for small pixels and large formats. UVAPD’s have been demonstrated as discrete devices demonstrating gain. The next frontier is to develop UV APD arrays with high gain to demonstrate high resolution imaging.

We will discuss model that can predict sensor performance in the UV band using APD’s with various gain and other parameters for a desired UV band of interest. SNR’s can be modeled from illuminated targets at various distances with high resolution under standard atmospheres in the UV band and the solar blind region using detector arrays with unity gain and with high gain APD’s.

We will present recent data on the GaN based APD’s for their gain, detector response, dark current noise and the 1/f noise. We will present various approaches and device designs that are being evaluated for developing APD’s in wide band gap semiconductors. The paper will also discuss state of the art in UV APD and the future directions for small unit cell size and gain in the APD’s.

Visible-blind ultraviolet photodetector fabricated on double heterojunction of n-ZnO/LAO/p-Si
D. Tsai, H. Wang, C. Kang, J. He, National Taiwan Univ. (Taiwan)
A visible-blind UV photodetector (PD) based on a double heterojunction of n-ZnO/insulating LaAlO3 (LAO)/p-Si grown by pulsed laser deposition has been fabricated. The photodetector shows a rectification ratio of similar to 104 at ±2 V and a dark current of 9 nA at a reverse bias of -2V. The photoresponse spectrum indicates a visible-blind UV detectivity of our devices with a high UV/visible rejection ratio. The LAO layer, acting as a barrier layer, prevents minority carrier to transport from p-Si base under visible light illumination due to the high potential barrier between p-Si and LAO. These results clearly demonstrate that n-ZnO/LAO/p-Si PDs hold high potential in the next-generation visible-blind UV PDs.

8155A-11, Session 2
Reducing the read noise of H2RG detector arrays by more efficient use of reference signals
B. J. Rauscher, NASA Goddard Space Flight Ctr. (United States)

We present a process for characterizing the correlation properties of the noise in large two-dimensional detector arrays, and describe an efficient process for its removal. In the case of the 2k × 2k HAWAII-2RG detectors (H2RG) detectors from Teledyne which are being used on the Near Infrared Spectrograph (NIRSpec) on the James Webb Space Telescope (JWST), we find that we can reduce the read noise by about half. Noise on large spatial scales is dramatically reduced. With this relatively simple process, we provide a performance improvement that is equivalent to a significant increase in telescope collecting area for high resolution spectroscopy with NIRSpec.

The method is based on Principal Components Analysis (PCA) of the NIRSpec detector subsystem (DS). The DS includes two H2RG detector arrays and a pair of cryogenic SIDECAR ASICs. The PCA showed that the covariance matrix’s eigenvectors are sines and cosines, and that the noise is temporally stationary in consequence. Building on this, we studied the correlation properties between the regular outputs, the reference output, the reference pixels, and blanked off pixels used as references in Fourier correlation properties between the regular outputs, the reference output, the reference pixels, and blanked off pixels used as references in Fourier space. A significant finding is that a set of frequency dependent weights must be applied to the reference output before it is used differentially. The correct weights reject noise at frequencies ~3 kHz, and correctly for non-unity gain at lower frequencies. When the correct frequency dependent weights are used with the other references in a similar manner, we find that we can significantly reduce the noise and greatly reduce the degree of noise correlation.

8155A-12, Session 2
A 260 megapixel visible/NIR mixed technology focal plane for space
R. W. Besuner, Univ. of California, Berkeley (United States); C. J. Bebek, Lawrence Berkeley National Lab. (United States); G. M. Haller, SLAC National Accelerator Lab. (United States); S. E. Harris, Univ. of California, Berkeley (United States); P. A. Hart, SLAC National Accelerator Lab. (United States); H. D. Heetderks, P. N. Jelinsky, M. L. Lampton, Univ. of California, Berkeley (United States); M. E. Levi, Lawrence Berkeley National Lab. (United States); S. E. Maldonado, SLAC National Accelerator Lab. (United States); N. A. Roe, Lawrence Berkeley National Lab. (United States); A. J. Roodman, L. Sapozhnikov, SLAC National Accelerator Lab. (United States)

Mission concepts for NASA’s Wide Field Infrared Survey Telescope (WFIRST). ESA’s Euclid mission; as well as next-generation ground-based surveys, require large mosaic focal planes to image visible and near infrared (NIR) wavelengths. We have developed space-qualified detectors, readout electronics and focal plane design techniques that can be used to intermingle CCDs and NIR detectors on a single, silicon carbide (SiC) cold plate. This enables optimized, wideband observing strategies. The CCDs, developed at Lawrence Berkeley National Laboratory, are fully-depleted, p-channel devices that are backside illuminated and capable of operating at temperatures down to 110K. The NIR detectors are 1.7um and 2.0um wavelength cutoff H2RG® HgCdTe, manufactured by Teledyne Imaging Sensors under contract to LBNL. Both the CCDs and NIR detectors are packaged on 4-side abuttable SiC pedestals with a common mounting footprint supporting a 44mm mosaic pitch. Both types of detectors have direct-attached, readout electronics that convert the detector signal directly to serial, digital data streams and allow a flexible, low cost data acquisition strategy to enable large data rates. A mosaic of these detectors can be operated at a common temperature that achieves the required dark current and read noise performance necessary for dark energy observations. We report here the qualification testing and performance verification for a focal plane that accommodates a 4x8 array of CCDs and HgCdTe detectors.

8155A-46, Session 2
Nondestructive moisture sensing in in-shell nuts using near infrared (NIR) reflectance spectroscopy
C. V. Kandala, J. Sundaram, Agricultural Research Service (United States)

Ability to determine the moisture content (MC) of certain nuts such as peanuts and pecans, while they are in their shells, rapidly and nondestructively is useful in their harvest, sale and processing. It was found earlier that, with commercially available NIR spectrometers the moisture contents of Valencia type in-shell peanuts could be estimated within permissible accuracies. In this work a custom made NIR instrument was used to predict MC of two varieties of peanuts, while they are in their shells, and the results were compared with those obtained by standard methods. Spectral data from 1000 nm to 2500 nm was collected for Valencia and Virginia types of in-shell peanuts in the moisture range of 6% to 26%. Partial least squares (PLS) analysis was performed on calibration groups in each type, certain pretreatments were applied, and models were developed for prediction. Models with low standard error of calibration and best R2 values were selected for MC predictions. Predicted values were compared with reference values obtained by standard methods and goodness of the fit was judged from the standard error of prediction (SEP) and the R2 values. Results obtained for both types were good, and suggest the possibility of designing a low-cost NIR instrument useful for the peanut industry.

8155A-48, Session 2
Novel EO/IR sensor technologies
K. L. Lewis, Electro Magnetic Remote Sensing Defence Technology Ctr. (United Kingdom)

The Electro-Magnetic Remote Sensing (EMRS DTC) was established in 2003 to provide a centre of excellence in sensor research and development, supporting new capabilities in key military areas such as precision attack, battlespace manoeuvre and information superiority. The DTC was set up as a partnership between UK Industry, the academic science base and the UK Ministry of Defence, to develop advanced and affordable technology in support of mission-oriented defence capabilities. In the area of advanced electro-optic technology, the DTC has supported work on discriminative imaging, advanced detectors, laser components/technologies, and novel optical techniques. This paper will summarise some of the results achieved in the DTC’s programme, using examples drawn from each of the key theme areas, supported by the results of field trials in realistic military environments.
three different IR cameras and by proposing a simple yet effective metric proposed models has been illustrated by both synthesizing FPN from sources, and the theoretical as well as practical applicability of the multiplicative and additive components of the FPN. Experimental the empirically estimated distributions of the intensity values of both the random intensity of FPN has been also modeled by matching manner by approximating the spectral response of the FPN. Moreover, Thus, the spatial structure of FPN can be abstracted in a straightforward

The Corrugated Quantum Well Infrared Photodetector (C-QWIP) holds significant performance and other advantages over other infrared detectors. However, one disadvantage of the detector is the relatively low operating temperature needed to suppress the dark current. By coating two additional layers (thin insulator and high critical temperature (Tc) superconductor) on the top contact layer of a C-QWIP wafer, the top three layers of the detector form a high-Tc superconducting single electron tunneling junction. It could act as an electron filter because of the presence of an energy gap in superconductors. Since the photo electrons and dark electrons of a C-QWIP are well separated in energy, most dark current is conducting below the quantum well (QW) barrier height and most photo current is conducting above the barrier height. Most dark electrons thus could be blocked by the junction while most photo electrons pass the junction by applying an appropriate voltage. Our calculation shows that the filter could provide 40% or 70% improvement in Noise Equivalent Temperature Difference (NETD) of detector focal plane arrays (FPAs) at normal operating temperature depends on the detector emitter photocurrent to dark current ratio is = 1 (emitter is BLIP) or = 0.1 (emitter is far from BLIP). For both cases, the filter could increase the detector FPAs operating temperatures up to 90K (30K improvement) with 10% to 20% NETD improvement respectively.

A frequency domain model for the spatial fixed-pattern noise in infrared focal plane arrays
O. J. Medina, J. E. Pezoa, S. N. Torres, Univ. de Concepción (Chile)
The multiplicative and additive components of the Fixed-pattern Noise (FPN) in Infrared (IR) Focal Plane Arrays (FPAs) are typically modeled as time-stationary, spatially unstructured random processes. Even though the latter assumption is convenient, it is also inaccurate due to FPN is indeed observed as a spatial pattern, with random intensity values, superimposed over the true images. In this paper, the spatial structure in both the multiplicative and the additive components of the FPN has been modeled in the frequency domain. The key observation in the proposed models is that regular spatial patterns manifest themselves as narrowband components in the magnitude spectrum of an image. Thus, the spatial structure of FPN can be abstracted in a straightforward manner by approximating the spectral response of the FPN. Moreover, the random intensity of FPN has been also modeled by matching the empirically estimated distributions of the intensity values of both multiplicative and additive components of the FPN. Experimental characterization of FPN has been conducted using black-body radiator sources, and the theoretical as well as practical applicability of the proposed models has been illustrated by both synthesizing FPN from three different IR cameras and by proposing a simple yet effective metric to assess the amount of FPN in FPA-based cameras.

Striping noise compensation (SNC) algorithms for push-broom hyperspectral cameras (PBHCs) are primarily based on image processing techniques. These algorithms rely on the spatial and temporal information available at the readout data; however, they disregard the large amount of spectral information also available at the data. In this paper, such flaw has been tackled and a multidimensional approach for SNC is proposed. The main assumption of the proposed approach is the short-term stationary behaviour of the spatial, spectral, and temporal input information. This assumption is justified after analyzing the optoelectronic sampling mechanism carried out by PBHCs. Namely, when the wavelength-resolution of hyperspectral cameras is high enough with respect to the target application, the spectral information at neighbouring photodetectors in adjacent spectral bands can be regarded as a stationary input. Moreover, when the temporal scanning of hyperspectral information is fast enough, consecutive temporal and spectral data samples can also be regarded as a stationary input of a single photodetector. The strength and applicability of the multidimensional approach presented here is illustrated by compensating for striping noise real hyperspectral images. To this end, a laboratory prototype, based on a Photonfocus Hurricane hyperspectral camera, has been implemented to acquire data in the range of 400-1000 [nm], at a wavelength resolution of 1.04 [nm]. A mobile platform has been also constructed to simulate and synchronize the scanning procedure of the camera. Finally, an image-processing--based SNC algorithm has been extended yielding an approach that employs all the multidimensional information collected by the camera.

Study of unipolar HgCdTe nBn and Auger-suppressed hybrid structure photodetectors
A. M. Itsuno, J. D. Phillips, Univ. of Michigan (United States); S. Velicu, EPIR Technologies, Inc. (United States)

Conventional state-of-the-art HgCdTe p-n heterojunction infrared devices face performance limitations due to thermal generation-recombination mechanisms and challenges related to processing technology, particularly with achieving low, controllable in-situ p-type doping using molecular beam epitaxy (MBE) growth techniques. These issues motivate the need for improved device performance at higher operating temperatures and/or device structures requiring simplified fabrication processes. To address these challenges, two proposed alternative HgCdTe detector structures are investigated in further detail: 1) a unipolar HgCdTe implementation of the nBn structure and 2) a novel Auger-suppressed unipolar hybrid nBn structure. Both structures rely on bandgap engineered barrier layers to suppress SRH and Auger processes, respectively, contributing to the dark current density and performance limitations. The unipolar devices provide the benefit of a simplified fabrication process, where p-type doping requirements are eliminated. Numerical physics-based device simulations utilizing established HgCdTe material parameters and incorporating tunneling contributions and generation-recombination mechanisms will be used to study the performance characteristics of both devices, with more emphasis placed on the proposed nBn architecture. Past work has predicted near equivalent performance characteristics of nBn devices to those achieved by ideal p-n heterojunction devices. Alternatively, the nBn device is expected to exhibit both SRH and Auger suppression due to the nature of the structure, thus, achieving a lower dark current density than that observed in current detector technology for the same temperatures. This demonstration would have significant implications for high temperature detector operation regarding reduction in power and cooling requirements without sacrificing device performance.
New approach to noise factor measurement on microchannel plate of optoelectronic detector
L. Liu, Y. Qiu, Y. Qian, Nanjing Univ. of Science & Technology (China)

The micro-channel plate (MCP) is an important part to imaging quality of image intensifier. To do research and analysis work on the MCP parameter have practical significance to the understanding of the performance and then can help to know where improvement should be made and then achieve a best performance entire tube. In most of parameters of MCP, the inspection of noise characteristics is a key point. In this paper, a new method for noise factor determination in MCP is described, which allows one to carry out the measurement on the MCP instead of overall image intensifier.

Firstly a math model to noise power factor of MCP is established. The noise factor is defined as the ratio of the square of input signal to noise ratio to the square of output signal to noise ratio.

Then a measurement system is developed, which consists of vacuum chamber, electron gun, high voltage supply, imaging luminaire meter, control units, signal processing circuit, A/D converter, D/A converter, communication unit, industrial computer and measurement software.

Based on this system, we carry out the testing of the noise power factor of MCP. The noise power factor results are obtained. Through the comparison to the sample MCP’s noise characteristics, it can be concluded that this new approach and testing device to noise power factor measurement of MCP are reliable.

Study of recombination mechanisms limiting the performance of Sb-based III-V type II superlattices for infrared detectors

Type II strained layer superlattice (T2-SLS) technology is currently being developed as an alternative to existing HgCdTe photodetectors and quantum well infrared photodetectors for use as large format focal plane arrays in the 8-12 um long-wave infrared (LWIR) and 3-5 um mid-wave infrared (MWR) wavelength ranges. T2-SLSs are expected to possess lower Auger recombination rates than HgCdTe detectors due to the ability to engineer the bandgap. However, T2-SLS material is currently limited by non-radiative Shockley-Read-Hall (SRH) recombination, resulting in short minority carrier lifetimes (10’s of nanoseconds at 77 K) that do not approach the theoretical limit of the Auger recombination rate. It is important to investigate the minority carrier lifetime, since it is a primary limiting factor in the performance of these devices. We use time-resolved photoluminescence (TRPL) measurements to study the minority carrier lifetime as a function of temperature and excitation density for a series of SLS absorber samples. Experimental results on sets of samples that vary the SLS absorber width, the doping level of the SLS and the hole-well and SLS period will be presented along with modeling results. Time-domain measurements of the photoluminescence signal demonstrate multiple exponential decay, which provide information on background carriers, acceptor states and trap states. The temperature dependence of the TRPL signal shows that the carrier lifetime is dominated by SRH recombination. Limits to the radiative and Auger recombination coefficients are determined from high-injection measurements.

Photoluminescence study of long-wavelength infrared superlattice detectors

Photoluminescence (PL) is a non-destructive characterization method that reveals information about the optical properties and the material quality of the material studied. Information about the material quality is obtained from the PL intensity and the width of the PL peak. By measuring the variation of PL amplitude and the peak position with temperature and excitation power, the physical properties of the superlattice such as the carrier recombination processes and the variation of the band gap with temperature can be studied. In this work, we investigated the temperature and wavelength dependence of the PL intensity for type II InAs/GaSb long wavelength complementary barrier infrared detector (CBIRD) superlattices in the temperature range 10 - 298 K. The influence of Shockley Read Hall and Auger recombination processes on the minority carrier lifetime was determined from the temperature and excitation power dependence of the PL intensity. These studies show full suppression of the Auger recombination processes for CBIRD detectors with 10 micrometer cut-off wavelength. Furthermore, we observed a linear decrease of the PL intensity with increasing cut-off wavelength of LWIR CBIRDs and found this trend unchanged in the temperature range 10 - 77 K. The observed dependence originates from the decreasing overlap between the electron and hole wave functions as the superlattice period increases.

Cryogenic focal plane flatness measurement with optical zone slope tracking
J. Edelstein, M. M. Sirk, Univ. of California, Berkeley (United States); M. Hoff, Lawrence Berkeley National Lab. (United States); P. N. Jelinsky, R. W. Besuner, Univ. of California, Berkeley (United States); P. E. Perry, M. E. Levi, C. J. Bebek, Lawrence Berkeley National Lab. (United States); H. D. Heeders, Univ. of California, Berkeley (United States)

Large-area cryogenic focal planes for visible to near infra-red astronomical imaging and spectroscopic space-based observatories, on missions such as WRIEST or EUCLID, must be planar in order to match the sensor plane to the focal surface of their fast optical telescope feeds. The plane flatness requirements are demanding, as focal planes of half-meter scales must be held flat to within a few 10’s of microns while cooled to 140K. Verifying cryogenic focal plane flatness is challenging as micron level excursions need to be measured within and across a dozen 5-cm sensors inside a high-vacuum chamber and without using physical contact. We report an optical flatness measurement scheme applied to the LBL 35 x 18 cm, 32-sensor, CCD / HgCdTe focal plane developed for the JDEM. The scheme uses a telescope-fed micro-lens array that samples the focal plane to measure changes in the slope of local sensor zones.

Temperature dependence of electron transport in GaN/AlGaN quantum cascade detectors
S. V. Gryshchenko, M. V. Klymenko, O. V. Shulika, Kharkov National Univ. of Radio Electronics (Ukraine); I. A. Sukhoivanov, Univ. de Guanajuato (Mexico)
Quantum cascade detectors are promising structures for high-efficiency detection of infrared radiation. The quantum efficiency and response in these structures are strongly dependent on phonon mediated electron transport in the extractor region. In this work we investigate the influence of extractor design and temperature on transport properties of quantum cascade detector. For this purpose we realize numerical calculation of electron lifetimes considering electron-phonon and electron impurities scattering. Electron-phonon interactions are treated using Harrison’s formula (Harrison P., Quantum wells, wires and dots, John Wiley & Sons, 2010, 564 p.) which allows to calculate lifetime of carriers with temperature and structure design taking into account. Transport characteristics of quantum cascade detectors have been computed using density matrix theory. As a result, we have obtained the system of ordinary differential equations describing dynamics of electron distribution functions and intersubband correlations. The theory has been developed using Hartree-Fock approximation for Coloumb interactions of electrons. Managing carrier lifetime in quantum wells gives us possibility to increase quantum efficiency and response. Obtained results are evidence that there exists optimal temperature range for high efficiency detecting. This range is dependent on structure design parameters including widths and materials of semiconductor layers. Also we have provided band engineering intended for minimization of electron lifetimes in the extractor.

8155A-24, Session 4

AlGaAn-based III-nitride tunnel barrier hyperspectral detector

F. Shahedipour-Sandvik, Univ. at Albany (United States); N. Tripathi, College of Nanoscale Science & Engineering (United States); L. D. Bell, Jet Propulsion Lab. (United States)

We report on the recent progress made toward development of a III-nitride based tunable hyperspectral detector pixel with the potential advantages of reduced system complexity and increased dynamic control on the detection parameters in the context of existing hyperspectral detection systems. We discuss the concept, experiments and simulation of devices along with the different obstacles to be overcome before this technology can mature into a commercial application. Currently available hyperspectral detectors, apart from being bulky, have limited detection range for visible and IR regions of the spectrum. The proposed device has the potential to provide a wider range of detection wavelengths extending to the UV, visible and IR region, and real-time wavelength tunability without the use of filters and gratings.

This provides a great advantage over the existing hyperspectral detectors. The small size along with other important properties offered by the III-nitride material system, including the possibility of growth of the device structure on silicon substrate, enables integration with Si CMOS for system-on-chip realization.

8155A-25, Session 4

Earth limb infrared clutter model from measurements

M. Kendra, K. Kraemer, Air Force Research Lab. (United States); D. Mizuno, R. R. O’Neil, Boston College (United States)

Mid-Course Space Experiment (MSX) infrared (IR) observations in the earth limb were used to obtain spatial power spectral densities (PSD’s) for five sensor bands over a wide range of earth limb background clutter conditions. These backgrounds include daytime, nighttime, terminator, aurora, polar mesospheric cloud, atmospheric gravity wave, stratospheric warming, airlow, and other observations collected over approximately 100 episodic data collection events. Using a subset of detectors and restricting detector tangent altitude variations, a total of more than 33,000 high-quality PSD’s were generated. For infrared detection of unresolved objects where the solid angle of the object is much smaller than the instantaneous field-of-view of a sensor element, the spectral component at high spatial frequencies is a critical metric. PSD’s were therefore constructed in the spatial domain using one minute data segments, which allowed spatial scale assessment from 0.01-10 cycles/km. PSD’s that met the clutter model selection criteria were identified, accumulated, and processed to obtain a small set of empirical, altitude-based model parameters. We describe the MSX sensor bands, data and data processing employed for PSD generation and final reduction to obtain model parameters. Key model features are discussed with emphasis on object detection against stressing limb backgrounds. The model was constructed in a way that facilitates optical design and system engineering application. In particular, it may be used to address important space situational awareness (SSA) questions concerning detection thresholds, loss of track, false positive detections, and object identification, discrimination, and object state determination.

8155A-26, Session 4

Heat bearing device “Waermepeilgerät 60”

M. Krake, Helmut-Schmidt-Univ. (Germany); H. Rothe, Helmut-Schmidt Univ. (Germany)

The “Wärmepeilgerät 60” was a passive infrared device, meaning in this case it collected the infrared emissions radiated by ships. The advantage of passive devices versus active devices was, (i) that the enemy could not detect a passive device because it was not using a spotlight or something like this,(ii) and a much bigger detection range. Being developed in the beginning of the 40’s by Zeiss the “Wärmepeilgerät 60” was used e.g. for coastal defense in Denmark. A squadron consisted of a pilot unit and four heat bearing devices. When a ship was detected by one of the heat bearing devices, the other ones were also directed to that target. Because of the distance of the devices always different target angles were measured. This gave the possibility for the pilot unit to transform the measured angles into fire control data for the coastal defense artillery. The devices were able to detect battleships up to 25 kilometers away and smaller ships, like torpedo boats, could be detected up to 15 kilometers away. This is more than current devices can achieve. Optical layouts and circuit diagrams will be presented and discussed in the paper.

8155A-27, Session 4

Evaluation of H2RG stability for infrared Earth-observing systems


Although originally developed for low-flux astronomical applications, the space qualification and availability of the Teledyne HAWAII H2RG detector makes it appealing for high-precision Earth-observing systems. We have evaluated the performance of a science-grade H2RG detector for the GEO-CAPE gas correlation radiometer instrument concept in which North America would be imaged from geosynchronous orbit alternately through gas species cells (carbon monoxide and methane) and reference cells to measure the column density of these trace gases. In this shot noise-limited measurement, the signal-to-noise ratio is determined by the co-adding time afforded by the detector’s stability and the required temporal resolution.

To assess temporal stability, the detector was operated in a cryogenic dewar with monitored blackbody illumination. Parallel 32-channel, 16-bit digitization of the detector output is accomplished by the Teledyne SIDEARC ASIC which clocks the detector to achieve subframe integration times of 10 milliseconds. We will present findings on the temporal instabilities of the detector system, including burst noise and bias drifts. With proper use of available reference signals, the instability can be reduced well below 0.1%. The read noise and power consumption of this operational mode have also been measured against increased clock speed. These findings are relevant to many applications requiring high relative sensitivity in a limited co-adding time, from Earth and planetary science to transiting exoplanet detection.
8155A-28, Session 4

IR detector for hydrocarbons concentration measurement in emissions during petroleum and oil products storage and transportation

A. Vasilyev, Kuban State Technological Univ. (Russian Federation)

Oil storage in reservoirs and its transportation in tanks of liquefied cargo carrier accompany with loss of hydrocarbons, which leads to economic damage and environmental pollution.

Oil contains about 99.2% of saturated hydrocarbons. We offer to measure its concentration by method of infrared spectra absorption on the wavelength range 3.4-5.2 µm. Oil sampling device is to be set on the pressure-and-vacuum valve of tanks and reservoirs.

This method based on spectral transparency with reference channel and synchronous detection. Introduced infrared detector will allow to carry on automatic and continuous monitoring of saturated hydrocarbons evaporation which will help to choose correct methods of prevention such losses and to control its faultless operation.

8155A-29, Session 4

eSNR improvement in indirect detection of mid-IR signals by wavelength conversion in SOS waveguides

Y. Huang, S. K. Kalyoncu, E. Tien, S. Gao, Q. Song, F. Qian, E. Adas, D. Yildirim, O. Boyraz, Univ. of California, Irvine (United States)

With a transparency window up to 6 µm, sapphire can serve as a platform to support silicon photonic integrated circuit in MWIR. Planar waveguide devices based on silicon-on-sapphire (SOS) are emerging as a bridge between MWIR and SWIR through frequency band conversion process. While these devices are widely proposed to amplify MWIR signals and generate MWIR source, it can also be inversely utilized to achieve MWIR light detection. Here MWIR signals are down-converted to telecommunication wavelength (1.55 µm) through SOS waveguides and indirectly detected by SWIR detectors. Since detectors at telecommunication wavelengths exhibit superior performances in terms of speed, noise and sensitivity, the indirect detection scheme can be a promising candidate to improve the detection performance.

In this report, we analyze performance of the indirect detection of MWIR signals by wavelength conversion in SOS waveguides. Particularly we modeled and compared the noise performance of the indirect detection with direct detection using state-of-the-art MWIR detectors. We show that, in addition to advantages of room temperature and high speed operation, the proposed indirect detection can improve the electrical signal-to-noise ratio up to 50dB, 23dB and 4dB compared to direct detection by PbSe, HgCdTe and InSb detectors respectively. The improvement is more pronounced in detection of weak MWIR signals.

8155A-30, Session 4

Compact LC-tuned Fourier transform imaging spectrometer

X. Xia, A. V. Parfenov, E. A. DeHoog, A. Shapoury, T. M. Aye, M. Shih, Physical Optics Corp. (United States)

Multispectral and hyperspectral imaging devices have numerous military and industrial applications, including reconnaissance, targeting, guidance, remote sensing, biomedical imaging, environmental and agricultural monitoring, pollution monitoring, navigation, and law enforcement. Grating-based hyperspectral imaging remote sensor systems such as the Compact Airborne Spectral Sensor (COMPASS) hyperspectral imager (HSI), have been developed by the Army Night Vision and Electronic Sensors Directorate (NVESD), which operates from 400 nm to 2350 nm, and represents a major step in the practical implementation of visible and infrared (IR) sensors. State-of-the-art airborne hyperspectral imagers with two-dimensional (2D) focal plane arrays (FPA) for midwave infrared (MWIR) and longwave infrared (LWIR) have been built and deployed. Examples include the ARES and SEBASS that use prism dispersive imaging spectrometers covering the MWIR (3-5 µm) or LWIR (7.6-13.4 um). GIFTS for NASA is an example of imaging Michelson Fourier transform spectrometers (FTS) operating in the MWIR/LWIR bands. However, the potential applications of all these hyperspectral systems are limited by their large size, high power consumption, heavy weight, and significant cost. In this paper, we demonstrate the novel hyperspectral imaging using a LC-based electro-optic (EO) tuning imaging Fourier-Transform spectrometer (FTS) which could result in a compact, lightweight, low-cost, low-power, spectral imaging sensor, that can be integrated with small airship platforms for reconnaissance, surveillance, and target acquisition missions. Details of fabrication and experimental results will be presented.

8155A-31, Session 4

Real-time 4D subsurface corrosion inspection using ultrahigh-speed, Fourier-domain optical coherence tomography (OCT)

A. Rodriguez, Naval Sea Systems Command (United States); J. U. Kang, The Johns Hopkins Univ. (United States)

Optically-gated reflectometry based on low coherence interferometry has found important applications in surface and sub-surface imaging. This is because of the high spatial resolution, the relative simplicity, and the superior signal discrimination of the technique when used in highly scattering materials.

When this type of optically gated reflectometry is used in a scanning mode it is termed optical coherence tomography (OCT). Until recently, the vast majority of applications for OCT have been in biology. In our work we will demonstrate the application of high speed, common path optical coherence tomography system techniques to detect and study defects and subsurface structures in a variety of non-biological coated metallic materials. This is particularly useful for inspection of corrosion under coated surfaces. We have also imaged through plastic and composite materials. In most cases, the material under study was highly scattering, which rendered non-gated imaging impossible. In each case the spatial positions of internal defects were determined, both qualitatively and quantitatively.

Our OCT apparatus utilizes a design that allows rapid scans in a plane perpendicular (X-Z) or parallel (X-Y) to the sample surface while also maximizing the spatial resolution over the entire scan area. The system uses a GPU (general processing unit found on many video cards) multi-processor algorithm to create a 3D rendering of the scanned area in real time at more than 30 frames per second and a resolution of 2 to 5 µm (10-6 meters).

8155A-32, Session 4

High-speed, multispectral, thermal instrument development in support of HypsIRI-TIR

W. R. Johnson, S. J. Hook, M. C. Foote, B. T. Eng, B. M. Jau, Jet Propulsion Lab. (United States)

The Jet Propulsion Laboratory is currently developing a prototype multispectral thermal instrument in support of the Hyperspectral Infrared Imager (HypsIRI) - Thermal Infrared (TIR) space mission. HypsIRI mission was recommended by the National Research Council Decadal Survey (DS) and includes a visible shortwave infrared (SWIR) pushbroom spectrometer and a multispectral whiskbroom thermal infrared (TIR) imager. Data from the HypsIRI mission will be used to address key science questions related to the Solid Earth and Carbon Cycle and...
Ecosystems focus areas of the NASA Science Mission Directorate. The prototype instrument addresses the technology readiness level (TRL) of a few key subsystems of the TIR. Current designs for the HypsIRI-TIR space borne imager utilize eight spectral bands delineated with filters. The system will have 60m ground resolution, better than 200mK noise equivalent delta temperature (NEDT), 0.5C absolute temperature resolution with a 5-day repeat from LEO orbit. The prototype instrument will use mercury cadmium telluride (MCT) technology at the focal plane and operate in time delay integration mode. A custom read out integrated circuit (ROIC) will provide the high speed readout hence allowing the high data rates needed for the 5 day repeat. The current HypsIRI requirements dictate a ground knowledge measurement of 30m (3sigma), so the prototype instrument will tackle this problem with a newly developed interferometric metrology system. This system will provide an absolute measurement of the scanning mirror to an order of magnitude better than conventional optical encoders. This will minimize the reliance on ground control points hence minimizing post-processing (e.g. geo-rectification computations).

8155A-33, Session 4

Summary of the Operational Land Imager Focal Plane Array for the Landsat Data Continuity Mission

K. A. Lindahl, W. L. Burmester, K. Malone, R. J. Schrein, R. Irwin, Ball Aerospace & Technologies Corp. (United States)

The Landsat missions are the longest continuous record of changes in the Earth’s surface as seen from space. The next follow-on activity is the Landsat Data Continuity Mission (LDCM). The LDCM objective is to extend the ability to detect and quantitatively characterize changes on the global land surface at a scale where natural and man-made causes of change can be detected and differentiated. The Operational Land Imager (OLI) is one of two instruments on the LDCM spacecraft. OLI will produce science data for the reflective bands, which include 6 visible and near-infrared (VNIR) and 3 short-wave infrared (SWIR) bands. The OLI instrument utilizes a pushbroom design with 15.5 degree field of view. As a result, the OLI Focal Plane Array (FPA) cross track dimension is large, and the FPA is a critical technology for the success of the mission. The FPA contains 14 critically aligned Focal Plane Modules (FPM) and consists of 6916 imaging pixels in each of the 8 multi-spectral bands, and 13,832 imaging pixels in the panchromatic band. Prior to integration into the FPA, the FPMs were characterized for radiometric, spectral, and spatial performance. The Flight FPA has been built and its performance has also been characterized. In this paper, the critical attributes of the FPMs and FPA are highlighted. A detailed description of the FPM and FPA test sets is provided. The performance results that demonstrate compliance to the science mission requirements are presented.

8155A-34, Session 5

Nanoengineered optics using carbon nanotubes and graphene

S. Kar, S. Sridhar, Northeastern Univ. (United States)

No abstract available

8155A-35, Session 5

Low-cost solution processed quantum dots for SWIR imaging

E. J. Klem, J. S. Lewis, C. Gregory, D. Temple, RTI International (United States)

While InGaAs-based focal plane arrays (FPAs) provide excellent detectivity and low noise for SWIR imaging applications, wider scale adoption of systems capable of working in this spectral range are limited by high costs, limited spectral response, and costly integration with Si ROIC devices. RTI has demonstrated a novel photodiode technology based on IR-absorbing solution-processed PbS colloidal quantum dots (CQD) that can overcome these limitations of InGaAs FPAs. We have fabricated devices with quantum efficiencies exceeding 50%, and detectivities that are competitive with that of InGaAs. Dark currents of ~2 nA/cm² were measured at temperatures compatible with solid state coolers. Additionally, by processing these devices entirely at room temperature we find them to be compatible with monolithic integration onto readout ICs, thereby removing any limitation on device size. We will show early efforts towards demonstrating a direct integration of this sensor technology onto a Si ROIC IC and describe a path towards fabricating sensors sensitive from the visible to 1700 nm at a cost comparable to that of CMOS based devices. This combination of high performance, dramatic cost reduction, and multispectral sensitivity is ideally suited to expand the use of SWIR imaging in current applications, as well as to address applications which require a multispectral sensitivity not met by existing technologies.

8155A-36, Session 5

MBE growth of ZnTe and HgCdSe on Si: a new IR material

Y. Chen, G. N. Brill, U.S. Army Research Lab. (United States); D. J. Benson, U.S. Army Night Vision & Electronic Sensors Directorate (United States); P. S. Wijewarnasuriya, U.S. Army Research Lab. (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States) and U.S. Army Research Lab. (United States)

Recently we have explored the potential of a new class of IR materials based on HgCdSe grown by molecular beam epitaxy (MBE). Since scalable large area and high quality bulk substrate, such as GaSb, is commercial available and is closely lattice matched to HgCdSe and exact lattice matched to HgCdSeTe, one will expect to obtain scalable large area, high quality HgCdSeTe with low dislocation density, once the optimized growth conditions are established. This new IR material system, if proved successful, will mitigate the problems associated with lack of scalable large area and low cost substrates for HgCdTe/CdZnTe and relatively high dislocation density for scalable large area HgCdTe/Si IR materials. However, direct growth of HgCdSe on GaSb appears to be very challenging due to lack of dual III-V and II-VI chambers needed to properly prepare GaSb for the growth. As an alternate approach we use MBE grown ZnTe/Si as substrate, which is also closely lattice matched to HgCdSe. In this paper we will discuss our effort to utilize our expertise and extensive experience in the growth of CdTe on Si and HgCdTe on CdTe/Si to optimize the growth of high quality ZnTe on Si and the growth of HgCdSe on ZnTe/Si, with emphasis on growth temperature, material fluxes, growth rate and alloy composition. X-ray full-width at half-maximum (FWHM), chemical decorating etch for dislocation density and IR transmission measurement were used to evaluate the quality of the epilayers and calibrate the growth conditions.

8155A-37, Session 5

Material characteristics of HgCdSe grown on GaSb and ZnTe/Si substrates by MBE

G. N. Brill, Y. Chen, P. S. Wijewarnasuriya, U.S. Army Research Lab. (United States)

The Army Research Laboratory has recently initiated research on the growth and characterization of HgCdSe material by molecular beam epitaxy (MBE). HgCdSe is an infrared material that can be engineered to detect any wavelength of infrared (IR) light by controlling the Cd composition within the alloy. This compound is completely analogous to...
the much more common II-VI IR material HgCdTe, except that large area, scalable, and lattice matched substrates are commercially available for HgCdSe, specifically, GaSb. In addition, ZnTe/Si composite substrates are nearly lattice matched to HgCdSe making this a viable, and potentially cheaper, substrate for HgCdSe growth.

In this work, we will report on the first ever growth of HgCdSe on GaSb substrates by MBE and compare/contrast results to HgCdSe grown on ZnTe/Si. A systematic study of MBE growth temperature and material flux ratios were varied to ascertain the best growth conditions. HgCdSe defect structures were examined as a function of growth temperature with smooth, defect-free HgCdSe surface morphologies obtained using a growth temperature much lower than HgCdTe for comparable material fluxes. X-ray rocking curve measurements were also made to ascertain the overall crystalline quality of the material. To date, the best HgCdSe/GaSb material as measured by x-ray double crystal rocking curve resulted in a full width at half maximum (FWHM) of 160 arcsec whereas the best HgCdSe/ZnTe/Si material resulted in a FWHM of 200 arcsec. Transmission electron microscopy (TEM) was used to investigate the epilayer - substrate interface with electron diffraction showing aligned crystal structures between the HgCdSe epilayer and the substrate, as expected. FTIR data shows a linear relationship between the Se/Cd flux ratio and cut-off wavelength and indicates the easily tunable nature of the alloy. Additionally, Hall Effect measurements were taken on as-grown material as well as material annealed under varying Hg saturation conditions.

8155A-38, Session 5

Carbon nanotube-based microbolometer development for IR imager and sensor applications

A. K. Sood, Magnolia Optical Technologies, Inc. (United States); N. K. Dhar, Defense Advanced Research Projects Agency (United States); P. S. Wijewarnasuriya, U.S. Army Research Lab. (United States)

EO/IR Sensors and imagers using nanostructure based materials are being developed for a variety of Defence Applications. In this paper, we will discuss recent modeling effort and the experimental work under way for development of next generation carbon nanostructure based infrared detectors and arrays. We will discuss detector concepts that will provide next generation high performance, high frame rate, and uncooled nano-bolometer for MWIR and LWIR bands. The critical technologies being developed include carbon nanostructure growth, characterization, optical and electronic properties that show the feasibility for IR detection. Experimental results on CNT nanostructures will be presented. We will discuss the path forward to demonstrate enhanced IR sensitivity and larger arrays.

8155A-39, Session 5

A review of growth and characterization of ZnO nanostructures for optoelectronic sensor and energy harvesting applications

A. K. Sood, Magnolia Optical Technologies, Inc. (United States); N. K. Dhar, D. L. Polla, Defense Advanced Research Projects Agency (United States); T. Manzur, Naval Undersea Warfare Ctr. (United States); A. F. M. Anwar, Univ. of Connecticut (United States); Z. L. Wang, Georgia Institute of Technology (United States)

Next generation EO/IR integrated sensors using nanostructures are under development. Several materials are being investigated for these applications include ZnO nanostructures that have the potential applications in the UV part of the spectrum. ZnO is a unique material that exhibits both Semi conducting and piezoelectric properties and has applications in optical sensors and energy harvesting. We will discuss current status of the effort and the path forward.

E-O Sensors are being developed for a variety of Military Systems Applications. These include UV, Visible, SWIR, MWIR and LWIR Sensors. In this paper, we will discuss growth and characterization of ZnO Nanowires on a variety of substrates that include Si, ZnO, GaN, SiC and flexible substrates.

8155A-40, Session 6

DRS on multicolor bolometers

C. C. Li, DRS Technologies, Inc. (United States)

No abstract available

8155A-41, Session 6

Driving experience and special skills reflected in eye movements

R. Paeglis, K. Bliss, A. Atvars, Biomechanics and Physical Research Institute (Latvia)

When driving a vehicle, people use the central vision both to plan ahead and to monitor their performance feedback (research by Donges, 1978, and after). Discussion is ongoing if making eye movements do more than gathering information. Moving eyes may also prepare the following body movements like steering.

Different paradigms exist to explore vision in driving. Our perspective was to quantify eye movements and fixation patterns of different proficiency individuals, a driving learner, a novice, an experienced driver and a European level car racer. Thus for safety reasons we started by asking them to follow a video tour through a known city, remote from an infrared eye tracker sampling at 250 Hz.

The learner and novice had mean fixations shorter than the experienced driver, 0.62 sec, but longer than the racer, 0.20 sec. Both less experienced drivers often shifted their central vision away from the lane center. On the contrary, decades of driving experience enabled a person to follow the situation to the left by peripheral vision. Any eye shifts to the right were made by longer single saccades.

Experience in a motor action provides skills different from sports training. We are aiming at testing this finding in real world driving.

8155A-42, Session 6

A parametric analysis of microbolometer pixel designs

M. J. Dumas, B. A. Lail, Florida Institute of Technology (United States)

As microbolometer pixel dimensions for infrared imagers continue to decrease the need for full-wave analysis in the design process is enhanced. Using reflectance as the validation point, an electromagnetic model of a dual layer microbolometer pixel design was created for a 25μm pixel design, and an in-depth study of the design was performed. With this model validated, further explorations were completed with a reduced size pixel. While simulating multiple variations of specific parameters, such as bridge thickness, upper and lower cavity heights, and different absorber configurations, a new evaluation metric of dissipated power in the structure was studied. This metric, provided by finite element analysis, provides great insight into absorption properties within the microbolometer structure, properties that cannot be directly measured but that are critical to the functionality of the pixel design. In this paper parametric analysis of microbolometer pixel designs are presented via both reflectance and dissipated power full-wave analysis.
Cytochrome c thin film with high temperature of coefficient resistance for infrared detection

C. H. Chu, G. J. Su, National Taiwan Univ. (Taiwan)

The cytochrome c (protein) thin film on the oxide surface has been reported high temperature coefficient of resistance (TCR). The protein thin film resistance acts as exponential grow under the constant voltage bias. It presented the TCR exceeding 20% 1/K, which is Stimes better than popular VOx. We also found the protein thin film can be attached on to the SU8 photoresist surface by changing the SU8 surface more hydrophilic and simple spinning coat technique. The cytochrome c thin film on SU8 showed the high TCR. With easy fabrication methods and lower thermal conductivity of SU8 and protein, we believe that it is possible to fabricate new generation microbolometer based on cytochrome c protein and SU-8 photoresist.

Simulation and fabrication of poly(methyl methacrylate) infrared rays lenses

C. Tsui, G. J. Su, National Taiwan Univ. (Taiwan)

Infrared thermography is a promising solution that can help improve our lives. However, most of the common materials used to fabricate lenses, such as glass, are opaque in the infrared range. Silicon and germanium are better solutions. But shaping these two materials are truly complicated and time-consuming. Many research works have been devoted to develop cost-effective infrared lenses. Due to material restriction, traditional lenses to focus infrared rays are expensive. On the other hand, we found that PMMA (Poly methyl methacrylate) is an ubiquitous polymer material. It is cheap and transparent in mid-IR range. More importantly, liquid PMMA can be shaped and solidified easily. Therefore, we chose PMMA as the material to design and make our IR lenses. In this paper, we choose PMMA and discuss its optical properties in mid-IR ange. We believe PMMA is a highly potential material for low-cost infrared lenses. Also, we show simulation results of a f/2.47, diameter = 11mm and focal length = 27.2mm Fresnel lens made by PMMA to demonstate its feasibility. We made a PMMA Fresnel lenses, by using MEMS processes and embossing. The experimental results agree well with simulation data.
**8156-09, Poster Session**

**Statistical normalization of 1981 - 2010 brightness temperature records from the NOAA/AVHRR**

M. Vargas, National Oceanic and Atmospheric Administration (United States)

Time series of Brightness Temperature (BT) derived from the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) sensors are affected by atmospheric effects, satellite orbital drift and differences between satellite missions which in turn introduce spurious trends in the data stream. Brightness temperatures from the NOAA-GVI dataset are currently used to produce the Temperature Condition Index (TCI) and the Vegetation Health Index (VHI); therefore, satellite derived BTs need to be corrected with sufficient accuracy before being input into any algorithm to generate remotely sensed products to prevent biases in global long-term monitoring studies. In this research we have applied a statistical technique based on Empirical Distribution Functions (EDF) to normalize the NOAA BT records from the GVI-x dataset for the combined effect of the sources of uncertainty mentioned above, avoiding the need for physics based corrections. Results across most latitudes show that the normalized time series have no spurious trends, the estimated slope (trend) for normalized time series is close to zero at low and mid-latitudes, and the time series show improved stability. The results are tested to verify that the normalization improves the data.

**8156-10, Poster Session**

**The extraction of multiple cropping index of China based on NDVI time-series**

H. Huang, Z. Gao, Institute of Geographical Sciences and Natural Resources Research (China)

Multiple cropping index reflects the intensity of arable land been used by a certain planting system. The bond between multiple cropping index and NDVI time-series is the crop cycle rule, which determines the crop process of seeding, jointing, tasseling, and harvesting and so on. The cycle rule can be retrieved by NDVI time-series for that peaks and valleys on the time-series curve correspond to different periods of crop growth. In this paper, we aim to extract the multiple cropping index of China from NDVI time-series.

Because of cloud contamination, some NDVI values are depressed. MVC (Maximum Value Composite) synthesis is used to SPOT-VGT data to remove the noise, but this method doesn’t work sufficiently. In order to accurately extract the multiple cropping index, the algorithm HANTS (Harmonic Analysis of Time Series) is employed to remove the cloud contamination. The reconstructed NDVI time-series can explicitly characterize the biophysical process of planting, seedling, elongating, heading, harvesting of crops. Based on the reconstructed curve, we calculate the multiple cropping index of arable land by extracting the number of peaks of the curve for that one peak represents one season crop.

This paper presents a method for extracting the multiple cropping index from remote sensing image and then the multiple cropping index of China is extracted from VEGETATION decadal composites NDVI time series of year 2000 and 2010. From the processed data, we can get the spatial distribution of cropping system of China, and then further discussion about cropping index change between the 10 years is conducted.

**8156-18, Poster Session**

**Aerosol optical depth and angstrom exponent of aerosols observed using ground-based measurements in China**

C. Liu, East China Normal Univ. (China)

MFRSR (multi-filter rotating shadow-band radiometer) is a ground-based instrument and used to make measures of irradiance and aerosol. This paper introduces the instrument of MFRSR, the method of calibration and data processing, and then analyses statistical properties of aerosol using observation of MFRSR during 2004-2005 in Xianghe. In order to illuminate the reliability of observing aerosol optical depth with MFRSR, we compare the results of MFRSR with AERONET data. It shows the mean differences of the two results respectively are -0.021, -0.009, -0.004 at the wavelengths of 500nm, 670nm, 870nm, and the standard deviations are 0.067, 0.051, 0.050. We also discuss the reasons for deviation of the two.

**8156-19, Poster Session**

**Integrating satellite for drought impact assessment in a developed coastal region**

Z. Gao, Institute of Geographical Sciences and Natural Resources Research (China)

This paper presents a new drought assessment method by spatially and temporally integrating the regional water stress index (RWSI) with the temperature vegetation dryness index (TVDI). With the aid of LANDSAT TM/ETM data, we were able to retrieve the land-use and land-cover (LULC), vegetation indices (VIs), and land surface temperature (LST), and derive three types of TVDI, including TVDI_SAVI, TVDI_ANDVI and TVDI_MSAVI, for the drought impact assessment in a well-developed coastal region, northern China. The classification of four drought impact categories associated with the RWSI values enables us to refine the spatiotemporal relationship between the LST and the VIs in a greater detail. Holistic drought impact assessment between 1987 and 2000 in our study area was carried out by linking RWSI with TVDIs group wise.

**8156-21, Poster Session**

**Spatiotemporal characteristics of drought in southwest China using MODIS-based normalized difference drought index**

K. Bai, C. Liu, R. Shi, East China Normal Univ. (China)

Abstract: Recently, drought has brought huge damage to local agricultural production and ecological environment in China because of its high frequency. In order to catch the large-scale land surface water information used to assess land surface drought severity quickly and accurately, normalized difference drought index (NDDI) was proposed which based on visible and near infrared band reflectance. In this thesis, drought happened in southwest China in 2010 was taken for instance, and Yunnan, Guangxi and Guizhou provinces were taken as the study area. The drought severity was evaluated with NDDI index and then the drought spatial-temporal distribution was displayed in different drought severity. Moreover, land area in different drought severity in Guizhou province was calculated.

In the paper, MODIS images and meteorological data were used. Firstly, MODIS images were preprocessed and NDDI was calculated with different index derived from MODIS images. During this process, pixel reliability data acquired from MODIS product was introduced. The main
8156-23, Poster Session

**Research on spatial interpolation of meteorological elements in AnHui Province based on ANUSPLIN**

S. Shu, C. Liu, R. Shi, W. Gao, East China Normal Univ. (China)

High precision data fields of meteorological element is essential inputs for most kinds of large-scale regional and global models. Improvements on data accuracy can make models running more effectively and exactly. We often use IDW, Kriging and Splines as common interpolation tools, but for meteorological data the accuracy is not enough and the result has not essential smoothness. This paper attempts to use ANUSPLIN, a spatial interpolation software based on the theory of thin plate smoothing spline, to interpolate average temperature and precipitation data in different time scales. We obtained daily, monthly and annual data from 71 meteorological stations in Anhui Province as sample data. Before interpolation, we have experiments on different tactics in using ANUSPLIN models with the combination of three variants (Longitude, Latitude and Elevation) to ensure the best one corresponding every time scale source data and we find that CO2 (elevation as a covariate and the order of spline is 2) model fits daily and monthly temperature data most, CO3 model is effective for monthly and annual precipitation data. Then a comparison between the interpolated surfaces using ordinary kriging method and ANUSPLIN showed the latter one performs more accuracy and smoothness in all the time scales of temperature and precipitation: daily mean temperature interpolation’s mean error can be reduced by 0.103 , monthly one’s by 0.091 , annual one’s by 0.078 , monthly precipitation interpolation’s mean error can be reduced by 4.64mm, annual one’s by 22.194mm. Furthermore, we refer to other reaserches about quantitative effects on temperature with land cover changes and set a method adding land cover type as second covariate in former ANUSPLIN model. Interpolation errors show us a ideal result.

8156-24, Poster Session

**The evaluation of the applicability of MODIS aerosol optical depth product in the lower and middle reaches of Yangtze River**

Y. Chen, R. Shi, C. Liu, East China Normal Univ. (China); W. Gao, Colorado State Univ. (United States) and East China Normal Univ. (China)

As an index to estimate regional air quality, aerosol plays an important role in air pollution. MODIS has a fast access to a wide range of aerosol data, however, there is no guarantee for the accuracy of its AOD product in China. This paper is an attempt to evaluate the applicability of MODIS AOD product in the lower and middle reaches of Yangtze River supported by a large amount of AERONET ground-based data from Lin’an, Taihu and Hefei sites, which, in turn, provides the dependability for monitoring aerosol by using MODIS AOD product in the future. In this research, the author used MODIS AOD value for the 10km×10km central pixel-closest to the site to match the average of AERONET data within the 1-hour period centered on the MODIS overpass times, then made an analysis and evaluation of the fitting results. The results indicated that MODIS AOD product is not well correlated with AERONET data in 2007-2010, especially the correlation coefficient is only about 0.55 in 0.55µm band at Taihu site. MODIS AOD product is underestimated at Lin’an site, while overestimated at the others. Similarity exists in the quality of MODIS AOD product between Terra and Aqua, and the estimation of aerosol value by Terra was lower than that by Aqua. MODIS AOD product in 0.47µm band has an advantage over that in 0.66µm band as far as product accuracy is concerned. All the year around, MODIS AOD product at Taihu site is the best in quality in spring.

8156-25, Poster Session

**Ten-day response of vegetation to temperature and precipitation in Xinjiang, China during the period of 1998-2009**

X. Cao, Graduate Univ. of the Chinese Academy of Sciences (China); X. Chen, A. Bao, Xinjiang Institute of Ecology and Geography (China)

In this paper, 10-day (ten-day) spatio-temporal response of vegetation to the change of temperature and precipitation was analyzed in spring, summer, autumn and whole year in Xinjiang, China during the period of 1998-2009 based on the SPOT VEGEATION-NDVI data and 10-day average temperature or precipitation data observed by 54 meteorological stations in Xinjiang through correlation analysis. The results show that the response of 10-day NDVI to temperature was more significant than that to precipitation, and the maximal response of vegetation to temperature and precipitation lagged for two 10-day periods. Seasonally, the effect of temperature and precipitation on vegetation NDVI was the highest in autumn, then in spring, and it was the lowest in summer. The response of vegetation to 10-day change of meteorological factors was positive in spring, the affecting duration was long, and it was relatively short in autumn and summer. Spatially, the 10-day maximal response of NDVI to temperature in northern Xinjiang was higher than that in southern Xinjiang. The results indicated that interannual change of temperature was not the dominant factor affecting the change of vegetation NDVI in Xinjiang, but the decrease of annual precipitation was the main factor resulting in the fluctuation of vegetation coverage. 10-day average temperature was an important factor to promote vegetation growth in Xinjiang within a year, but the effect of precipitation on vegetation growth within a year was not strong.

8156-26, Poster Session

**An analysis of the relations between underlying surfaces and air temperature around city meteorological stations**

K. Liu, T. Yu, Institute of Remote Sensing Applications (China); W. Gao, East China Normal Univ. (China); Z. Gao, Institute of Geographical Sciences and Natural Resources Research (China); X. Gu, Institute of Remote Sensing Applications (China)

Based on Landsat TM remote sensing images obtained on May 28, 2007, and With 20 Beijing meteorological stations as research object, this study aims at finding the correlation between different types of underlying surfaces and Urban Heat Island (UHI) by analyzing various underlying surface types intercepted from the different-radius (1km,2km,3km,4km,5km) circular buffer zones (with 20 Meteorological Station as their center) and their corresponding air temperatures (annual average, maximum/minimiums). It finds a strong positive correlation between land for construction and UHI; a negative correlation between land/grassland and UHI; but the correlation between water bodies and UHI could not be found. As far as distance of influence is concerned, land for construction is within 4 km; woodland/grassland is within 3 km. As the distance influence of land surfaces, there is also impartment...
8156-27, Poster Session
The carbon dioxide monitoring from remote sensing based on fusion algorithm
W. Chao, East China Normal Univ. (China)

The IPCC fourth scientific assessment report suggested that the global average temperature increased by 0.74° in the past 100 years from 1906 to 2005 which will cause a tremendous impact on climate, ecosystem and energy cycle of the earth. The IPCC hold that the increasing of the greenhouse gas is the primary reason. The carbon dioxide is the second highest concentration of greenhouse gases other than water vapor and it will be very conducive to studying global climate change if we study it first. In terms of monitoring of carbon dioxide on a global scale, it costs more time and money but not a better effect by traditional methods. The greenhouse gas can be monitored by several satellites with the development of the remote sensing, such as METOP-A/IASI, ENVISAT/SCIAMACHY, GOSAT, AIRS. However, the comprehensive utilization is the difficulty caused by the difference between spatial and temporal coverage, resolution and digital format among the datasets from different sensors. In this paper we try to find a appropriate fusion algorithm from numbers and assessed from scientific views, such as information content, integration of information, spectral fidelity. A complete fusion system will be constructed to provide data base for research in the related fields.

8156-28, Poster Session
Remote sensing of LAI-FPAR fluctuations and Synchrotron EXAFS investigation of metal absorption under stress
T. M. Holden, S. Dehipawala, E. Cheung, R. Regan, G. Tremberger, Jr., U. Golebiewska, P. J. Marchese, T. D. Cheung, Queensborough Community College (United States)

The fluctuations of leaf area index (LAI) and Fraction of Photosynthetically Active Radiation (FPAR) as reported by the MODIS 8-day product MOD15A2 over a section of Harriman State Park, New York were studied with reference to another nearby local park. The area selected for study, a seven km square grid with one km resolution, is known for its biodiversity. Time series datapoints were generated using the sums of the grid’s 49 pixel measurements for each of the 46 entries that make up the annual time series. A quadratic relation has been observed that suggests LAI/FPAR is proportional to FPAR if FPAR is considered as the forcing parameter via chlorophyll (a, b, c, d and f), in an application model for the study of biodiversity. The LAI annual time series from 2000 to 2009 follows the corresponding FPAR annual time series as expected, but with different proportionality ratios in different seasons. The fractal analysis results of the time series data suggest that the LAI sequences have a lower fractal dimension (~1.35) than those of the FPAR sequences (~1.55), consistent with the idea that biological systems are capable of regulating fluctuation. The regression of LAI sequence fractal dimension versus FPAR sequence fractal dimension exhibits an R-square of about 0.7 (N = 10). The observed regression outlier for the year 2009 could be indicative of the presence of additional factors. Synchrotron EXAFS investigation of leaf samples reveals data consistent with metal absorption under stress. Further study is warranted.
the fusion of the change detection results through the other methods, the studied method in this paper can be further improved.

8156-33, Poster Session

Seepor object recognition on level-set with shape prior clustering

W. Wang, Z. Jia, Henan Polytechnic Univ. (China)

In this paper, in order to get a desirable image segmentation result of the interested buildings (round oil-can and square-roof buildings) in a seepor, a level-set based segmentation algorithm with shape priors is proposed. Since the algorithm inherits the advantages of the classic level-set segmentation algorithm, the contour topological changes can be automatically handled. In addition, by introducing the shape priors in the algorithm, the non-interested targets are filtered, therefore the object detection procedure is simplified. The corrupted boundary of a target is reconstructed in the segmentation process. Experiments show the algorithm studied in this paper is robust to anti-noise, compared to the other algorithms.

8156-34, Poster Session

Research on the hydrographic net change of Jing-Hang Great Canal in Nanwang part during 300 years

X. Wang, Ctr. for Earth Observation and Digital Earth (China)

Jing-Hang Great Canal is the earliest canal in the world, it has an important role in the transportation between south and north China during almost 2,000 years. But with the development new technologies, the Great Canal has lost its role from 19th century. Especially in Nanwang part of canal, it has disappeared as a dry drain now. In order to find the reason of Nanwang canal disappeared from 1700 gradually, we put forward a new method to find the change of it. In this paper, we first use an old map which draw in 300 years ago to obtain the old time environment status and correct it into nowadays remote sensing data to reveal the old sub-rivers which has run into canal in the old time. We also use some history materials to get the social information such as population data, county and village data. Second we using present remote sensing data to extract river, farmland data, we also collect the population data now in this area. In the end we compared this two period data to find the different hydrographic net in 300 years. The result will give us the answer for the canal change and give us a hint for reconstruction the Great Canal in the future.

8156-35, Poster Session

Soil moisture spatial heterogeneity and its remote sensing scale analysis in arid area

Q. Zhang, Ctr. for Earth Observation and Digital Earth (China); K. Zhou, Xinjiang Institute of Ecology and Geography (China) and Peking Univ. (China); W. Gao, Colorado State Univ. (United States)

For one typical characteristic of soil moisture in arid areas is the heterogeneity in space, what scales should the soil moisture remote sensing retrieval be based on so as to not only meet the application requirements but also be provided with operability? To think over this issue, the scale features of surface water heat energy parameters was analyzed, and a scale curve was introduced in this paper. Then after analyzing the relationship of spatial scale between spatial heterogeneity of surface parameters and remote sensing observational ability, it was believed that the point of intersection in these two curves is helpful to determine the remote sensing observation scale of regional soil moisture. Therefore, to study the spatial scale characteristics of surface parameters, in particular to test the critical point of key parameters which exists possibly is very important. From a case study, the spatial scale was quantitatively tested from four aspects: Polygon scale analysis of land cover, pixel scale analysis of land cover, spatial semi-variance analysis of land attributes, multi-Scale consistency index. As a result, the suitable spatial scale is less than 1 km, 250 m, 1 km and 240-480 m respectively. In sum, the optimum soil moisture remote sensing research scale is between 300-1000m in arid areas.

8156-36, Poster Session

Research on the method of extracting alteration information and metallogenic prediction based on multi-information

K. Zhou, Xinjiang Institute of Ecology and Geography (China) and Peking Univ. (China); Q. Zhang, Ctr. for Earth Observation and Digital Earth (China)

With the leaping of geolcica data, the demand to application of geological data is increasing and complex. how better to extract the excrecent information of geochemical anomalies and models of extracting altered information have been the important problem of geologists concerned. We analyzed the spectral characteristics of typical altered minerals, summarized the spectral response characteristics of typical altered minerals on ETM+. We contrasted three kinds of models of extracting altered information, the threshold model which was basis on PCA and the SAM model which was basis on spectrum vectors, and we firstly built the MPS model on the base of analysis the method of eliminating familiar interference information. The research discovered the result of MPS model tallied with the location of the known gold spots, and avoided the obviously false abnormality information. And we made use of this model to extracting the altered information in whole study area.

8156-37, Poster Session

A modified NDSI for the forest area for the snow cover mapping

S. Chen, Jilin Univ. (China); P. Lu, J. Wang, Institute of Remote Sensing Applications (China)

The snow cover plays an important role in the Earth’s climate system and it is also the main source of water use and an important input to the snowmelt model. The Normalized Difference Snow Index (NDSI) is proposed to distinguish snow cover from other land covers. However, it is challenge to identify the snow under the forest by the optical NDSI. In other words, there are big errors for the snow cover products in the forest. In the study, a model is applied to simulate the mixed spectrum of the snow and vegetation. The canopy of the vegetation is assumed as a sphere and the leaf area of the canopy quantity per volume is constant with the stochastic distribution function of the leaf area. The snow and crown surface are all thought as Lamberts and the multiple scattering between crown and ground are neglected. The gap between the vegetation canopies was calculated by the geometry optical model. Within a pixel, the vegetation and snow coverage fraction are taken into consideration for the mixed albedo model. Three situations, the snow is above and under the vegetation canopy, no snow above the canopy but the snow is under the vegetation, the snow is above the canopy but no snow under the canopy, are simulated separately. The simulated BRF values is near to the pure snow spectrum when the snow is above the canopy, and the BRF are similar to the pure vegetation pixel when the snow is just exist under the vegetation. In the principal plane, the simulated BRF is owe to the hot spot effect and there is a peak value in the hot spot. The sensitive analysis indicated the BRF is sensitive to the density and fraction of the vegetation. With the increase of the density and fraction, the BRF is decreased. However, the BRF is not sensitive to the LAI. By the results, the NDSI is proposed for different density and fraction of the vegetation. And the snow cover is also identified and compared to the snow cover products of EOS MODIS.
Spectral significance to investigate the distribution of metal elements under dense vegetation cover

S. Chen, Jilin Univ. (China); J. Wang, Institute of Remote Sensing Applications (China); C. Zhou, Jilin Univ. (China)

About two thirds of land surface are covered by vegetation. It is challenge to identify the rocks by spectral analysis under the dense vegetation cover. But it is necessary to take the distribution of the metal mines under the large area of vegetation for the state need with the economy developing. In the study, the leaf spectra have been field-measured for four main vegetation types in Daxin’an Mountains, Northeast China. The nodes of spectral abrupt variations are located in the wavelength 718nm for two known metal mine areas, but they are located in the wavelength 720nm for the other areas. Meanwhile, the metal elements are analyzed chemically in the laboratory for the samples of soil and vegetation (root, trunk, and leaf). It is discovered that there are high contents of metal elements for the vegetation in the known mines compared to the other area. All the pixels with the nodes in the wavelength 718nm are then calculated using Hypersion Data. Thus, the distributions of metal elements in the study area are outlined by the vegetation spectrum. The results are comparable to the geo-chemical analysis of the soil samples and it is significant to investigate the metal mine. Obviously, the method is much efficient and economic to the metal mine investigation under the dense vegetation cover.

MODIS-based spatiotemporal patterns of soil moisture and evapotranspiration interactions in Tampa Bay urban watershed due to the hurricane impact

N. Chang, Univ. of Central Florida (United States)

The advent of urban hydrology and remote sensing technologies opens new and innovative means to undertake event-based assessment of ecohydrological effects in urban regions. In the these landfalls, the multispectral MODIS remote sensing images can be used for the estimation of such soil moisture change in connection with the Enhanced Vegetation Index (EVIm), Land Surface Temperature (LST). Supervised classification based on these patterns was performed fro Tampa Bay area on the 2 kmx2km grid with MODIS images. Machine learning with genetic programming model for soil moisture estimation shows advances in image processing, feature extraction, and change detection of soil moisture. ET data that were derived by GOES data and hydrologic models can be retrieved from the USGS web site directly. Overall, the derived soil moisture in comparison with ET time series changes on a seasonal basis shows that spatial and temporal variations of soil moisture and ET that are confined within a defined region for each type of surfaces, showing clustered patterns and featuring space scatter plot in association with the land use and cover map. These concomitant soil moisture patterns and ET fluctuations vary among patches, plant species, and, especially, location on the urban gradient. Such ecohydrological assessment can be applied for supporting the urban landscape management in hurricane-stricken regions.

A MODIS-based vegetation index climatology

R. Bindlish, Science Systems and Applications, Inc. (United States); T. J. Jackson, T. Zhao, U.S. Dept. of Agriculture (United States)

Our motivation here is to provide information for the NASA Soil Moisture Active Passive (SMAP) satellite soil moisture retrieval algorithms (launch in 2014). Vegetation attenuates the signal and the algorithms must correct for this effect. One approach is to use data that describes the canopy water content or biomass, which can be estimated using vegetation indices such as the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). Vegetation parameters need to be included from ancillary sources since SMAP does not include any sensor that can provide them. This presents challenges to data processing and integration and concerns about data availability. As an alternative or back-up to routine updating of the NDVI, we are suggesting the development of a global NDVI and EVI annual cycle. This is based on the most recent long term set of observations from the MODIS instrument (10 years). A technique was developed to process the NASA MODLAND NDVI and EVI data base to produce a 10-day annual cycle for each 1 km pixel covering the Earth’s land surface. Since our focus was on soil moisture, the classification rules and flags took this into consideration.

Remote detection of water stress in orchard canopies using MODIS/ASTER airborne simulator (MASTER) data

T. Cheng, D. Riano, A. Koltunov, M. L. Whiting, S. L. Ustin, Univ. of California, Davis (United States)

Vegetation canopy water content (CWC) is one of the key factors in successful monitoring of natural and agricultural ecosystems. In particular, accurate estimation of water content in orchard canopies could provide valuable information on water stress and help make informative decisions on irrigation strategies. As part of a Terrestrial Hydrology NASA funded project on validating algorithms and models for estimating multi-temporal vegetation CWC from satellite imagery, an experiment was initiated in summer 2010.
to conduct a few field campaigns in the Central Valley of California. Concurrent with CWC sampling on the ground, MASTER (MODIS/ASTER airborne simulator) mounted on DC-8 aircraft was flown on June 29 and July 1 of 2010 to acquire morning and afternoon airborne imagery at a spatial resolution of 5.8 meters.

The aim of this experimental study was to evaluate the diurnal differences in remote estimates of CWC over Almond and Pistachio orchards to which different predefined irrigation strategies were applied. Our preliminary analysis indicates a statistical significant difference in CWC between morning and afternoon field measurements. This study will contribute to assessing the performance of MASTER data in capturing water stress signals and provide spatial and temporal patterns of CWC for further validation of estimates from ASTER and MODIS imagery.

8156-05, Session 1

Comparison of hyperspectral retrievals with vegetation water indices for leaf and canopy water content

E. R. Hunt, Jr., C. S. T. Daughtry, Agricultural Research Service (United States); J. J. Qu, L. Wang, X. Hao, George Mason Univ. (United States)

Leaf and canopy water contents provide information for leaf area index, vegetation biomass, and wildfire fuel moisture content. Hyperspectral retrievals of leaf and canopy water content are determined from the relationship of spectral reflectance and the specific absorption coefficient of water over the wavelength range of a water absorption feature. Vegetation water indices such as the Normalized Difference Water Index [NDWI = (R850 - R1240)/(R850 + R1240)] and Normalized Difference Infrared Index [NDII = (R850 - R1650)/(R850 + R1650)] may be calculated from multispectral sensors such as Landsat Thematic Mapper, SPOT HRG, or MODIS. Predicted water contents from hyperspectral data were much greater than measured water contents for both leaves and canopies. Furthermore, simulated spectral reflectances from the PROSPECT and SAIL models also had greater retrieved leaf and canopy water contents compared to the inputs. Used simply as an index correlated to leaf and canopy water contents, hyperspectral retrievals had better predictive capability than NDII or NDWI. Atmospheric correction algorithms estimate canopy water content in order to estimate the amount of water vapor. These results indicate that estimated canopy water contents should have a systematic bias, even though this bias does not affect retrieved surface reflectances from hyperspectral data. Field campaigns in a variety of vegetation functional types are needed to calibrate both hyperspectral retrievals and vegetation water indices.

8156-06, Session 1

Spectral bio-indicator simulations for tracking photosynthetic activities in a corn field

Y. Cheng, Earth Resources Technology, Inc. (United States); E. M. Middleton, NASA Goddard Space Flight Ctr. (United States); K. F. Huemmrich, Q. Zhang, Univ. of Maryland, Baltimore County (United States); L. A. Corp, Sigma Space Corp. (United States); P. K. E. Campbell, Univ. of Maryland, Baltimore County (United States); W. P. Kustas, U.S. Dept. of Agriculture (United States)

Accurate assessment of vegetation canopy optical properties plays a critical role in monitoring natural and managed ecosystems under environmental changes. In this context, radiative transfer (RT) models simulating vegetation canopy reflectance have been demonstrated to be a powerful tool for understanding and estimating spectral bio-indicators. In this study, two narrow band spectroradiometers were utilized to acquire observations over corn canopies for two summers. These in situ spectral data were then used to validate a two-layer Markov chain based canopy reflectance model for simulating the Photochemical Reflectance Index (PRI), which has been widely used in recent vegetation photosynthesis and light use efficiency (LUE) studies. The PRI derived from in situ narrow band hyperspectral reflectance exhibited clear response to 1) viewing geometry corresponding to the light environment and 2) seasonal variation corresponding to the growth stage. The RT model utilized (ACRM; Kuusk, 2001) successfully simulated the response to the viewing geometry. The best simulations were obtained when the model was set to run in the two layer mode using the sunlit leaves as the upper layer and shaded leaves as the lower layer. Simulated PRI values yield much better correlations with in situ observations during the early growth, vegetative and reproductive stage (r=0.78 to 0.86) than in the senescence stage (r=0.65). Further sensitivity analysis was conducted to show the importance of leaf area index (LAI) and the sunlit/shaded ratio for the PRI simulations.

8156-07, Session 2

Evaluations of scattering-order and vegetation structure on modeling microwave vegetation signals and their impacts on applications

J. Shi, Institute for Remote Sensing Applications (China)

Passive microwave satellite measurements have been widely used in monitoring geophysical properties of the land surfaces, including surface temperature, snow depth or snow water equivalence, soil moisture, and vegetation properties. The techniques for above applications are mainly derived from the 0-order radiative transfer model, commonly called as the o-t-m model. This basic supporting theory assumes that scattering magnitude in vegetation canopy is not significant and considers the vegetation as an absorption material. In this study, we evaluate the effects in modeling microwave vegetation signals due to the scattering-order: we compared the 0-th, 1-th, and multi-scattering radiative transfer model simulations with the experimental measurements (ground radiometer) for the short vegetation (Soybean and Cotton). It was found that 1) the 0-th and 1-th radiative transfer model were under-estimating the emissivity at C-band or higher frequencies due to a great impact of scattering effects in vegetation canopy. 2) At L-band, no significant differences between all 3 different scattering radiative transfer models in predicting the emissivities. The vegetation structure: to simulate the vegetation structure effects in forests, we used the dynamic vegetation growth models (L-System) to simulate the different type of vegetation’s geometric and structural in a statistical characteristics that including the sizes and number densities for trunks, different level of branches, and leaves. We compared the simulated results between the emissivities with the vegetation structure consideration and with that assumed the random orientation. It was found that there is a significant difference between above two considerations at L-band. It indicated that the vegetation effects might differ at the different polarizations and need to be considered in the algorithms for soil moisture and vegetation monitoring.

8156-08, Session 2

Estimations of deciduous forest biomass by analyzing vegetation microwave emission

Z. Zhang, Beijing Normal Univ. (China); J. Shi, Institute of Remote Sensing Applications (China); L. Zhang, Beijing Normal Univ. (China)

Forest biomass is an important factor in global carbon cycle and has potential impact on global climatic change. With the advantage of being independent of weather and day time, and the penetration ability, microwave techniques of active or passive are used in remote sensing. The radiometers carried in SMOS, Chinese FY-3B, or future SMAP would measure over fully or partially forested sites. The relationship between forest biomass and its microwave emissivity is of interest to be studied. The microwave emission contribution received by the radiometer above
the viability of infrared imagery for cetacean detection and classification. Imagery was obtained at Lime Klin Park, Washington from 7/6-10-7/9/10 using a FLIR Thermovision A40 camera (7.5-14µm, 37°HFOV, 30x24 pixels) under ideal atmospheric conditions (clear skies, calm seas, and wind speed 0-3 m/s). Whales were detected during both day (9 detections) and night (75 detections) at distances ranging from 42 to 160 m. The temperature contrast between dorsal fins and the sea surface ranged from 0.5 to 4.6 °C. Differences in emissivity from sea surface to dorsal fin are shown to aid detection at high incidence angles (near grazing). A comparison to theory is presented, and observed deviations from theory are investigated. A guide for infrared camera selection based on site geometry and desired target size is presented, with specific considerations regarding marine mammal detection. Atmospheric conditions required to use visible and infrared cameras for marine mammal detection are established and compared with 2008 meteorological data for the proposed tidal energy site. Using conservative assumptions, infrared observations are predicted to provide a 74% increase in hours of possible detection compared with visual observations.

8156-11, Session 3

Progress in the development of airborne remote sensing instrumentation for the National Ecological Observatory Network (NEON)


The National Ecological Observatory Network (NEON) is a planned facility of the National Science Foundation. NEON's mission is to enable understanding and forecasting of the impacts of climate change, land use change and invasive species on continental-scale ecology. Airborne remote sensing plays a critical role by providing measurements at the scale of individual shrubs and larger plants over hundreds of square kilometers. The NEON Airborne Observation Platform is designed to bridge scales from organism and stand scales, as captured by plot and tower observations, to the scale of satellite based remote sensing. Fused airborne spectroscopy and waveform LiDAR will quantify vegetation composition and structure. Panchromatic photography at better than 30 cm resolution will retrieve fine-scale information regarding land use, roads, impervious surfaces, and built structures. NEON will build three airborne systems to allow for routine coverage of NEON sites and the capacity to respond to investigator requests for specific projects. The system design achieves a balance between performance, and development cost and risk, taking full advantage of existing commercial airborne LiDAR and camera components. To reduce risk during NEON construction, an imaging spectrometer design verification unit is under development by the Jet Propulsion Laboratory to demonstrate that operational and performance requirements can be met. As part of this effort, NEON is also focusing on science algorithm development, computing hardware prototyping and early airborne test flights with similar technologies. This paper presents an overview of system design, key requirements and development status of the NEON airborne instrumentation.

8156-12, Session 3

Land-based infrared imagery for marine mammal detection

J. L. Graber, J. Thomson, B. Polagye, A. T. Jessup, Univ. of Washington (United States)

A land-based infrared (IR) camera is used to detect endangered Southern Resident Killer Whales in Puget Sound, Washington, USA. The observations are motivated by a proposed tidal energy pilot project, which will be required to monitor for environmental effects. Potential monitoring methods also include visual observation, passive acoustics, and active acoustics. The effectiveness of observations in the infrared spectrum is compared to observations in the visible spectrum to assess the viability of infrared imagery for cetacean detection and classification.

8156-13, Session 3

Exploring the nutrient inputs and cycles in Tampa Bay and coastal watersheds using MODIS images and data mining

N. Chang, Univ. of Central Florida (United States)

A magnitude of dominant phytoplankton in estuary and bay systems may be related to water quality parameters such as dissolved oxygen, salinity, nutrient concentration, water temperature, and turbidity. Phytoplankton, nutrient level, and MODIS images of Tampa Bay in Florida were studied to explore the possibility of estimating nutrient levels (i.e., Total Nitrogen (TN) and Total Phosphorus (TP)) in the water using MODIS images. However, the dominant phytoplankton species vary spatially and temporally throughout the bay, especially near river mouths. Salinity level and river inflows may alter the abundance of phytoplankton species. There is no clue in regard to how these spatial correlations and associative links between the five sub-bay areas and the four coastal watersheds around the Tampa Bay could be in terms of nutrient inputs and cycles on a seasonal basis. The modeling effort is thus designed to retrieve the associative links by using fuzzy K-mean models and association rules that may aid in examining the nutrient inputs and cycles in Tampa Bay, Florida. It will lead to the improvement of nutrient control in terrestrial watersheds for both anthropogenic and natural sources and ultimate amelioration of the eutrophication impacts in the bay.

8156-15, Session 3

Standoff Raman measurement of nitrates in water

S. Sadate, A. Kassu, C. Farley III, A. Sharma, Alabama A&M Univ. (United States); P. Ruffin, C. Brantley, E. Edwards, U.S. Army Research, Development and Engineering Command (United States)

The identification and real time detection of explosives and hazardous materials are of great interest to the Army and environmental monitoring/ protection agencies. The application and efficiency of the remote Raman spectroscopy system for real time detection and identification of explosives and other hazardous chemicals of interest, air pollution monitoring, planetary and geological mineral analysis at various standoff distances have been demonstrated. In this paper, we report the adequacy of stand-off Raman system for remote detection and identification of chemicals in water using dissolved sodium nitrate and ammonium nitrate in water for concentrations between 200ppm and 5000ppm. Nitrates are used in explosives and are also necessary nutrients required for effective fertilizers. The nitrates in fertilizers are considered as potential sources of atmospheric and water pollution. The standoff Raman system used in this
work consists of a 2-inch refracting telescope for collecting the scattered Raman light and a 785nm laser operating at 400mW coupled with a small portable spectrometer.

8156-16, Session 3

**Design and package of a 14CO2 field analyzer, the Global Monitor Platform (GMP)**

M. R. Bright, G. Gronniger, Honeywell Federal Manufacturing & Technologies, LLC (United States)

Carbon Capture and Sequestration (CCS) is widely accepted as a means to reduce and eliminate the fossil fuel CO2 (ff-CO2) emissions from coal fired power plants. The success of CCS depends on near zero leakage rates over decadal time scales. Currently no commercial methods to determine leakage of ff-CO2 are available. The Global Monitor Platform (GMP) field analyzer provides high precision analysis of CO2 isotopes [12C (99%), 13C (<1%), 14C (1.2x10^-10%)] that can differentiate between fossil and biogenic CO2 emissions. Since fossil fuels contain no 14C; their combustion should lower atmospheric amounts. There is a clear mandate for monitoring, verification and accounting (MVA) of carbon capture and storage systems nationally and globally to verify CCS integrity, treaty verification (Kyoto Protocol) and to characterize the nuclear fuel cycle. Planetary Emissions Management (PEM), working with the National Secure Manufacturing Center (NSMC), has the goal of designing, ruggedizing and packaging the GMP for field deployment. The system will conduct atmosphere monitoring then adapt to water and soil evaluations. Measuring 14CO2 will provide quantitative data for fossil fuel related CO2 in the atmosphere and for CCS leakage. The initial design and packaging of the gas laser-optical system with custom and commercial off the shelf (COTS) optics and gas lasers was fielded in October 2010. The design consists of a 12C, 13C and 14C laser along with two sample cells and reference cells. The data gathered and results of the packaged system will be discussed along with design changes for manufacturability, environment and cost reduction.

8156-17, Session 3

**Estimation of suspended sediment concentrations in the Yellow River (China) by network monitoring records and satellite data**

L. Qu, X. H. Yang, Univ. of Connecticut (United States); T. Lei, China Agricultural Univ. (China)

The sediment concentration in river flow is very important in monitoring of water quality, operation of the hydraulic facilities, and management of water resources. Commonly used sampling method is time consuming, labor intensive, and providing only point data at gauging station. The study focuses on presenting a remote sensing approach to quantify suspended sediment concentration (SSC) of the high turbid flow in the Yellow River in China, where the high sediment transportation from severe soil erosion is a big environmental concern. The new approach is based on public accessible satellite images and surface networking monitoring data. With the longest time series records, the Landsat MT and Landsat EMT+ images are chosen to establish the remote sensing approach. A large number of daily sediment records from 125 hydrological stations from 1990 to 2005 across the entire Yellow River are associated with available satellite imaginary. The water reflectance is retrieved from the Landsat images by using an effective easy-to-use atmospheric correction method. Sensitivity analysis is conducted to water reflectance from Bands 2 to 5 to establish the SSC indices. According to the significance of SSC indices from the water reflectance, a correlation model between SSC and water reflectance is developed. The model is calibrated and validated by the daily sediment records from surface observation. With the result from this study, it is not only possible to map out the dynamic SSC distribution along the river, but also has the potential to recall the SSC when the historical surface observation is absent.
8157-01, Session 1

Improving a DWT-based compression algorithm for high image-quality requirement of satellite images

C. Thiebaut, C. Latry, R. Camarero, Ctr. National d’Études Spatiales (France); G. Cazanave, Magellium (France)

Past and current optical Earth observation systems designed by CNES are using a fixed-rate data compression processing performed at a high-rate in a pushbroom mode (also called scan-based mode). This process generates fixed-length data to the mass memory and data downlink is performed at a fixed rate too. Because of on-board memory limitations and high data rate processing need, the rate allocation procedure is performed over a small image area called a “segment”. For both PLEIADES compression algorithm and CCSDS Image Data Compression Recommendation, this rate allocation is realised by truncating to the desired rate a hierarchical bitstream of coded and quantized wavelet coefficients for each segment. Because the quantisation induced by truncation of the bit planes description is the same for the whole segment, some parts of the segment have a poor image quality. These artefacts generally occur in low energy areas within a segment of higher level of energy. In order to locally correct these areas, CNES has studied “exceptional processing” targeted for DWT-based compression algorithms. According to a criteria computed for each part of the segment (called block), the wavelet coefficients can be amplified before bit-plane encoding. As usual Region of Interest handling, these multiplied coefficients will be processed earlier by the encoder than in the nominal case (without exceptional processing). The image quality improvement brought by the exceptional processing has been confirmed by visual image analysis and fidelity criteria. The complexity of the proposed improvement for on-board application has been analysed too.

8157-02, Session 1

Adaptive compressed sensing with joint-sparsity reconstruction for hyperspectral images

H. Liu, Y. Li, Xidian Univ. (China); P. Lv, Xi’an Institute of Optics and Precision Mechanics (China); J. Song, J. Zhang, Xidian Univ. (China)

Hyperspectral imaging is an effective tool for detecting the nature of materials being imaged. However, the traditional hyperspectral image acquisition uniformly samples a large volume of data at or above the Nyquist rate and discards most of them during the compression stage to facilitate efficient storage and transmission. Obviously, this process of massive data acquisition followed by compression is extremely wasteful. Compressed sensing (CS) is a novel technology to acquire and reconstruct signals below the Nyquist rate, which explores the data redundancy to significantly reduce the number of sampled data and has great potential in hyperspectral imaging applications.

Considering that hyperspectral images have strong spectral correlation, it is not efficient enough to individually apply CS to acquire and reconstruct each band. To exploit the spectral correlation for achieving higher reconstruction performance, an efficient joint-sparisty reconstruction scheme for compressed hyperspectral image measurements is proposed in this paper. It classifies hyperspectral images into several different groups depending on their spectral correlation, and adaptively allocates the number of measurements collected for each band accordingly. In addition, the hyperspectral image similarity is introduced as a regularization term into the CS recovery problem to jointly explore the sparsity in the intra-band and inter-band domain. The experimental results show that the proposed method achieves much better performance than many state-of-the-art algorithms in terms of both PSNR and computational complexity.

8157-03, Session 1

Further GPU acceleration of predictive partitioned vector quantization for ultraspectral sounder data compression

S. Wei, Tamkang Univ. (Taiwan); B. Huang, Univ. of Wisconsin-Madison (United States)

Large-volume ultraspectral sounder data requires compression for data storage and transfer. Predictive partitioned vector quantization (PPVQ) has been proven to be an effective lossless compression scheme for ultraspectral sounder data. It consists of linear prediction, bit depth partitioning, vector quantization, and entropy coding. In previous work, the two most time consuming stages of linear prediction and vector quantization were identified for GPU implementation. By exploiting the data parallel characteristics of these two stages, a new spatial division design will be tested in this work for further speedup compared to previous spectral division design.

8157-04, Session 1

Design of JPEG-LS encoder on GPUs

Y. Fang, Northwest A&F Univ. (China); B. Huang, Univ. of Wisconsin-Madison (United States)

Lossless JPEG (JPEG-LS) is a lossless/near-lossless image compression standard with low complexity, which consists of three independent and distinct stages called prediction, residual modeling, and context-based coding of the residuals. To parallelize the prediction and modeling stages, each thread processes each row of pixels. Then parallelized AC is run to do entropy coding of the residuals, which can be modeled as a discrete Laplace process.

8157-05, Session 1

Opportunistic network coding retransmission algorithm based on packet loss pattern

S. Xiao, Xidian Univ. (China)

Broadcast and multicast schemes are very popular for the satellite data transmission applications such as the file distribution of images that used for remote sensing, forecasting, geographic information system etc. since they are effective in bandwidth consumption in a spectrum-limited wireless space. However, providing reliable broadcast and multicast transmission over wireless networks is still a challenging problem, due to the erratic and time-varying nature of a wireless channel.

Usually, the transmission reliability is achieved through Automatic Repeat Request (ARQ) or/and Forward Error Correction (FEC) schemes. For traditional ARQ schemes, the lost packets will be sent one by one from the source node to the receiver, which is called retransmission. An efficient retransmission strategy is very important to the reliability of transmission and the bandwidth utility of the wireless network.

In this paper, an opportunistic network coding retransmission algorithm based on packet loss pattern was proposed to improve the transmission efficiency of broadcast and multicast over wireless networks. At first, a loss pattern matrix of the received packets in multiple terminals
was set up. Then a coding strategy was designed which generate retransmission packets by employing the opportunistic network coding according to the packet loss pattern. Finally, the coding packets were transmitted to different terminals from which the lost packets can be retrieved respectively. The theoretical analysis reveals the feasibility and effectiveness of proposed algorithm.

To verify the efficiency of the proposed algorithm, different criterions are defined and used in the performance comparison with previous methods. The simulation results show that the algorithm can effectively reduce the retransmission times and increase the transmission efficiency over wireless networks. It leads to better performance compared with other approaches for all pre-defined criterions under various channel conditions.

8157-06, Session 2
Fast endmember extraction method using the geometry of the hyperspectral datacube
R. Rashidi Far, S. Qian, Canadian Space Agency (Canada)

This paper proposes a new method to extract the endmembers of a hyperspectral datacube. The method finds the endmembers using a method that depends upon high computing performance of algorithm analysis. The algorithm used to find the endmembers in this method is the volume of the simplex. Unlike the widely used endmember extraction method “N-FINDR”, which calculates the volume of a simplex as many times as the number of the vertices of the simplex for each pixel of the datacube in searching for the replacers for the vertices, the proposed method calculates the volume only once for each pixel of the datacube by taking into account of the geometry of the hyperspectral datacube that is tackled. For each pixel, the method finds the closest vertex of the simplex to that pixel. Then the closest vertex is replaced with the pixel in calculating the volume of the potential new simplex. Computational complexity of the proposed method is one order of magnitude less than the N-FINDR. As the proposed method is using the same criterion as N-FINDR we refer it to as fast N-FINDR (FN-FINDR). The performance of the proposed method was compared with N-FINDR using an AVIRIS datacube and a HYDICE datacube. The performance of the proposed method was evaluated using three different distance measures. The comparison was also made using two different dimensionality reduction methods. It is observed that the FN-FINDR with a modified Euclidean distance works as well as the N-FINDR.

8157-07, Session 2
A new morphological anomaly detection algorithm for hyperspectral images and its GPU implementation
A. Paz, A. J. Plaza, Univ. de Extremadura (Spain)

Automatic target and anomaly detection are considered very important tasks for hyperspectral data exploitation. These techniques are now routinely applied in many application domains, including defence and intelligence, public safety, precision agriculture, geology, or forestry. Many of these applications require timely responses for swift decisions which depend upon high computing performance of algorithm analysis. However, with the recent explosion in the amount and dimensionality of hyperspectral imagery, this problem calls for the incorporation of parallel computing techniques. In the past, clusters of computers have offered an attractive solution for fast anomaly and target detection in hyperspectral data sets already transmitted to Earth. However, these systems are expensive and difficult to adapt to on-board data processing scenarios, in which low-weight and low-power integrated components are essential to reduce mission payload and obtain analysis results in near real-time, i.e., at the same time as the data is collected by the sensor. An exciting new development in the field of commodity computing is the emergence of commodity graphics processing units (GPUs), which can bridge the gap towards on-board processing of remotely sensed hyperspectral data. In this paper, we develop a new morphological algorithm for anomaly detection in hyperspectral images along with its efficient GPU implementation. The parallel is implemented on latest-generation GPU architectures, and evaluated using hyperspectral data collected by the NASA’s Airborne Visible Infra-Red Imaging Spectrometer (AVIRIS) over the World Trade Center (WTC) in New York, five days after September 11th, 2001.

8157-08, Session 2
Color/mono classification of scanned images
S. Youn, Yonsei Univ. (Korea, Republic of); S. W. Han, Samsung Electronics Co., Ltd. (Korea, Republic of); C. Lee, Yonsei Univ. (Korea, Republic of)

We propose a new algorithm for color/mono classification of scanned images. During scanning process, various artifacts are generated by scanner sensors. These artifacts make it difficult to design a classifier for color and mono classification. The proposed algorithm utilizes a color index that reflects pixel colorfulness. The scanned image is divided into a number of sub-blocks, a color index is computed for each sub-block. Half-tone regions are removed by low-pass filtering and clustering in the RGB space is performed to analyze neighbor pixels. All the pixels within a block are projected into RGB space and the Euclidean distances between the block center and pixels within the block are computed. If the number of pixels which are located within a certain distance from the center and are connected to the block center is larger than a threshold, we determine that the pixel has homogeneous neighbors. In this case, the achronomic distance, which is the Euclidean distance from the pixel to the gray line(R=G=B), is calculated. If the average of achronomic distances is bigger than a threshold, the center pixel is classified as a color pixel. To enhance reliability, the color pixel percentile can be used to classify the entire document.

8157-09, Session 2
Accelerating the Hilbert-Huang Transform on GPUs
J. Wang, B. Huang, Univ. of Wisconsin-Madison (United States)

The Hilbert-Huang Transform (HHT) is an empirical algorithm for analysis of nonlinear and nonstationary data. It consists of the empirical mode decomposition (EMD) and the Hilbert spectral analysis (HSA). The EMD method is to decompose a signal into a collection of the intrinsic mode functions (IMFs), while the HSA method is to obtain the instantaneous frequencies. The HHT has been widely used in various science and engineering applications, including remote sensing data processing. The process of extracting an IMF is to connect all the local maxima by a cubic spline line as the upper envelope and all the local minima as the lower envelope. This sifting procedure is suitable for parallel implementation. In recent years graphics processing units (GPUs) with hundreds of compute cores have become an affordable alternative to a CPU cluster for high performance computing. In this study we exploit the GPU massively parallel capabilities to accelerate the HHT with an expected significant speedup.

8157-10, Session 3
Field programmable gate array design of implementing simplex growing algorithm for hyperspectral endmember extraction
W. Xiong, Univ. of Maryland, Baltimore County (United States); C. Wu, National Taipe Univ. of Technology (Taiwan); C. Chang, Univ. of Maryland, Baltimore County (United States)

N-FINDR has been widely used for endmember extraction in hyperspectral imagery. Due to its high computational complexity
developing fast computing N-FINDR has become interest. One approach is to design field programmable gate array (FPGA) architecture for N-FINDR to reduce computing time. However, two major issues still need to be addressed. One is that the number of endmembers must be fixed regardless of applications. The other is computation of simplex volumes. This paper investigates a progressive version of N-FINDR, previously known as simplex growing algorithm (SGA) for its FPGA implementation which basically resolves these two issues.

8157-11, Session 3

GPU implementation of the maximum likelihood solution to the inverse problem for retrieval of geophysical parameters from high-resolution sounder data
S. Wei, Tamkang Univ. (Taiwan); B. Huang, Univ. of Wisconsin-Madison (United States)

The radiative transfer equation (RTE) describes the observed radiance as a result of contributions from surface properties, atmospheric temperature and absorbing gas profiles. Retrieval of these geophysical parameters from the sounder data requires an inverse solution to the RTE. In the presence of noise in observation data, the maximum likelihood estimator is often used to find the most probable solution from an ensemble described by a probability density function. In recent years graphics processing units (GPUs) with hundreds of computing cores have become affordable for scientific computation. This work explores the GPU massively parallel capabilities in accelerating the maximum likelihood solution to the remote sensing retrieval problem.

8157-12, Session 3

Visual analytics of terrestrial lidar data for cliff erosion assessment on large displays
T. Hsieh, Y. Chang, National Taipei Univ. of Technology (Taiwan)

Heavy development on cliffs places a heavy emphasis on maintaining a healthy natural environment. The ability to explore, conceptualize and correlate spatial and temporal changes of topographical records is required for the development of new analytical models that capture the mechanisms contributing towards cliff erosion. This paper presents a visualization based approach using large displays in a digital immersive environment. Visual analytics are performed for cliff erosion assessment from a terrestrial LIDAR (Light Detection And Ranging) data, including visualization techniques for the delineation, segmentation, and classification of features, change detection and annotation. Research findings are described in the context of a cliff failure observed in Solana Beach in California. The visualization system presented in this paper demonstrates the insights that can be gained by observing the temporal change of a failure mass using frequent site monitoring.

8157-13, Session 3

GPU implementation of orthogonal matching pursuit for compressive sensing
Y. Fang, Northwest A&F Univ. (China)

Compressive sensing (CS) is useful in image compression. Recovery algorithms play an important role in CS. Among those CS recovery algorithms, the orthogonal matching pursuit (OMP) algorithm achieves good performance at low complexity. The complexity of OMP comes mainly from matrix operations, e.g. matrix multiplication, matrix inverse, etc., which makes it very suited to parallelized implementation. This paper considers the GPU implementation of OMP algorithm for the CS application.

8157-14, Session 3

Real-time implementation of a full hyperspectral unmixing chain on graphics processing units
S. Sanchez, A. J. Plaza, Univ. de Extremadura (Spain)

Hyperspectral unmixing is a very important task for remotely sensed hyperspectral data exploitation. It amounts at estimating the abundance of pure spectral signatures (called endmembers) in each mixed pixel of the original hyperspectral image, where mixed pixels arise due to insufficient spatial resolution and other phenomena. The full spectral unmixing chain comprises three main steps: 1) dimensionality reduction, in which the original hyperspectral data is brought to an adequate subspace; 2) endmember extraction, in which endmembers are automatically identified from the image data; and 3) abundance estimation, in which the fractional coverage of each endmember is estimated for each pixel of the hyperspectral scene. The hyperspectral unmixing process can be time-consuming, particularly for high-dimensional hyperspectral images. Parallel computing architectures have offered an attractive solution for fast unmixing of hyperspectral data sets, but these systems are expensive and difficult to adapt to on-board data processing scenarios, in which low-weight and low-power integrated components are essential to reduce mission payload and obtain analysis results in (near) real-time. In this paper, we develop a real-time implementation of a full unmixing chain for hyperspectral data on graphics processing units (GPUs). These hardware accelerators can bridge the gap towards on-board processing of this kind of data. The considered chain comprises principal component analysis (PCA) for dimensionality estimation, extraction of endmembers using the N-FINDR algorithm, and unconstrained linear spectral unmixing. The proposed GPU implementation is shown to perform strictly in real-time for hyperspectral data sets collected by the NASA's Airborne Visible Infrared Imaging Spectrometer (AVIRIS).

8157-15, Session 3

GPU-accelerated CIMSS radiative transfer model
J. S. Mielikainen, Yonsei Univ. (Korea, Republic of); B. Huang, A. H. L. Huang, Univ. of Wisconsin-Madison (United States)

Radiative transfer equation (RTE) computes radiance as a nonlinear functional of surface properties and atmospheric temperature and absorbing gas profiles. Currently, operational numerical weather prediction systems are still limited by the radiative transfer model (RTM) performance. Thus, only a few hundred of channels out of 8461 channel Infrared Atmospheric Sounding Interferometer (IASI) measurements are utilized. In this paper, we develop a Graphics Processing Unit (GPU)-based high-performance RTM for the IASI launched in 2006 onboard the first European meteorological polar-orbiting satellites, METOP-A.

In recent years the programmable commodity graphics processing unit (GPU) has evolved into a highly parallel, multi-threaded, many-core processor with tremendous computational speed and very high memory bandwidth. The radiative transfer model is very suitable for the GPU implementation to take advantage of the hardware’s efficiency and parallelism where radiiances of many channels can be calculated in parallel in GPUs.

Our GPU-based IASI radiative transfer model is developed to run on a low-cost personal supercomputer with 4 NVIDIA Tesla C1060 GPUs with total 960 cores, delivering near 4 TFlops theoretical peak performance. We propose two different types of GPU RTMs. The first one, processes one profile at a time. The second proposed GPU RTM processes more than one profile at a time in order to gain a significant speedup compared to the case of processing just one profile at a time.

The IASI radiative transfer model consists of three modules. The first
module for computing the regression predictors takes less than 0.004% of CPU time, while the second module for transmission computation and the third module for radiance computation take approximately 92.5% and 7.5%, respectively. By massively parallelizing the second and third modules, we reached 364x speedup for 1 GPU on single-profile processing and 1455x speedup for all 4 GPUs. Both with respect to the original CPU-based single-threaded Fortran code. Similarly, using multi-profile processing, to compute 10 IASI radiance spectra simultaneously on a GPU, we reached 763x speedup for 1 GPU and 3024x speedup for all 4 GPUs, both with respect to the original single-threaded Fortran CPU code. The significant 3024x speedup means that the proposed GPU-based high-performance forward model is able to compute one day’s amount of 1,296,000 IASI spectra within 6 minutes.

8157-16, Session 4
An efficient feedback-channel-based distributed video coding system
X. Wu, Y. Li, J. Song, J. Lei, Xidian Univ. (China)

Distributed Video Coding (DVC) shifts the complexity from encoder to decoder. In syndrome based DVC systems, Feedback-Channel (FC) is used to determine the required bits at the decoder, which is difficult to realize in practice. If the decoding fails, the decoder sends a request to encoder for more syndrome bits. To decrease the encoder computation complexity, the side information is only constructed at the decoder so the rate estimated at the encoder is not exact. Although better rate distortion performance could be achieved by FC rate control, the time delay of the DVC is increased. In this paper, we use an efficient correlation model to detect the correlation between source frame and simply constructed side information at the encoder. The encoder determines the initial rate for the decoder to decrease the request times for decoder efficiently. At the decoder, side information refinement algorithm is adopted to increase system efficiency while decrease the final rate. The previous decoded information is used to improve the side information quality which effects the LDPC decoding efficiency significantly. Compared with other methods, better RD performance is achieved by our proposed algorithm compared with other encoder rate control algorithms and the time delay is decreased compared with traditional FC based algorithms.

8157-17, Session 4
FAPEC in an FPGA: a simple low-power solution for data compression in space
A. G. Villafranca, Institut Cartogràfic de Catalunya (Spain) and Institut d’Estudis Espacials de Catalunya (Spain); S. B. Mignot, Observatoire de Paris à Meudon (France); J. Portell de Mora, Univ. de Barcelona (Spain) and Institut d’Estudis Espacials de Catalunya (Spain); E. García-Berro, Univ. Politècnica de Catalunya (Spain)

Future space missions are based on a new generation of instruments. These missions find a serious constraint in the telemetry system, which cannot download the large volumes of data generated to the ground. Hence, data compression algorithms are often mandatory in space, despite the modest processing power usually available on-board. We present here a compact solution implemented in hardware for such missions. FAPEC is a lossless compressor which typically outperforms the CCSDS 121.0 recommendation on realistic data sets. With efficiencies higher than 90% of the Shannon limit in most cases - even in presence of noise or outliers - FAPEC has been successfully validated in software as a robust low-complexity alternative to the recommendation. This work describes the FAPEC implementation on an FPGA, targeting the space-qualified Actel RTAX family. We have proved that FAPEC is hardware-friendly and that it does not require external memory. We have assessed the correct operation of the prototype for an initial throughput of 32 Mbits/s with very low power consumption (<50 mW). Finally, we discuss further potential applications of FAPEC, and we set the basis for the improvements that will boost FAPEC performance beyond the 100 Mbit/s barrier.

8157-18, Session 4
Lossless compression of 3D Aurora images using adaptive-context-based prediction model in China’s Arctic Yellow River Station
J. Wu, T. Teng, Xidian Univ. (China)

It is well-known that a proper prediction model and method can obviously improve the performance of prediction. But, the state-of-art compression algorithms cannot effectively capture the characteristics of 3-D aurora images and can not achieve optimal compression performance. This paper proposes a lossless compression algorithm using adaptive-context-based prediction model. Prediction models used in traditional algorithms are either too small or not accuracy enough to capture the variances of aurora edges. So, we adopt a larger context prediction model according to the correlation characteristics of aurora images. Unlike conventional prediction algorithms which always use intra-prediction or inter-prediction, we choose intra-prediction or inter-prediction adaptively by testing the correlation strength among pixels in the prediction model. For intra-prediction, we adopt the prediction method used in JPEG-LS. In order to reduce the complexity and achieve high accuracy, we proposed a new algorithm for inter-prediction. Through bubble sort, we can get the eight pixels which have stronger correlations with current pixel instead of using all the pixels in the prediction model to predict current pixel. However, it does not always hold true that the eight chosen pixels all have higher inter-frame correlations. So we use a criterion to further select the pixels which are used as the final pixels for prediction. Experimental results show that the proposed adaptive-context-based prediction model can significantly reduces the complexity and guarantees the accuracy. The prediction algorithm with proposed adaptive-context-based prediction model performs better than wavelet-based lossless algorithms such as 3D-SPECK and JPEG-2000, and still outperforms JPEG-LS with a slight degradation in coding time.

8157-19, Session 4
Three-dimensional error correcting with matched interleaving for holographic data storage
H. Gu, L. Cao, Q. He, G. Jin, Tsinghua Univ. (China)

This paper presents a three-dimensional error correcting with matched interleaving (3DEC-MI) scheme for holographic data storage (HDS). For applying to various error patterns, including random errors, burst errors, and inhomogeneously distributed errors, in the HDS channel, the 3DEC-MI scheme combines the advantages of the three-dimensional error correcting scheme and the matched interleaving scheme, makes full use of the priori knowledge of the error patterns in the HDS channel, distributes errors more uniformly, and decodes data iteratively in three dimensions. It is able to eliminate the influences of non-uniform distribution of errors within a page and across pages, overcome the effects of burst errors, and correct random errors. Simulation results show that the bit-error rate (BER) of the HDS channel can be effectively reduced after correcting with the proposed scheme, the performance of which is validated in a terabyte optical disc HDS system.

8157-20, Session 4
Development of GPU-based CCSDS Rice coding
X. Wu, Y. Li, Xidian Univ. (China); B. Huang, Univ. of Wisconsin-Madison (United States)
The Rice coding is the Consultative Committee for Space Data Systems (CCSDS) recommendation for lossless data compression on several different types of data. The CCSDS Rice coding is an adaptive entropy coder with a preprocessor, applied to each block of J samples. The default preprocessor uses a unit-delay predictor with positive mapping. The adaptive entropy coder concurrently applies a set of variable-length codes to a block of J consecutive preprocessed samples. The code option that yields the shortest codeword sequence for the current block of samples is selected for transmission. A unique identifier bit sequence is attached to the code block to indicate to the decoder which decoding option to use. The CCSDS Rice decoding is suitable for parallel implementation where all codeword blocks can be decoded independently and simultaneously. In order to perform high-performance Rice decoding on satellite images compressed by the CCSDS Rice coding, we propose to accelerate the Rice decoding on the Graphics Processing Units (GPUs) using Compute Unified Device Architecture (CUDA). The GPU-based Rice decoder will process many codeword blocks in a massively parallel fashion by different GPU multiprocessors. It is expected to achieve a remarkable speedup over its single-threaded CPU counterpart.

8157-21, Session 5
Unsupervised clustering and spectral unmixing for feature extraction prior to supervised classification of hyperspectral images
I. Dopido, A. Villa, A. J. Plaza, Univ. de Extremadura (Spain)
Classification and spectral unmixing are two very important tasks for hyperspectral data exploitation. Although many studies exist in both areas, the combined use of both approaches has not been widely explored in the literature. Since hyperspectral images are generally dominated by mixed pixels, spectral unmixing can particularly provide a useful source of information for classification purposes. In previous work, we have demonstrated that spectral unmixing can be used as an effective approach for feature extraction prior to supervised classification of hyperspectral data using support vector machines (SVMs). Unmixing-based features do not dramatically improve classification accuracies with regards to features provided by classic techniques such as the minimum noise fraction (MNF), but they can provide a better characterization of small classes. Also, these features are potentially easier to interpret due to their physical meaning (in spectral unmixing, the features represent the abundances of real materials present in the scene). In this paper, we develop a new strategy for feature extraction prior to supervised classification of hyperspectral images. The proposed method first performs unsupervised multidimensional clustering on the original hyperspectral image. The cluster centres are then used as representative spectral signatures for a subsequent unmixing process, and the resulting features are used as inputs to a standard (supervised) classification process. The proposed strategy is compared to other classic and unmixing feature extraction methods presented in the literature. Our experiments, conducted with several reference hyperspectral images widely used for classification purposes, reveal the effectiveness of the proposed approach.

8157-22, Session 5
Low-complexity pixel-based halftone detection
J. Ok, Yonsei Univ. (Korea, Republic of); S. W. Han, Samsung Electronics Co., Ltd. (Korea, Republic of); J. Mieliikainen, C. Lee, Yonsei Univ. (Korea, Republic of)
With the advances of the internet and multimedia technologies, the digital document market grows steadily. Since most digital documents use halftone technologies, quality degradation occurs when one tries to scan and reprint such halftone images. Typically, halftone areas occupy a portion of documents. For improved picture quality, low pass filtering is applied to the halftone areas before reprinting the scanned images. Therefore, it is necessary to extract halftone areas to produce high quality printing.

In this paper, we propose a low complexity pixel-based halftone detection algorithm. For each pixel, we consider a surrounding sub-block. If the sub-block contains any flat back ground, text, thin line, continuous and non-homogeneous regions, the pixel is classified as a non-halftone pixel. To reduce the complexity, we first detect flat background. Then, text and thin lines are detected. Finally, continuous and non-homogeneous regions are located. After excluding non-halftone pixels, the remaining pixels are considered as halftone pixels. Classifying a document as halftone printing or Silver-halide photo is performed by calculating the halftone pixel ratio. The proposed algorithm is memory-efficient and requires low computation cost. The proposed algorithm can easily implemented using GPU.

8157-23, Session 5
2D orthogonal matching pursuit
Y. Fang, Northwest A&F Univ. (China); B. Huang, Univ. of Wisconsin-Madison (United States)
The problem of 2D sparse signal recovery plays an important role in practice, e.g. compressive imaging, image/video compression, etc. To exploit the correlation of 2D signals along two directions, 2D separable measuring (along row and column directions) has been proposed, which can convert the problem of 2D sparse signal recovery into a standard 1D sparse signal recovery problem with the complexity of $O(m^2 \times n^2)$. Different from 1D sparse signal recovery, we have developed the 2D orthogonal matching pursuit (2D-OMP) algorithm for separable measurements of 2D sparse signals, which reduces the complexity from $O(m^2 \times n^2)$ to $O(m \times n^2)$. The 2D-OMP is a natural extension of the 1D-OMP. In the 2D-OMP, the dictionary contains $(n \times n)$ atoms and each atom is an $(m \times m)$ matrix. The decoder projects the $(m \times m)$ sample matrix onto the atoms and records the most significant atom. Then the decoder updates the weights of all the already selected atoms by least squares. Such procedure iterates until the Frobenius norm of the residual matrix is less than the given threshold.

8157-24, Session 5
GPU acceleration of the solution to a polarized atmospheric radiative transfer model with multiple scattering
C. Song, Y. Li, Xidian Univ. (China); B. Huang, Univ. of Wisconsin-Madison (United States)
The plane-parallel polarized radiative transfer model developed in a seminal paper by Evans and Stephens (1991) has been widely used for passive atmospheric remote sensing of the planets in the solar system. The model considers both solar and thermal energy sources and computes the monochromatic polarized radiance emerging from a vertically inhomogeneous atmosphere with multiple scattering and randomly-oriented particles of arbitrary shapes. The diffuse radiance field is expressed as a four-vector of Stokes parameters. The solution method converts the single-scattering information into a form suitable for applying the doubling and adding method to compute the optical properties of the whole atmosphere from the local properties of each infinitesimal layer. The computation for a more accurate solution could be time-consuming in many applications involving Rayleigh or Mie atmospheres in sunlight or microwave transfer through a precipitating atmosphere. In recent years the Nvidia GPUs provide affordable supercomputing power with Compute Unified Device Architecture (CUDA) as the GPU programming tool. In this paper we take advantage of GPU massively parallel capabilities to speed up the computation of the solution to the polarized radiative transfer problem.
Early detection of RFI in SMOS radiometric measurements

É. Anterrieu, Observatoire Midi-Pyrénées (France) and Univ. de Toulouse (France)

The SMOS mission is a European Space Agency project devoted to the global monitoring of surface Soil Moisture and Ocean Salinity from spaceborne radiometric observations. The single payload of the mission is MIRAS, the very first Microwave Imaging Radiometer using Aperture Synthesis ever launched into space. Cross-correlating the signals collected by each pair of antennas provides samples of the so-called visibility function of the brightness temperature distribution of the scene under observation. Although MIRAS is operating in the protected L-band, the contamination of such interferometric measurements by man-made sources of radio-frequency interferences (RFI) operating very close to this band has been evidenced during the commissioning phase. Owing to the software and hardware architectures of MIRAS, the standard approaches found in the literature for detecting RFI in such signals do not solve the problem for SMOS because the sampling rate of the signals downloaded to the ground segment is too low for this purpose. A specific method should be implemented for the SMOS mission by taking into account the specificities of MIRAS with regards to the sensitivity to RFI. Contamination by RFI is an important issue for the success of the mission since it propagates from measurements to reconstructed brightness temperature maps and then to higher level products. RFI should be detected as soon as possible in the processing pipeline, namely at the L1a level of the measurements provided by MIRAS. A detection and quantification approach tailored to these measurements is presented and illustrated with data acquired during the commissioning phase.

Scanning pattern simulation for the meteorological payload of polar communication and weather satellites

R. Ksantini, S. Qian, Canadian Space Agency (Canada)

The Canadian Space Agency is developing a polar communication and weather (PCW) mission to provide high quality radiometric data, high spatial resolution temporal image calibration, and comprehensive ongoing ground validation of generated data and products. To improve the meteorological images (geometrically, spatially, and radiometrically) and to overcome the challenges of the meteorological payload with scan mirrors and multiple Focal Plane Arrays in a Molinya orbit imposed on the images, we carried out study to simulate and analyze the scan mirror geometry and error sources to better model the scan mirror and errors for providing guide to the system design, to overcome the problems of multiple freedom rotations and distortions of the imaging mechanism. In fact, a scanning device will not always generate a perfect orthogonal and regular grid pattern. This is because of the effects of the view zenith angle and the Earth curvature. The grid pattern is originally represented by a Field of Regard (FOR) which is sampled into identical and rectangular Fields of View (FOVs). We transform these FOVs using mirror scanner and combined rotation transformations, with least distortions and FOV slanting comparatively to the initial FOR. Then, a semi-analytical error function of the mirror rotation angles is developed to model the parametric and non-parametric errors of the meteorological images. This error function will allow better simulation and analysis of the meteorological payload scanning pattern and then improvement of the meteorological image. Experimental results of the scanning pattern analysis and simulation are provided with interpretations and conclusions.

Hyperspectral image spatial resolution improvement using wavelet-based Bayesian framework

Y. Zhang, M. He, Northwestern Polytechnical Univ. (China)

Hyperspectral (HS) images employ hundreds of contiguous spectral bands to capture and process spectral information over a range of wavelengths, compared to the tens of discrete spectral bands used in multispectral (MS) images. This increase in spectral accuracy is delivering more information, allowing a whole range of new and more precise applications. However, usually a trade-off exists in remote sensors, between spatial and spectral resolutions due to physical limitations, data-transfer requirements and some other practical reasons. Therefore, in most cases, high spatial and spectral resolutions are not available in a single image. Normally, the spatial resolution of HS images is still lower than that of MS images. In many applications, there is need for high accuracy both spectrally and spatially, which inspires the research on spatial resolution enhancement of HS images. In this work, a spatial resolution improvement approach for HS image is proposed, which is developed on a Bayesian estimation framework. The technique works in the wavelet domain, assuming a joint statistical model for the observed image and a blurring and additive noise imaging model for the HS image. To keep the calculation feasible, an appropriate and applicable estimation strategy is also proposed. In the simulated experiment, the technique is validated and also compared to the state-of-the-art techniques. The experimental results illustrate that the newly proposed approach is capable of effectively improving spatial resolution of HS image and robust to noise in the observed image.
from hyperspectral images, particularly due to the presence of mixed pixels which generally prevents the localization of pure spectral signatures in transition areas between different land-cover classes. A possible strategy to address this problem is to guide the endmember extraction process to spatially homogeneous areas. For this purpose, several preprocessing methods (intended to be applied prior to the endmember extraction stage) have been developed in the literature. However, most of these methods only include spatial information during the preprocessing and disregard spectral information until the subsequent endmember extraction stage. In this paper, we develop a new joint spatial and spectral preprocessing method which can be combined with any endmember extraction algorithm from hyperspectral images. The proposed method is intended to retain spectrally pure pixels which belong to spatially homogeneous areas. Our assumption is that spectrally pure signatures are more likely to be found in spatially homogeneous areas rather than in transition areas between different land-cover classes, which are expected to be dominated by mixed pixels. Our experimental results, conducted with a variety of hyperspectral images, reveal the robustness of the proposed method when compared to other similar preprocessing strategies.

8157-30, Session 7
Classified coset coding-based lossless compression of hyperspectral images
J. Song, Y. Li, H. Liu, X. Wu, K. Wang, Xidian Univ. (China)

Due to the restrained resources on board, compression methods with low complexity are desirable for hyperspectral images. Distributed source coding (DSC) based on Slepian-Wolf theorem is applied to hyperspectral image compression owing to its low complexity and high performance. E.Magli et al. proposed a scalar coset based distributed compression method (s-DSC). In their proposed scheme, each block is compressed by just retaining least significant bits (LSB) that can be viewed as index of coset, while discarding the most significant bits (MSB). Then, the decoder recovers the MSBs with the help of predicted value by choosing the MSBs that minimize the distance between the reconstructed value and predicted one. However, there still exists much redundancy since the bitrate of the whole block is determined by its maximum prediction error. In fact, much fewer LSBs are enough to recover the most pixels in the block. In order to further reduce the bitrate, a classified coset coding based lossless compression method is proposed in this paper. Since the current band has similar spectral correlation with the previous band and the number of LSB to be transmitted is determined by the spectral correlation, the current block is classified using the corresponding prediction errors in the previous band to make the pixels with similar inter-band correlation cluster together. Then each class of pixels is coset coded respectively according to its own maximum prediction error. The experimental results show that the classification could reduce the bitrate efficiently. Compared to s-DSC method without classification, the lossless compression bitrate of the proposed method is reduced by about 0.4bpp.

8157-31, Session 7
On-board compression of hyperspectral satellite data using band reordering
J. GAUCEL, Thales Alenia Space (France); C. THIEBART, R. CAMARERO, Ctr. National d’Études Spatiales (France)

Hyperspectral remote sensing has been widely utilized notably in high-resolution climate observation, environment monitoring, resource mapping. However, it brings undesirable difficulties for transmission and storage due to the huge amount of the data. The compression of the cube has been demonstrated to be an efficient strategy to solve these problems. Moreover, the data features have strong similarity in disjoint spectral regions due to the same type of absorbing gases. That is why a pre-processing scheme based on a similarity measurement and a re-ordering strategy permits to enhance the compression ratio.

In this work, we first propose a review of similarity measurements and re-ordering strategies, and we give the field of application of each of them. In particular, we propose a pre-selection of these measurements and re-ordering strategies with the expected performance, the complexity and the robustness to an on-board implementation. In a second part, we give the performance gap between a high performance / complex approach and a spatializing approach for two compression schemes: a 3D transform (SPHIT3D) and a 3D predictive algorithm. Finally, we present the capability to implement the re-ordering in a semi-optimal, semi-fixed or fixed manner, and thereby characterize the performances in a space borne system.

8157-32, Session 7
Accelerating arithmetic encoder on GPUs
Y. Fang, Northwest A&F Univ. (China)

Arithmetic Coding (AC) is widely used in lossless data compression. However, compared to Huffman coding, its computational complexity is much more high due to multiplication and branching operations. Though any non-binary AC can be converted into binary AC of multiple bit-planes, binarization usually causes performance degradation. This paper researches the implementation of AC encoder on GPUs. The main idea is to use block AC. Each thread processes one block, so that data blocks can be encoded in parallel.

8157-33, Session 7
A novel video delivery algorithm based on 802.11e EDCA mechanism
J. Du, S. Xiao, Xidian Univ. (China)

Currently, there are still many challenges for video delivery over WLAN due to the contention of channel among four access categories (ACs) in EDCA and requirement of quality of service (QoS) for video packet delivery. In this paper, we propose a Cyclic Enqueueing Algorithm (CEA) which schedules video packets cyclically into all four AC queues based on the queue analysis of average service rate (ASR) and average arrival rate (AAR). Since each AC queue is able to transmit packets without queue delay if AAR is less than ASR, the proposed algorithm makes full use of the available capacity of each AC queue, which could obtain better delivery performance than the default configure in EDCA. The main contributions of our work can be summarized as follows.

i. By enqueuing video packets cyclically into all four AC queues rather than only the queue of AC_VI, the proposed CEA method can balance the load of different AC queues and reduce the queue delay of video packets so as to obtain better video delivery quality.

ii. By using a simplified calculation of error propagation estimation within a GOP, we introduce a video packet ordering algorithm which helps obtain quality gains in the case of traffic congestion.

To verify the efficiency of the proposed algorithm, the video packets are generated from the JM reference software and the EDCA wireless network simulations are performed on NS-3 platform. Several similar algorithms are compared. The results show that the proposed algorithm offers better performance than existing methods in preserving video quality in the case of heavy load of video packets over 802.11e wireless networks.

8157-34, Session 7
Real-time lossless compression for HDTV video using GPGPU
G. Seo, J. Mielikainen, C. Lee, Yonsei Univ. (Korea, Republic of)

HD video services have been widely available in recent years. To transmit
or store these HD video programs, compression is required. For example, HD video signals require about 1 Gbps and UHD (Ultra High Definition) video signals require about 4 Gbps (4k) or 15 Gbps (8k). Various lossy compression schemes have been developed, which include H.264/AVC and HEVC (high efficiency video coding). On the other hand, there are some applications which require lossless compression. For example, lossless or near lossless compression is required in studio programs. Also, video quality assessment and coding areas need efficient lossless video compression algorithm. Most conventional lossless coding methods have high complexity and require long processing time for encoding and decoding.

GPGPU (General purpose graphics processing unit) is widely used to assist CPU (Central processing unit) in computing massive data sets. Modern GPUs have programmable processors with a large amount of memory cells and processing cores.

In this paper, a parallel lossless compression algorithm with low complexity is proposed. The algorithm can encode and decode HD video sequences in real-time. The proposed algorithm compresses HD video sequences in half. Furthermore, the encoding and decoding time can be significantly reduced using GPU. The average encoding time per frame is about 17ms and decoding time is about 11ms. The algorithm can be implemented in real time for HD video sequences.

8157-35, Session 7

**GPU-accelerated IDWT with SPIHT and Reed-Solomon decoding for satellite images**

C. Song, Y. Li, Xidian Univ. (China); B. Huang, Univ. of Wisconsin-Madison (United States)

The discrete wavelet transform (DWT)-based Set Partitioning in Hierarchical Trees (SPIHT) algorithm is widely used in many image compression systems. In order to perform real-time Reed-Solomon channel decoding and SPIHT+DWT source decoding on a massive bit stream of compressed images continuously down-linked from the satellite, we propose a novel graphic processing unit (GPU)-accelerated decoding system. In this system the GPU is used to compute the time-consuming inverse DWT, while multiple CPU threads are run in parallel for the remaining part of the system. Both CPU and GPU parts were carefully designed to have approximately the same processing speed to obtain the maximum throughput via a novel pipeline structure for processing continuous satellite images. Through the pipelined CPU and GPU heterogeneous computing, the entire decoding system approaches a speedup of 84x as compared to its single-threaded CPU counterpart.
Conference 8158: Imaging Spectrometry XVI
Monday-Tuesday 22-23 August 2011  Part of Proceedings of SPIE Vol. 8158 Imaging Spectrometry XVI

8158-01, Session 1
Large format imaging spectrometers for future hyperspectral Landsat mission
J. F. Silny, Raytheon Space & Airborne Systems (United States); T. G. Chrien, The Aerospace Corp. (United States)

This paper describes a design concept for a Landsat-class imaging spectrometer. The challenge is to match the Landsat data parameters, including a 185 km swath and a 30 meter ground sample distance (GSD) from a 705 km sun-synchronous orbit with a sensor that has contiguous spectral coverage of the solar reflected spectrum (400 to 2500 nm). The result is a remote sensing satellite that provides global access imaging spectrometer data at moderate spatial resolution. Key design trades exist for the spectrometer, focal plane array, dispersive element, and calibrator. Recent developments in wide field-of-view imaging spectrometers at Raytheon are presented in support of a monolithic spectrometer approach. Features of the design include (1) high signal-to-noise ratio, (2) well-corrected spectral fidelity across a 6,000 pixel pushbroom field-of-view, (3) straightforward calibration of the data to units of absolute spectral radiance, and (4) real-time simulation of Thematic Mapper bands, vegetation indices, and water vapor maps for direct continuous downlink.

8158-02, Session 1
Optically fast, wide field-of-view five-mirror anastigmat imager for remote sensing applications
J. F. Silny, E. D. Kim, L. G. Cook, E. M. Moskun, R. L. Patterson, Raytheon Space & Airborne Systems (United States)

Recent trends in focal plane array (FPA) technology have led naturally to the development of very large format remote sensors that require optically fast, wide field of view imaging optics. Systems that cover broad spectral ranges, such as multispectral imagers (MSI) and hyperspectral imagers (HSI), require reflective optics to provide aberration and distortion control without the complication of wavelength dependent errors induced by refractive elements. These large format systems require even wider fields of view than offered by the conventional three-mirror anastigmat (TMA) and four-mirror anastigmat (4MA) designs. Recently, Raytheon has demonstrated in hardware the first-ever aligned and tested five-mirror anastigmat (5MA) imager. The 5MA was designed with an F/3.0 optical speed and a 36 degree cross-scan FOV for use with a pushbroom imaging spectrometer. The 5MA imager has useful features such as: (1) a real entrance pupil to support full-aperture calibration or a small scan mirror, (2) an intermediate image for stray light control, and (3) a real exit pupil for optimal cold-shielding in infrared applications. A computer-aided alignment method was used to align the 5MA imager with a final target of balanced wavefront error (WFE) across the full 36 deg FOV. This paper discusses the design and development of the first-ever 5MA imager and some potential space and airborne remote sensing applications.

8158-03, Session 1
Hyperspectral microscopic imaging by multiplex coherent anti-Stokes Raman scattering (CARS)
A. T. Khmaladze, J. Jasensky, C. Zhang, X. Han, Z. Chen, Univ. of Michigan (United States)

Coherent anti-Stokes Raman Scattering (CARS) microscopy is a powerful technique to image the chemical composition of complex samples in biophysics, biology and material science. CARS is a four-wave mixing process. The application of a narrow pump and spectrally wide Stokes pulses excites multiple Raman transitions, which are probed by a probe pulse, generating a coherent directional CARS signal with several orders of magnitude higher intensity relative to spontaneous Raman scattering. Recent advances in the development of ultrafast lasers, as well as Photonic Crystal Fibers (PCF) enable multiplex CARS. In this study, we used two scanning imaging methods. In one, the detection is performed by a photo-multiplier tube (PMT) attached to the spectrometer. The acquisition of series of images, while tuning the wavelengths allows for subsequent reconstruction of spectra at each image point. The second method executes a simultaneous detection of multiple wavelengths by a cooled CCD camera. Coupled with point-by-point scanning, it allows for a hyperspectral microscopic imaging. In particular, since the intensity of CARS signal is proportional to the product of intensities of pump, probe and stokes scanning beams, the intensity of out of focus CARS signal drops rapidly. Thus, it is possible to use a laser scanning microscope without a confocal pinhole. In the focal plane, CARS signal is only generated where both pump/probe and stokes beams are overlapped. Therefore, if the beams are slightly spatially shifted against one another, the spatial resolution of the CARS signal is better than the resolution achievable by a single scanning beam.

8158-04, Session 1
Novel dispersing element for a computed tomographic imaging spectrometer
C. J. Vandervlugt, M. W. Kudenov, E. L. Dereniak, College of Optical Sciences, The Univ. of Arizona (United States); G. Cord, Missile Defense Agency (United States)

A Computed Tomographic Imaging Spectrometer (CTIS) is an imaging spectrometer which can acquire a hyper-spectral data set in a single snapshot (one focal plane array integration time) with no moving parts. A specially designed dispersing element which separates light from the object cube into a grid of prismatic diffraction orders is the key element in the instrument. The capabilities of the CTIS instrument can be improved by employing a more optimized grating design. In this paper, we discuss the design of a new CTIS disperser incorporating a novel radial design pattern. Initial test results with the CTIS instrument are also presented.

8158-05, Session 1
A self-reliant RSI payload development in Taiwan
S. Weng, Y. Lian, National Space Organization (Taiwan)

Instead of outsourcing the whole FORMOSAT-2 satellite to a foreign prime contractor, the National Space Organization in Taiwan is stepping ahead to take the full responsibility of consolidating self-reliant space technology capabilities. A newly initiated program FORMOSAT-5 satellite, not only to build a heritage design of a spacecraft bus but also, self-reliantly, to leap a big step toward Remote Sensing Instrument payload development, is sailing on its voyage. Among the payload development effort, an integrated circuit of the kind Complementary Metal Oxide Semiconductor instead of Charge-coupled Device is chosen as the imaging sensor playing the lead role for the instrument. A Time Delay Integration scheme is applied to ideally achieve high Signal to Noise Ratio. With the advanced CMOS Image Sensor, FORMOSAT-5 is anticipated potentially to be one of the first spacecraft flying in the space. And how a supporting structure, the so-called Iso-static Mount, bearing the optical has to be implemented cautiously to eliminate the microscopic displacements ought not to be overwhelmed by its seemingly simple appearance. A simulated ISM modal analysis had been conducted and the method of bonding between the mirror and ISM had also been tested on an experimental model. Despite the foresee technical concerns, management issues over scheduling and documentation are constantly
emerging owing to the payload development underwent is collaborated by several domestic industries and research centers. Regardless of challenges we may confront with, a carefully planned strategy emphasizing on the product realization processes is discussed.

8158-06, Session 2

**Hyperspectral target detection and discrimination using the ACE algorithm**

M. L. Pieper, D. Manolakis, R. Lockwood, MIT Lincoln Lab. (United States); T. Cooley, P. S. Armstrong, J. Jacobson, Air Force Research Lab. (United States)

One of the fundamental challenges for a hyperspectral imaging system is the detection and discrimination of subpixel objects in background clutter. The background surrounding the object, which acts as interference, provides the major obstacle to successful detection and discrimination. In many applications we look for a single signature and discrimination among different signatures is not required. However, there are important applications where we are interested for multiple signatures. In these cases, the use of spectral discrimination algorithms is both necessary and valuable. In this paper, we develop an approach to spectral discrimination based on the adaptive cosine estimation (ACE) algorithm. The basic idea is to jointly exploit the detection statistics from the various signatures and set a common threshold that ensures larger separation between signatures of interest and background. The operation of the proposed detection-discrimination approach is illustrated using real hyperspectral imaging data.

8158-08, Session 2

**Effective use of sample spectral statistics to design hyperspectral imaging algorithms via unsupervised training samples**

R. M. Patterson, D. Paylor, K. Liu, E. Wong, C. Chang, Univ. of Maryland, Baltimore County (United States)

Sample spectral correlation statistics (SSCS) have been used to characterize spectral targets of interest in hyperspectral data exploitation. A key issue is to how to effectively use SSCS to design and develop many hyperspectral imaging algorithms. This paper develops an approach which produces an appropriate set of training samples to generate SSCS that can be used to design various algorithms. In order for the proposed approach to work effectively two main issues need to be addressed. One is the number of training samples required to generate the other is to design an unsupervised algorithm for finding a set of desirable training samples. Regarding the first issue a recently developed concept, virtual dimensionality (VD), OSP-based method, maximum orthogonal complement algorithm (MOCA) can be used for this purpose. As for the second issue several candidate unsupervised algorithms such as automatic target generation process (ATGP), unsupervised least squares-based algorithms can be considered. One immediate benefit from our proposed approach is to reduce computational complexity, specifically for many kernel-based algorithms such as kernel-based RX detector, kernel-based constrained minimum energy (CEM) which requires entire image pixels to produce SSCS.

8158-09, Session 2

**Quantifying the co-registration of bands in spectral imaging**

T. Skauli, Norwegian Defence Research Establishment (Norway); A. Fridman, Norsk Elektro Optikk AS (Norway)

In multi- and hyperspectral imaging, it is well recognized that the spatial co-registration of different spectral bands is an important performance characteristic. It has been pointed out that both the position and shape of the point spread function must be matched between spectral bands to produce a good spectral fidelity. A hyperspectral camera with imperfect co-registration may produce spectra with severe artifacts when imaging an inhomogeneous scene. Thus the co-registration is a crucial performance parameter for a hyperspectral imager, and is often specified as “percent of a pixel”. It appears, however, that there is no universally accepted definition of this measure of co-registration. This paper discusses a specific definition of a co-registration metric based on the integrated difference between normalized point spread functions. This metric accounts for differences in both position and shape of the point spread function. The metric can be reasonably interpreted as “percent of a pixel” in a well defined sense, and it produces reasonable results in several limiting cases. The metric is illustrated by simulated and experimental data.

8158-22, Session 3

**Production of imagery-derived maps to aid the Japanese earthquake/tsunami relief effort**

D. Messinger, D. M. McKeown, N. G. Raqueno, S. A. Cavillia, C. R. DeAngelis, S. Maitra, W. Sun, Rochester Institute of Technology (United States)

On March 11, 2011, the magnitude 9 Tohoku earthquake and resulting tsunami struck off the coast of Japan. An estimated over 400,000 persons were displaced from their homes and the damage to the coastline and nearby urban areas was extensive. Additionally, the combined effects of the earthquake and tsunami caused damage to the Fukushima Dai’ichi Nuclear Power Station. As part of the International Charter “Space and Major Disasters”, the US Geological Survey coordinated a volunteer effort to aid in the response to the disaster. The goal of the project was to produce maps derived from civilian (NASA Landsat and ASTER) and commercially available (DigitalGlobe and GeoEye), high resolution satellite imagery to be delivered to the Japanese authorities. The MIT Lincoln Lab. (United States) was part of the international response to the disaster. The purpose of this presentation will describe the timeline of the response, the challenges faced in this effort, the workflow developed, and the products that were distributed. Lessons learned from the response will also be described to aid the remote sensing community in preparing for responses to future natural disasters.

8158-10, Session 4

**A hyperspectral imager for high radiometric accuracy Earth climate studies**

J. Espejo, G. A. Kopp, P. Smith, G. A. Drake, K. F. Heuerman, A. Lieber, B. Vermeer, Univ. of Colorado at Boulder (United States)

We demonstrate a visible and near-infrared prototype pushbroom hyperspectral imager for Earth climate studies that is capable of using direct solar viewing for on-orbit cross calibration and degradation tracking. Direct calibration to solar spectral irradiances allow the Earth-viewing instrument to achieve required climate-driven absolute radiometric accuracies of 0.2% (1σ).

A solar calibration requires viewing scenes having radiances 10^5 higher than typical Earth scenes. To facilitate this calibration, the instrument features an attenuation system that uses an optimized combination of different precision aperture sizes, neutral density filters, and variable integration timing for Earth and solar viewing. The optical system consists of a three-mirror anastigmat telescope and an Offner spectrometer. The as-built system has a 12.4” cross track field of view with 2.5” arcminute spatial resolution and covers a 350-1050 nm spectral range with 10 nm resolution. A polarization compensated configuration using the Offner in an out of plane alignment is demonstrated as a viable approach to minimizing polarization sensitivity.

The mechanical design takes advantage of relaxed tolerances in the
optical design by using rigid, non-adjustable diamond-turned tabs for optical mount locating surfaces. We show that this approach achieves the required optical performance. A prototype spacecraft unit is also demonstrated to prove the applicability of these solar cross calibration methods to on-orbit environments. This unit is evaluated for optical performance prior to and after GEVS shake, thermal vacuum, and lifecycle tests.

8158-11, Session 4
A climatology of mid-tropospheric carbon dioxide from the Atmospheric Infrared Sounder
T. S. Pagano, M. T. Chahine, E. T. Olsen, Jet Propulsion Lab. (United States)

The Atmospheric Infrared Sounder (AIRS) is a hyperspectral infrared instrument on the EOS Aqua Spacecraft, launched on May 4, 2002. AIRS has 2378 infrared channels ranging from 3.7 µm to 15.4 µm and a 13.5 km footprint at nadir. The AIRS is a “facility” instrument developed by NASA as an experimental demonstration of advanced technology for remote sensing and the benefits of high resolution infrared spectra to science investigations. AIRS, in conjunction with the Advanced Microwave Sounding Unit (AMSU), produces temperature profiles with 1K/km accuracy on a global scale, as well as water vapor profiles and trace gas amounts for CO₂, CO, SO₂, O₃ and CH₄. AIRS data are used for weather forecasting, climate process studies and validating climate models.

With over eight years of data now available, we have developed a climatology of AIRS Mid-Tropospheric Carbon Dioxide. The climatology is a fit to the observations and shows the regular seasonal structure of the horizontal distribution of CO₂ in the mid-troposphere. The climatology also allows one to study anomalies on the distribution and relate these to known global circulation patterns including El Nino Southern Oscillation (ENSO), and the Madden Julian Oscillation (MJO). The climatology is also useful for regional modeling of CO₂ fluxes by providing a nominal background field. Studies have demonstrated assimilation of AIRS mid-tropospheric observations improve prediction of near surface concentrations. Early results from the AIRS stratospheric and lower-tropospheric retrievals is discussed.

8158-13, Session 4
Early algorithm development efforts for the National Ecological Observatory Network Airborne Observation Platform imaging spectrometer and waveform lidar instruments

The National Ecological Observatory Network (NEON) will be the first observatory network of its kind designed to detect and enable forecasting of ecological change at continental scales over multiple decades. NEON will collect data at sites distributed at 20 ecoclimatic domains across the United States on the impacts of climate change, land use change, and invasive species on natural resources and biodiversity. The Airborne Observation Platform (AOP) is an aircraft platform carrying remote sensing instrumentation designed to achieve sub-meter to meter scale ground resolution, bridging the scales from organisms and individual stands to satellite-based remote sensing. AOP instrumentation consists of a VIS/SWIR imaging spectrometer, a scanning small-footprint waveform LIDAR, and a high resolution airborne digital camera. AOP data will provide quantitative information on land use change and changes in ecological structure and chemistry including the presence and effects of invasive species. A Pathfinder Flight Campaign was conducted over a two week period during late August to early September 2010 in order to collect representative AOP data over one NEON domain site. NASA JPL flew the AVIRIS imaging spectrometer and NCALM flew an Optech Gemini waveform LIDAR over the University of Florida Ordway-Swisher Biological Station and Donaldson tree plantation near Gainesville Florida. The Pathfinder data are discussed in detail along with how the data are being used for early algorithm and product development prototyping activities. The data collected during the campaign and prototype products are openly available to scientists to become more familiar with representative NEON AOP data.

8158-14, Session 4
Overview of the Cooperative Atmospheric Measurement Program (CAMP)
P. E. Lewis, National Geospatial-Intelligence Agency (United States)

No abstract available

8158-15, Session 5
Enhanced DIRSIG scene simulation by incorporating process models
J. Sun, D. Messinger, M. G. Gartley, Rochester Institute of Technology (United States)

The Digital Imaging and Remote Sensing Image Generation (DIRSIG) tool is a first principles-based synthetic image generation model, developed at the Rochester Institute of Technology. By calculating the sensor reaching radiance between the bandpass 0.2 to 20µm, it produces multi/hyper-spectral images. By integrating independent first principles based sub-models, DIRSIG generates a representation of what a sensor would see with high radiometric fidelity. Currently, DIRSIG only models spatial-spectral synthetic images. In order to detect temporal changes in a process within the scene, a ‘process model’, which links the observable signatures of interest temporally, should be developed and incorporated into DIRSIG. This ‘process model’ could be external time-dependent sub-models or pre-defined by the users to predict the specific state of the objects in the scene at a specific time. In this paper, a notional system of two tanks connected by a pipe is built, with hot water coming into tank A through a second pipe and with cooled water released from tank B through a third pipe. This is a simple hydrodynamic & thermodynamic model, controlled by the state of valves in the scenario. The initial temperature and height of the water in the two tanks are pre-defined by users. Surface temperatures as a function of time are then predicted and captured as characterization maps. Users could also further define the resolution of the maps to better characterize the temporal changing information. These are then mapped onto DIRSIG geometry using uv mapping technique. Finally, a spatial-spectral-temporal synthetic image is produced.

8158-16, Session 5
PICASSO: an end-to-end image simulation tool for space and airborne imaging systems II: extension to the thermal infrared
S. A. Cota, C. J. Florio, R. A. Keller, T. S. Lomheim, B. M. Muto, The Aerospace Corp. (United States)

No abstract available
8158-17, Session 5

**PICASSO: an end-to-end image simulation tool for space and airborne imaging systems III: extension to the thermal infrared: a worked example**

P. B. Cameron, S. A. Cota, C. J. Florio, G. A. Franz, B. A. Jacoby, L. S. Kalman, M. G. Martino, The Aerospace Corp. (United States)

Adequate signal to noise for laboratory calibration targets. Preliminary results show the system has passband. Assembly of the system is nearly complete. Alignment results are presented which show low keystone and smile distortion. This is fact it has a single monolithic prism-like grating design which allows fast system (F/1.6). It also minimizes cooling requirements due to the high performance convex diffraction grating, a quantum well infrared photodetector focal plane array, and a compact Dyson-inspired optical telescope, covers the range 380-2500 nm with 5 nm sampling. A discussion will be given on each of the various measurements used to inform these adjustments, including experimental setup and preliminary test results.

8158-18, Session 6

**Alignment and characterization of high uniformity imaging spectrometers**

H. A. Bender, P. Mouroulis, M. L. Eastwood, R. O. Green, S. Geier, E. B. Hochberg, Jet Propulsion Lab. (United States)

Imaging spectrometers require precise adjustments, in some cases at the sub-micrometer level, in order to achieve a uniform response over both the spectral and spatial dimensions. We describe a set of measurement techniques and their corresponding alignment adjustments to achieve the 95% uniformity specifications required for the Next-Generation airborne Imaging Spectrometer (NGIS) under development at The California Institute of Technology’s Jet Propulsion Laboratory. The instrument, consisting of an Offner-type spectrometer and a two-mirror anastigmat telescope, covers the range 380-2500 nm with 5 nm sampling. A discussion will be given on each of the various measurements used to inform these adjustments, including experimental setup and preliminary test results.

8158-19, Session 6

**Hyperspectral thermal emission spectrometer: alignment and preliminary results**


The Hyperspectral thermal emission spectrometer will be the premiere airborne imaging spectrometer system used for the long wave infrared (LWIR). The pushbroom design has 512 spatial pixels over a 50-degree field of view and 256 spectral channels between 7.5 m to 12 m. Development is being undertaken end-to-end at the Jet Propulsion Laboratory and offers a complete system for understanding science concerns related to earth and water skin surface measurements. At its field of view and 256 spectral channels between 7.5 m to 12 m. The high optical throughput (F/1.25) of this design coupled with a fast-framing focal plane array permits large whiskbroom scans while maintaining low noise performance (<0.1K NEDT), allowing swath widths up to +/-45 degrees at pixel resolutions of ~0.5 mrad. The nominal flight altitude of the instrument was designed to be 12,000 ft, resulting in a 2-m pixel on the ground at nadir. The sensor is carried on a commercial gyro-stabilized platform, which provides for considerable flexibility in collection strategy. For example, by controlling the pitch of the sensor gimbal mirror it is possible to either stare at targets or execute multiple looks. Following successful engineering trials, flights were conducted over selected science targets with known sources of gaseous emission and thermal inhomogeneity. One such location was the southern extent of California’s San Joaquin Valley, where ammonia emissions from intensive dairy farming and agriculture reach notable levels. A second flight measured the active hydrothermal vent fields in the Salton Sea locale (also in Southern California). Data from these flights (the first being during daytime and the second being at night) demonstrate the radiometric sensitivity, high spatial resolution, and broad area coverage afforded by this new sensor and attest to its emission measurement capabilities.

8158-20, Session 6

**Optical design and performance of the Ultra-Compact Imaging Spectrometer**


We present the optical design and performance of the Ultra-Compact Imaging Spectrometer (UCIS) currently under development at Caltech’s Jet Propulsion Laboratory. The new instrument demonstrates a low optical bench mass of 0.5kg and compact size that enables Mars Rover or other in situ planetary applications. UCIS is a (F/4), wide field (32o) design, covering the spectral range 600-2600 nm and is enabled by a simple all aluminum two-mirror telescope and Offner spectrometer. We discuss here the optical design and alignment method that enables this compact and low mass imaging spectrometer.

8158-21, Session 6

**Performance of a new airborne thermal-infrared imaging spectrometer with broad area coverage and high spatio-radiometric resolution**


Results from the inaugural flight series of a new high-performance airborne thermal-infrared imaging spectrometer are described. The sensor incorporates a novel spectrometer design employing a concave diffraction grating in conjunction with a Dyson lens and acquires data in 128 spectral channels over the spectral range 7.5 - 13.5 microns. The high optical throughput (F/1.25) of this design coupled with a fast-framing focal plane array permits large whiskbroom scans while maintaining low noise performance (<0.1K NEDT), allowing swath widths up to +/-45 degrees at pixel resolutions of ~0.5 mrad. The nominal flight altitude of the instrument was designed to be 12,000 ft, resulting in a 2-m pixel on the ground at nadir. The sensor is carried on a commercial gyro-stabilized platform, which provides for considerable flexibility in collection strategy. For example, by controlling the pitch of the sensor gimbal mirror it is possible to either stare at targets or execute multiple looks. Following successful engineering trials, flights were conducted over selected science targets with known sources of gaseous emission and thermal inhomogeneity. One such location was the southern extent of California’s San Joaquin Valley, where ammonia emissions from intensive dairy farming and agriculture reach notable levels. A second flight measured the active hydrothermal vent fields in the Salton Sea locale (also in Southern California). Data from these flights (the first being during daytime and the second being at night) demonstrate the radiometric sensitivity, high spatial resolution, and broad area coverage afforded by this new sensor and attest to its emission measurement capabilities.
state is important for assessing these impacts. High spectral resolution data in hyperspectral imagery (HSI) sensors such as Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) provide a valuable source of information that can be used for analysis by semi-automated approaches for tracking an oil spill's areal extent, oil thickness, and oil categories. However, the spectral behavior of oil in water is inherently a highly non-linear and variable phenomenon that changes depending on oil thickness and oil/water ratios. For certain oil thicknesses there are well-defined absorption features, whereas for very thin thicknesses sometimes there are almost no observable features. Feature-based imaging spectroscopy methods are particularly effective at classifying materials that exhibit specific well-defined spectral absorption features. Statistical methods are effective at classifying materials with spectra that exhibit a considerable amount of variability and that do not necessarily exhibit well-defined spectral absorption features. This study investigates feature-based and statistical methods for analyzing oil spills using hyperspectral imagery. It investigates the appropriate use of each approach and the possible combined use of both.

8158-24, Session 7

Detection of aircraft exhaust in hyperspectral image data
L. L. West, S. E. Lane, G. G. Gimmestad, Georgia Tech Research Institute (United States); W. L. Smith, Hampton Univ. (United States); E. M. Burdette, Georgia Tech Research Institute (United States)

The use of hyperspectral imaging systems for detection of gases has been investigated and algorithms have been developed previously; these algorithms depend on proper modeling of the target gas and background in order for successful detection to occur. A dataset in which a LWIR Telops FIRST Hyper-Cam is utilized for the measurement of hyperspectral datacubes of aircraft plumes is investigated. The dataset itself was created at Hartsfield Jackson International Airport in Atlanta, Georgia. The Telops Hyper-Cam was oriented to allow oncoming landing aircraft to pass through the field of view of the instrument; each set of data collected consists of several datacubes of sky background pre-flight, aircraft passage, and sky background post-flight. This analysis focuses on different methods for the detection of aircraft exhaust in these hyperspectral image cubes. Gases that are known to exist in aircraft exhaust, such as water vapor and CO2, are modeled by different methods. The modeling of these target gases is limited due to lack of specific data regarding chemical constituents or concentration. The target gases are searched for in the hyperspectral image cubes by utilizing different hyperspectral gas detection algorithms; the results shown here demonstrate the ability to detect the aircraft exhaust in hyperspectral data using multiple methods. These detections are of interest due to the fact that these exhaust gases are entrained in wake vortices; the possibility of a hyperspectral means of wake vortex detection is of great interest due to its capability to aviation safety. This work is supported through funding from NASA.

8158-25, Session 7

IFTS measurements of laboratory-scale smokestack and flare plumes
J. L. Harley, M. Rhoby, K. C. Gross, Air Force Institute of Technology (United States)

A laboratory is being stood up for testing the capability of optical remote sensing techniques in the quantification of smokestack effluents and flare combustion efficiencies. A Telops Hyper-Cam midwave infrared (1.5-5.5 µm) imaging Fourier-transform spectrometer (IFTS) will be used to measure plumes from these laboratory-scale smokestack and flare sources. The turbulent nature of these flow fields produce instantaneous fluctuations in scene radiance. Methods have been devised to minimize scene-change artifacts in the spectra and also make use of the radiance fluctuations for velocity estimation and turbulence characterization. Total effluent mass flow rates (kg/s) will be estimated by combining spectrally-determined species concentrations with flow rates estimated via analysis of sequential images in the raw interferogram cube. Effects of a cross-wind will be studied as it may be an important parameter in understanding flare combustion efficiencies.

8158-26, Session 7

Hyperspectral face recognition after expression changes
G. E. Healey, Univ. of California, Irvine (United States)

The performance of face recognition degrades with expression changes. In this work, we propose an algorithm that combines spectral and spatial information for face recognition. 3D Gabor filters are used for the extraction of spatial features. A principal components approach is used to predict how the spatial features change with expression changes. We demonstrate the effectiveness of the algorithm using a database of hyperspectral face images.

8158-27, Session 7

RGB imaging system for mapping and monitoring of hemoglobin distribution in skin
D. Jakovels, J. Spigulis, Univ. of Latvia (Latvia)

Multi-spectral imaging has found applications for non-contact skin chromophore mapping, providing information about concentration distribution of chromophores, e.g. oxy-/deoxy-hemoglobin and melanin. However, commercial multi-spectral imaging cameras are bulky and expensive, so limiting their clinical implementation. Color digital camera can be regarded as an alternative, since it acquires three spectral (red (R), green (G) and blue (B)) images simultaneously. In combination with specific narrow-band spectral light sources, R-G-B imaging could become competitive for some specific applications, including the mapping of skin chromophores.

A prototype R-G-B imaging system for mapping of skin hemoglobin distribution has been designed and tested. Device basically consists of a commercial RGB sensor (CMOS, max. frame rate 87 fps for VGA resolution), RGB LED ring-light illuminator and orthogonally orientated polarizers for reducing specular reflectance. The system was examined for monitoring of hemoglobin concentration changes during specific provocations - arterial/venous occlusions and heat test. Besides, hemoglobin distribution maps of several skin malformations were obtained.

8158-28, Session 7

Hyperspectral mapping of mineral using Chang’e-1 hyperspectral data
J. Chen, X. Wang, China Univ. of Geosciences (China)

In this paper, We use the chinese-made interference image spectrometer (IIM) to map the lunar mineral distribution for the first time. According to the discrepancy between the spectrum characteristic of IIM and end-members mineral spectrum , and the influence to the spectrum in rocks which is caused by the different proportion mineral Combination, we adapt gaussian model of correction ( mixtul discriminant analysis) which is based on class pixel to map spectrogram diagram of lunar nearside. This paper analyzed the spectrum of regions which has known, obtained gaussian model parameter and residual , and made quantitative analysis on the distribution of clinopyroxene, orthorhombic pyroxene, olivine and other major lunar mafic minerals, and even the plagioclase. In terms of the Mineral distribution, We extract information of the lunar surface structure and topography and so on. Compared with the mineral map of the lunar surface of mature areas, the results are reliable.
Conference 8159:  
Lidar Remote Sensing for Environmental Monitoring XII

Sunday-Monday 21-22 August 2011 • Part of Proceedings of SPIE Vol. 8159  
Lidar Remote Sensing for Environmental Monitoring XII

8159-01, Session 1  
Active optical technology: recent developments and lessons learned  
G. Komar, NASA Goddard Space Flight Ctr. (United States)

This paper provides an overview of the active optical technology developments underway for the Earth Science Division at NASA. It summarizes key results from a multiyear NASA investment program aimed at enabling new Earth science measurement capabilities, developing new techniques in the 1- and 2-micron wavelengths, and improving reliability and longevity of future NASA active sensing instruments. Examples for Earth Science measurements such as aerosols, altimetry, winds, ozone levels, and vegetation change are discussed.

8159-02, Session 2  
High-efficiency laser designs for airborne and space-based lidar remote sensing systems  

The increasing use of lidar remote sensing systems in the limited power environments of unmanned aerial vehicles and satellites is motivating laser engineers and designers to put a high premium on the overall efficiency of the laser transmitters needed for these systems. Two particular examples upon which we have been focused are the lasers for the ICESat-2 mission and for the Laser Vegetation Imaging System-Global Hawk (LVIS-GH) system. We have recently developed an environmentally hardened candidate laser for ICESat-2 that has achieved over 11 W of 532 nm output at 10 kHz with a true wall plug efficiency over 6%. For the LVIS-GH lidar we recently delivered a 4.2 W, 2.5 kHz, 1064 nm laser transmitter that achieved a true wall plug efficiency of over 10%. In our presentation we discuss the design approaches used to achieve these results.

8159-03, Session 2  
Critical laser technology developments and ESA space qualification approach in support of ESA’s Earth observation missions  
M. Zahir, Y. Durand, European Space Research and Technology Ctr. (Netherlands)

In this paper, ESA’s approach to lasers and detectors space evaluation and qualification will be explored. ESA has its own international qualification system, the ESCC system. This system guarantees reliability, assurance and quality of components, and hence a successful space mission. An overview of the ESCC (European Space Component Coordination) system, as well as the relevant ECSS (European Cooperation for Space Standards) related standards addressing components and hybrid qualification will be given. These standards are being constantly updated, through well structured working groups, constantly coming up with new ways of qualifying space components. These components are themselves constantly changing in terms of material, technology, and manufacturing processes.

The development of advanced Lidar systems for space applications and their evaluation by airborne or ground based test campaigns is an important strategic element of the ESA Earth Observation Programme. These systems depend on robust and reliable lasers and detector at their core function. Since the early eighties, ESA has been supporting the development of the critical subsystems of any Lidar, i.e. lasers and detectors. Several missions, involving different kinds of lidars, provide the requirements to be addressed in the Lidar risk mitigation activities. They also present a challenge concerning their space qualification and reliability assurance. These missions are: ADM-Aeolus flying ALADIN a Doppler Wind Lidar; EarthCARE embarking ATLID an Atmospheric Backscatter Lidar; three missions studied for their feasibilities: WALES, A-SCOPE and ACCURATE, all using Differential Absorption Lidar in different ways to measure respectively profiles of water vapour, total column of CO2 and greenhouse gases in an occultation geometry.

8159-04, Session 2  
Conductively cooled 2 µm laser for space-based wind lidar  

NASA, NOAA and the DOD have been pursuing global wind measurements since the 1970s. Recently, it was determined that a hybrid system utilizing both coherent and direct detection wind lidar systems would provide the maximum science content for a space-based wind lidar. A key component of the coherent system is a conductively cooled 2 µm laser source capable of 250 mJ at 5-10 Hz. Researchers at Fibertek and NASA Langley have undertaken a jointly funded program to develop the required transmitter. The technical basis for the diode pumped head is a conductively cooled design that was previously developed at NASA Langley. Working with NASA Langley, Fibertek has further refined this design approach and incorporated it into an injection-seeded, single-frequency, master oscillator/power amplifier (MOPA) that can meet the requirements of the space-based coherent wind lidar. Packaging of the transmitter that can be transitioned to a space-based system has also been developed. In our presentation we will discuss the design details, performance, and testing of the laser.

8159-05, Session 2  
Qualification testing of the laser transmitter for ESA’s BepiColombo Laser Altimeter (BELA)  
K. Weidlich, M. Rech, Carl Zeiss Optronics GmbH (Germany); R. Kallenbach, Max-Planck-Institut für Sonnensystemforschung (Germany)

The BepiColombo Laser Altimetre (BELA) is one of 11 instruments aboard ESA’s Mercury Planetary Orbiter scheduled for launch in 2014. BELA will record the surface profile of the planet while orbiting around it at a distance of about 1,000 km. The altimetry data constitute an important prerequisite for a number of remote sensing and observation techniques residing on the same orbiter. The BELA instrument comprises a laser transmitter and a receiver part, the design of the former is being presented and discussed in this paper. The laser transmitter encompasses a pair of diode-pumped, actively q-switched Nd:YAG rod oscillators which have been miniaturized, light-weighted and dimensioned for high electrical to optical efficiency. The key performance parameters of the laser will be presented. Laser design trades which are relevant for a space mission to Mercury and the BELA instrument in particular are discussed. Selection criteria for critical optical and optoelectronics components are presented.
Lidar Remote Sensing for Environmental Monitoring XII

1. **Adaptive lidar for Earth imaging from space**
   C. S. Weimer, T. Ramond, Ball Aerospace & Technologies Corp. (United States)

   Laser remote sensing of the Earth from space offers many unique capabilities stemming from the unique properties of lasers. Lasers make possible three-dimensional characterizations that help to enable new scientific understanding of the natural processes that shape the planet’s oceans, surface, and atmosphere. The recent successes of GLAS (on ICESat) and CALIOP (on CALIPSO) have begun to explore the possibilities. However, the challenges to further expand on these successes remain complex. Operation of lidars from space is limited in part by the relatively low power available to the lasers, the low signal scattered back to the instrument because of the large distance to the surface, and the need for reliable and autonomous operation because of the large investment required for satellites. The instrument complexities are compounded by the large diversity in the Earth scenes; the large variability in albedo from cloud, ice, vegetation, desert, or ocean, combined with the highly variable transmission of the laser beam through clouds, forest canopy, or ocean surface and near-surface. This paper will discuss the development of a new approach to space-based lidars that illustrates one method to dramatically expand on the capability of space-based lidars. By combining the new imaging and ranging technology of flash focal plane arrays, with the multi-beam electronic steering capability of acousto-optic beam deflectors, an adaptive lidar can be created. The lidar can adapt to ensure adequate signal-to-noise plus reduce sources of systematic errors in measurements. In addition, by using inputs from secondary sensors, or a prior knowledge of the Earth scene below, it can vary the spatial sampling to maximize science return from its measurements. Demonstration of some of the possibilities is shown from laboratory and aircraft-based testing.

2. **The MERLIN mission: a space-based methane monitor**
   C. Stephan, M. Alpers, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); B. Millet, Ctr. National d’Études Spatiales (France); G. Ehret, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); P. H. Flamant, Lab. de Météorologie Dynamique (France); C. Deniel, Ctr. National d’Études Spatiales (France)

   Methane is a powerful greenhouse gas, which has a Greenhouse Warming Potential of 23 years relative to carbon dioxide time scale of about 100 years. Thus, the radiative forcing caused by methane contributes significantly to the warming of the atmosphere. To better understand the complex global methane cycle, it is necessary to apply space-based measurements techniques in order to obtain global coverage at high precision.

   The Methane Remote Sensing Lidar Mission (MERLIN) is a joint French-German cooperation on a small satellite mission for space-based measurement of spatial and temporal gradients of atmospheric methane columns on a global scale. MERLIN will be the first Integrated Path Differential Absorption (IPDA) LIDAR for methane monitoring from space. In contrast to passive methane missions like GOSAT, the lidar instrument allows to monitor methane fluxes at all-latitudes, all-seasons and during night as it is not relying on sunlight. Range-gated signal detection ensures that possible measurement biases from unknown aerosol scattering or scattering from thin cirrus clouds are avoided. First scientific studies show a substantial reduction of the prior methane flux uncertainties in key observational regions when using synthetic MERLIN observations in the flux inversion experiments. Furthermore, MERLIN observations can be used to quantify and verify in a scientific credible way the national emission reductions of the Kyoto protocol.

   The presentation gives an overview on the joint DLR and CNES mission concept with the German IPDA LIDAR on the French small satellite platform MYRIADE, its present status and briefly reports on results from scientific impact studies.
Pulsed airborne lidar measurements of atmospheric CO2 column absorption to 13 km altitude

G. R. Allan, Sigma Space Corp. (United States) and NASA Goddard Space Flight Ctr. (United States)

We have developed a LiDAR technique for remotely measuring atmospheric CO2 concentrations as a candidate for NASA's ASCENDS mission. Using a step-tuned pulsed laser transmitters, receiver scope and photon counting detectors we simultaneously measure a CO2 absorption line in the 1570 nm band, O2 extinction in the Oxygen A-band, surface height and backscatter. Signal processing isolates the surface echo, measures the range, and rejects laser photons scattered in the atmosphere. The gas extinction and column densities for the CO2 and O2 gases are estimated via the Integrated Path Differential Absorption technique. During Summer of 2009 we made 5 flights on the NASA Glenn Learjet-25 measuring atmospheric CO2 absorption line shapes using the 1572.335 nm line at stepped altitudes from 3 to 13 km over a variety of surfaces. For 2010 measurements, we have increased the number of wavelength samples increased the receiver sensitivity and dynamic range. Incorporated an oxygen LiDAR channel measuring the doublet near 764.7 nm. We integrated the twin channel LiDAR onto the NASA DC-8 and participated in the NASA ASCENDS field campaign flying 5 science flights over the central valley of California, desert areas, the Pacific Ocean, and the DOE SGP ARM site. Clear CO2 and O2 line shapes, which changed as expected with range and altitude, were observed on all flights to 13 km altitude. The data is currently being analyzed and compared to readings from radiosondes and on board gas sensors. Details of the CO2 measurements analysis and comparisons will be described in the presentation.

Carbon Dioxide Laser Absorption Spectrometer (CO2LAS) aircraft measurements of CO2

G. D. Spiers, R. T. Menzies, L. E. Christensen, J. C. Jacob, J. J. Hyon, Jet Propulsion Lab. (United States)

The Jet Propulsion Laboratory Carbon Dioxide Laser Absorption Spectrometer (CO2LAS) utilizes Integrated Path Differential Absorption (IPDA) at 2.05 μm to obtain CO2 column mixing ratios weighted heavily in the boundary layer. CO2LAS employs a coherent detection receiver and continuous-wave Th:Ho:YLF laser transmitters with output powers around 100 milliwatts. An offset frequency-locking scheme coupled to an absolute frequency reference enables the frequencies of the online and offline lasers to be held to within 200 kHz of desired values. We describe results from 2009 and 2010 field campaigns when CO2LAS flew on the Twin Otter and DC-8 performing measurements over varying terrains at altitudes up to 5 km. We also describe spectroscopic studies aimed at uncovering potential biases in lidar CO2 retrievals at 2.05 μm.

8159-13, Session 3

Development of optical parametric amplifier for lidar measurements of trace gases on Earth and Mars

K. Numata, NASA Goddard Space Flight Ctr. (United States) and Univ. of Maryland, College Park (United States); H. Riris, S. X. Li, S. T. Wu, M. A. Krainak, J. B. Abshire, NASA Goddard Space Flight Ctr. (United States)

Trace gases in planetary atmosphere offer important clues as to the origins of the planet’s hydrology, geology, atmosphere, and potential for biology. Remote measurements of methane (CH4), water (H2O), and other biogenic molecules (such as ethane and formaldehyde) on Mars have important connections to questions related to the existence of life on Mars. Carbon dioxide (CO2) and CH4 are the most important anthropogenically produced greenhouse gases. We report on the development effort of a nanosecond-pulsed optical parametric amplifier (OPA) for remote measurements of these trace gases on Mars and Earth. The OPA is pumped by a passive Q-switch NPRO (non-planar ring oscillator) at 1064nm and seeded by a continuous-wave DBF laser at 1550-1650nm. A 50-mm, MgO-doped PPLN was used as a nonlinear crystal. The OPA output light is single frequency with high spectral purity and is widely tunable both at 1600nm and 3300nm with an optical-optical conversion efficiency of ~40%. We demonstrated open-path atmospheric measurements of CH4 (3291nm and 1651nm), CO2 (1573nm), and H2O (1652nm) with this laser source. The results agreed well with calibrated in situ measurements, demonstrating the suitability of space implementation of this system.

An investigation of high spectral resolution lidar measurements over the ocean

E. Saiki, C. S. Weimer, M. Stephens, Ball Aerospace & Technologies Corp. (United States)

Analysis of data measured by the NASA Langley airborne High Spectral Resolution Lidar is presented focusing on measurements over the ocean. The HSRL is a dual polarized system (1064 and 532 nm) with the inclusion of a molecular backscatter channel at 532 nm. Data from aircraft flights over the Pamlico Sound out to the Atlantic Ocean, over the Caribbean west of Barbados, and off the coast of Barrow Alaska are evaluated. Analysis of the data demonstrates that the molecular channel detects the presence of water due to its ability to separate the Brillouin-Mandelstam spectrum, i.e. the scattering spectrum of water, from the Rayleigh/Mie spectrum. The characteristics of thelidar measurements over water, land, ice, and mixed ice/water surfaces are examined. Correlations of the molecular channel lidar signals with bathymetry (ocean depth) and extraction of attenuation from the HSRL lidar measurements are presented and contrasted with ocean color data.
8159-15, Session 4
High precision long range laser altimeter for avionics and space applications
D. F. Pierrottet, Coherent Applications, Inc. (United States); F. Amzajerdian, B. W. Barnes, NASA Langley Research Ctr. (United States); T. D. Jones, G. E. Lockard, Coherent Applications, Inc. (United States); L. B. Petway, NASA Langley Research Ctr. (United States); B. D. Taylor, ATK Space Systems (United States)

A compact, high precision, long range, laser altimeter implemented for space and avionics applications is described. It was developed under the Autonomous Landing and Hazard Avoidance Technology (ALHAT) project for terrain relative navigation during the approach phase to a lunar or planetary landing.

8159-16, Session 4
Development of wide-bandwidth and low-noise HgCdTe avalanche photodiode detectors
J. Wang, M. D. Jack, Raytheon Co. (United States); X. Sun, A. W. Yu, NASA Goddard Space Flight Ctr. (United States); D. N. Hall, Univ. of Hawai‘i (United States)

There are strong needs for wide bandwidth and low noise avalanche photodiode detectors (APDs) for astronomy and lidar remote sensing. Wide bandwidth requirements are driven by the use of very narrow pulse lasers, about 1 ns, for future space-based laser altimetry and the use of APDs in adaptive optics in astronomy. Low noise is driven by the extremely small number of photons bouncing back from distant objects. High sensitivity and low noise APDs can meet signal-to-noise requirements with reduced telescope aperture size and less laser power, and thereby reducing overall instrument size and cost. Investment in the development of more sensitive APDs often results in the biggest savings in overall instrument and mission cost. Traditional silicon and InGaAs APDs suffer from high excess noises. Excess noises increase rapidly at high gain, thereby reducing the advantages of high gain APDs based on silicon or InGaAs. HgCdTe APDs, with its more deterministic electron avalanche mechanism, lead to very low excess noise, very close to the theoretical limit of excess noise factor of 1. Raytheon Vision Systems (RVS), with support from NASA through NASA Goddard Space Flight Center (GSFC) and the University of Hawai‘i, has made breakthrough advancement in wide bandwidth and low noise HgCdTe APDs for the near infrared (NIR) region that is much more challenging then mid-wave infrared (MWIR) APDs. In this paper we will discuss RVS HgCdTe APD design, fabrication, and characterization results at RVS, NASA GSFC, and the University of Hawai‘i.

8159-17, Session 4
Interactive aerosol lidar monitor for multiple users via network multicast
J. P. Herron, Utah State Univ. (United States); J. T. Pearson, U.S. Army Dugway Proving Ground (United States)

Dugway Proving Ground is a major range test facility charged with testing chemical and biological defense systems and materials. The facilities at DPG include state-of-the-art laboratories and extensive field test grids. A suite of mobile elastic backscatter lidar systems are used as referee systems to track and quantify biological and interferent aerosol releases on the test range. While each lidar has its own display software, it typically is only intended for and available to the system operator. The display is typically not adequate for every test scenario and requires the data to be post-processed into an acceptable format for presentation to a test client. The lidar systems are typically positioned several kilometers from any release point or the command post. This geographic separation caused major limitations in certain test scenarios, as the data output from the lidar system was only available to other test personnel via verbal comments from the lidar operator until post test. To increase the utility and impact of the lidar systems on field testing, a real-time data visualization software package was developed for the DPG lidar systems. Multiple display types are included in the software to accommodate various testing and calibration scenarios. Data from a fielded system is uploaded to the local test network via either a direct or wireless connection. The data is sent via a UDP multicast which allows for multiple end users to receive the data without increasing the load on the server or network as there is minimal error checking, and duplication of the data is done at the router level. The software is designed for test personnel and clients of DPG to operate without significant training and only a passing familiarity with lidar systems. In addition to providing a real-time display the software can capture the data locally making a test event available for immediate review. A software description and the display philosophy for various field test scenarios are included in this presentation.

8159-18, Session 4
Lidar as a tool for fisheries management
J. H. Churnside, National Oceanic and Atmospheric Administration (United States); D. A. Hanan, Z. D. Hanan, Hanan & Associates, Inc. (United States); R. D. Marchbanks, Univ. of Colorado (United States) and National Oceanic and Atmospheric Administration (United States)

Effective management of fisheries resources requires accurate information on the population of the species under consideration. This information can be very difficult to obtain in many cases, because the fish have a wide distribution and are very mobile. Traditional ship-based techniques are limited in the area that can be covered by the speed of the vessel, which is typically less than 5 m/s. A much larger area can be surveyed in a shorter time by aircraft, and this becomes a very attractive technique for those species close enough to the surface to be observed by airborne remote sensors.

This paper describes the results of a series of airborne observations of sardine schools off the coast of California in the fall of 2010. The lidar system used a linearly-polarized transmitter and a single receiver that was sensitive to the backscattered light in the orthogonal polarization. The aircraft was also equipped with a camera to photograph schools. The camera had a broader swath than the lidar, so was able to see more of the schools at the surface. However, the lidar detected schools much deeper in the water, was not hampered by waves and sun glare, and could survey at night. The combination of lidar and photographs proved to be a very powerful survey tool for sardines, since the latter was able to identify surface targets that appear very similar to fish schools in the lidar return. Examples of these include floating mats of kelp and ship wakes.

8159-19, Session 4
Numerical simulation of the Doppler lidar measurements with high spatial resolution
E. A. Shelekhova, A. P. Shelekhov, V.E. Zuev Institute of Atmospheric Optics (Russian Federation)

To study and predict local atmospheric processes, scientists widely use mesoscale meteorological models WRF and MM5. For domain they introduce a uniform grid, the horizontal spatial resolution is defined by a cell size of this grid. Initial and boundary conditions for models are set using data of wind, which were taken from meteorological stations. It is necessary to obtain information about wind velocity with higher spatial resolution to improve a weather prediction in future. We can get this information from the Doppler lidar measurements. For VAD technique the Doppler lidar measurements are performed along arc of VAD vector scan. The arc size defines the horizontal spatial resolution of measurements.

8159-20, Session 4
Lidar for environmental applications with high spatial resolution
J. H. Churnside, National Oceanic and Atmospheric Administration (United States); D. A. Hanan, Z. D. Hanan, Hanan & Associates, Inc. (United States); R. D. Marchbanks, Univ. of Colorado (United States) and National Oceanic and Atmospheric Administration (United States)

Effective management of fisheries resources requires accurate information on the population of the species under consideration. This information can be very difficult to obtain in many cases, because the fish have a wide distribution and are very mobile. Traditional ship-based techniques are limited in the area that can be covered by the speed of the vessel, which is typically less than 5 m/s. A much larger area can be surveyed in a shorter time by aircraft, and this becomes a very attractive technique for those species close enough to the surface to be observed by airborne remote sensors.

This paper describes the results of a series of airborne observations of sardine schools off the coast of California in the fall of 2010. The lidar system used a linearly-polarized transmitter and a single receiver that was sensitive to the backscattered light in the orthogonal polarization. The aircraft was also equipped with a camera to photograph schools. The camera had a broader swath than the lidar, so was able to see more of the schools at the surface. However, the lidar detected schools much deeper in the water, was not hampered by waves and sun glare, and could survey at night. The combination of lidar and photographs proved to be a very powerful survey tool for sardines, since the latter was able to identify surface targets that appear very similar to fish schools in the lidar return. Examples of these include floating mats of kelp and ship wakes.
The necessary condition of correct measurements is the sizes of arc and cell are equal for uniform grid. In this paper the numerical simulation results of measurement error profiles of wind velocity components depending on range and direction sensing for different horizontal spatial resolutions are presented. It shows that when calculating wind velocity components by least-squares method the measurement error depends on angle of VAD sector scan and direction sensing. Since size of the arc must be constant for every grid cell, therefore angle of VAD sector scan decreases inversely proportional to the range. So measurement precision decreases essentially with increasing range for high horizontal spatial resolution, even for a fixed SNR. The results of numerical simulation show that projections of wind velocity to directions North and East (U and V respectively) are measured with different precision. For example, measurement precision of the component U is a maximum in the direction sensing of North and South and at the same time the component V is measured with large error. The components U and V are measured with the same errors in the direction sensing of north-east, north-west, south-east, south-west.

8159-20, Poster Session

Supercontinuum under the filamentation of the femtosecond laser pulse in the fused silica

E. Smetanina, V. P. Kandidov, A. E. Dormidonov, Lomonosov Moscow State Univ. (Russian Federation); V. O. Kompanets, S. V. Chekalin, Institute of Spectroscopy (Russian Federation)

Supercontinuum generation under filamentation is a result of strong non-linear interaction of high-power femtosecond pulses with Kerr media. [1,2]. The spectral broadening of light ranges from the ultraviolet to the infrared. It has been observed in transparent solids, liquids and gases. An important property of such white light is a coherence of its spectral components.

The white light continuum generated by a filament in air can be exploited for remote sensing of atmospheric gases and aerosols, lightning control, laser induced spectroscopy [1]. Supercontinuum source formed under filamentation in silica used in Cavity Ring-Down Absorption Spectroscopy (CRDS), which is a spectroscopic tool, that permits the detection of trace absorbers in gaseous, liquid, as well as solid phase [3].

In this work the supercontinuum under filamentation of the spectrally limited femtosecond laser pulses in the fused silica at different wavelengths is investigated. An influence of media dispersion on supercontinuum (SC) spectra formation was analysed.

SC generation was analysed theoretically by using a numerical model of filamentation of femtosecond laser pulses in condensed media. The model describes the diffraction and nonlinear-optical interaction of femtosecond radiation with a medium taking into account the material dispersion in the condensed medium according to the Sellmeyer formula.

In a regime of one filament, in area of normal dispersion we worked with wavelengths \( \lambda = 400 \text{ nm} \) and \( \lambda = 800 \text{ nm} \). Spectra broadening under filamentation of pulses with central wavelength \( \lambda = 800 \text{ nm} \) is more than for spectra with central wavelength \( \lambda = 400 \text{ nm} \): \( \Delta \lambda_{400 \text{nm}} = 760 \text{ nm} > \Delta \lambda_{800 \text{nm}} = 160 \text{ nm} \). The broadening is asymmetric, anti-Stokes wind is more than Stokes. This results are in agreement with the statement that there is a bandgap threshold for continuum generation: \( \text{Egap}/h \nu = 2 \), where \( \text{Egap} \) is a width of bandgap of media, and \( h \nu \) is an energy of quantum on the central wavelength. Above that threshold the continuum’s width increases with increasing the wavelength [4].

So, broadening for \( \lambda = 1300 \text{ nm} \), in area of zero dispersion in silica, is \( \Delta \lambda_{1300 \text{nm}} = 1600 \text{ nm} \). In area of anomalous dispersion the broadening for wavelength \( \lambda = 1900 \text{ nm} \) is \( \Delta \lambda_{1900 \text{nm}} = 2400 \text{ nm} \). It was found for this wavelength, that the decreasing of spectra intense in anti-Stokes wing is nonmonotonic.

There are a local minimum in spectra from 800 nm to 1200 nm, and then there are a local peak in visible range of spectra from 400 nm to 700 nm. Such spectra was observed experimentally for \( \lambda = 1540 \text{ nm} \) in fused silica [5]. This nonmonotonic superbroadening can’t be explained by 3-rd harmonic generation, because our numeric model does not takes into account a process of 3-rd harmonic generation in fused silica. Nonmonotonic spectra behaviour we explained by interference effects of SC generated under filamentation in media with anomalous dispersion [6].

\( \Delta \lambda \) was found for level: \( \text{Ig}(S(\lambda))/S(0,0) = -7 \), where \( S(\lambda) \) is an intense of spectral component, \( \lambda \) - central wavelength.

References

5. Naudue M.L. et al Observation of nonlinear optical phenomena in air and fused silica using a 100 GW, 1.54 \( \mu \)m source. // Optics Express, 1998, 14, 13.
8159-23, Poster Session

**Frequency stepped pulsed wind sensing lidar**

A. S. Olesen, A. T. Pedersen, K. T. Rottwitt, Technical Univ. of Denmark (Denmark)

A wind sensing lidar utilizing a Frequency Stepped pulse Train (FSPT) is demonstrated for the first time. A proof of concept is performed and wind measurements are shown. One of the advantages of the FSPT lidar is that it enables direct measurement of wind speed as a function of distance from the lidar. We show measurements in a range from 20 meters to 350 meters.

Theoretically the FSPT lidar continuously produces measurements as is the case with a CW lidar, but at the same time with a spatial resolution, and without the range ambiguity originating from e.g. clouds.

The FSPT lidar utilizes a frequency sweeping source for generation of the FSPT. The source generates a pulse train where each pulse has an optical carrier frequency shifted Δf relative to the carrier frequency of the previous pulse. In the scheme presented here, the measured frequency is dependent on which distance the signal originates from. The measured frequency is related to the Doppler frequency shift induced by the wind plus an integer number of Δf corresponding to a specific distance. The special resolution depends on the repetition rate of the pulse in the pulse train.

In this work we discuss the influence of different parameters including pulse duration, pulse power and pulse shape on the signal to noise ratio as well as spatial resolution. Proof of accuracy of the wind speed measurement will likewise be presented in the form of a comparison between measurements from the FSPT lidar to anemometers.

8159-24, Poster Session

**Feature extraction from lidar point clouds using image processing methods**

L. Zhu, Beijing Univ. of Civil Engineering and Architecture (China) and Michigan State Univ. (United States); A. Shortridge, D. Lusch, Michigan State Univ. (United States); R. Shi, Beijing Univ. of Civil Engineering and Architecture (China)

Airborne Lidar data have become cost-effective to collect, and data are being collected at the local and regional scales across the United States and internationally. These data are typically collected and processed into surface data products by contractors for state and local communities. Current algorithms for advanced processing of Lidar point cloud data are normally implemented in specialized, expensive software that is not available for many users, and these users are therefore unable to experiment with the Lidar point cloud data directly for extracting customized features. The objective of this research is to identify automated, readily implementable GIS procedures to extract features like buildings, vegetated areas, parking lots and roads from Lidar data using standard image processing tools. Image processing is a relatively mature set of techniques with many effective classification methods. We explore its potential to process Lidar data in conjunction with high-resolution aerial imagery. The final procedure adopted runs as follows. First, interpolation is used to transfer the 3D points to a high-resolution raster. Raster grids of both height and intensity are generated. Second, a raster of relative height above the ground is created by subtracting bare ground height from the first return Lidar data. Third, the relative height map, a colocated high resolution aerial image, and the Lidar intensity map are conflated to generate a multi-channel image. A feature space of this image is created. Finally, supervised classification on the feature space is implemented. The approach is demonstrated and its strengths and limitations are compared to existing techniques.
Scannerless laser imaging radar will be the trend of laser imaging radar in future because it has several advantages of high frame rate, wide field of view, small size and high reliability owing to giving up mechanical scanner. A scannerless gain-modulated three-dimensional laser imaging radar is developed: Our system consists of a pulsed laser which is capable of generating 100mJ pulses with a pulse width of 10ns and a center wavelength of 532 nm, and a receiver which is a digital CCD sensor coupled to a GEN II intensifier with a 10nm bandwidth optical filter. The homogenized light beam passes through a diverging lens to flood illuminate the targets. The return light is collected by a Nikon camera lens and amplified by the image intensifier which is electronically driven and can be set to exponentially modulated gain or constant gain. The CCD sensor can record a 12 bit gray-level image with a resolution of 780×582 pixels at a 50 Hz frame rate. For a range image of the target can be extracted by processing an intensity image with exponentially modulated gain and an intensity image with constant gain, the range image is acquired at a 25 Hz frame rate. During our outdoor experiment, the range image of the targets at 500m is acquired with 2m range accuracy and the range image of the targets at about 1 kilometer is acquired with 5m range accuracy in daytime.
Detection and tracking of RC model aircraft in LWIR microgrid polarimeter data

B. M. Ratliff, Space Computer Corp. (United States); D. A. LeMaster, R. T. Mack, Air Force Research Lab. (United States); P. V. Villeneuve, J. J. Weinheimer, Space Computer Corp. (United States); J. Middendorf, Air Force Research Lab. (United States)

The LWIR microgrid Polarized InfraRed Advanced Tactical Experiment (PIRATE) sensor was used to image several types of RC model aircraft at varying ranges and speeds under different background conditions. The data were calibrated and preprocessed using recently developed scene-based microgrid processing algorithms prior to estimation of the thermal (s0) and polarimetric Stokes vector images (s1 and s2). The data were then analyzed to assess the utility of polarimetric information when the thermal s0 data is augmented with s1 and s2 information for several model aircraft detection and tracking scenarios. Multi-variate analysis tools are applied in conjunction with multi-hypothesis detection schemes to assess detection performance of the aircraft under difficult background clutter conditions. In most cases we find that polarization is able to improve detection performance when compared with the corresponding thermal data. Tracking algorithms were applied to s0 and the corresponding full polarimetric images for several model aircraft datasets. An initial assessment is performed to determine whether the added polarimetric information provides utility over s0 alone in these model aircraft tracking scenarios.

Frequency-domain scene-based non-uniformity correction and application to microgrid polarimeters

W. T. Black, J. S. Tyo, College of Optical Sciences, The Univ. of Arizona (United States)

Non-Uniformity Noise is common in infrared imagers, and is usually corrected through calibration. In some classes of imagers, an initial calibration is often updated during operation by momentarily blocking the optical system with a relatively uniform temperature shutter. This periodic correction is necessary because the non-uniformity patterns (also called fixed-pattern noise) will drift in time as the sensor or scene temperatures change, and requires periodic recalibration. During these recalibration episodes, there is temporary loss of imaging functionality. A microgrid polarimeter is a special focal plane array in which pixels have different polarization filters, permitting simultaneous measurement of polarization images with minimal loss of the original signal. Microgrid polarimeters are especially sensitive to fixed-pattern noise because the polarization signal is acquired by differentiation (or demodulation) of different pixels. Scene-based algorithms attempt to alleviate the need for recalibration of the imager through image processing techniques.

We introduce a new frequency-domain scene-based non-uniformity estimation and correction technique potentially suitable for real-time implementation. We apply the technique to infrared and microgrid polarimeter imagery and examine performance. Specific application to polarization imagery is explored. The technique demonstrates promising results for shutter-assisted (recalibration) video, for microgrid polarization systems, and for most spatially modulated sensor systems.

On the study of low-contrast polarization between man-made objects and natural clutter for LWIR

J. M. Romano, U.S. Army Armament Research, Development and Engineering Ctr. (United States); E. Niver, New Jersey Institute of Technology (United States)

LWIR polarimetric imagery has shown the potential in detecting man-made targets in environments where target signal to clutter ratio (SCR) is low. In conventional imagery this low contrast can be found during the diurnal changes that happen during sunrise and sundown. Some studies have demonstrated the presence of a polarimetric diurnal change in S1 where the contrast between the clutter and the polarizing signal is close to zero. In the proposed paper we will revisit and expand the study of zero polarimetric SCR by introducing an extensive analysis of target and clutter. Our study deviates from previous published work, which compares the target signal and background signal using only the mean. Instead, in order to decide if the occurrence of SCR equal or less than zero, we propose using the following decision framework: 1) Determine the area-under-the-curve metric as a first order understanding if the SCR is close to zero. 2) Threshold the selected imagery throughout all possible thresholds and retain joint pixels while removing singletons; and finally 3) Compare the target and background statistics using the ROC curves to decide if indeed SCR is less or equal to zero. By using the ARDEC-ARL SPICE data collection, we will analyze the signal variability using the proposed method and demonstrate in what conditions low SCRs occur in S1 and S2.

Defining a process to assess the value of multiple remotely sensed polarimetric images for target detection using spectral and polarimetric data fusion

B. M. Flusche, M. G. Gartley, J. R. Schott, Rochester Institute of Technology (United States)

A process is defined to model a particular set of image acquisition scenarios, to determine which polarimetric image (from a set of many) will produce the most impact on target detection performance, to quantify the impact of incorporating polarimetric information from multiple viewing geometries and to evaluate the performance degradation introduced by a reasonable degree of registration error. Variations of the spectral polarimetric integration (SPI) decision fusion algorithm are described, adapting the decision fusion process to accept information from multiple images as inputs, with each image taken from a different viewing geometry. A metric is introduced to assess the quality of off-nadir polarimetric information-balancing the increased ability to detect polarimetric target signatures with the degradation in performance due to the increased sensor ground sample distance. After logically identifying the best two sensor zenith angles for capturing polarimetric imagery, performance improves by exploiting those angles but a minimal return on investment is observed when additional polarimetric imagery is captured from more than two sensor zenith angles. Finally, incorporating a modest amount of registration error between each of the polarimetric images and the spectral image is shown to degrade fusion performance slightly, but often still outperforms spectral information alone.
8160-06, Session 1

**Modulated polarimeters and their null spaces**

R. A. Chipman, J. S. Tyo, C. F. LaCasse IV, College of Optical Sciences, The Univ. of Arizona (United States)

Since optical detectors respond only to intensity, polarimeters must modify the intensity so that the polarization parameters can be reconstructed after a series of several measurements. The traditional DRM description develops a system of linear equations that can be inverted. The DRM formalism takes a dot product between the unknown incident Stokes parameters and the analyzer vector that describes the polarimeter at that location in space and time. One of the preferred methods for obtaining the N measurements is to modulate the intensity in space, time, or wavelength with a periodically varying element. When N is greater than the number of Stokes parameters that are being reconstructed, it is common to use the pseudoinverse to affect the reconstruction because it prevents elements of the null space of the set of analyzer vectors from coupling into the estimated Stokes parameters. In this talk we demonstrate that any oscillation frequencies other than the specific ones used to modulate the signal are in that null space for the DRM; conventional DRM reconstruction assumes that any variations in the signal at other frequencies are noise that should be discarded. This assumption is perfectly valid in a range of static sensing applications. In dynamic applications, or in other modulation schemes such as microgrid polarimeters, it is desirable to reconstruct varying polarization signatures. We have developed reconstruction strategies that assume that all frequencies up to some band limit are desired, and places higher frequencies in the null space. These two examples represent the extreme cases, and in this talk we discuss how to develop an intermediate reconstruction strategy that is tailored to the SNR in any particular sensing task.

8160-07, Session 1

**Target discrimination of man-made objects using passive polarimetric signatures acquired in the visible and infrared spectral bands**

D. A. Lavigne, Defence Research and Development Canada (Canada); M. Breton, AEREX avionique inc. (Canada); G. R. Fournier, J. Charette, M. Pichette, Defence Research and Development Canada (Canada); V. Rivet, A. Bernier, AEREX avionique inc. (Canada)

Surveillance operations and search and rescue missions regularly exploit electro-optic imaging systems to detect targets of interest in both the civilian and military communities. By incorporating the polarization of light as supplementary information to such electro-optic imaging systems, it is possible to increase their target discrimination capabilities, considering that man-made objects are known to depolarized light in different manner than natural backgrounds. As it is known that electro-magnetic radiation emitted and reflected from a smooth surface observed near a grazing angle becomes partially polarized in the visible and infrared wavelength bands, additional information about the shape, roughness, shading, and surface temperatures of difficult targets can be extracted by processing effectively such reflected/emitted polarized signatures.

This paper presents a set of polarimetric image processing algorithms devised to extract meaningful information from a broad range of man-made objects. Passive polarimetric signatures are acquired in the visible, shortwave infrared, midwave infrared, and longwave infrared bands using a fully automated imaging system developed at DRDC Valcartier. A fusion algorithm is used to enable the discrimination of some objects lying in shadowed areas. Performance metrics, derived from the computed Stokes parameters, characterize the degree of polarization of man-made objects. Field experiments conducted during winter and summer time demonstrate: 1) the utility of the imaging system to collect polarized signatures of different objects in the visible and infrared spectral bands, and 2) the enhanced performance of target discrimination and fusion algorithms to exploit the polarized signatures of man-made objects against cluttered backgrounds.

8160-08, Session 1

**The imaging equation for a microgrid linear Stokes polarimeter**

I. Vaughn, College of Optical Sciences, The Univ. of Arizona (United States)

Imaging polarimeters have currently and historically been largely used for remote sensing tasks. They have also been used to evaluate the defects and calibrate the polarization of liquid crystal displays. A particular type of polarimeter that has a great deal of unrealized potential is the microgrid array linear Stokes polarimeter. This type of polarimeter is not often used because of reconstruction errors. If these errors could be minimized, or mitigated via proper algorithmic reconstruction, then they have advantages over other types of polarimeters, mainly calibration (not much is needed) and proper operation over wide wavelength bands (due to the use of wire grid linear polarizers). In the paper I analyze an ideal imaging equation of the microgrid Stokes polarimeter, using the full vectorial electric field and Maxwell’s equations. This is the forward imaging operator and assumes no noise, an ideal wiregrid polarizer, and a diffraction limited optical system.

8160-09, Session 2

**Polarization state generator (PSG): a polarimeter calibration standard**

A. Mahler, R. A. Chipman, College of Optical Sciences, The Univ. of Arizona (United States)

A polarization state generator (PSG) was built and calibrated which outputs weakly linearly polarized light with uniform linear polarization (DoLP) varying from 0.0005 to 0.4 with uncertainty of 0.0005. Known, low DoLP light is generated by passing collimated, unpolarized light with a defined range of field angles through a tilted plane parallel plate. The PSG was intended to act as a calibration standard based on calculated DoLP, but proved difficult to model. Therefore, DoLP was instead measured to repeatability of 0.0005.

8160-10, Session 2

**System characterization and analysis of the multispectral aerial passive polarimeter system (MAPPS)**

B. D. Bartlett, C. Salvaggio, J. Faulring, Rochester Institute of Technology (United States)

Passive polarimetry has been used for many different remote sensing applications and can provide useful signatures for certain types of phenomenology. While broadband polarimeters have many advantages, such as high signal to noise and small ground sample distance, there has been growing interest in the development of algorithms that take advantage of both spectral and polarimetric signals. The Multispectral Aerial Passive Polarimeter System (MAPPS) aims to produce multispectral polarimetric imagery of test scenes that can be used in algorithm development efforts. Preliminary data is presented along with a calibration and processing workflow that produces registered spectral Stokes imagery.
Near-infrared simultaneous Stokes imaging polarimeter: integration, field testing, and estimation error analysis

J. D. Mudge, M. Virgen, Lockheed Martin Space Systems Co. (United States)

In 2009 we reported on an optimal design of a simultaneous Stokes’ imaging polarimeter in the near-infrared. The optimal design is a result the polarization elements chosen to reduce sensitivity to noise, minimize differential aberrations, and reduce image registration to a simple calibration. A polarimeter was built to the specified design, field tested and shown to produce estimated polarization of a scene, e.g., Stokes’ images, near real time. This system estimates the polarization of particular scene elements relevant to remote sensing applications. The details of instrument integration and an error analysis are presented in this paper. Several sets of data will also be presented showing the instruments remote detection capabilities of disparate objects from various platforms, highlighting the versatility and durability of the polarimeter and its output.

M&m’s: an error budgeting and performance simulator code for polarimetric systems

M. de Juan Ovelar, F. Snik, C. U. Keller, Utrecht Univ. (Netherlands)

Polarimetry is a very valuable remote-sensing technique that often yields information that is unobtainable through other techniques. Because of the increasing size and complexity of current instrumentation projects, the design of these polarimeters is only now starting to demand a formal systems engineering approach, which is common practice when designing optical systems. Although different approaches to model a polarimeter’s accuracy have been described before, a complete error budgeting tool has not been developed due to the complexity of the error propagation in such systems. Errors have to be expressed as vectors, and their values are often larger than the signal itself. Such a tool will allow us to identify the components in the system that significantly degrade the polarimetric performance and estimate the polarimetric accuracy of a given design. Based on the mathematical framework established by Keller & Snik (2009), we present the M&m’s code that constitutes the first attempt to get a generic error budgeting tool to model the performance and accuracy of a given polarimeter including all the potential error contributions, due to, e.g., misalignment and varying material properties, and their dependencies on physical parameters, e.g., wavelength and temperature. We also present some preliminary results from validation of the code with a laboratory set-up that mimics the EPICS polarimeter for the E-ELT, which will directly image and characterize exoplanets.

Modeling the polarimetric scattering properties of diffuse reflectance standards

T. A. Germer, H. J. Patrick, National Institute of Standards and Technology (United States)

Sintered polytetrafluoroethylene (PTFE), marketed as Spectralon or Fluorilon-99W, is often used as a diffuse reflectance scattering standard. Near normal incidence, its behavior is relatively close to Lambertian with a reflectance close to one. At larger angles of incidence, marked deviations from Lambertian are observed and its polarization dependence becomes more pronounced. In this paper, we will present Mueller matrix bidirectional reflectance distribution function (BRDF) measurements, performed both in and out of the plane of incidence, and compare them to a theoretical model that assumes multiple scattering occurs in the volume of the material. These simulations use a Henyey-Greenstein phase function, generalized to account for polarization, together with a full polarimetric implementation of the adding-doubling method to account for multiple scattering. The agreement between the measured behavior and the predictions of the model (requiring only a few adjustable parameters) is quite good. These measurements and calculations may pave the way to improved standards by guiding the development of newer, better materials, and by providing a means to interpolate or extrapolate limited sets of data.

Polarization analysis of scattering light using a facet model

L. Jin, T. Tsutaki, Univ. of Yamanashi (Japan); B. Gelloz, Tokyo Univ. of Agriculture and Technology (Japan)

There were several approaches to predict optical scattering from rough surface, such as the Kirchoff diffraction theory, the Rayleigh-Rice vector perturbation theory, etc. These approaches require the surfaces to be smooth at nanometer-order. Surfaces of objects such as tissue or skin are mostly macroscopically rough, and the incident light is to be often diffusely scattered by these diffuse surfaces. To overcome the limitation of diffraction theory, we have proposed a facet model to analyze the
polarization states of light diffusely scattered light by rough surface. In this paper, we present results of scatter measurements from diffuse glass surfaces with Stokes parameters and polarization degree. The Stokes parameters are analyzed as a function of a virtual scattering angle and a longitude scattering angle. Both the virtual scattering angle and the longitude scattering angle are defined for the facet model. The facet model for scattering from a diffuse surface predicts the polarization states of scattering quite well.

The method and results of this analysis have a significant impact on the application of light scattering to the inspection and process-evaluation industry, material science, etc.

In this paper, we explain advantage of the facet model as well as the limitation of it.

8160-16, Session 3

Comparison of observed full sky polarization to radiative transfer model using AERONET retrieval data

N. J. Pust, A. Dahlberg, J. A. Shaw, Montana State Univ. (United States)

Observed polarization and radiance images from a ground-based full-sky polarimeter are compared against a Successive Order of Scattering (SOS) radiative transfer model for cloud-free days from 2009 to 2011 in Bozeman, Montana, USA. The imaging polarimeter measures radiance and polarization in 10-nm bands centered at 450, 490, 530, 630, and 700 nm. The AERONET-retrieved aerosol optical depth, size distribution, and refractive indices are used as inputs to the SOS model. MISR BRDF retrievals are used for the surface reflectance. We discuss radiance and degree of polarization comparisons between observations and models.

8160-17, Session 3

Exploring the relation between polarized light fields and optical and physical characteristics of the ocean particles for remote sensing applications

A. Ibrahim, A. Tonizzo, A. Gilerson, T. Harmel, I. Ioannou, S. Ahmed, The City College of New York (United States)

Measurements of light intensity, usually from spaceborne sensors, have been used to investigate the optical properties of the constituents of Earth’s ecosystem. In the ocean color research, water-leaving radiance can give useful information about inherent optical properties (IOPs). Additional consideration of polarization of the water-leaving radiance can lead to a better understanding of the physical and optical characteristics of the water body. Polarization properties strongly depend on particle microphysics, such as refractive index, effective radius, size distribution, and single scattering albedo. We used a Neural Network (NN) statistical tool to examine the relations between IOPs of the water medium and their impact on light polarization and to provide a sensitivity analysis of data sets, which were simulated using a fast polarized radiative transfer code named RayXP (Zege et al.) for different water conditions. Because of the complexity of the analysis, and in order to both simulate data and apply NN techniques to it, we simulated two separate data sets. In the first data set, we varied the IOPs and kept particles microphysics constant. In the second data set, particles compositions were varied according to a uniform distribution while keeping the IOPs of the water body fixed. The analysis of the two separate data sets allowed us to develop a comprehensive insight into the effects of oceanic physical and optical properties on the polarization of light, and set the basis for further studies on inversion techniques using polarized light. Results of simulations are compared with measurements obtained using our custom-built underwater hyperspectral multi-angular polarimeter.

8160-18, Session 3

Dual-polarization lidar identification of ice in a corona-producing wave cloud

J. A. Shaw, N. J. Pust, Montana State Univ. (United States)

Corona and iridescence are optical phenomena that create beautifully colored patterns of scattered light in optically thin clouds. The typical explanation is that these displays are caused by sunlight or moonlight being diffracted by small liquid water droplets with diameters near 10 micrometers and relatively uniform droplet size distribution. Ice crystals are generally considered to be too large to create diffraction patterns large enough to be seen by a human observer. However, a few previous publications have shown evidence for the possible existence of unusually small ice crystals that create these displays in clouds at temperatures far too cold to contain even super-cooled liquid water. Both ground-based lidar and airborne particle sampling have been used to confirm this situation in thin cirrus clouds. This paper presents ground-based lidar data that confirms this same situation in a mountain wave cloud.

8160-19, Session 4

Overlay measurement by angle resolved Mueller polarimetry

A. De Martino, C. Fallet, T. Novikova, Ecole Polytechnique (France); C. Vannuffel, Lab. d’Electroinique de Technologie de l’Information (France); B. H. Haj Ibrahim, Ecole Polytechnique (France)

The use of optical metrology techniques for process control is now widespread. They are fast and non-destructive, allowing higher throughputs than non-optical techniques like electron microscopies or AFM.

We present here new developments using complete Mueller polarimetry in the back focal plane of a microscope objective to characterize overlay for microelectronics industry. Based on fundamental symmetries in the physics of periodic structures and polarized light and redundancies in the angle-resolved Mueller images we define estimators which vary linearly with the overlay. As a result, overlay measurement is sensitive to both the direction and sign of the overlay, and it does not require any detailed modelling of the target structures, provided two independent targets with known overlay values are available on the wafer. Realistic simulations on optimized structures suggest that accuracies in the order of 1 or 2 nm or better should be achievable. Moreover, with high NA objectives the proposed technique can be implemented with targets with lateral sizes as small as a few μm.

Experimental results of both grating line profiles and overlay determinations will be presented. The samples, elaborated at LETI, have been accurately characterized by state-of-the-art AFM or optical imaging “box-in-box” techniques.

The latest developments on the device itself as well as the advantages, possibilities and limitations of this new metrology technique will be discussed and some relevant estimators of the overlay will be proposed.

8160-20, Session 4

Spatio-temporal modulated polarimetry

C. F. LaCasse IV, J. S. Tyo, College of Optical Sciences, The Univ. of Arizona (United States)

Recently, a polarimetric data reduction technique has been developed that in the presence of a time varying signal and noise free measurement process can achieve an error free reconstruction provided that the signal was band limited to a limit that is set by the modulation scheme employed. Error free reconstruction for such a signal is not possible using conventional data reduction methods. The new approach provides
Insight for processing arbitrary modulation schemes in space, time, and wavelength. Theory predicts that a polarimeter that employs a spatio-temporal modulation scheme may be able to use the high temporal resolution of a spatially modulated device combined with the high spatial resolution of a temporally modulated system to attain greater combined resolution capabilities than either modulation on scheme can produce alone. A polarimeter that contains both spatial and temporal modulation can be constructed (for example) by placing a rotating retarder in front of a micropolarizer array (microgrid). This study develops theory and analysis for the rotating retarder microgrid polarimeter to show how the available bandwidth for each channel is affected by additional dimensions of modulation and demonstrates a working polarimeter with a simulation of Stokes parameters that are band limited in both space and time with a noisy measurement process.

8160-22, Session 4

**Correction of temporal division polarimeter artifacts with an optical flow technique**

P. Marconnet, L. Gendre, A. Foulonneau, L. Bigué, Univ. de Haute Alsace (France)

The MIPS laboratory has implemented a high-speed portable imaging polarimeter based on the temporal division scheme. As pointed out by many authors in the literature, the temporal division scheme leads to some artifacts when the acquired scene is not static. In a previous work, we presented a first approach to solve this issue. A temporal median filtering was successfully applied to Degree of Polarization images estimated only with two cross-polarized states images. This method permits an attenuation of the artifacts at a very high rate (we implemented it at 300 Hz on a "standard" PC, with a 320x240 image resolution), but it may alter accurate values. Since then, we have rather worked on the implementation in a polarimetric framework of general-purpose motion-compensation-based methods. We considered global registration and block matching methods, but we finally focussed on optical flow techniques such as that presented by Brox et al. Compensating the motion of each state of polarization image allows the polarimeter to estimate the real polarization information as if there was no motion.

In this paper we detail the implementation of our technique and show how it can greatly improve the estimation of the Stokes vector obtained by a division of time polarimeter. In a first time we explain how a motion compensation technique can be adapted to such a polarimeter, then we give some details about our implementation of the optical flow technique. Finally, comparison between various implementations is provided using synthetic and experimental data in the case when full linear polarization (i.e. the first three Stokes components) is considered.

8160-23, Session 4

**Stokes vector analysis of LWIR polarimetric in adverse weather**

J. M. Romano, L. E. Roth, J. Michalson, U.S. Army Armament Research, Development and Engineering Ctr. (United States)

It is understood that LWIR polarimetric imagery has the potential in detecting man-made objects in natural clutter backgrounds. Unlike Spectral and conventional broadband, polarimetric imagery takes advantage of the polarized signals emitted by the smooth surfaces of man-made materials. Studying the effect of how meteorological conditions affect polarization signals is imperative in order to understand where and how polarimetric technology can be beneficial to the warfighter. In the proposed paper we intend to demonstrate the effects of weather on the performance of Stokes vector components, S1 and S2, and the degree of linear polarization (DOLP) as detectors of man-made materials. Using the SPICE data collection, we analyze over 1,000 images and correlate the performance of each of the detection metrics to individual meteorological measurements. The chosen metrics for such analysis are: AUC or area under the curve and optimum ROC point. By using such metrics we are able to correlate background and target variability in order to understand the underlying trends between target signature and background clutter to the different weather conditions parameters.

8160-43, Session 4

**Vehicle tracking through the exploitation of remote sensing and LWIR polarization science**

H. S. Clouse, H. Krim, North Carolina State Univ. (United States); W. A. Sakla, O. Mendoza-Schrock, Air Force Research Lab. (United States)

Vehicle tracking is an integral component in layered sensing exploitation applications. The utilization of a combination of sensing modalities and processing techniques provides better insight about a situation than can be achieved with a single sensing modality. In this work, several robust features are explored for vehicle tracking using data captured in a remote sensing setting. Particularly, a video sequence is evaluated in a layered sensing framework. The target area is surveyed by two sensors operating across two different modalities: a LWIR polarized sensor and a LWIR sensor. We here extend our previous work (§1) to experimental analysis on several feature sets including three classic features (Stokes images, DoLP, the Degree of Linear Polarization, and AoP, the Angle of Polarization) and two experimental features (p, an extension of the DoLP, and δ, the phase difference between two orthogonal projections of an observed electromagnetic wave).

8160-24, Session 5

**On the optimization of polarimetric imaging systems for target detection**

F. Goudall, G. Anna, Institut d’Optique Graduate School (France)

Active polarimetric imaging systems consist of illuminating a scene with polarized light and analyzing the polarization state of the scattered light before forming the image. They are invaluable tools for detecting objects in biomedical or remote sensing applications since they can reveal contrasts that do not appear in classical images. However, such systems usually have higher cost and complexity than standard imagers, and their complexity grows with the number of measurements they require (e.g., measurements for a Stokes imager, 16 for a Mueller imager). Important issues are thus to determine under which condition they yield better performance than simple intensity Imaging, and what is their optimal number of measurements. Recent advances have made it possible to give quantitative answers to these questions, and we will illustrate these results on two examples.

First, we will compare the contrasts obtained with Mueller, Stokes and single (scalar) polarimetric measurements in the presence of additive noise. We will show that the best contrast is always obtained with a single measurement performed with optimized illumination and analysis states. Second, we will quantitatively determine the conditions in which polarimetric imaging yields better performance than classical intensity imaging, and the conditions in which polarized illumination is preferable to illumination with natural light. We will show in particular that the answers to these questions depend on the statistics of the noise that perturbs the image.
8160-25, Session 5

Observations on the Polarimetric Imagery Collection Experiment database

M. C. Woolley, J. Michalsohn, J. M. Romano, U.S. Army Armament Research, Development and Engineering Ctr. (United States); D. B. Chenault, Polaris Sensor Technologies, Inc. (United States)

The Spectral and Polarimetric Imagery Collection Experiment (SPICE) is an ongoing collaborative effort that commenced in February 2010 between the US Army ARDEC and ARL. SPICE is focused on the collection of mid-wave and long-wave infrared imagery using hyperspectral, polarimetric, and broadband sensors.

The overall objective of SPICE is to collect a comprehensive database of the different modalities spanning multiple years to capture sensor performance encompassing a wide variety of meteorological (MET) conditions, diurnal, and seasonal changes inherent to Picatinny's northern New Jersey location.

Utilizing the Precision Armament Laboratory (PAL) tower at Picatinny Arsenal, the sensors are autonomously collecting the desired data around the clock at multiple ranges containing surrogate 253 Self-Propelled Howitzer targets positioned at different orientations in an open woodland field. This database allows for: 1) Understanding of signature variability under adverse weather conditions; 2) Development of robust algorithms; 3) Development of new sensors; 4) Evaluation of polarimetric technology; and 5) Evaluation of fusing the different sensor modalities.

In this paper, we will revisit the SPICE data collection objectives and the sensors deployed. We will present, in a statistical sense, the integrity of the data in the long-wave infrared (LWIR) polarimetric database collected from February through September 2010 and issues and lessons learned associated with a fully autonomous, around the clock data collection. We will also demonstrate sample LWIR polarimetric imagery and the performance of the Stokes parameters under adverse weather conditions.

8160-27, Session 6

Study of Stokes polarimeters based on a single twisted nematic liquid crystal panel

A. Peinado, A. Lizana, Univ. Autònoma de Barcelona (Spain); J. Vidal González, Univ. Autònoma de Barcelona (Spain) and CELLS - ALBA (Spain); C. C. Iemmi, Univ. de Buenos Aires (Argentina); J. Campos, Univ. Autònoma de Barcelona (Spain)

Polarimeters are the basic instruments to perform polarization metrology. Nowadays, they are present in many scientific and industrial applications. For instance, in a burn depth assessment for injured patients, scanning living retinal tissues, in solar imaging, in the characterization of photonic structures and detecting buried landmines.

By taking advantage that Liquid Crystal Displays act as variable retarders depending on the voltage addressed, many authors have introduced them on the setups allowing to perform dynamic polarimetric measurements. Consequently, these instruments avoid experimental errors from misalignment by conducting an accurate calibration.

In this work, we present the design, optimization and implementation of dynamic Stokes polarimeters based on a single Twisted Nematic Liquid Crystal (TNLC) panel. TNLC material enables both to introduce a retardance and to rotate the polarization ellipse orientation. For this reason, a simple setup composed by a transmissive TNLC panel and a polarizer can be built leading to a complete Stokes polarimeter. Variations of the initial setup are analyzed with the aim of minimizing the noise propagation to the Stokes vector calculations. In particular, working out of normal incidence to the TNLC panel and working on TNLC reflective mode. Moreover, we carry out an optimization of the polarization analyzers used in each configuration. Finally, we implement the optimized polarimeters and some incident Stokes vectors are measured, proving their correct operation. Results are compared with those provided by the optimal polarimeter based on a two Parallel Aligned LCD panels and so, the suitability of applying a TNLC panel on polarimeters design is confirmed.

8160-28, Session 7

Channeled spectropolarimeter using a wavelength-scanning laser and a channeled spectroscopic polarization state generator

K. Oka, T. Kinoshita, A. Ise, Hokkaido Univ. (Japan)

Channeled spectropolarimetry is a method to measure polarimetric characteristics of a light or an object utilizing the strong dispersions of high order retarders. This method requires no mechanical polarization-modulation elements and it can determine plural polarimetric parameters from a single channeled spectrum. In the previous implementations of this method, a spectrometer in the receiving optics is mainly employed for the acquisition of the channeled spectrum. This presentation discuss about another implementation of the channeled spectropolarimeter that uses a wavelength-scanning laser and a channeled spectroscopic polarization state generator (CSPSG).

This implementation has a feature that it is applicable for the spatial mapping of the polarimetric parameters. For this type of measurement, the wavelength-scanned laser light emerging from the CSPSG is expanded in diameter and then illuminates the object whose polarimetric characteristics depend on the spatial coordinates. Since no spectrometer is used and both the wavelength scanning and the polarization modulation are made by the illumination optics, an imaging optics followed by a CCD camera can be easily incorporated in the receiving optics. Two-dimensional distributions of the polarimetric parameters of the object can be determined from the flickering images. This principle was experimentally demonstrated by use of a laser diode and a CSPSG made of calcite.

Another feature of the channeled spectropolarimeter using a wavelength-scanning laser is its capability for the high wavelength-resolution acquisition of the channeled spectrum. This feature is useful for the
applications such as the full Mueller matrix measurement by use of four high-order retarders.

8160-29, Session 7

Preliminary results from an infrared hyperspectral imaging polarimeter

J. Craven-Jones, M. W. Kudinov, M. G. Stapelbroek, E. L. Dereniaik, College of Optical Sciences, The Univ. of Arizona (United States)

We present results from a SWIR/MWIR infrared hyperspectral imaging polarimeter (IHIP). The sensor includes a pair of sapphire Wollaston prisms and several high order retarders to form an imaging Fourier transform spectropolarimeter. The Wollaston prisms serve as a birefringent interferometer with reduced sensitivity to vibration versus an unequal path interferometer, such as a Michelson. Polarimetric data are acquired through the use of channeled spectropolarimetry to modulate the spectrum with the Stokes parameter information. The collected interferogram is Fourier filtered and reconstructed to recover the spatially and spectrally varying Stokes vector data across the image. The IHIP operates over a +/-5 degree field of view and implements a dual-scan false signature reduction technique to suppress polarimetric aliasing artifacts. In this paper, we discuss the layout and operation of the IHIP sensor, in addition to the radiometric, spectral, and polarimetric calibration techniques. Lastly, spectral and spectropolarimetric results from the laboratory and outdoor tests with the instrument are presented.

8160-30, Session 7

Spectorsocpic Stokes polarimeter based on dual liquid crystal modulators

M. Tanaka, Y. Nakashima, H. Amamiya, Atago Co., Ltd. (Japan); Y. Otani, Utsunomiya Univ. (Japan)

The purpose of this research is to establish a spectroscopic Stokes polarimeter based on dual liquid crystal modulators, which are consisted of two types of phase modulator by nematic liquid crystal. It is powerful tool with some superior characteristics, non-mechanical, miniature and low consumption electricity. The polarization states of light are expressed by 4 parameters called Stokes parameters. We evaluated all Stokes parameters using some samples that are used for the evaluation of Stokes parameters by birefringence of Babinet-Soleil compensator.

8160-31, Session 7

Spectrally broadband channeled imaging polarimeter using polarization gratings

M. W. Kudinov, College of Optical Sciences, The Univ. of Arizona (United States); M. J. Escuti, North Carolina State Univ. (United States); E. L. Dereniaik, The Univ. of Arizona (United States); K. Oka, Hokkaido Univ. (Japan)

A snapshot channeled linear imaging (CLI) polarimeter is demonstrated by incorporating two identical polarization gratings (PGs) into a shearing polarization interferometer. Placing the PGs in series causes the shear to become linearly proportional to the wavelength, thereby generating white-light polarization fringes at the focal point of an imaging lens. These fringes amplitude modulate the incident Stokes parameters corresponding to linearly polarized light (S0, S1, and S2). In this paper, we theoretically and experimentally demonstrate the CLI polarimeter. Additional validation of the technique is conducted through outdoor measurements of moving targets. Furthermore, extending the CLI polarimeter’s measurement capacity to include circularly polarized light is overviewed with theoretical calculations. This would make the instrument capable of measuring a complete Stokes vector image (S0, S1, S2, and S3) in white-light.

8160-32, Session 7

A pixelated micropolarimeter-based camera for instantaneous interferometric measurements

N. Brock, 4D Technology Corp. (United States)

A pixel-level micropolarimeter array bonded to a scientific camera has been developed for use in commercial dynamic interferometers. The pixelated array includes the 0, 45, 90, 135 degree polarizations. Micropolarizer arrays with elements as small as 7.4 microns have been fabricated for use across the visible spectrum.

8160-33, Session 7

Full Stokes polarization camera

M. Vedel, S. Breugnot, Bossa Nova Technologies (United States)

Objective and background: We present a new version of Bossa Nova Technologies’ passive polarization imaging camera. The previous version was performing live measurement of the Linear Stokes parameters (S0, S1, S2), and its derivatives (DOLP, AOP and others). This new version presented in this paper performs live measurement of Full Stokes parameters, i.e. including the fourth parameter S3 related to the amount of circular polarization. A dedicated software was developed to provide live images of any Stokes related parameters such as the Degree Of Linear Polarization, the Degree Of Circular Polarization, the Angle Of Polarization among others.

Results: First we give a brief description of the camera and its technology. It is a Division Of Time Polarimeter using a custom ferroelectric liquid crystal cell. A description of the method used to calculate Data Reduction Matrix (DRM) linking intensity measurements and the Stokes parameters is given. The calibration was developed in order to maximize the condition number of the DRM. It also allows very efficient post processing of the images acquired. Complete evaluation of the precision of standard polarization parameters is described. Then we present the standard features of the dedicated software that was developed to run the camera. It provides live images of the Stokes vector components and the usual associated parameters. Finally some tests already conducted are presented. It includes indoor laboratory and outdoor measurements. This new camera will be and useful tool for many application such as biomedical, remote sensing, metrology, material studies, and others.

8160-34, Session 8

Imaging polarimeters based on liquid crystal variable retarders: an emergent technology for space instrumentation

A. Alvarez-Herrero, N. Uribe-Patarrayo, P. García Parejo, J. Vargas, R. L. Heredero, R. Restrepo, Instituto Nacional de Técnica Aeroespacial (Spain); V. Martínez-Pillet, Instituto de Astrofísica de Canarias (Spain); J. C. del Toro Iniesta, A. López, Instituto de Astrofísica de Andalucía (Spain); S. Fineschi, G. Capobianco, Istituto Nazionale di Astronomia (Italy); M. Georges, Univ. de Liège (Belgium); M. López, Visual Display S.L.L. (Spain); G. Boer, Arcoptix S.A. (Switzerland); I. G. Manolis, European Space Research and Technology Ctr. (Netherlands)

Polarimetric remote sensing in the range of the radar wavelengths has demonstrated its importance in many applications; however this
technique applied in the optical range is a relative new field which interest is quickly increasing. Applications in solar physics, astronomy, even earth observation are being extensively developed.

In this context, the use of Liquid Crystal Variable Retarders (LCVRs) as polarization modulators are envisaged as a promising novel technique for space instrumentation due to the advantage of avoiding the utilization of traditional rotary polarizing optics which implies the inclusion of mechanisms. LCVRs is a mature technology for ground applications; they are well-know and during the last ten years have undergone an important development, driven by the fast expansion of commercial Liquid Crystal Displays.

In this work a review of the state of the art of imaging polarimeters based on LCVRs is presented. All of them are ground instruments, except the solar magnetograph iMx which flew in 2009 onboard of a stratospheric balloon as part of the SUNRISE mission payload, since we have no knowledge about spaceborne polarimeters using liquid crystal up to now. Likewise, an assessment report of the possible effects of the space environmental conditions on the LCVRs is presented. Finally, the baseline of the polarisation modulation package including LCVRs of the instruments PHI (Polarimetric and Helioseismic Imager) and METIS/COR (Multi Element Telescope for Imaging and Spectroscopy, Coronagraph) for Solar Orbiter will be described briefly as well as the activity, currently in progress, to validate this technology for the mission.

8160-36, Session 8

MgII linear polarization measurements using the MSFC Solar Ultraviolet Magnetograph

e. a. west, j. curtian, nasa marshall space flight ctr. (united states); k. kobayashi, g. a. gary, j. m. davis, the univ. of alabama in huntsville (united states)

This paper will describe the Marshall Space Flight Center’s Solar Ultraviolet Magnetograph Investigation (SUMI) sounding rocket program, with emphasis on the polarization characteristics of the VUV optics and their spectral, spatial and polarization resolution. SUMI’s first flight (7/30/2010) met all of its mission success criteria and this paper will describe the data that was acquired with emphasis on the MgII linear polarization measurements.

8160-37, Poster Session

Achromatic, athermalized retarder fabrication

A. Mahler, S. McClain, R. A. Chipman, College of Optical Sciences, The Univ. of Arizona (United States)

A retarder made from sapphire, MgF2 and quartz was designed, fabricated and its performance validated for the 0.47 m to 0.865 m wavelength region. Its specifications are as follows: at wavebands centered at 0.470 m, 0.660 m, and 0.865 m, the band-averaged retardance should be 90° ± 10° for all fields and retardance should change less than 0.1° for a 1° change in temperature. Analysis indicated that a design specified by thickness alone was unlikely to meet the requirements due to uncertainties in birefringence. To address this, the following fabrication method was developed that involves monitoring retardance during polishing. The first plate was polished to a target thickness. The retardance spectrum of the first plate was then measured and used to determine a retardance target for the second plate. The retardance spectrum of the combined first and second plates was then used to specify a retardance target for the third plate. The retardance spectrum of the three plates in combination was then used to determine when the final thickness of the third plate was reached.

8160-38, Poster Session

Large format HgCdTe focal plane arrays for dual-band long-wavelength infrared detection

N. R. Malone, Raytheon Co. (United States)

Polarimetry sensor development has been in work for some time to determine the best use of polarimetry to differentiate between manmade objects and objects made by nature. Both MWIR and LWIR Focal Plane Arrays (FPAs) have been built at Raytheon Vision Systems each with exceedingly higher extinction ratios. LWIR polarimetry has the largest polarimetric signal level and an emissive polarimetric signature which allows detection at thermal crossover and is less dependent on sun angles. Polished angled glass and metal objects are easily detected using LWIR polarimetry. While LWIR polarimetry has many advantages its resolution is not as good as MWIR.

To gain acceptance polarimetric sensors must provide intelligence signatures that are better than existing non-polarimetric Infrared sensors.

8160-39, Poster Session

Broadband Mueller matrix polarimeter

P. Raman, K. A. Fuller, D. A. Gregory, The Univ. of Alabama in Huntsville (United States)

A dual rotating retarder Mueller matrix polarimeter will be described.
that operates in the UV-VIS-NIR region. The components were selected to allow the instrument to span the 300 nm to 1100 nm region with a resolution of 2nm. Complete Mueller matrix polarimetric characterizations of a host of optical components have been performed and a select few will be presented. This instrumentation is expected to enable exploratory research into novel methods for point and standoff detection of chemical and biological threats in the atmosphere. To this end, surrogates of hazardous materials as well as background aerosols must be characterized and differentiating features in the polarization properties correlated to specific morphologies. This potential capability is currently being explored and preliminary results will be presented.

8160-40, Poster Session

A comparison of polarization image processing across different platforms
T. York, S. Powell, R. D. Chamberlain, V. Gruve, Washington Univ. in St. Louis (United States)

Division-of-focal-plane (DoFP) polarimeters for the visible spectrum hold the promise of being able to capture both angle and degree of linear polarization in real time and at high spatial resolution. These sensors are realized by monolithic integration of CCD imaging elements with metallic nanowire polarization filter arrays at the focal plane of the sensor. These novel sensors capture large amounts of raw polarization data and present unique computational challenges as they aim to provide polarimetric information at high spatial and temporal resolution. The image processing pipeline in a typical DoFP polarimeter is: dead-pixel compensation, per-pixel gain and offset correction, interpolation of the four sub-sampled polarization pixels, Stokes parameter estimation, angle and degree of linear polarization estimation, and conversion from polarization domain to color space for display purposes. The entire image processing pipeline must operate at the same frame rate as the CCD polarization imaging sensor (40 frames per second) or higher in order to enable real-time extraction of the polarization properties from the imaged environment. To achieve the necessary frame rate, we have implemented and evaluated the image processing pipeline on four different platforms. The first two implementations of the image processing pipeline are for a general purpose CPU using single threaded and multi-threaded paradigms. The third implementation is for a general purpose graphics processor (GPU) and the fourth is for an embedded FPGA platform. The computational throughput, power consumption, precision and physical limitations of the four implementations are described in detail and experimental data is provided.

8160-41, Poster Session

Hyperspectral measurement of the scattering of polarized light by skin
A. Alenin, College of Optical Sciences, The Univ. of Arizona (United States); L. Morrison, C. Curiel, The Univ. of Arizona (United States); J. S. Tyo, College of Optical Sciences, The Univ. of Arizona (United States)

The goal of this study is to develop a dedicated spectropolarimeter for purposes of assessing polarization signatures in skin scattering on a regional scale. Prior research has that certain skin lesions have identifiable polarization signatures; however, those studies were limited to single lesion evaluation and do not account for the task of diagnosing a patient with a significant number of lesions over a wide area. A spectropolarimeter with enough resolution to capture whole-body images would be extremely useful in identifying and monitoring the progress of lesions of interest, as well as enabling much earlier detection of cancerous and potentially life threatening lesions. As a precursor to the future instrument, a simpler actively illuminated Stokes spectropolarimeter was constructed to ensure the viability of such a device. This spectropolarimeter consists of a rotating retarder and a hyperspectral camera, which scans through wavelengths by means of a Liquid Crystal Tuning Filter (LCTF). Data is captured in a serial fashion, where LCTF scans through eight wavelengths at each of the four retarder orientations. With a single acquisition taking 23 seconds to complete, it makes the issue of image registration very important. After proper alignment, the acquired images reveal that polarization sensing has merit even on a regional scale. In particular, it was found that polarization factors such as Degree of Linear Polarization (DoLP) tend to suppress many uninteresting skin features like wrinkles and skin texture, while capturing information that is not necessarily apparent in the intensity image.

8160-42, Poster Session

Multispectral measurements of atmospheric aerosols over an urban area
M. Yasumoto, Kinki Univ. (Japan)

Polarization measurements of atmospheric aerosols have been undertaken with a portable multi-spectral polarimeter (PSR-1000) since 1996 at Kinki University campus in Higashi-Osaka in Japan, where such various instruments as NASA/AERONET photometer, PM sampler (PM2.5/PM10/OBC Dichotomous Monitor), sky camera and Mie-scattering-polarization LIDAR are set up for monitoring of the atmospheric environment. For estimation of aerosol characteristics, e.g. optical thickness of aerosols, size distribution parameters etc, PSR-1000 observes radiance of the direct sunlight and radiance/polarization of atmospheric light at wavelengths of 443, 490, 565, 670, 765 and 865nm. PSR-1000 has been calibrated once a year based on Langley plot method at Mt. Haleakala Observatory in Maui Island in Hawaii. In order to improve the derivation of aerosol optical thickness (AOT), precise correction of molecular scattering and gaseous absorption is desired. Therefore the gaseous absorption by water vapor at 565, 670, 765, and 865nm, O2 at 670 and 765nm and NO2 for 443 and 490nm are reexamined at present. It is of interest to mention that PSR-1000 detects atmospheric particles over an urban area recorded among our long-term observations.

8160-44, Poster Session

Use of polarization imaging in air-to-air detection systems
S. Bencuya, C. A. White, S. Lin, EmergentViews, Inc. (United States)

Polarization imaging can substantially enhance detection of aircraft due to the high polarization contrast of sky and manmade objects. Air-to-air detection tests using polarization cameras were conducted for the development of a Detect Sense and Avoid (DSA) system that can be used by unmanned aircraft systems (UAS) navigating in the U.S. national airspace system (NAS). A visible spectrum polarization camera equipped with a custom pixilated wire grid polarizer was developed for this project. The flight tests were structured to compare the performance of this polarization-camera to that of a reference conventional-camera at different flight orientations, altitudes and times of day. A number of different polarization image processing algorithms were evaluated. A precision kernel interpolation method developed specifically for pixilated polarization cameras was determined to best maintain the native resolution of the image sensor. A novel polarization algorithm combining intensity and polarization data was constructed that clearly outperformed all other methods evaluated. Under good visibility conditions that were not expected to favor polarization, detection range or available evasion response time, was improved by an average of 2000 feet. Under the 250 knot closing rate conditions of this test, the increase in response time available is 4 seconds. Even under the 500 knot worst case closing rate scenario for airspace under 10,000 feet, the increased available response time is 2
seconds.
The tests also demonstrated that conditions that differentially favor polarization camera are significantly broader than anticipated. In particular, orthogonal sun-to-camera orientation yields clearly better results. Given the prevalence of this condition (the 70% of the day when the sun angle is not very low in the sky plus all headings either not directly toward or away from the sun when it is low in the sky) this implies that the polarization would provide improvement in optical DSA performance in the vast majority of flights.
8161-01, Session 1

**Atmospheric scintillations and laser safety**

A. Zilberman, E. Golbraikh, N. S. Kopeika, Ben-Gurion Univ. of the Negev (Israel)

Laser devices are currently in widespread use in particular by armed forces for different tasks. Electro-optical sensors as well as unprotected human eyes are extremely sensitive to laser radiation and can be permanently damaged from direct or reflected beams. Laser damage depends on the interaction between the laser beam and the atmosphere in which it traverses. The atmospheric conditions, including the range, terrain features, turbulence, and atmospheric particulates, may alter the laser’s effect on different electro-optical devices and systems.

When a laser beam passes through the atmosphere the refractive index inhomogeneities or optical turbulence affect the beam. As a result, temporal intensity fluctuations (scintillations) or spatial variation in intensity within a beam cross-section occur, which give rise to a rapidly varying pattern of bright and dark patches or “hot spots” at the observation or target plane. The “hot spots” are areas where the localized beam irradiance is greater than the average across the beam.

Atmospheric scintillations pose a safety problem because small turbulent eddies and associated scintillation spots can move in an unpredictable way within the laser beam, so that an observer or sensor can be subjected to the risk of a localized irradiance (local focusing effect) much greater than that which would occur in a non-turbulent medium.

In the present work, the influence of the atmospheric channel on laser safety is investigated by use of experimental data of laser beam propagation statistics for different scenarios and atmospheric conditions. The results can be important in the area of laser remote sensing, wireless optical communications, and active imaging.

8161-03, Session 1

**Arago spot and turbulent distortions**

M. I. Charnotskii, Zel Technologies, LLC (United States)

Arago (Poisson) spot is a small bright spot that is formed in the shadow of the circular obscurer, and is typically observed on the image of the entrance pupil of the Cassegrain-type telescopes. The coherent nature of the Arago spot makes it susceptible to the turbulence-induced distortions of the incident wave. Since Arago spot is easily accessible in the common free-space optical communication system, it provides a convenient way to measure the turbulence effects on the propagation path without interfering with the principal function of the optical system.

We describe the formation of the Arago spot for the annular aperture using the Fresnel optics technique, and develop a simple equation for the field and irradiance distributions in the center of the shadow area behind an obscurer. We show that, consistent with the Fresnel zone theory, the presence of the larger aperture causes the axial irradiance oscillate along the optical axis, with Arago spots changing from the unimodal to the ring shape between the maxima and minima.

We calculate the effect of the atmospheric turbulence on the average intensity distribution in the Arago spots, and propose the axial contrast degradation as a potential measure of the turbulence perturbation. Random wander of the Arago spot caused by turbulence can be an alternative way to estimate the turbulence effects. We calculate the variance of the turbulent wander, and relate it to the turbulence structure constant distribution along the propagation path. Finally, we calculate the scintillation index on the Arago spot axis, and analyze the parameters determining the weak and strong scintillation conditions for the unimodal and ring-type Arago spots.

8161-04, Session 2

**Adaptive optics solutions for turbulence mitigation in different scenarios**

G. Marchi, C. Scheifling, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Several studies on different adaptive optics concept are presented in the article. Each of the adaptive optics procedures shows its peculiar advantages when considering different situations where the image distortion due to atmospheric or artificial turbulence becomes problematic.

A setup based on the usual wavefront reconstruction techniques using a Shack-Hartmann wavefront sensor in a closed loop with a deformable mirror and a computer is shown. The reconstruction method follows the modal compensation which has been demonstrated to be more robust and suitable than the zonal one concerning the correction of the first Zernike polynomials. Some turbulence compensation results deriving from the studies are reported. A second procedure based on the control of a deformable mirror through a fast iterative procedure is also treated and the relative results about the compensation of laser beams as well as extended images are also shown.

A third concept, based on holographic wavefront sensing, is also presented together with the main steps in the development and application of this promising technique. A final part in the article describes the measurements and the characteristics of the atmospheric turbulence present in direct tests.

8161-05, Session 2

**The effect of free parameter estimates on the reconstruction of images corrupted by horizontal turbulence using the bispectrum**

J. Bos, M. C. Roggeman, Michigan Technological Univ. (United States)

In our previous work we quantified the performance improvement resulting from using the bispectrum to reconstruct extended scenes from image sets corrupted by atmospheric seeing over horizontal path. Here we expand on that work and explore claims in literature that image reconstruction quality using the bispectrum is relatively immune to poor estimates of the point spread function used for amplitude estimation. Similar claims have been made regarding the number of paths used in the bispectrum phase estimate. The performance bounds of each of these parameters are explored in terms of the MSE of the resulting reconstructions relative to a diffraction-limited reference image. We have found that as using more than six distinct phase paths in the bispectrum phase estimate does not result in improvement enough to justify the additional computation time. Similarly, estimates of the turbulence strength used in the inverse filter PSF may deviate from the optimum by 50% or more while incurring only a 10% reduction in MSE improvement for low to moderate turbulence conditions.

8161-06, Session 2

**Simulation of extended scenes imaged through turbulence over horizontal paths**

J. Bos, M. C. Roggeman, Michigan Technological Univ. (United States)

We describe the formation of the Arago spot for the annular aperture using the Fresnel optics technique, and develop a simple equation for the field and irradiance distributions in the center of the shadow area behind an obscurer. We show that, consistent with the Fresnel zone theory, the presence of the larger aperture causes the axial irradiance oscillate along the optical axis, with Arago spots changing from the unimodal to the ring shape between the maxima and minima.

We calculate the effect of the atmospheric turbulence on the average intensity distribution in the Arago spots, and propose the axial contrast degradation as a potential measure of the turbulence perturbation. Random wander of the Arago spot caused by turbulence can be an alternative way to estimate the turbulence effects. We calculate the variance of the turbulent wander, and relate it to the turbulence structure constant distribution along the propagation path. Finally, we calculate the scintillation index on the Arago spot axis, and analyze the parameters determining the weak and strong scintillation conditions for the unimodal and ring-type Arago spots.
We have developed an imaging simulator which accounts for the anisoplanatic effects encountered while imaging extended scenes over horizontal paths. Using a geometric optics approach, an extended scene is divided into discrete point source. For each point source a ray is traced through discrete Kolmogorov-turbulence phase screens toward each pixel in virtual detector. The resulting images express non-uniform tilt and distortion characteristics typical in horizontal surveillance imagery. Using this simulator several large data sets were created based on a known high-resolution source image. By utilizing turbulence corrupted image sets with a known reference image, the performance of image reconstruction techniques can be expressed in terms of common metrics such as Mean Squared Error (MSE). The MSE statistics of a single image corrupted using the simulator over three turbulence conditions are examined relative to a diffraction-limited version of the reference image. To fully explore the statistics of images created by the simulator, 1000 frames have been generated.

8161-07, Session 2

Anisoplanatic wavefront error estimation using coherent imaging

R. L. Kendrick, Lockheed Martin Advanced Technology Ctr. (United States)

We have developed a technique for extracting atmospheric turbulence induced wavefront error by means of digital holography. The technique enables wavefront error determination as a function of field angle. Closed form expressions for the anisoplanatic wavefront error caused by atmospheric turbulence have been developed for comparison. We show very good agreement between experimental data and the closed form solution. The comparison is made over Cn2 values from approximately 10-12 to 10-15 m^-2/3.

8161-08, Session 3

The Advanced Navy Aerosol Model (ANAM): validation of small-particle modes

A. M. J. van Eijk, TNO Defence, Security and Safety (Netherlands); J. T. Kusmierczyk-Michulec, Institute of Oceanography (Poland); A. Demoisson, J. J. Piazzola, Univ. du Sud Toulon-Var (France)

The Advanced Navy Aerosol Model (ANAM) aims at providing an estimate of aerosol extinction in the maritime environment. Over the years, various upgrades have been implemented to accommodate the coastal zone, which is characterized by a mixture of maritime and land-originated aerosols. The present contribution reports on a validation experiment at Porquerolles Isalnd in Southern France, specifically aiming at the validation of the smaller (continental) particle modes.

8161-09, Session 3

Optical propagation profiles for shipboard application: turbulence and extinction

B. Bachmann, S. M. Hammel, Space and Naval Warfare Systems Ctr. Pacific (United States)

We describe work that will enable the comparison of collected data to beam propagation models. Optical and meteorological data will be collected over various angles of geometry during an ongoing electro-optical field campaign. Turbulence and aerosol extinction play a critical role in the maritime environment of Navy vessels, and observed extinction estimates would serve to determine model fidelity in a shipboard engagement scenario.

8161-10, Session 3

Application of year-round atmospheric transmission data, collected with the MSRT multiband transmissometer during the FATMOSE trial in the False Bay area

A. N. de Jong, TNO Defence, Security and Safety (Netherlands)

The FATMOSE trial (False Bay Atmospheric Experiment) is a continuation of the cooperative work between TNO and IMT on atmospheric propagation and point target detection and identification in a maritime environment (South Africa). The atmospheric transmission, being of major importance for target detection, was measured with the MSRT multiband optical/IR transmissometer over a path of 15.7 km over sea. Simultaneously a set of instruments was installed on a mid-path lighthouse for collection of local meteorological data, including turbulence, scintillation, sea surface temperature and visibility. The multiband transmission data allow the retrieval of the size distribution (PSD) of the particles (aerosols) in the transmission path. The retrieved PSDs can be correlated with the weather data such as windspeed, wind direction, relative humidity and visibility. This knowledge will lead to better atmospheric propagation models. The measurement period covered nearly a full year, starting in November 2009 and ending in October 2010. The False Bay site is ideal for studies on propagation effects over sea because of the large variety of weather conditions, including high wind speed from the South East with maritime air masses as well as Northerly winds, bringing warm and dry air from the continent. From an operational point of view the False Bay area is interesting, being representative for the scenery around the African coast with warships in an active protecting role in the battle against piracy. The year-round transmission data are an important input for range performance calculations of electro-optical sensors against maritime targets. The data support the choice of the proper spectral band and contain statistical information about the ranges to be expected. In the paper details on the instrumentation will be explained as well as the methods of calibration and PSD retrieval. Data are presented for various weather conditions, showing correlations between different parameters and including statistical behaviour over the year. Examples will be shown of special conditions such as refractive gain, gravity waves and showers.

8161-11, Session 3

Scintillation measurements over False Bay, South Africa

M. van Iersel, A. M. J. van Eijk, TNO Defence, Security and Safety (Netherlands)

A commercial long-range scintillometer was deployed over a 2-km path in False Bay, South Africa, for a timeframe of more than 1 year. The turbulence data retrieved from the instrument is compared to turbulence parameters inferred from micrometeorological data and models, and the relation between experimental and model-data is explored.

8161-12, Session 4

Long-range beam propagation for single-photon communications

I. Capraro, A. Tormaello, A. Dall’Arche, P. Villoresi, Univ. degli Studi di Padova (Italy)

The optical propagation in atmosphere for links of over 100 km in length is affected by several transformations of the beam parameters, resulting in an increase of the link losses. The long range optical communication at the single photon limit exploiting the quantum protocols, on the other side, differs from the classical protocols in that the signal to be transmitted cannot be intensified, being a train of very weak pulses with an average about one photon per pulse. The understanding of the
propagation induced effects in both the irradiance at the receiver as well as in the temporal statistics is crucial to assess the quality of the communication and eventually the feasibility of the link. Moreover, due to large wandering of the beam centroid, the induced losses due to decoupling of the beam with the receiver are severe.

We address in this work the propagation of optical beams in scale length of several tens to a few hundreds kilometres, introducing in the experiment the collection of the whole beam combined to the measure of local irradiance at the receiver side. In addition, with the aim to stabilize the centroid position at the receiver, the propagation of two beams forming a small mutual angle is studied in the framework of the isoplanatic angle spread for low and high orders of the beam spatial modes.

The experimental models were realized in different localities of Italian Alps as well as between Tenerife and La Palma Islands of the Canary archipelagos. The whole beam at the receiver was acquired and the scintillation analysis carried out and compared to models including the local meteorological conditions.

Our study aims to point out the optimal configuration for the optical setup for the long range quantum communications, as well as to predict the modifications of the photon statistics.

8161-13, Session 4
Impact of optical turbulence on sparse aperture imaging
M. M. Bold, Lockheed Martin Space Systems Co. (United States)

Sparse aperture telescope arrays are increasingly being used for ground based imaging of stellar and resident space objects and for making astrometric measurements as they provide exquisite angular resolution without heroic efforts to construct very large monolithic telescopes. Still, sparse aperture arrays are impacted by optical turbulence yet in some ways they make mitigation of turbulence effects easier. This paper will survey the different approaches for sparse aperture imaging arrays, discuss the impacts of optical turbulence and approaches for mitigating optical turbulence effects.

8161-14, Session 4
Design of a differential image motion monitor for measurement of optical turbulence in support of dynamic range tests
R. Dewees, Naval Air Warfare Ctr. Aircraft Div. (United States)

We report on the development, construction, and use of a Differential Image Motion Monitor (DIMM) for measuring optical atmospheric turbulence over static, semi-dynamic, and dynamic maritime ranges. The optical properties of the DIMM that make it suitable for such measurements will be presented along with a detailed overview of its software systems. Particular emphasis will be given to the numerical methods, image feature recognition, and learning filters implemented in the DIMM software. We conclude with examples of measurements we have taken over static desert ranges at China Lake and over dynamic ship-to-boat ranges at sea.

8161-15, Session 4
Measurement and modeling of beam wander
S. M. Hammel, K. McBryde, Space and Naval Warfare Systems Command (United States)

We investigate the effects of beam wander on an uncorrected laser system. We use field experiments to investigate atmospheric propagation effects, and the variation in irradiance at the receiver position is measured in several different ways. We present appropriate models for the beam fluctuations and discuss the comparison between model and experimental data.

8161-16, Session 4
Measurement and impact of inner scale of turbulence and temporal variation in turbulence strength
T. J. Brennan, D. C. Mann, Optical Sciences Co. (United States)

Predictions of optical performance degradation due to turbulence, whether analytic predictions or detailed physical optics simulations, often neglect the impact of short term temporal variation in turbulence strength and the inner scale of turbulence. Typical techniques for measuring turbulence parameters are only able to capture average and long term trend data. Subsequent performance modeling is generally parameterized by r0 without consideration of short time trending of r0 or the impact of an inner scale. A technique for measuring short time r0 trending from a high sample rate, high resolution Shack-Hartmann wavefront sensor will be described and illustrated with horizontal path field data. The Greenwood frequency can also be estimated. The field sensor has 32x32 Hartmann subapertures and can operate at frames rates up to 8639 frames per second. Data from this sensor are also processed with a multi-resolution measurement algorithm to estimate the Hill inner scale of turbulence. Data has been collected under a range of weak to strong turbulence conditions and illustrates both high turbulence variability and credible estimates of inner scale and Greenwood frequency.

8161-05, Session 5
Twelve mortal sins of the turbulence propagation science
M. I. Charnotskii, National Oceanic and Atmospheric Administration (United States)

In this review paper we discuss a series of typical mistakes and omissions that are made by engineers and scientists involved in the theoretical research and modeling of the optical propagation through atmospheric turbulence.

We show how the use of the oversimplified Gaussian spectral model of turbulence delivers the completely erroneous results for the average irradiance distribution, beam wander and scintillation index. We discuss the meaning and potential dangers of the use of the quadratic structure function for modeling of the turbulent perturbations. We address a series of common misconceptions related to calculations of the average beam intensity: unnecessary use of the approximations when rigorous result is available, invalid application of the RMS beam size and M2 beam quality factor to the turbulence-distorted beams, overlooking the simple theoretical result - average beam intensity is a convolution with the turbulent Point Spread Function (PSF).

We discuss a series of misconceptions that very common in of the scintillation index calculations. We recall the history of the so-called Rytov's approximation, and show that for the optical propagation in turbulence it has no advantages compare to the perturbation theory. We will clarify the infamous misunderstanding of the Rytov's approximation: vanishing scintillation at the beam focus, and show the correct weak and strong scintillation solutions for the scintillation index at the beam focus. We discuss the flaws of the Fried model of the short-term PSF, and reveal some more accurate PSF models. We will briefly review the propagation of the polarized optical waves through turbulence and discuss the inadequacy of the recently published calculations of the electromagnetic beams calculations. We will also address the issues related to the energy conservation principle and reciprocity that have some very important consequences for the turbulence propagation, but are frequently overlooked in the current literature.
Direct observation of length scales in clear air turbulence

J. D. Harris, C. C. Davis, Univ. of Maryland, College Park (United States)

Light can scatter off turbulent vortex filaments in the air that have different densities and indices of refraction. These filaments, or eddies, are distributed through a turbulent air flow and their scale size represents the boundary between an energy cascade down size scales that ends in viscous energy dissipation. By examining the two point transmission spatial correlation function through a slab of steady flow turbulent air, we are capable of resolving turbulent scales down to the Kolmogorov microscale. This has been verified by a separate hotwire measurement on the same flow and comparison to hotwire data in the literature. We are measuring with high spatial and temporal precision spatial and temporal correlation functions that reveal the turbulence dynamics and inner scale in conditions of single scattering. These robust measurements are made over short path lengths in conditions of known Reynold’s number and average temperature without disturbing or decorating the flow. By changing the characteristics of the air flow in a volume, different length scales can be associated with different conditions. This creates a “fingerprint” that characterizes the turbulence.

Experimental analysis of orbital angular momentum-carrying beams in turbulence

J. A. Anguita, J. Herreros, Univ. de Los Andes (Chile)

The study of optical vortices has gained interest for their potential use in laser communications, as they could significantly increase the photon efficiency of the communication system. Optical vortices carry orbital angular momentum (OAM), a property that is related to the azimuthal phase of the complex electric field. Because OAM eigenstates are orthogonal, an arbitrary number of bits per photon can be transmitted in principle. Vortex beams with different OAM states can be easily generated and analyzed using holographic methods and this fact may stimulate the achievement of FSO communication systems with very high photon efficiencies.

In a laboratory experiment we generate, propagate, and detect laser vortex beams carrying OAM by means of computer-controlled spatial light modulators (SLM). We demonstrate that beams with OAM states from -10 to +10 can be effectively generated using different types of phase gratings, and that the generated beams keep their structure as they propagate. A turbulent air flow is induced on the propagation path using a hot plate to emulate the effects of atmospheric turbulence. The fast motion of the distorted beams is recorded with a CCD camera at high-frame rates to observe the effects of optical turbulence on the beams properties, such as radius, axial displacement, and phase structure. We analyze these attributes as they change over time, as well as we evaluate their long-term features. We show that the beam’s axis displacement induced by turbulence decreases as the OAM state increases. We are working towards an effective transmitter/receiver architecture to enable the use of OAM in a modulation/multi-user scheme.

Atmospheric channel transfer function estimation from experimental free-space optical communications data

C. N. Reinhardt, Space and Naval Warfare Systems Command (United States); Y. Kuga, J. A. Ritcey, A. Ishimaru, Univ. of Washington (United States); S. M. Hammel, D. Tsintikidis, Space and Naval Warfare Systems Command (United States)

The performance of terrestrial free-space optical communications systems is severely impaired by atmospheric aerosol particle distributions where the particle size is on the order of the operating wavelength. For optical and near-infrared wavelengths, fog droplets cause severe multiple-scattering and absorption effects which rapidly degrade received symbol detection performance as the optical depth parameter increases (visibility decreases). Using a custom free-space optical communications system we acquired field data for the transmitted and received signals in fog for a range of optical depths within the multiple-scattering regime. We use statistical estimation theory and stochastic analysis to derive estimators for the atmospheric channel transfer function and the related coherency function, which we then compute directly from the experimental data. We discuss the characteristics of the resulting channel transfer function estimates in terms of the physics of the atmospheric propagation channel. We investigate the behavior of the transfer function estimator using both real field-test data and simulated propagation data based on field-test conditions. We then compare the channel transfer function estimates against the predictions computed using a radiative-transfer theory model-based approach which we also developed for the free-space optical atmospheric channel.

Experimental generation of non-Kolmogorov turbulence with a liquid crystal spatial light modulator

I. Toselli, B. N. Agrawal, Naval Postgraduate School (United States); C. C. Wilcox, S. Restaino, U.S. Naval Research Lab. (United States)

Several experiments showed that the classical Kolmogorov power spectral density of the refractive-index sometimes does not properly describe the statistics of the atmosphere. In this paper we describe an experimental testbed able to generate non-classical Kolmogorov turbulence by using a liquid crystal spatial light modulator. The testbed is used at Naval Postgraduate School for laboratory investigation of laser beam propagation in maritime environment where a power law different from classical Kolmogorov, 11/3, could be present. Applications of this testbed are ship-to-ship free space optical communication, imaging and high energy laser weapons.

Computation on propagation of the femtosecond laser pulses in air by phase screen method

P. Zou, J. Zu, X. Zhou, Shanghai Institute of Optics and Fine Mechanics (China)

The propagation and split of the filamentation of femtosecond pulses in air have been paid much attention since last a few years, however, most research works are performed without considering the turbulence effects of atmosphere due to the difficulties of utilizing analytical solutions and experiment conditions. In this paper, we will attempt to introduce a kind of numerical simulation method to analyze the transmission features of femtosecond laser pulses in turbulent air, namely, it is called multi-phase screen method which use phase screen to simulate atmospheric turbulence. The laser parameters in this presentation are as follows: 85 fs and 3.5 TW operating at 800 nm. Then some simulating results are discussed by comparing with some others works, such as irregular shapes of focal spot. Finally, in order to control the propagation or split of the filaments, some different types of phase plates are applied, although the lengthening of laser pulses propagating distance is not achieved, on the contrary, a speeding split and an exchange of energy flow are firstly observed that it is potentially helpful to other works.
An investigation into the Paulding Mystery Lights

J. Bos, M. C. Roggeman, W. C. Norkus, Jr., M. A. Maurer, D. A. Sims, C. T. Middlebrook, Michigan Technological Univ. (United States)

The Paulding Mystery Light is a purportedly unexplained optical phenomenon, occurring nightly, deep in the woods of Michigan’s Upper Peninsula. Each evening up to a hundred spectators gather at the end of a washed out road to observe the flickering light. In local legends, the origin of the light is often attributed to the paranormal. As a student-run research project The Michigan Tech Student Chapter of the SPIE initiated a project in 2008 to understand the cause of the Paulding Lights. A team was formed pairing graduate and undergraduate researchers and under guidance from faculty. Previous investigations by paranormal skeptics attributed the lights to automobile headlights though the exact source location was not identified. These investigators also failed to address claims that the light appeared to move or dance along the horizon. Our team applied a number of techniques toward identifying and then verifying the source location of the Paulding Light. Beginning with observation through a telescope, the team moved to using tools such as detailed topographical maps and more common tools such as Google Street View to identify a candidate source location. The candidate source location was then validated by first, recreating the light using a stopped vehicle. Additional verification was achieved by recording the traffic flow at the source location and examining the correlations both heuristically and stochastically. A spectrometer was also brought to bear on the light allowing the team to compare the spectrum of the Paulding light to the spectrum of various automotive headlamps. Our findings, presented here, indicate that the source of the Paulding light is automobile traffic on a stretch of road about 7 km from the viewing location. This conclusion is supported overwhelming by the data we have collected. In addition to our findings, we also provide some speculation on the cause of the more spectacular claims surrounding these mystery lights and possibilities for future work.
8162-01, Session 1

Lunar optical wireless communication and navigation network for robotic and human exploration

S. Arnon, Ben-Gurion Univ. of the Negev (Israel)

Robotic exploration can improve lunar missions, increase crew productivity and reduce operational risks and cost. Broadband communication, together with location & orientation acquisition are fundamental parameters in space expeditions. We propose an optical wireless laser communication (LC) system, which provides high data-rates, that is integrated with an accurate ranging and direction finding system. In addition LC will not contaminate the moon with unwanted RF signals that could interfere with scientific measurement. The project’s main goal is to examine the theoretical background and the engineering feasibility of an optical wireless communication system and an optical positioning system for ground units on the moon. This project is part of Israeli collaboration with NASA lunar science institute.

8162-02, Session 1

Lightweight, mobile free-space optical communications in disaster scenarios for transmission of Earth observation data: feasibility study

O. Topcu, L. Grobe, Technische Univ. Ilmenau (Germany); H. Henniger, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany) and Technische Univ. Ilmenau (Germany) and Codex GmbH & Co. KG (Germany); M. Haardt, Technische Univ. Ilmenau (Germany)

Free-space optical (FSO) links are an effective alternative to radio frequency (RF) links to handle high-rate data transmission in case of a general communication service failure in disaster scenarios. Establishing high data rate links under the impacts of extreme environmental conditions, like the unregulated RF spectrum, is a very challenging issue. This paper focuses on quadrocopter based earth observation system designs. Its main objective is to show that FSO communication can provide a high-rate link for dumping earth observation data from a quadrocopter to a ground-station, even under disaster conditions. Before analyzing the feasibility of such an optical quadrocopter downlink system, the main system structure of the FSO link will be discussed in detail. Several system designs will be compared and evaluated based on link budget calculations. In this process, a novel Grating Light Valve (GLV) retro-reflector modulator technology will be introduced in this work. The study will emphasize that a reliable 100 Mbit/s FSO data transmission will be feasible to provide necessary downlink capacity for quadrocopter based earth observation systems.

8162-03, Session 1

Improved climatological characterization of optical turbulence for free-space optical communications

B. D. Felton, R. J. Alliss, Northrop Grumman Corp. (United States)

Optical turbulence (OT) acts to distort light in the atmosphere, degrading the quality of service of free-space optical communications links. Some of the degradation due to turbulence can be corrected by adaptive optics. However, the severity of OT, and thus the amount of correction required, can vary considerably from location to location. Therefore, it is vital to understand the climatology of OT at locations of interest. In many cases, it is impractical and expensive to deploy instrumentation to characterize the climatology of OT, making simulations a less expensive and convenient alternative.

The strength of OT is characterized by the refractive index structure function Cn2. While attempts have been made to estimate Cn2 using empirical models, Cn2 can be calculated more directly from Numerical Weather Prediction (NWP) simulations using pressure, temperature, thermal stability, vertical wind shear, turbulent Prandtl number, and turbulence kinetic energy (TKE). In this work, we use the Weather Research & Forecast (WRF) NWP model to generate Cn2 climatologies in the planetary boundary layer and free atmosphere, allowing for both point-to-point and ground-to-space estimates of the Fried Coherence length (r0) and other seeing parameters.

Nearly two years of simulations have been performed over various regions including the Desert Southwest and Haleakula and Mauna Kea on Hawaii. The results, which have shown good agreement with in situ turbulence measurements, are being used to assist engineers in free-space optical system design and site selection studies. Results of these simulations including comparisons with in situ measurements will be presented at the conference.

8162-05, Session 2

Twelve mortal sins of the turbulence propagation science

M. I. Charnotskii, National Oceanic and Atmospheric Administration (United States)

In this review paper we discuss a series of typical mistakes and omissions that are made by engineers and scientists involved in the theoretical research and modeling of the optical propagation through atmospheric turbulence.

We show how the use of the oversimplified Gaussian spectral model of turbulence delivers the completely erroneous results for the average irradiance distribution, beam wander and scintillation index. We discuss the meaning and potential dangers of the use of the quadratic structure function for modeling of the turbulent perturbations. We address a series of common misconceptions related to calculations of the average beam intensity: unnecessary use of the approximations when rigorous result is available, invalid application of the RMS beam size and M2 beam quality factor to the turbulence-distorted beams, overlooking the simple theoretical result - average beam intensity is a convolution with the turbulent Point Spread Function (PSF).

We discuss a series of misconceptions that very common in of the scintillation index calculations. We recall the history of the so-called Rytov’s approximation, and show that for the optical propagation in turbulence it has no advantages compare to the perturbation theory. We will clarify the infamous misunderstanding of the Rytov’s approximation: vanishing scintillation at the beam focus, and show the correct weak and strong scintillation solutions for the scintillation index at the beam focus.

We discuss the flaws of the Fried model of the short-term PSF, and reveal some more accurate PSF models. We will briefly review the propagation of the polarized optical waves through turbulence and discuss the inadequacy of the recently published calculations of the electromagnetic beams calculations. We will also address the issues related to the energy conservation principle and reciprocity that have some very important consequences for the turbulence propagation, but are frequently overlooked in the current literature.
8162-06, Session 2

**Direct observation of length scales in clear air turbulence**

**J. D. Harris, C. C. Davis, Univ. of Maryland, College Park (United States)**

Light can scatter off turbulent vortex filaments in the air that have different densities and indices of refraction. These filaments, or eddies, are distributed through a turbulent air flow and their scale size represents the boundary between an energy cascade down size scales that ends in viscous energy dissipation. By examining the two point transmission spatial correlation function through a slug of steady flow turbulent air, we are capable of resolving turbulent scales down to the Kolmogorov microscale. This has been verified by a separate hotwire measurement on the same flow and comparison to hotwire data in the literature. We are measuring with high spatial and temporal precision spatial and temporal correlation functions that reveal the turbulence dynamics and inner scale in conditions of single scattering. These robust measurements are made over short path lengths in conditions of known Reynolds' number and average temperature without disturbing or decorating the flow. By changing the characteristics of the air flow in a volume, different length scales can be associated with different conditions. This creates a “fingerprint” that characterizes the turbulence.

8162-07, Session 2

**Experimental analysis of orbital angular momentum-carrying beams in turbulence**

**J. A. Anguita, J. Herreros, Univ. de Los Andes (Chile)**

The study of optical vortices has gained interest for their potential use in laser communications, as they could significantly increase the photon efficiency of the communication system. Optical vortices carry orbital angular momentum (OAM), a property that is related to the azimuthal phase of the complex electric field. Because OAM eigenstates are orthogonal, an arbitrary number of bits per photon can be transmitted in principle. Vortex beams with different OAM states can be easily generated and analyzed using holographic methods and this fact may stimulate the achievement of FSO communication systems with very high photon efficiencies.

In a laboratory experiment we generate, propagate, and detect laser vortex beams carrying OAM by means of computer-controlled spatial light modulators (SLM). We demonstrate that beams with OAM states from -10 to +10 can be effectively generated using different types of phase gratings, and that the generated beams keep their structure as they propagate. A turbulent air flow is induced on the propagation path using a hot plate to emulate the effects of atmospheric turbulence. The fast motion of the distorted beams is recorded with a CCD camera at high-frame rates to observe the effects of optical turbulence on the beams properties, such as radius, axial displacement, and phase structure. We analyze these attributes as they change over time, as well as we evaluate their long-term features. We show that the beam's axis displacement induced by turbulence decreases as the OAM state increases. We are working towards an effective transmitter/receiver architecture to enable the use of OAM in a modulation/multi-user scheme.

8162-18, Session 2

**Atmospheric channel transfer function estimation from experimental free-space optical communications data**

**C. N. Reinhardt, Space and Naval Warfare Systems Command (United States); Y. Kuga, J. A. Ritcey, A. Ishimaru, Univ. of Washington (United States); S. M. Hammel, D. Tsintikidis, Space and Naval Warfare Systems Command (United States)**

The performance of terrestrial free-space optical communications systems is severely impaired by atmospheric aerosol particle distributions where the particle size is on the order of the operating wavelength. For optical and near-infrared wavelengths, fog droplets cause severe multiple-scattering and absorption effects which rapidly degrade received symbol detection performance as the optical depth parameter increases (visibility decreases). Using a custom free-space optical communications system we acquired field data for the transmitted and received signals in fog for a range of optical depths within the multiple-scattering regime. We use statistical estimation theory and stochastic analysis to derive estimators for the atmospheric channel transfer function and the related coherency function, which we then compute directly from the experimental data. We discuss the characteristics of the resulting channel transfer function estimates in terms of the physics of the atmospheric propagation channel. We investigate the behavior of the transfer function estimator using both real field-test data and simulated propagation data based on field-test conditions. We then compare the channel transfer function estimates against the predictions computed using a radiative-transfer theory model-based approach which we also developed for the free-space optical atmospheric channel.

8162-21, Session 2

**Experimental generation of non-Kolmogorov turbulence with a liquid crystal spatial light modulator**

**I. Toselli, B. N. Agrawal, Naval Postgraduate School (United States); C. C. Wilcox, S. Restaino, U.S. Naval Research Lab. (United States)**

Several experiments showed that the classical Kolmogorov power spectral density of the refractive-index sometimes does not properly describe the statistics of the atmosphere. In this paper we describe an experimental testbed able to generate non-classical Kolmogorov turbulence by using a liquid crystal spatial light modulator. The testbed is used at Naval Postgraduate School for laboratory investigation of laser beam propagation in maritime environment where a power law different from classical Kolmogorov, 11/3, could be present. Applications of this testbed are ship-to-ship free space optical communication, imaging and high energy laser weapons.

8162-04, Poster Session

**Control analysis of acquirement and locking in inter-satellite laser communications**

**W. Lu, J. Sun, Y. Zhou, Y. Wu, A. Yan, E. Dai, Y. Zhi, L. Liu, Shanghai Institute of Optics and Fine Mechanics (China)**

Process of acquirement and locking-up of complex axis system in inter-satellite laser communication has been studied. The effect of different condition parameters on the process of acquirement and locking-up have also been researched and simulated. Simulation results show that when the system with appropriate bandwidth has been adopted, both fine pointing system and coarse pointing system can satisfy three requirements of step response, stability criterion and dwell time and then finish the acquirement and locking-up of beacon laser beam. The simulation results provide the suited condition parameters for both fine pointing system and coarse pointing system, which is very helpful to the subsequent point and tracking processes.
An aperture-matched phase-compensated differential phase shift keying receiver with a 90° hybrid

Z. Luan, Y. Zhou, Y. Zhi, E. Dai, J. Sun, L. Liu, Shanghai Institute of Optics and Fine Mechanics (China)

Space to ground laser communication is limited by the effects of atmosphere. Differential phase shift keying (DPSK) is suited for high data rate space to ground communication links due to its immunity of the wave front of a beam passing atmospheric turbulence, which carry information in optical phase changes between bits. The benefit of DPSK over OOK is the 3 dB lower optical signal to noise ratio to reach a given bit error rate (BER) using a balanced receiver. An aperture-matched phase-compensated DPSK receiver with a 90° hybrid is proposed here. The receive optics are based on free-space optics. A Mach-Zehnder delay interferometer is used for differential delay which is equal to the bit period. The input pupil is imaged onto the same place by two afocal systems composed of 4f imaging lenses. The optical path difference is stabilized to a fraction of the wavelength with a fine phase adjustment which is measured by a 2×4 90° optical hybrid and closed loop electric circuit. The design and experiments are given in this paper.

Designing and implementation of free-space optical communication link for last mile solution

A. Sharma, R. S. Kaler, R. Kaler, Thapar Univ. (India)

A Free Space Optical (FSO) Laser Communication Link is presented. We deal with the development of a full-duplex FSO transceiver. Experimental results explain the performance of the completed system and offer methods of maximizing efficiency of such FSO-based communication systems. We have discussed and analyzed the details technical issues related to FSO deployment in context of India. Several parameters need to analyze the performance of FSO transmission. The external parameters are the non-system-specific parameters which are related to the environment and cannot be influenced by the designer, such as the climatology of the installation location, atmospheric attenuation, scintillation, window loss, and pointing loss. We have present simplified link budgets for non tracking and automatic tracking systems. It is interesting to note the improvement in link margin that can be obtained by use of an automatic tracking system.

Ghost imaging of a Gaussian Schell pulse beam propagation in a slant non-Kolmogorov turbulent channel

Y. Zhang, Jiangnan Univ. (China)

Lensless ghost imaging with Gaussian Schell-mode pulses beam through a slant non-Kolmogorov turbulent atmosphere channel has been studied based on the optical coherent theory and the extended Huygens-Fresnel integral. The analytical ghost-imaging formulas have been derived by the approximation of the form of spatial-temporal coherence function of the laser field in the product of the spatial and temporal coherence function, and the quadratic approximation of the wave structure function. Based on these formulas, we find that the image quality is influenced by the turbulence strength, the propagation distance, the zenith angle of communication channel, the fractal constant of the non-Kolmogorov power spectrum of atmospheric turbulence, the pulse duration of source and the coherent parameters of the partially coherent light.

Analysis of facular orientation deviation during tracking and pointing in the intersatellite laser communication

B. Shen, J. Sun, Y. Zhou, B. Li, L. Pu, L. Liu, Shanghai Institute of Optics and Fine Mechanics (China)

The facular orientation during tracking and pointing in the intersatellite laser communication dominates the tracking accuracy, so it is crucial to the establishment of optical communication link. The redistribution of the facular energy, caused by atmospheric turbulence in inter-satellite laser communication, makes it difficult to orientate the barycenter of the facula detected by the charge-coupled device, influencing the pointing accuracy finally. Therefore, it is necessary to analyse the orientation deviation in advance to provide reference to practical experiment and verification.

First of all, using a charge-coupled device, the influence of the facular energy to the orientation is studied through simulation. And then a Kolmogorov phase screen generated with modified inverse fast Fourier transform is used to simulate the effect of atmospheric turbulence. Using a charge-coupled device, the influences of time-dependent atmospheric turbulence intensity to the orientation deviation and the size of the charge-coupled device to the orientation deviation are analysed respectively. The simulated results offer significant practical benefits to the intersatellite laser communication.

Simple phase-shifting method in Jamin double-shearing interferometer for testing of diffraction-limited wavefront

L. Wang, L. Liu, Z. Luan, J. Sun, Y. Zhou, Shanghai Institute of Optics and Fine Mechanics (China)

In the inter-satellite laser communication, a diffraction-limit wavefront is required. To test the wavefront, we have developed a Jamin double-shearing interferometer. The interferometer is consists of two Jamin plates to form lateral shearing and four wedge plates to divide the aperture. To improve the measurement accuracy of the wavefront, phase-shifting must be introduced to reduce its detectable wave-front height. For the interferometer, simple phase-shifting methods by laterally moving four wedge plates or one Jamin plate are proposed in this paper. When the wedge plates are laterally moved, the phase difference of two interferometric beams is changed to form phase shifting. If the first Jamin plate is laterally moved, two emitted beams are laterally shifted to change the incidence position on the wedge plates. The shift of incidence position is equivalent to movement of the wedge plates. The relation between the phase-shifting amount and the lateral displacement of the wedge plates or the Jamin plate is calculated. The lateral displacement for the phase unwrapping with four-step phase-shifting algorithm can be obtained. To avoid strict phase-shifting amount of 90 degrees, four wedge plates or one Jamin plate can also be laterally moved in five steps with equal interval and the phase can be unwrapped using the five-step phase-shifting algorithm. In experiments, phase-shifting interference patterns are obtained and analyzed. The usefulness of these simple phase-shifting methods is verified.

Influence of laser beam profiles on received power fluctuation

L. Dordova, O. Wilbert, Brno Univ. of Technology (Czech Republic)

In an optical wireless link the laser beam carrying the information is propagating through the atmosphere. The situation is different if the
optical communication is proceeding in a horizontal direction (e.g. the transmitter and the receiver are placed on a fixed building) or when it is proceeding vertically (e.g. communication between ground station and HAP). In both cases it is necessary to know the characteristics of the atmosphere. Phenomenon of extinction, which causes optical signal attenuation, and atmospheric turbulence, generated by temperature inhomogeneities causing scintillation, are two main negative effects influencing optical signal quality.

Gaussian beam is very often used for the transmission of information in optical wireless links. The usage of this optical beam has its advantages and, of course, disadvantages. This work focuses on possibilities of using laser beams with different distribution of optical intensity (e.g. Top Hat, central and boundary beam). Creation of the optical beams with selected optical intensity profiles will be described. Geometrical parameters of particular beams will be compared with the Gaussian beam. Optical beams will propagate through the “clear” and stationary atmosphere in the experimental part of this work. These results will be compared with the data obtained after a laser beam is passed through the turbulent and attenuated atmosphere. We will use an ultrasound fog generator for laser beam attenuation testing. To create the turbulence, infra radiators will be applied. Particular results obtained from different atmospheric conditions will be compared and using different types of optical beams will be assessed.

8162-30, Poster Session

Acquisition strategy for the satellite laser communications under the laser terminal scanning errors situation
J. Sun, L. Liu, W. Lu, A. Yan, Y. Zhou, Shanghai Institute of Optics and Fine Mechanics (China)

Acquisition strategy is very important during the inter-satellite laser communications systems. Spatial acquisition of the companion terminals using very narrow beacon laser beams is a very difficult task especially under the laser terminal scanning errors situation. Acquisition is a statistical process. In this paper, we detailed the optimized scanning overlap factor of the beacon laser beam which depends on the scanning accuracy of the laser terminals.

8162-31, Poster Session

Influence of optical elements on the laser beam profile
O. Wilfert, Z. Kolka, J. Poliak, Brno Univ. of Technology (Czech Republic)

In an optical wireless link the optical signal is transmitted by optical beams. The resistance of signal transmission to atmospheric phenomena is possible to solve partially by means of the special optical intensity distribution at the beam spot, i.e. by means of the special beam profile. In practice the resultant beam profile can be a surprise for users of the link if only computer models of the optical beams are used and any diffraction effect at the transmitting lens is not considered. The transmitted beam is generally given by the diffraction integral which is mathematical description of Huygens-Fresnel principle.

On the basis of Huygens-Fresnel principle it’s possible to calculate the waves in a point of the receiver plane as a sum (or integral) of spherical waves coming from all individual points of transmitting aperture. It is not easy to calculate the diffraction integral namely if intensity distribution on the transmitting aperture is not constant, the spot is not circular symmetrical, and the receiver is located in near field. Let us assume the circular symmetrical beam with the constant intensity distribution at the transmitting aperture. In the receiving plane we obtain intensity distribution (so called diffraction pattern) which depends on the link range, diameter of transmitting lens, and the wavelength. We can see minima and maxima in the diffraction pattern at the receiving aperture which causes difficulties when aiming the link.

Two models of diffraction of optical beam radiated from the optical transmitter are presented and two methods of beam modeling are clarified (the method based on Bessel function integrating and the method based on FFT). Confirmation of the models elaborated is a part of the contribution.

8162-32, Poster Session

Power budget model for indoor wireless optical link
O. Wilfert, P. Hrbackova, Brno Univ. of Technology (Czech Republic)

In an indoor optical wireless link laser beam carrying the information propagates through a room and reflects on walls and various objects. Multiple reflections and multipath distortions occur when using this link. A power budget of the indoor optical wireless link includes not only the transmitted and received power but also reflection and placement loses. The directional properties of surface reflectivity are characterized by directional reflectance of surface.

The power budget of the indoor optical wireless link and a model of the surface reflectivity are presented in the contribution. The surface reflectivity includes both diffusive and specular components. Model of the surface reflectivity is a part of the power budget of the link. The directional properties of the surface reflectivity are simulated by a special mathematical function characterizing the reflectivity and directional reflectance of surface.

The model presented in the article allows us to assess the link communication quality and make a wall surface design. In the last part of the contribution an experimental work is presented and verification of the model proposed is demonstrated.

8162-33, Poster Session

Decoding nonsystematic Reed-Solomon codes using the Berlekamp-Massey algorithm
T. Lin, T. Truong, I-Shou Univ. (Taiwan)

It is well-known that the Euclidean algorithm can be used to find the systematic errata-locator polynomial and the errata-evaluator polynomial simultaneously in Berlekamp’s key equation that is needed to decode a Reed-Solomon (RS) codes. In this paper, a simplified decoding algorithm to correct both errors and erasures is used in conjunction with the Euclidean algorithm for efficiently decoding nonsystematic RS codes. In fact, this decoding algorithm is an appropriate modification to the algorithm developed by Shiozaki and Gao. Based on the ideas presented above, a fast algorithm described from Blahut’s classic book is derived and proved in this paper to correct erasures as well as errors by replacing the Berlekamp-Massey (BM) algorithm with the Euclidean algorithm.

Moreover, the simple decoding algorithm proposed in this paper is based on the fact that the codeword used in Euclid’s algorithm is a nonsystematic RS code so that Truong et al’s algorithm can be modified to solve the key equation for the errata-locator polynomial. Then it uses the recursive extension to compute the remaining unknown syndromes. Finally, the message symbols are thus obtained by only subtracting all known syndromes from the coefficients of the corrupted information polynomial. In other words, a polynomial division used to evaluate the messaging polynomial in the Lin-Chen-Truong (LCT) algorithm [1] can be replaced by a recursive extension and a simple addition. The speed of the new Euclidean-algorithm-based decoding approach is shown to be slightly faster than that of the LCT algorithm. Actually, a further reduction in the number of arithmetic operations of the algorithm mentioned above can be achieved by using the BM algorithm [2-6] instead of Euclid’s algorithm. It can also be utilized to find the errata-locator polynomial from Berlekamp’s key equation provided that the message vector has the same format as the one given previously. In fact, the decoder depicted in the seconding block algorithm in Fig 9.2 of Reference 17 is of the general derivation from the frequency-domain point of view. The derivation of this
algorithm was missing in the literature. The advantage of the proposed decoding algorithm is that the separate computation of the Forney syndrome polynomial and the errata-evaluation polynomial usually needed in the RS decoder using Euclid’s algorithm is completely avoided. Simulation results show that this new decoder is considerably faster in computational time than those of existing efficient algorithms including the one using Euclid’s algorithm proposed in this paper for correcting both errors and erasures of nonsystematic RS codes over GF(2m). It is expected that this fast decoding method may be adapted to the Chase algorithm [7], a soft-decision decoding, for RS codes.

8162-34, Poster Session

Two-dimensional Doppler imaging experiment for reflective tomography laser radar

X. Jin, J. Sun, Y. S. Yan, L. Liu, Shanghai Institute of Optics and Fine Mechanics (China)

Doppler-resolved reflective tomography using single-frequency continuous lasers has been shown to be an image reconstruction which can be used to recover image information about an object with a non-imaging laser radar system. This paper presents a continuous heterodyne laser radar experimental system for Doppler imaging in reflective tomography techniques. The resulting time-dependent return signal is collected by a non-imaging optical system, which provides a one dimensional signal about the target as a function of Doppler frequency after the short time FFT at each view. Then the Filtered back-projection or Radon-Fourier transform algorithm can be used to reconstruct the target from these one dimensional signals at different views. Compared with the imaging results reported by R. M. Marino in MIT Lincoln laboratory, the innovation in our experiments is that the imaging result is the whole region covering the target, not only the outline of the target. Due to the simplification in configuration and operations without involving signal phase processing, this technique has a great potential for applications in extensive Laser radar imaging fields.

8162-35, Poster Session

Two-dimensional image construction for range-resolved reflective tomography laser radar

Y. S. Yan, J. Sun, X. Jin, L. Liu, Shanghai Institute of Optics and Fine Mechanics (China)

Range-resolved reflective tomography is one of the most effective high-resolution imaging methods for laser sensing and imaging technologies. In experiments reported earlier by MIT Lab, only the outline of the target was recovered using reflective tomography algorithm. In our experiment, we adopted a novel imaging method which can get an imaging result of the whole region covering the target. A target of letter “E” was placed on a plane with a tilt angle to the horizontal plane and rotated about the axis perpendicular to it, the target was illuminated by parallel light pulses, the range-dependent return signal is collected by a non-imaging optical system. Filtered back-projection and Radon-Fourier transform algorithm were used to reconstruct the target, then we got a image result which has clear description of the target. After that, the imaging quality and resolution of this new approach are discussed. Our experiment system reported in this paper can achieve high imaging quality in real two-dimension image construction using reflective tomography algorithm, thus it has a great practical significance for applications in extensive imaging fields.

8162-08, Session 3

Optical scintillation measurements in a desert environment I: direct links


Optical scintillation is an effect that limits the performance of many optical systems including imagers and free space optical communication links. While there is a great deal of theoretical modeling of these effects, there is much less experimental data. The Naval Research Laboratory is undertaking a series of measurement campaigns of optical scintillation in a variety of environments. In December of 2010 measurements were made over a one week period in the desert at China Lake, CA. The NRL TATS system was used to measure time resolved scintillation over a variety of different ranges and terrains. Simultaneous weather data was also taken. In this paper we present an analysis of this data for direct lasercom links including scintillation index, power spectral density and probability distribution functions. Data was taken from sunrise to sunset with scintillation ranging from week to saturated. The correlation of scintillation with weather and time of day will also be quantified.

8162-09, Session 3

Optical scintillation measurements in a desert environment II: retroreflector links


Optical scintillation is an effect that limits the performance of many optical systems including imagers and free space optical communication links. The Naval Research Laboratory is undertaking a series of measurement campaigns of optical scintillation in a variety of environments. In December of 2010 measurements were made over a one week period in the desert at China Lake, CA. The NRL TATS system was used to measure time resolved scintillation over a variety of different ranges and terrains. Simultaneous weather data was also taken. In this paper we present an analysis of this data for direct lasercom links including scintillation index, power spectral density and probability distribution functions. Data was taken from sunrise to sunset with scintillation ranging from week to saturated. The correlation of scintillation with weather and time of day will also be quantified.

8162-10, Session 3

Optical scintillation measurements in a desert environment III: high-speed imaging of scintillation


Optical scintillation is an effect that limits the performance of many optical systems including imagers and free space optical communication links. The Naval Research Laboratory is undertaking a series of measurement campaigns of optical scintillation in a variety of environments. In December of 2010 measurements were made over a one week period in the desert at China Lake, CA. The NRL TATS system was used to image optical scintillation at the pupil plane of a receiver. A high speed infrared camera allowed imaging at rates of several hundred Hertz enabling scintillation to be resolved both spatially and temporally. Analysis of this data allows estimation of coherence radii, aperture averaging effects and the spatial frequency of scintillation.
8162-11, Session 3

Optical scintillation measurements in a desert environment IV: simulated effects of scintillation on communications links


Optical scintillation is an effect that limits the performance of many optical systems including imagers and free space optical communication links. The Naval Research Laboratory is undertaking a series of measurement campaigns of optical scintillation in a variety of environments. In December of 2010 measurements were made over a one week period in the desert at China Lake, CA. The NRL TATS system was used to measure time resolved scintillation over a variety of different ranges and terrains. This data has been used to determine fade rate and duration as a function of weather and link margin. Temporal correlation of fades has also been calculated. This data allows simulation of a variety of communication protocols and the effects of those protocols on link throughput. In this paper we present a comparison of different protocols for both direct and retroreflector links.

8162-12, Session 4

Combined optical modulating retroreflector/radio frequency Ethernet link for controlling small robots

W. S. Rabinovich, J. L. Murphy, M. R. Suite, U.S. Naval Research Lab. (United States); W. T. Freeman, Smart Logic, Inc. (United States); M. Ferraro, R. Mahon, U.S. Naval Research Lab. (United States); K. A. Hacker, S. Reese, Naval Explosive Ordnance Disposal Technology Div. (United States)

Small, tele-operated, robots often use radio frequency based Ethernet links for control and for relaying video images back to an operator. These robots must sometimes work in noisy RF environments in which these links fail. Previous work has shown that a free space optical link using modulating retroreflector can replace the RF link and allow operation in this kind of environment. However, free space optical links are inherently line-of-sight. Many applications require the robot to be able to maneuver to positions that are not within line-of-sight. In this work we demonstrate a serially combined FSO-RF link that allows non-line-of-sight operation. In these links an optical interrogator communicates to a pod carrying modulating retroreflectors at ranges up to 1 km. The pod also carries an RF transceiver and can be dismounted from the robot. When the robot needs to move out of line-of-sight, it can dismount the pod. The Ethernet link then flows serially from the interrogator to the pod over free space optical and then, over shorter distances, from the pod to the robot over RF. Details of the design and performance of the system will be presented.

8162-13, Session 4

InGaAs avalanche photodiode arrays for simultaneous communications and tracking

M. Ferraro, W. S. Rabinovich, J. L. Murphy, R. Mahon, H. R. Burris, Jr., L. M. Wasiczko Thomas, U.S. Naval Research Lab. (United States); W. T. Freeman, Smart Logic, Inc. (United States)

Free space optical communication uses photodetectors for two purposes: as communications receivers and, in the form of a quadrant cell or a position sensitive detector, for tracking. Generally two separate detectors are used. In this work we describe combining these functions into one device through the use of heterostructure avalanche photodiode (APD) arrays. Combined functionality more efficiently uses the available light and allows for large area communications detector arrays that maintain the bandwidth and sensitivity of smaller, single-element, arrays. In this paper we describe a prototype 2x2 arrays and associated electronics and processing. The design tradeoffs in balancing both functions are explored and future geometries that are more effective than square arrays are described.

8162-14, Session 4

Design and implementation of pan-tilt FSO transceiver gimbals for real-time compensation of platform disturbances using a secondary control network

J. Rzasa, S. D. Milner, C. C. Davis, Univ. of Maryland, College Park (United States)

FSO systems are highly directional, and a robust system is required to keep two transceivers aligned, even when both are on moving platforms. To date, most systems have used fast steering mirrors and coarse pan-tilt platforms tied to a feedback loop based on received optical power to accomplish this task. This approach can encounter problems if the alignment of one of the transceivers is severely disrupted, or is obstructed (possibly by the geometry of an airborne platform). In developing systems for air- or space-borne FSO networks, a robust way is needed to keep the entire array of FSO platforms aligned with minimal packet loss. In this paper, we present an approach to this problem using a secondary, low data-rate, omni-directional RF network that disseminates pointing commands to all the platforms in the network, so that if the main FSO channels are disrupted, the network can recover much more quickly than if a purely RSSI-based approach were used. Utilizing custom-made high precision direct drive servo pan-tilt platforms coupled with GPS and angular orientation sensors, we can construct a pointing matrix for the entire network that is calculated and disseminated in real time over the secondary channel. We present theoretical calculations about the update rate required for alignment at certain ranges and platform speeds (and beam sizes), as well the required secondary channel capacity with respect to update rate and number of nodes. Experimental results are then presented for a link where each transceiver is mounted on a coarse vibration platform to simulate disturbances in a real network.

8162-15, Session 4

Visible light communication link study for outdoor automotive use case

K. Cui, G. Chen, Z. Xu, Univ. of California, Riverside (United States); R. D. Roberts, Intel Corp. (United States)

Outdoor visible light communication (VLC) between LED traffic lights and automobiles has been proposed for Intelligent Transportation System. However, their work was mainly based on some ideal assumptions and theoretical analysis, and link study using commercial off-the-shelf LED traffic lights under a practical application scenario has not been carried out. In this paper, we characterized visible light communication links between traffic lights and a vehicle in real environments, including background interference measurement, LED traffic lights device characterization, and corresponding link budget analysis. A prototyping system was built for both real-time BER measurement and demonstration of the feasibility of outdoor VLC for the automotive use case based on COTS components.
8162-16, Session 5

On the LDPC-coded OAM modulation for communication over atmospheric turbulence channels

I. B. Djordjevic, The Univ. of Arizona (United States); J. A. Anguita, Univ. de Los Andes (Chile); B. V. Vasic, The Univ. of Arizona (United States)

Increasing free-space optical (FSO) communication link capacity can in principle be achieved by modifying any controllable physical property of the transmitted light that augments the dimensionality of the signal space. While modulation of amplitude, phase, frequency and polarization have been extensively studied, the understanding of practical ways to use momentum modulation is in its infancy. Photons can carry spin angular momentum, a well-known property associated with polarization, and orbital angular momentum (OAM), which is associated with the azimuthal phase of the electric field of an optical beam. The OAM is a property present in certain types of laser beams, called vortex beams, which can attain multiple discrete state levels. Because the OAM states are orthogonal to each other they can be used as basis for multidimensional signal constellations. The ability to generate and analyze states with different OAMs by using interferometric or holographic methods allows the realization of energy-efficient FSO communication systems. Unfortunately, FSO communications links suffer from atmospheric turbulence and their quality-of-service (QoS) depends on weather conditions. In the presence of atmospheric turbulence, the orthogonality among OAM channels is no longer maintained.

In this paper, we study the communication over atmospheric turbulence channels based on low-density parity-check (LDPC) coded, multidimensional OAM signal constellations. The multidimensional signal constellation under study is obtained as the Cartesian product of one-dimensional signal constellation X={(x_1,...x_d)|x_i is from X, for every i}. This scheme represents an energy efficient alternative, since log2(M^N) bits/symbol can be transmitted. We evaluate the performance of this scheme by determining conditional symbol probability density functions (PDFs) from numerical propagation data, for different turbulence strengths. Two cases of interest are considered: (i) when conditional PDFs are known on the receiver side, and (ii) when conditional PDFs are not known and Gaussian approximation is used instead. We show that in case (ii) an early error floor occurs because of inaccurate PDF assumption. The error floor is caused by OAM crosstalk introduced by atmospheric turbulence. We also show that the OAM modulation is more sensitive to atmospheric turbulence as the number of dimensions increases.

8162-17, Session 5

Performance analysis of optical wireless communications on long-range links

B. Epple, Codex GmbH & Co. KG (Germany)

Optical wireless communications over long-range atmospheric links experience strong fading that heavily influences the performance of communication systems. Most research on this topic is focused on simulation or measurement of the link performance in terms of the bit error ratio. In this work a statistical channel model derived from measurements is used for simulations of the link performance on packet layer. For analysis of a possible improvement of packet layer performance by error protection techniques like forward error correction and automatic repeat request, additional simulations are done. All simulations are done for several communication scenarios like the maritime environment, land mobile and air-to-ground links.

8162-18, Session 5

Statistical analysis of chaotic signals generated by acousto-optic or electro-optic modulators with feedback

A. K. Ghosh, P. Verma, The Univ. of Oklahoma - Tulsa (United States)

Nonlinear optical systems with feedback may produce chaotic optical signals. Generation of chaos from such bistable optical systems has been studied for several years. Chaotic optical signals can be utilized in secure encryption of free-space optical communication systems. In general, chaos encryption of data is known to provide higher levels of security than what is available by standard cryptographic techniques. To realize a secure optical communication link using optically generated chaos we need to know how to obtain a chaotic response and the properties of the chaotic signal. We found that an understanding of the Lyapunov exponent (LE) is essential in building a chaos-encrypted optical communication system. The LE is a measure of the amount of ‘uncertainty’ in the chaotic signal [1].

In this paper, we calculate the LE of a one-dimensional optical system consisting of either an electro-optic (EO) or an acousto-optic (AO) modulator with feedback to characterize and understand the behavior of the optical chaos generated. Analyzing the LE we determine several conditions on optical system’s parameters so that a chaotic response is obtained. We found that the chaos generated by an EO or AO system follows a beta distribution and we determine the relation between the system parameters and the statistics of the distribution.

References

8162-19, Session 5

Chaotic bandgaps in hybrid acousto-optic feedback and their implications

M. R. Chatterjee, M. A. Al-Saedi, Univ. of Dayton (United States)

The nonlinear dynamics of a hybrid acousto-optic device was examined from the perspective of the Lyapunov exponent (LE). The plots for LE versus system parameters and bifurcation maps are examined in this paper against known simulation results including chaotic encryption experiments conducted recently. It is verified that the “loop gain” (feedback gain ) times incident light amplitude (lin) needs to be greater than one as a necessary, but not sufficient condition for the onset of chaos. It is found that for certain combinations of , net bias voltage (α-tot), and the initial value of the first-order scattered light (I(0)), there are pronounced regions of chaos in the parameter field, while for others, chaos is minimal. It is also observed that in some cases, the negative “spikes” in the LE are far larger than its positive amplitudes, hence indicating a greater tendency to become non-chaotic. Additionally, we have examined the bifurcation plots versus the two most salient system parameters, α-tot and β. These maps have revealed behavior that is by no means uniformly chaotic. It is found that the system moves in and out of chaos within distinct bands along the α-tot and β axes. These results imply strong sensitivity vis-à-vis these parameters around the passbands and stopbands, and may indicate control of chaos by appropriate parameter adjustment. Such control may have applications in biological chaos, such as arresting malignant, chaotic cell multiplication. Overall, the dynamical results compare favorably with time-domain characteristics of encrypted chaotic waveforms in signal modulation and transmission applications.
A 280Mbit/s infrared optical wireless communications system
D. C. O'Brien, G. E. Faulkner, R. G. Turnbull, Univ. of Oxford (United Kingdom); H. Le Minh, Northumbria Univ. (United Kingdom); M. Wolf, L. Grobe, J. Li, Technische Univ. Ilmenau (Germany); O. Bouchet, France Telecom R&D (France)

In this paper we describe an angle diversity system that operates at 280Mbits/s with a wide coverage area. The system uses commercially available components, operating at a wavelength of 860nm. Three terminals, each using seven transmitter and receiver channels were implemented, and the system was operated over a wide range of different conditions. Implementation challenges, design and performance are also discussed, together with future directions for this work.

Broadcast of four HD videos with LED ceiling lighting: optical-wireless MAC
O. Bouchet, P. Porcon, France Telecom R&D (France); E. Gueutier, Apside Groupe (France)

The European project "hOME Gigabit Access network" (OMEGA) targeted various wireless and wired solutions for 1-Gb/s connectivity in Home Area Networks (HANs).

One objective of this project was to evaluate the suitability of optical wireless technologies in two spectral areas: visible light (visible-light communications - VLC) and near infrared (infrared communications - IRC). Several demonstrators were be built, all of them to a large extent relying on over-the-shelf commercial components. They included a "wide-area" VLC broadcast link based on LED ceiling lighting and a laser-based high-data-rate large-coverage IRC prototype.

In this paper we discuss an adapted optical-wireless media-access-control sublayer (OWMAC), which was developed and implemented during the project. It is suitable for both infrared and visible-light communications.

The VLC prototype is based on DMT signal processing and provides broadcasting at ~ 100 Mb/s over an area of approximately 10 m2. The IRC prototype provides around 300 Mbps half duplex communication over an area of approximately 30 m2. This mesh network, composed by one base station and two modules, is based on OOK modulation, multi-sector transceivers, and an ultra-fast sector switch.

After a brief discussion of the design optical-wireless data link layer and the optical-wireless switch card (OWS), we address the card development and implementation. We also present application demonstrations for the VLC and IRC prototypes and measurement results on MAC layer.

Full duplex ultraviolet scattering channel test and simulation
G. Chen, Z. Xu, Univ. of California, Riverside (United States)

Ultraviolet (UV) atmospheric scattering includes forward and backward scattering. For a simplex link, we simulated and tested the non-line-of-sight scattering path loss and pulse broadening in coplanar geometry earlier, accounting for forward scattering. For a full duplex link, the backscattering and off-axis effects must be taken into account. In this paper, we experimentally test and also simulate the off-axis path loss, as well as backscattering interference from a transmitter to a co-located receiver. The elevation angles and off-axis angles vary from 0° to 90°. The experimental results are compared with Monte Carlo simulation results.
8163-01, Session 1

Exploiting PDC spatial correlations for innovative quantum imaging protocols

M. Genovese, Istituto Nazionale di Ricerca Metrologica (Italy)

Quantum properties of the optical field represent a resource of the utmost relevance for the development of quantum technologies, allowing unprecedented results in disciplines ranging from quantum information and metrology to quantum imaging.

In particular, in the last case various protocols have been proposed ranging from ghost imaging [1] to quantum illumination [2]. In particular Ghost Imaging can have very interesting practical applications [3].

Another kind of protocols of interest for possible application is offered by the possibility of sub shot noise measurements with quantum optical states.

In particular a very interesting example is provided by the detection of weak objects by exploiting the quantum correlations of parametric down conversion (PDC) emission: a result that could have important practical applications. A little more in detail the principle of this technique is to take advantage of the correlation in the noise of two conjugated branches of PDC emission: in fact, subtracting the noise measured on one branch from the image of a weak object obtained in the other branch, the image of the object, eventually previously hidden in the noise, could be restored [4].

In this talk, after a general summary of quantum imaging techniques, firstly we will show how we have reached a sub shot noise [5] regime and then improved this result up to reach a regime where it was possible to achieve the first experimental realisation of sub shot noise imaging of a weak absorbing object [6].

Then we will present some recent experiments addressed to realise improved ghost imaging protocols in view of practical applications.

Finally, we will present some innovative interferometric scheme exploiting spatial correlation of light.


8163-02, Session 1

Secrets of subwavelength imaging and lithography

P. R. Hemmer, Texas A&M Univ. (United States)

To understand the limits and tradeoffs of nearly all existing subwavelength imaging techniques it sufficient to understand magnetic resonance imaging (MRI) and its generalizations. In many cases, subwavelength optical lithography can be viewed as the inverse problem to imaging and so the same principles apply. I will give a simple review of MRI and show how the most popular subwavelength imaging techniques naturally arise as special cases. I will also discuss how these techniques can be used for nanoscale optical lithography.

8163-03, Session 1

Turbulence-free quantum ghost imaging experiments and results

R. E. Meyers, K. S. Deacon, A. Tunick, U.S. Army Research Lab. (United States)

Turbulence is a serious problem for long distance imaging such as from satellites or telescopes. In this paper we discuss our turbulence-free ghost imaging approach that is virtually free from the degrading effects of turbulence. We discuss motivation for the experiments, theory, experimental setup, procedures, and results. The results suggest that thermal two-photon interference may not only be used to improve imaging through turbulence but may also lead to a resource for quantum information processing.

8163-04, Session 1

Enhanced optical resolution in target detection with phase-sensitive pre-amplification

O. Lim, Northwestern Univ. (United States); Z. Dutton, BBN Technologies (United States); G. Alon, C. Chen, Northwestern Univ. (United States); M. Vasilyev, The Univ. of Texas at Arlington (United States); P. Kumar, Northwestern Univ. (United States)

The resolution of an optical imaging system depends on the signal-to-noise ratio (SNR) of the detected optical power. The amount of spatial information lost at the image plane across all spatial frequencies determines the maximum achievable resolution of the system. Some of the lost resolution can be recovered by spatially-broadband optical pre-amplification to overcome the imperfect detection efficiency of the imaging sensors. Two types of optical amplifiers can be used to boost the received signal: Phase-insensitive amplifiers (PIAs) and Phase-sensitive amplifiers (PSAs). PSAs are capable of providing noise-free signal gain that can out-perform PIAs in SNR by 3 dB at large gains. A spatially broadband signal such as that from a LADAR can also be noiselessly amplified with a PSA. Here, we demonstrate enhanced resolution in optical detection by boosting the incoming signal with a PSA. We employ the method of hypothesis testing to investigate the optical resolution of a standard imaging system in a typical one vs. two targets sensing scenario. Optical resolution is quantified in terms of the error probability of deciding one hypothesis in the presence of the other. We show that images that are otherwise unresolved can be distinguished with higher probability after phase-sensitive pre-amplification than is possible without amplification. In this work, we demonstrate 5-dB resolution enhancement in homodyne detection at 15 dB PSA gain. We will also show the superiority of a PSA over a PIA in terms of their noise figure performance.

8163-05, Session 1

Quantum enhancement of a coherent ladar receiver using phase-sensitive amplification

P. A. Wasi1osky, K. H. Smith, R. Glasser, G. L. Burdge, L. Burberry, B. Deibner, M. Silver, R. C. Peach, C. Visone, Harris Corp. (United States); P. Kumar, O. Lim, G. Alon, C. Chen, A. Bhagwat, P. Manurkar, Northwestern Univ. (United States); M. Vasilyev, M. Annamalai, N. Stelmakh, The Univ. of Texas at Arlington (United States); Z. Dutton, S. Guha, C. Santivanez, J.
Typical LADAR receivers suffer from losses in their optical train that routinely limit overall photon detection efficiency (PDE) to less than 50%, thus degrading SNR. These losses arise from sub-unity quantum efficiency detectors, array fill factors, signal-local oscillator (LO) mixing efficiency (in coherent receivers), and other sources. Incorporating a phase-sensitive amplifier (PSA) into a coherent receiver allows for noiseless amplification of the target return signal, which allows effective PDE to approach 100%. We demonstrate improved SNR in a balanced-homodyne LADAR receiver by employing a PSA to raise the effective PDE to nearly 100%. We also demonstrate that the PSA offers better performance than a phase-insensitive amplifier, which cannot amplify noiselessly. We show how this PSA-enhanced receiver can be extended to simultaneously amplify multiple optical modes and how it can be used in imagery and vibrometry applications.

Short pulses (~200 ps pulse width, ~20 MHz repetition rate) from a very narrow linewidth 1560 nm source laser are amplified and passed through a nonlinear crystal to generate second harmonic light which serves as the pump for the PSA. Some of the residual 1560 nm light serves as the LO and the remainder illuminates a target in the far field. The pump light and target return signal are simultaneously passed through a nonlinear crystal to provide amplification. The resultant amplified signal is then mixed with the LO in a balanced homodyne configuration. Lateral resolution is achieved by scanning a receive mirror and range discrimination is achieved by changing the pulse repetition rate.

**8163-06, Session 2**

**Designing quantum repeaters and networks**

W. J. Munro, NTT Basic Research Labs. (Japan); S. J. Devitt, K. Nemoto, National Institute of Informatics (Japan)

The twentieth century saw the discovery of quantum mechanics, a set of principles describing physical reality at the atomic level of matter. Quantum physics allows a new paradigm for the processing of information. Over the last decade there has been a huge worldwide effort to develop and explore quantum-information based devices and technologies. Quantum repeaters are a natural candidate to consider as they can be used both to distribute and process quantum information. There has been a significant effort worldwide to investigate and demonstrate the fundamental building blocks necessary for such repeaters. The next step is to look at the overall design of a repeater network, considering both the quantum and classical components. A repeater network must be underpinned by experimental techniques for entanglement generation, it must incorporate purification or quantum error correction to achieve high-fidelity entangled links, and must be controlled by classical communication across the network. Typically, the communication time required for classical messages to be transmitted between nodes severely limits the performance of repeater networks. In this talk we show how to maintain near-determinism throughout all aspects of a repeater network allowing for an efficient, pipe-lined architecture. More importantly we know when the end-to-end entangled pairs are going to be available and also how to minimize the requirements on resources such as quantum memories.

**8163-07, Session 2**

**Multiplexing schemes for quantum repeater networks**

L. Aparicio, The Univ. of Tokyo (Japan); R. Van Meter, Keio Univ. (Japan)

Real-world quantum repeater networks will operate in heterogeneous conditions, including complex topologies with multiple connections competing for resources. For these scenarios, we are comparing several different classical multiplexing schemes using simulation, measuring the aggregate throughput and fairness for each case. Our engineering goal is to articulate the conditions in which classical multiplexing strategies can be applied to quantum networks.

The multiplexing schemes considered in this work are: circuit switching like that of traditional telephony service; statistical multiplexing with a best effort approach, as used in the Internet; time division multiplexing like that used in telephony trunk lines; and spatial multiplexing, in which the quantum buffer memory resources in each repeater are divided among competing requests. For this work, we use our proposed three-layer quantum network protocol stack designed for purify-and-swap repeaters. The physical layer simulated is a Qubus mechanism in which laser pulses of many photons generate low fidelity Bell pairs with high probability. Our results suggest that round-robin use of a congested link gives the highest aggregate throughput, improving over circuit switching by taking advantage of resources that are forced to remain idle in the simpler approach. Spatial multiplexing proved most effective as the reduction of resources extends the time needed to obtain a high-fidelity Bell pair between stations.

**8163-08, Session 2**

**Intersatellite quantum communication feasibility study**

A. Tomaello, A. Dall’Arche, G. Naletto, P. Villoresi, Univ. degli Studi di Padova (Italy)

The shift in the Communication paradigm from the bit to the qubit is increasingly exploited in terrestrial long range links and networks, with strong potentials in secure communications, quantum computing and metrology. Several studies have also studied the feasibility of the space to ground quantum key distribution with the experimental demonstration of the single photon exchange. A new different scenario for the quantum communications is that of the intersatellite link. Experiments of classical optical communications between the ESA Artemis GEO satellite and SPOT-4 LEO satellites as well as between the pairs TerraSAR and NFIRE, both in LEO orbits, that have reached multi gigabit per second data rates, while in mutual sight. Other advantages that were proven include the significant reduction of the transmitter power budget and the increasing of the carrier frequency and beam pointing with respect to radio communications.

In this study we focus on the extension of intersatellite communications into the quantum domain. The very recent demonstration of optical quantum memories as well as of effective schemes for the generation of entangled and hyperentangled photon states are providing complementary tools supporting the feasibility of a global quantum network scenario. The long distances involved in the link as well as the fast relative motion are factors that severely constrain the conception of the quantum transceiver. However, the absence of beam degradation due to the propagation in the atmosphere as well as the relatively low background noise level are positive aspects with respect to the Earth related links. In this work we address the conception of the optical terminal and the predicted performances in the case of constellations of LEO and MEO satellite including the quantum communications and quantum teleportation.

**8163-09, Session 2**

**Randomization techniques for the intensity modulation-based quantum stream cipher and progress of experiment**

K. Kato, O. Hirota, Tamagawa Univ. (Japan)

The quantum stream cipher by Yuen 2000 protocol (Y-00) provides a
We experimentally demonstrate a fiber-based QKD system that implements the BB84 protocol supplemented with decoy states. In our current setup, the homemade electronic drivers for the modulators and detectors limit the clock rate to 100 MHz, and the memory depth of the used FPGAs limits the effective time during which qubits can be generated per quantum frame to 10%. This results in a secret key rate over a 12 km real-world fibre link exceeding 10^4 bps.

8163-12, Session 3

Mixed-metric algorithms for information reconciliation in quantum cryptography

M. Mondin, Politecnico di Torino (Italy); F. Daneshgarian, California State Univ., Los Angeles (United States); F. Mesiti, M. T. Delgado, Politecnico di Torino (Italy); M. Laddomada, Texas A&M Univ. (United States)

This paper deals with the selection of the most appropriate metric in the mixed-channel scenario typical of Quantum Key Distribution (QKD), where both the private quantum channel and the public channel are jointly considered. On a composite private-public channel model, capacity achieving sparse-graph codes are employed for information reconciliation and pre-data sifting. The metrics derived from the two channels are jointly processed with a mixed-metric iterative decoder, with the goal of performing feed-forward error correction of the received q-bits, detect the possible presence of unauthorized eavesdroppers without the need for revealing information bits, and performing pre-data sifting.

The paper initially discusses the most suitable model for a composite scenario typical of QKD applications. Secondly, it shows how to best select and weigh appropriate metrics derived from the considered channel model, and then suggests employing forward error correction (FEC) coding as opposed to two-way communication for information reconciliation, minimizing the interactions between transmitter and receiver. The paper also shows that the average number of decoding iterations of the iterative decoder for the considered FEC code is strongly correlated with the quantum channel bit error rate (QBER). Since the QBER value is a possible indicator of the presence of an eavesdropper, this observation allows deriving a reliable method for eavesdropping detection. Systematic low density parity check (LDPC) codes have been considered in the paper, although the concepts could be applied to other iteratively decoded capacity achieving codes as well. Extensive simulations have been performed in order to derive the performance and the efficiency of the proposed algorithms as a function of the system parameters.

8163-13, Session 4

Simultaneous quadrature detection of suppressed-carrier weak-coherent-states using a homodyne optical Costas loop receiver

J. A. Lopez Leyva, Ctr. de Investigación Científica y de Educación Superior de Ensenada (Mexico); E. García, Univ. Autónoma de Baja California (Mexico); F. J. Mendieta, A. Arvizu, Ctr. de Investigación Científica y de Educación Superior de Ensenada (Mexico); P. Gallion, Telecom ParisTech (France)

Weak coherent states (WCS) are being extensively employed in
quantum communications and cryptography at telecommunications wavelengths. For these low-photon-number applications, simultaneous field quadrature measurements are frequently required, such as in the detection of multilevel modulations in the communications scenario or in cryptographic applications employing continuous variables. For this task, multiphoton balanced homodyne detection (BHD) structures are employed, based on the splitting of the received field into its (non-commutating) in-phase (I) and quadrature (Q) components and their separate beating with a local oscillator (LO) in two BHD. This allows the simultaneous measurements of the 2 quadratures at the price of an additional noise due to the vacuum fields that leak via the unused ports. These schemes require the proper optical phase synchronization between the LO and the incoming field, which constitutes a challenge for WCS reception, especially for suppressed carrier modulations that are required for power economy. For this task, a Costas loop is implemented for low photon number WCS, with the design of an optimum feedback scheme considering the phase diffusion of WCS generated by semiconductor lasers. We implemented an optical Costas loop at 1550 nm based on polarization splitting of the laser field to detect I and Q quadratures simultaneously. We present results on the performance in phase error and bit error rate and compare with corresponding quantum limit.

8163-15, Session 4
Characterization of a gradient echo memory using homodyne tomography
R. Thomas, C. M. Kupchak, A. Heinrichs, A. I. Lvovsly, Univ. of Calgary (Canada)

The fields of quantum cryptography and quantum computation offer distinct advantages over their classical counterparts, such as absolutely secure communication and an exponential increase in computational speed. Limitations in current implementations, such as loss in optical fibres or probabilistic optical quantum gates, prevent further development and application of these technologies. This issue can be addressed by developing quantum memory for light: a device that stores and retrieves arbitrary quantum optical states. Using a warm rubidium vapour, we demonstrate coherent storage of light based upon the gradient echo memory scheme. In this scheme, the Fourier components of the input light field are mapped to atomic dipoles at different spatial locations in the cell via a linearly varying frequency gradient. A reversal of the gradient causes the re-emission of the original light pulse. Gradient echo memory is an attractive technique because of potentially high retrieval efficiencies and long storage times. We characterize the storage and retrieval of coherent states of light for both high and low mean photon numbers. The action of the memory on input light fields is experimentally measured using time-domain homodyne tomography. Using homodyne tomography to characterize the retrieval of coherent states allows us to perform coherent state quantum process tomography on the memory, and therefore fully characterize it as a quantum process, so we can infer the effect of the memory on any other quantum state of light.

8163-16, Session 4
A single-atom quantum memory
E. V. Figueroa, H. Specht, C. Nölleke, A. Reiserer, M. Uphoff, S. Ritter, G. Rempe, Max-Planck-Institut für Quantenoptik (Germany)

The implementation of quantum networks requires the development of quantum interconnects, featuring the coherent and reversible mapping of quantum information between light and matter. So far, these interfaces have been based upon the engineered exchange of information between photons and collective atomic excitations. A promising alternative is the development of interfaces between single photons and single particles of matter (e.g., single atoms). This approach has fundamental advantages as it allows for the individual manipulation of the stored atomic qubit. We have shown previously that an atom-cavity system can be used for efficient and controlled single photon production via a vacuum stimulated adiabatic passage (vSTIRAP). Here we demonstrate the most fundamental implementation of a quantum memory based on the reverse process, by mapping arbitrary polarization states of light into and out of a single atom trapped inside an optical cavity.

By adiabatically ramping down the power of a strong control laser pulse, we cause the atom to absorb a single photon from of a weak coherent probe pulse impinging on the cavity. During this coherent process, the phase relation of the input circular polarization modes is mapped to a relative phase between Zeeman sub-states. After a variable storage time, a second control laser pulse converts the atomic qubit back onto the polarization of a produced single photon.

This experiment is a major step in the development of a universal node of a quantum network, capable of fully controlled photon generation, qubit storage and with intriguing perspectives towards the development of quantum gates.

8163-39, Session 4
Quantum information processing with light shift blockaded atomic ensembles coupled to a cavity
S. M. Shahrir, M. Kim, Y. Tu, Northwestern Univ. (United States)

Using the process of light shift blockade, it is possible to make an ensemble of atoms behave as a deterministic qubit. The vacuum Rabi frequency for such a qubit is stronger than that of a single atom by a factor equaling the square-root of the number of atoms in the ensemble. We are studying a clusters of Rb atoms held in an array of dipole force potential wells loaded from a magneto-optic trap and placed inside a meso-scale cavity as an elementary quantum computer. In this talk, we will describe how various nearest neighbor quantum gates can be realized using this system and techniques for creating a quantum link between two such arrays with an optical fiber. We will also present preliminary results from our experiment.

8163-32, Poster Session
Generation of broadband spontaneous parametric fluorescence and its application to quantum optical coherence tomography
M. Okano, R. Okamoto, A. Tanaka, S. Subashchandran, Hokkaido Univ. (Japan); S. Ishida, N. Nishizawa, Nagoya Univ. (Japan); S. Takeuchi, Hokkaido Univ. (Japan)

Optical coherence tomography (OCT) based on Michelson interferometer has widely been utilized in biology and medicine as a type of optical biopsy. Recently, quantum optical coherence tomography (QOCT) based on Hong-Ou-Mandel interferometer has experimentally been demonstrated. By use of quantum entangled photon pairs generated via spontaneous parametric down conversion (SPDC), axial resolution of QOCT can be twice better than that of OCT in principle for a source of same bandwidth. And more, the group velocity dispersion, which may reduce the resolution of OCT, can be automatically cancelled due to the frequency correlation of quantum entangled photon pairs.

To realize high resolution QOCT, we have generated broadband spontaneous parametric fluorescence via SPDC from two nonlinear crystals (BBO) pumped by the CW laser (λ = 405 nm). The bandwidth of spectrum of generated lights from two BBO crystals has been broadened up to approximately 170 nm and this bandwidth can lead to sub-micron axial resolution of QOCT. For comparison, we have demonstrated OCT using the super luminescence diode (SLD, λc = 810 nm), whose bandwidth of 77 nm can lead to 4 μm axial resolution, and measured axial resolution was approximately 5 μm. Next, we try to realize high resolution QOCT using broadband spontaneous parametric fluorescence generated via SPDC and will report our recent experimental progresses.
8163-33, Poster Session

Turbulence measurement and characterization for quantum ghost imaging
R. E. Meyers, K. S. Deacon, A. Tunick, U.S. Army Research Lab. (United States)

The measurement and characterization of turbulence for quantum ghost imaging and free-space quantum communications is a difficult problem. In this paper we discuss how to measure and characterize turbulence in a manner suitable to apply to quantum ghost imaging and free-space quantum communications analysis.

8163-37, Poster Session

Towards interferometric quantum lithography: observation of spatial quantum interference of the three-photon N00N state
Y. Kim, O. Kwon, S. M. Lee, Pohang Univ. of Science and Technology (Korea, Republic of); H. Kim, S. Choi, Korea Research Institute of Standards and Science (Korea, Republic of); H. S. Park, Korea Institute of Standards and Science (Korea, Republic of); Y. Kim, Pohang Univ. of Science and Technology (Korea, Republic of)

Spatial interference of quantum mechanical particles exhibits a fundamental feature of quantum mechanics. A two-mode entangled state of N particles known as N00N state can give rise to non-classical interference. We report the first experimental observation of a three-photon N00N state exhibiting Young's double-slit type spatial quantum interference. Compared to a single-photon state, the three-photon entangled state generates interference fringes that are three times denser. Moreover, its interference visibility of 0.49 is well above the limit of 0.1 for spatial super-resolution of classical origin. The demonstration of spatial quantum interference by a N00N state composed of more than two photons represents an important step towards applying quantum entanglement to technologies such as lithography and imaging.

8163-38, Poster Session

Quantum memory for a photonic polarization qubit using hot atomic vapor
Y. Cho, Y. Kim, Pohang Univ. of Science and Technology (Korea, Republic of)

We report an experimental realization of an atomic vapor quantum memory for the photonic polarization qubit. The performance of the quantum memory for the polarization qubit, realized with electromagnetically-induced transparency in two spatially separated ensembles of warm Rubidium atoms in a single vapor cell, has been characterized with quantum process tomography. The process fidelity better than 0.91 for up to 16 µs of storage time has been achieved.

8163-17, Session 5

Simulation of entangled multiphoton state with incoherent thermal light
H. Chen, T. Peng, Univ. of Maryland, Baltimore County (United States)

I would like to report an experimental study on thermal light multiphoton qubits. Taking advantage of two-photon interference, we have successfully observed Bell type correlation from mutually incoherent and orthogonally polarized thermal fields. The visibilities of the polarization correlation as well as the temporal anti-correlation both exceed 71%, indicating the behavior of a two-photon Bell state, or a 2-digit qubit. The success of this Bell-type experiment advances our capability of simulating the behavior of high-number-photon qubits for computation purposes.

8163-18, Session 5

Parameter dependence of the decoherence of orbital angular momentum entanglement due to atmospheric turbulence
A. Hamadou Ibrahim, F. S. Roux, CSIR National Laser Ctr. (South Africa); T. Konrad, Univ. of KwaZulu-Natal (South Africa)

The orbital angular momentum (OAM) states of light can potentially be used to implement higher dimensional entangled systems for quantum communication. Unfortunately, optical fibers in use today support only modes with zero OAM values. Free-space quantum communication is an alternative to the traditional way of communicating through optical fibers. However, the refractive index fluctuation of the atmosphere gives rise to random phase aberrations on a propagating optical beam. To transmit quantum information successfully through a free-space optical channel, one needs to understand how atmospheric turbulence influences quantum entanglement. Here, we present a numerical study of the evolution of quantum entanglement between a pair of qubits. The qubits consist of photons entangled in the OAM basis. The photons propagate in a turbulent atmosphere modeled by a series of consecutive phase screens based on the Kolmogorov theory of turbulence. Maximally entangled initial states are considered, and the concurrence is used as a measure of entanglement. We show how the evolution of entanglement is influenced by various dimension parameters, such as the beam waist, the strength of the turbulence and the wavelength of the beam. We restrict our analysis to the OAM values l = ±1 and we compared our results with previous work.

8163-19, Session 5

Towards a narrow linewidth non-degenerate source of correlated photon pairs
O. T. Slattery, L. Ma, X. Tang, National Institute of Standards and Technology (United States)

A non-degenerate entangled photon pair source can actively interface between flying qubits and stationary qubits. In this presentation, we will introduce our efforts to generate narrow linewidth non-degenerate pairs with one photon at a wavelength (1310 nm) suitable for long distance transmission and the second photon (895 nm) suitable for integration with an atomic (Cesium) ensemble for quantum memory. Spontaneous parametric down conversion (SPDC) is commonly used to produce degenerate photon pairs (both are the same wavelength), broadened to hundreds of gigahertz or a terahertz. For successful interaction with atomic ensembles, the interacting photon must achieve a very narrow linewidth, in the order of megahertz. We describe our efforts to use cavity enhanced SPDC to produce non-degenerate photon pairs with linewidths suitable for photon-atom interaction as well as long distance transmission. The experiment includes a non-linear periodically poled bulk crystal (2 cm lithium niobate) pumped at 532 nm and the resulting pairs of correlated photons are at 895 nm and 1310 nm, respectively. The single pass (no cavity) linewidth is about 4 nm at 1310 nm. By introducing the crystal into a cavity tuned to resonate at 895 nm and by relying on the principle of the conservation of energy in the non-linear interaction, the effect is to limit the generation of the pairs to the linewidths matching the resonant modes of the cavity. The resulting linewidth will be significantly narrower than the single pass linewidth. Applications include quantum repeaters and the advancement of quantum computer networks.
8163-20, Session 5

Broadband waveguide quantum memory for entangled photons

E. Saglamyurek, N. Sinclair, J. Jin, J. Slater, D. Oblak, Univ. of Calgary (Canada); F. Bussieres, Univ. of Geneva (Switzerland); M. George, R. Ricken, W. Sohler, Univ. Paderborn (Germany); W. Tittel, Univ. of Calgary (Canada)

Quantum information processing and communication relies on encoding information into quantum states of physical systems such as photons [1]. Photon-encoded quantum information travels quickly—excellent for long distance quantum communication. The resulting applications of properties of quantum physics offer secure encryption through quantum key distribution without relying on unproven mathematical assumptions [2] and, by means of quantum teleportation, allow for the disembodied transfer of quantum states between distant places [1]. Actualizing a quantum interface [3] between light and matter is imperative for construction of a quantum repeater [4], which is required to extend the current hundred kilometre quantum communication distance limit, and for information synchronization in a quantum network [5]. A pivotal characteristic of a quantum interface is the ability to faithfully map quantum entanglement [1] between light and matter.

In this work we report the reversible transfer of photon-photon entanglement into entanglement between a photon and a collective atomic exciton in a solid-state thulium-doped lithium niobate waveguide [6] (this transfer was simultaneously done in [7]). We do so using a photon-echo quantum memory protocol [8], and by increasing the spectral acceptance from the current maximum [9] of 100 megahertz to 5 gigahertz. We show, within statistical error, a perfect mapping process by violating a Bell inequality and comparing the amount of entanglement contained in the detected photon pairs before and after the reversible transfer [1]. Despite the necessity to increase the storage efficiency and storage time, this study paves the way to new explorations of fundamental and applied aspects of quantum physics.

References:

8163-21, Session 5

Quantum interference of single photons with orbital angular momentum by a triangular slit: a Born rule

E. J. S. Fonseca, A. A. J. Jesus-Silva, J. M. Hickmann, Univ. Federal de Alagoas (Brazil)

The double-slit at single photon or electron level has been the quintessential quantum interference experiment where optical path phase plays a key role, while photon’s orbital angular momentum (OAM) brings a new dimension to interference problems with the spiral phase degree of freedom. Using OAM’s two-dimensional properties, we have extended the double-slit to a triple-slit configuration in the shape of an equilateral triangle, obtaining a triangular single photon counting quantum interference pattern, whose size depends on the photon’s OAM. We have shown that this pattern is a manifestation of photon’s wave-particle duality, but in contrast with the parallel slit cases, the azimuthal phase plays a fundamental role, being undistinguishable from path phase. Our results confirm that only pairs, associated here to path and azimuthal phases, contribute to the photon detection probability, as established by Born rule.

Accordingly with Born’s rule, in quantum mechanics only pairs of amplitude probabilities interfere.

The results presented in this paper corroborate the principle that quantum interference always comes from correlating pairs and extend experimental verification of Born’s rule for systems where OAM provides an extra degree of freedom, i.e. the azimuthal angle which enhances indistinguishability. We also extend such experimental verification from zero dimension (one point) to two dimensions (2D).

8163-22, Session 6

Pulse-pumped up-conversion single photon detectors and their applications

L. Ma, O. T. Slattery, X. Tang, National Institute of Standards and Technology (United States)

Frequency up-conversion detectors have been developed for highly efficient single photon detection in telecommunication bands at the near infrared region. While CW pumping is commonly used in this type of detector, a pulse pumping scheme can have some advantages. For example, this type of scheme can reduce the dark count rate. The dark counts in an up-conversion detector are mainly caused by the strong pump. When the pump pulse width is equal or slightly larger than the optical signal pulse, the dark count rate can be reduced while the detection efficiency remains the same. Additionally, the limitation on the temporal resolution caused by the timing jitter of the Si-APD when used in CW pumped mode can be avoided since the pulse-pumped up-conversion detector acts as an optical sampling device, increasing the temporal resolution significantly. Finally, we make use the pulse pumped scheme into a communication system to increase its data transmission rate, which is still limited by the timing jitter, since it is usually larger than the pump pulse width itself. To increase the system’s data transmission rate, we developed a multi-wavelength pulse pumping technique, in which the data detected within a single time jitter period of the Si-APD can be projected into wavelength domain and then recovered back into time domain.

We will present our research on the pulse-pumped upconversion single photon detectors and their applications, including noise reduction in quantum key distribution systems, higher temporal resolution optical sampling, and better system data transmission rate with multi-wavelength pulse pumping.

8163-23, Session 6

Towards quantum computation with incoherent thermal light

V. Tamma, Y. Shih, Univ. of Maryland, Baltimore County (United States)

One of the main challenges in quantum computation is the realization of entangled states with a large numbers of particles. Although the study of such states has allowed a strong development in understanding the physics behind multi-particle superposition, the production of entangled states of more than three particles is still a critical issue.

The efficiency of the famous Shor’s algorithm decreases exponentially
with respect to the number of entangled particles. For this reason it is of fundamental importance first to understand the role played by entanglement in quantum computation and second to study alternative physical phenomena which are able to simulate such a role without necessarily using entanglement.

Inspired by the previous works on factoring using Gauss sums, we have experimentally demonstrated a novel factoring algorithm which relies only on physical interference and on the periodicity properties of Gauss sums with continuous arguments. An important advantage of this method stands in the possibility of factoring several numbers with a single experimental run. However, in its present form this algorithm still relies on an exponential number of resources.

A more recent approach to factorization aims to achieve an exponential speed-up without entanglement by exploiting multi-photon n-order interference. In this case, the basic requirement for quantum computation is interference of an exponentially large number of multi-particle amplitudes.

8163-24, Session 6

Two coupled Jaynes-Cummings systems

P. Xue, Southeast Univ. (China)

We fully characterize the spectrum, stationary states and linear susceptibility of two Jaynes-Cummings systems coupled together by the overlap of their respective longitudinal field modes. For weak coupling, the pair of systems are similar to a single Jaynes-Cummings system undergoing an AC Stark Effect, and for strong coupling the behavior is similar to two coupled harmonic oscillators. For in-between coupling strengths, the pair of atoms and the pair of field modes are highly entangled states, and, where the spectrum exhibits avoided crossings as a function of coupling strength, the atoms and fields are very close to being four-qubit entangled states.

Coupled Jaynes-Cummings systems are relevant to stitues of quantum information and of condensed matter. Cavity quantum electrodynamics provides one strategy for implementing scalable quantum computing, and coupled Jaynes-Cummings systems are required for providing scaling to an arbitrarily large qubits. Coupled Jaynes-Cummings systems are also important in condensed matter physics as a Jaynes-Cummings lattice comprises many coupled Jaynes-Cummings systems and could lead to new states of matter not seen or expected for any other system. Our analysis provides a foundation for studying multiple Jaynes-Cummings systems for these applications.

8163-25, Session 6

Perpetual quantum computation

K. Nemoto, S. J. Devitt, A. Stephens, National Institute of Informatics (Japan); W. J. Munro, NTT Basic Research Labs. (Japan)

Optical quantum information processing has been extensively developed both theoretically and experimentally in the last decade. The advances of optical QIP are clear in some demonstrations such as high fidelity gates and quantum walk simulations, however the scalability issue which these current implementation suffer needs to be solved before serious developments of optical quantum technology. Clearly, one way to solve this problem is to extend our capability of optical QIP to generate and control optically nonlinear operations. Towards this direction, cavity-based quantum devices has been attracted much attention. A new architecture for optical quantum computer utilizing such photon-atom coupling device, called photonic module, was introduced in 2009. This architecture illustrated the structure and operation of a fault-tolerant, fully error corrected quantum architecture. The architecture was based on components which were all theoretically deterministic. Not only deterministic photon-photon coupling by an atom/cavity system within each photonic module and also photonic sources and detectors were simply assumed to be deterministic and of high fidelity.

In this talk, we take the optical architecture and replace the sources and detectors with the photonic module and week coherent-light source. This will lead to a network running with highly probabilistic single photon sources and entirely constructed from one quantum component, namely the photonic module. To combat the issue of probabilistic sources, we introduce a perpetual design, where the photonic module acts as non-destructive photon detector and photons in the computer are simply recycled. In this way, probabilistic sources are responsible for two tasks. (1) Providing the photons to initialize the network and (2) replacing photons which are periodically lost during computation. This talk will demonstrate how a highly probabilistic source can be integrated into a large scale architecture without sacrificing performance or the overall design and operation of the system.

8163-26, Session 7

Toward single photon optical nonlinearities for quantum information and quantum metrology

S. Takeuchi, R. Okamoto, M.Fujiwara, H. Takashima, M. Okano, S. Subashchandran, Hokkaido Univ. (Japan); A. Tanaka, K. Toubaru, Osaka Univ. (Japan)

In this paper, we will present our two alternative efforts for the realization on single photon optical nonlinearities for quantum information and quantum metrology. The first approach is to utilize a single light emitters embeded in a high-finess micro sphere cavity coupled with a tapered optical fiber. We will report the control of coupling between the tapered fiber and the microsphere at the cryogenic temperature[1]. We have also succeeded in obtained phase shift spectra of the fiber microsphere system using a very week coherent light probe with the average number of photons per 10ns (typical decay time of the diamond nitrogen vacancy centers) below [2]. The second approach is to utilize ‘monocycle entangled photons’, which is the novel two-photon states with extreme time correlation down to a few femto-second level[3]. It is pointed out that the efficiency of the second harmonic generation between the two photons will be increased dramatically using such states. We will report our recent experimental progresses on the realization of monocyte entangled photon states.


8163-27, Session 7

The Dolinar receiver in an information theoretic framework

B. I. Erkmen, K. M. Birnbaum, B. E. Moisien, S. J. Dolinar, Jr., Jet Propulsion Lab. (United States)

It is well known that optical communication at the ultimate limits set by quantum mechanics requires measurement apparatuses that extract the information encoded in optical states of light with the highest efficiency. Unfortunately, it is often a difficult and elusive goal to realize measurements that achieve these quantum mechanical limits. The Dolinar receiver exemplifies a rare instance of success where the measurement meets the Helstrom lower bound with equality. In this receiver, a time-varying local oscillator is mixed with the incoming signal prior to photodetection, and the feedback for the local oscillator is chosen such that, both globally and incrementally, the probability of incorrectly distinguishing between two coherent state symbols is minimized. Inspired by this architecture, in this paper we investigate optical communication conducted with binary phase-shift keying (BPSK) modulation, and the same adaptive receiver structure, but using an information-theoretic optimization criterion. In particular, we seek the local oscillator field that will maximize the mutual information globally between the input symbols and the photon counts over the symbol duration. We show that this is
equivalent to maximizing the mutual information incrementally in each instant of time, conditioned on the past observations, and we derive the objective function that is satisfied by the optimal local oscillator. For the BPSK case, we show that the Dolinar receiver’s feedback function is the local oscillator function that also maximizes the mutual information. Our formalism extends to higher dimensional constellations, but, obtaining analytic expressions for the optimum local oscillator field are often not straightforward.

8163-28, Session 7

New developments in single-photon detection: superconducting nanowires and transition edge sensors

M. J. Stevens, B. Baek, B. Calkins, S. D. Dyer, T. Gerrits, A. E. Lita, S. W. Nam, National Institute of Standards and Technology (United States)

Superconducting detectors have emerged as among the highest-performing single-photon detectors at visible and infrared wavelengths. We will discuss our recent progress in developing two different single-photon sensitive superconducting detector systems. One system uses a superconducting nanowire single-photon detector (SNSPD), and the other employs a superconducting transition edge sensor (TES). This talk will cover device fabrication, packaging in cryogenic systems, and characterizing detector performance (detection efficiency, timing jitter, dark count rate, etc.). We have implemented these detector systems in a variety of quantum optics experiments, including polarization tomography of entangled photon pairs, high-order coherence measurements, and optical Schrödinger cat state generation.

8163-29, Session 8

Toward optical switches using the Zeno effect and two-photon absorption

B. C. Jacobs, The Johns Hopkins Univ. Applied Physics Lab. (United States)

All-optical switching and logic elements could be at the forefront of next generation computing and telecommunication systems, but only if a few key issues with the technology can be resolved. We have developed an approach based on the Zeno Effect that could overcome two of the biggest challenges with this technology: the need for relatively intense optical fields; and excessive power dissipation. We have previously shown that a classical version of the Quantum Zeno Effect (QZE) can be used to implement low-loss switching, logic, and memory operations. A significant feature of our basic design is that the envisioned devices could be cascaded on a single optical chip - potentially allowing scalable all-optical information processing networks. This cascading feature could also enable efficient signal regeneration and control signal energy reacquire, allowing the overall system dissipation to be very low. Here we review the basic gate operation, present theoretical estimates of the switching and signal regeneration applications, and report on experimental progress toward realizing these devices.

8163-31, Session 8

Emulating a quadrature-phase-shift state-discrimination receiver with error rate below the standard quantum limit

F. E. Becerra, J. Fan, S. Polyakov, National Institute of Standards and Technology (United States); J. Goldhar, Univ. of Maryland, College Park (United States); J. T. Kosioriski, The Johns Hopkins Univ. (United States); A. L. Migdall, National Institute of Standards and Technology (United States)

In optical communication information is encoded and sent in optical coherent states. The receiver measures the state and identifies the symbol that was sent. However, perfect discrimination of coherent states is impossible due to their inherent nonorthogonality. No physical measurement can unambiguously distinguish nonorthogonal states with total certainty. The minimum probability of error for conventional receivers is referred to as the homodyne limit. However this is not the lowest probability of error allowed by quantum mechanics. While the minimum error probability for the discrimination of nonorthogonal states is given by the Helstrom bound for binary phase-based communication, extending beyond binary phase schemes to a larger number of symbols in the alphabet may yield lower bounds.

We have experimentally emulated a receiver discriminating among four non-orthogonal states in a quadrature-phase-shift keying (4PSK) communication scheme with a low error rate approaching the standard quantum limit. The proposed receiver scheme works in a feed-forward manner, with the result of each phase-discrimination stage used to update the phase of the reference signal that operates as a local oscillator for the next stage. We analyze the experimental performance of our system which emulates, by post-selection, a Bayesian strategy to update the phase of the local oscillator in each subsequent stage. We observe that above a certain total-detection efficiency of the receiver a low number of stages is sufficient to surpass the homodyne limit for 4PSK signals. In our experimental setup we demonstrate that this total detection efficiency is achievable and thus this scheme can realistically be expected to lead to a communication system that surpasses the standard quantum limit.

8163-34, Session 8

Quantum enhanced lidar resolution with multi-spatial-mode phase sensitive amplification

C. Santivanez, S. Guha, Z. Dutton, BBN Technologies (United States); M. Annamalai, M. Vasiliev, The Univ. of Texas at Arlington (United States); B. J. Yen, R. Nair, Massachusetts Institute of Technology (United States); J. H. Shapiro, Massachusetts Institute of Technology (United States)

Phase-sensitive amplification (PSA) can enhance the signal-to-noise ratio (SNR) of an optical measurement suffering from detection inefficiency. Previously, we showed that this increased SNR improves LADAR-imaging spatial resolution when infinite spatial-bandwidth PSA is employed. Here, we evaluate the resolution enhancement for realistic, finite spatial-bandwidth amplification. PSA spatial bandwidth is characterized by numerically calculating the input and output spatial modes- and their associated phase-sensitive gains - under focused-beam pumping. We then compare the spatial resolution of a baseline homodyne-detection LADAR system with homodyne LADAR systems that have been augmented by pre-detection PSA with infinite or finite spatial bandwidth. The spatial resolution of each system is quantified by its ability to distinguish between the presence of 1 point target versus 2 closely-spaced point targets when minimum error-probability decisions are made from shot-noise limited measurements. At low (5-10 dB) SNR, we find that a PSA system with a 2.5 kW pump focused to 25 m x 400 m achieves the same spatial resolution as a baseline system having 5.5 dB higher SNR. This SNR gain is very close to the 6 dB SNR improvement possible with ideal (infinite bandwidth, infinite gain) PSA at our simulated system detection efficiency (0.25). At higher SNRs, we have identified a novel regime in which finite spatial-bandwidth PSA outperforms its infinite spatial-bandwidth counterpart. We show that this performance crossover is due to the focused pump system's input-to-output spatial-mode transformation converting the LADAR measurement statistics from homodyne to heterodyne performance.
8163-35, Session 8

Quantum-enhanced ladar ranging with squeezed-vacuum injection, phase-sensitive amplification, and slow photodetectors

R. Nair, B. J. Yen, Massachusetts Institute of Technology (United States); J. H. Shapiro, Massachusetts Institute of Technology (United States); J. Chen, Z. Dutton, S. Guha, M. P. da Silva, BBN Technologies (United States)

Theory has shown that the quantum enhancements afforded by squeezed-vacuum injection (SVI) and phase-sensitive amplification (PSA) can improve the spatial resolution of a soft-aperture, homodyne-detection LADAR system. Here we show they can improve the range resolution of such a LADAR system. In particular, because an experimental PSA-enhanced system is being built whose slow photodetectors imply multi-pulse integration, we develop range-measurement theory that encompasses its processing architecture. We allow the target to have an arbitrary mixture of specular and speckle components, and will present computer simulation results demonstrating the range-resolution improvement that accrues from quantum enhancement with SVI and/or PSA.

8163-36, Session 8

Physical implementation of non-physical quantum operations: realization of the universal transpose operation

H. Lim, Y. Ra, Y. Kim, Pohang Univ. of Science and Technology (Korea, Republic of); J. Bae, Korea Institute for Advanced Study (Korea, Republic of); Y. Kim, Pohang Univ. of Science and Technology (Korea, Republic of)

The universal transpose of quantum states is an anti-unitary transformation that is not allowed in quantum theory. In this work, we investigate approximating the universal transpose of quantum states of two-level systems (qubits) using the method known as structural physical approximation. We also report its experimental implementation in linear optics. The scheme is optimal in that the maximal fidelity is attained, and also practical as measurement and preparation of quantum states that are experimentally feasible within current technologies are solely applied.

8163-40, Session 8

Toward ghost imaging with cosmic ray muons

M. D’Angelo, F. Di Lena, Univ. degli Studi di Bari (Italy); M. D’Incecco, Istituto Nazionale di Fisica Nucleare (Italy); A. Garuccio, Univ. degli Studi di Bari (Italy); R. Moro, Istituto Nazionale di Fisica Nucleare (Italy); A. Regano, F. Romano, Univ. degli Studi di Bari (Italy); G. Scarcelli, Harvard Medical School (United States)

Muons generated by cosmic rays are an interesting source to study in the context of ghost imaging: As naturally available deeply penetrating particles characterized by an extremely small De Broglie wavelength, they are promising candidates for very long distance high resolution ghost imaging.

The project Extreme Energy Events (EEE) offers a platform to study the feasibility of muon ghost imaging. To detect cosmic ray muons, EEE uses “telescopes” composed by three Multigap Resistive Plate Chambers (MRPC) with lateral spatial resolution of 1cm. Coincidences between muons have been measured by MRPC telescopes installed in two neighbor schools of L’Aquila, Italy, 180 m apart. By tracing a histogram of both the temporal and the momentum distribution of muon coincidences obtained from 9 days of data accumulation, we observe a highly visible correlation peak.

From fundamental point of view, with light, ghost imaging either employs the quantum correlations exhibited by entangled photons from SPDC, or the Hanbury-Brown and Twiss effect exhibited by chaotic light sources. Interestingly, muon pairs detected from cosmic ray showers exhibit both a chaotic/thermal component (mostly due to the multitude of incoherent cosmic rays that simultaneously reach the earth atmosphere) and a strong spatio-temporal correlation. Such a correlation represents an encouraging starting point to understand the physics behind this naturally available source and to evaluate the feasibility of ghost imaging with massive particle.
8164-01, Session 1
Recent progress made in testing laser diode and optical materials subjected to exposure in space

N. S. Prasad, NASA Langley Research Ctr. (United States)

In this paper, progress made so far in the performance testing of high power laser diode and thermoelectric materials sent by NASA Langley Research Center on MISSE 6 mission will be discussed. The objective of the Materials International Space Station Experiment (MISSE) is to study the performance of novel materials when subjected to the synergistic effects of the harsh space environment for several months. MISSE missions provide an opportunity for developing space qualified materials. The results of post-testing of several optical materials that were recently returned back after more than one year of exposure on the International Space Station (ISS) will be presented. The items were part of the MISSE 6 mission that was transported to the ISS via STS 123 on March 11, 2008 and returned to the Earth via STS 128 that was launched on August 2009. The materials experienced no visible damage during lengthy exposure in space. In the case of laser diode, a comparison of elemental analysis with pre-flight conditions will be discussed. This will be followed by results of post-flight testing of thermoelectric material samples.

8164-02, Session 1
Proton radiation testing of laser optical components for NASA Jupiter Europa Orbiter Mission

W. J. Thomes, Jr., J. F. Cavanaugh, M. N. Ott, NASA Goddard Space Flight Ctr. (United States)

The Jupiter Europa Orbiter (JEO) is NASA's element of the joint Europa Jupiter System Mission (EJSM). Based on current trajectories, the spacecraft will spend a significant amount of time in the Jovian radiation belts. Therefore, research endeavors are underway to study the radiation effects on the various parts and components needed to assemble the instruments. Data from these studies will be used for component selection and system design to ensure reliable operation throughout the mission duration. The radiation environment on the way to Jupiter is nothing new for NASA designed systems, however, the long durations orbiting Jupiter and Europa present new challenges for radiation exposure. High-energy trapped electrons and protons at Jupiter dominate the expected radiation environment. Therefore, most of the initial component level radiation testing is being done using protons. In this paper we will present in-situ monitoring of the optical transmission of various laser optical components during proton irradiation. Radiation induced optical attenuation of some components is less than would be expected, based on the authors experiences, and is attributed to the interaction of the protons with the materials. This will be followed by results of post-flight testing of thermoelectric material samples.

8164-03, Session 1
Mesa-isolated InGaAs avalanche photodiode damage by ionizing radiation

A. S. Huntington, M. A. Compton, L. A. Sellstedt, Voxtel, Inc. (United States); E. W. Taylor, International Photonics Consultants, Inc. (United States)

InGaAs avalanche photodiodes (APDs) fabricated from epitaxial material by etching detector mesas and encapsulating the etched mesas under benzocyclobutene (BCB) resin were irradiated by Co-60 gamma-rays to simulate a total ionizing dose which might be experienced on a space environment. The APDs were not under bias during irradiation. Damage to the APDs was assessed by measuring the increase in dark current following irradiation.

8164-04, Session 1
Self-trapped holes in glassy silica: basic science with relevance to photonics in space

D. L. Griscom, impactGlass Research International (United States)

Development of radiation-hard silica-based fiber optics (FOs) is greatly aided by a fundamental understanding of the radiation-induced point defects in glassy SiO2 that absorb light in the wavelength ranges where high transmissivity is required. The molecular-scale structures of those defects that are paramagnetic are determined by electron spin resonance (ESR), and their associations with specific absorption bands are established by ESR-optical correlations involving post-irradiation thermal annealing experiments. In the past half century many point defects in pure silica have been characterized in great detail. Among the best understood trapped-hole defects are several variants of E' centers, the non-bridging-oxygen hole center, the peroxo radical, and two variants of self-trapped holes (STHs).[1] Unlike the others, the STHs decay rapidly at room temperature (according to fractal kinetics)[2] and their profound effects on transmission in the range ~400 - 1000 nm (with a tail to longer wavelengths)[2] depends on dose RATE,[2] not total dose, thus thwarting accelerated testing of FO systems for satellites - and threatening to momentarily black out FO systems exposed to radiation from nuclear detonations in space. Astonishingly, the transient absorption due to STHs can be suppressed by more than an order of magnitude by preirradiation at relatively low dose rates (at least as low as 0.25 Gy/sec) for periods ~3 months.[3,4]


8164-05, Session 1
Nanoneutron thrust measurement of photon pressure propulsion using semiconductor laser

K. Iwami, T. Akazawa, T. Ohitsuka, H. Nishida, N. Umeda, Tokyo Univ. of Agriculture and Technology (Japan)

To evaluate the thrust produced by photon pressure emitted from a 100 W class continuous-wave semiconductor laser, a torsion-balance precise thrust stand is designed and tested. Photon emission propulsion using semiconductor light sources attract interests as a possible candidate for deep-space propellant-less propulsion and attitude control system. However, the thrust produced by photon emission as large as several nanonewtons requires precise thrust stand. A resonant method is adopted to enhance the sensitivity of the bifiler torsional-spring thrust stand. The torsional spring constant and the resonant of the stand is $1.245 \times 10^{-3}$ Nm/rad and 0.118 Hz, respectively. The experimental results showed good agreement with the theoretical estimation. The thrust efficiency for photon propulsion was also defined. A maximum thrust of 499 nN was produced by the laser with 208 W input power (75 W of optical output) corresponding to a thrust efficiency of 36.7%. The
8164-06, Session 2

**Pulse shaping high-energy fiber laser at low repetition rate**

P. Wan, J. Liu, L. Yang, PolarOnyx, Inc. (United States); F. Amzajerdian, NASA Langley Research Ctr. (United States)

High energy pulsed fiber lasers have been considered as an enabling technology with many applications, such as Lidars, holography, free space optical communications, and material processing due to their many advantages such as compact, light-weight and high wall-plug efficiency. In eye safe wind-profiling Lidar applications, 200 ns pulse width is required at low repetition rates down to Hz level. However, due to ASE effect and the gain dynamics in Er-doped fiber lasers, the repetition rate is limited to kHz. Q-switched solid state lasers are usually applied with comparatively low pulse repetition rates.

In recent publications we demonstrated a 10 kHz repetition rate, 150 ßJ pulse energy at a wavelength of 1.5 ßm with a pulse width of 200 ns. In this paper, we have demonstrated a modulated pump scheme combined with a pulse shaping technology to generate high energy pulses at a wavelength of 1.5 ßm with low repetition rates. This method is proven to be an efficient way to mitigate SBS effects, pulse narrowing effects as well as ASE in high energy fiber lasers. We successfully generated a 200 ns seed macro-pulse comprising of a series of micro-pulses each with a pulse width less than 20 ns. After power amplification, we obtained pulse energy of 120 ßJ at 500 Hz repetition rate and 90 ßJ at ultra low repetition rates (10 Hz). Excellent pulse shape, high extinction ratio and power stability were achieved.

8164-07, Session 2

**Grating gated HEMT for tunable THz and mm-wave detection**

R. E. Peale, N. Nader, C. J. Fredrickson, H. Saxena, G. Medhi, Univ. of Central Florida (United States); J. Hendrickson, W. R. Buchwald, Air Force Research Lab. (United States); J. W. Cleary, Solid State Scientific Corp. (United States)

Gate-voltage tunable plasmon resonances in the two dimensional electron gas of high electron mobility transistors (HEMT) provide an opportunity for tunable terahertz array detectors with applications in spectral sensing and space situational awareness. Though tunable resonant absorption has been clearly observed in optical experiments, transduction to measurable electrical signal has been elusive for HEMTs made in the InP-based materials system. This is in part due to the paucity of suitable terahertz sources and the difficulties inherent in the use of those that exist. To uncover the desired electrical effects, mm-wave devices have been designed to allow use of backward wave oscillators. Such sources have advantages such as continuous frequency tuning, frequency and amplitude modulation for lock-in detection, stability, delivery and detection using standard microwave components, and the ability to control and enhance the field using suitable cavities. Calculated resonance spectra predict the expected lock-in output as functions of frequency and gate bias to enable interpretation of the observations. Detection of terahertz-to-photon-to-electronic transduction will inform optimization and migration to frequencies as high as 10 Thz. First observations of tunable resonant changes in channel conductance are reported.

8164-08, Session 2

**2um fiber laser sources and their applications**

J. Geng, S. Jiang, AdValue Photonics, Inc. (United States)

Mid-infrared fiber laser sources have attracted a lot of interest in space and defense applications. We review our latest developments of various fiber laser sources operating near 2um and beyond the wavelength, which include single-frequency CW sources, nanosecond pulsed sources, mode-lockd sources, and supercontinuum sources. Potential applications of these mid-infrared fiber sources will also be discussed.

8164-09, Session 3

**Ultrafast coherent optical signal processing technologies and applications using stabilized optical frequency combs**

P. J. Delfyett, Jr., CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

The development of nanophotonic systems and devices for high speed communications, interconnects and signal processing are critical for next generation space borne and on-board applications. Lightwave technologies offer the promise of high bandwidth connectivity from component development that is manufacturable, cost effective, and electrically efficient. The concept of optical frequency/wavelength division multiplexing has revolutionized methods of optical communications, however the development of optical systems using 100’s of wavelengths present challenges for network planners. The development of compact, efficient optical sources capable of generating a multiplicity of optical frequencies/wavelength channels from a single device could potentially simplify the operation and management of high capacity optical interconnects and links. Over the years, we have been developing mode-locked semiconductor lasers to emit ultrashort optical pulses at high pulse repetition frequencies for a wide variety of applications, but geared toward optical communications using time division multiplexed optical links. The periodic nature of optical pulse generation from mode-locked semiconductor diode lasers also make these devices ideal candidates for the generation of high quality optical frequency combs, or multiple wavelengths, in addition to the temporally stable, high peak intensity optical pulses that one is accustomed to. The optical frequency combs enables a variety of optical communication and signal processing applications that can exploit the large bandwidth and speed that femtosecond pulse generation implies, however the aggregate speed and bandwidth can be achieved by spectrally channelizing the bandwidth, and utilize lower speed electronics for control of the individual spectral components of the mode-locked laser. This presentation will highlight our recent results in the generation of stabilized frequency combs, and in developing photonic device technologies and approaches for filtering, modulating and detecting individual comb components. We then show how these technologies can be applied in signal processing applications such as arbitrary waveform generation, arbitrary waveform measurement, synthetic aperture imaging and matched filtering for pattern recognition.

8164-10, Session 3

**Photonic microdevice fabrication with femtosecond fiber laser**

H. Huang, L. Yang, J. Liu, PolarOnyx, Inc. (United States)

There is a great deal of interests and efforts in the area of femtosecond (fs) laser direct writing of transparent materials, which promises to be a powerful and flexible technique for rapid fabrication of photonic micro-devices, such as gratings, waveguides and optical amplifiers. Waveguide properties depend critically on the sample material properties and writing laser characteristics. In this paper, we present the results using fs fiber laser on the micro-scale design and fabrication of photonic micro-devices using fs fiber laser direct-writing technique. Single line writing of doped/undoped glasses with respect to the focused laser beam at different pulse energies, repetition rates and writing speeds has been investigated at first. Then the waveguide properties were characterized in terms of their transmission, reflection and gain data. It was found that specific consideration of the pulse energy and repetition rate, writing
speed and number of fabrication scans should be taken into account in order to fabricate low-loss positive index guiding waveguide devices in a specific type of glass. Furthermore, three-dimensional microfluidic networks in glasses have also been demonstrated. The channel size can be changed by using different laser pulse energy or different pulse repetition rate. The modified regions in both waveguides and microfluidic networks were checked by Scanning Electron Microscope to understand the spatial profile of the laser-exposed regions. These two techniques can be combined to produce miro-devices that incorporate on a single chip optical system with microfluidic system.

8164-11, Session 3

Design of microdisk modulators and detectors for high-speed integrated WDM systems

G. W. Taylor, Univ. of Connecticut (United States); J. Cai, B. Pile, Y. Zang, ODIS, Inc. (United States)

It is anticipated that future VLSI integrated circuits will be optoelectronic with optical and electronic I/O. It will also involve a significant level of on-chip optical interconnects to connect CPU cores with cache memory and perform routing functions between functional blocks. Thus, in conjunction with transistors, the circuits will require a significant density of lasers, detectors and modulators. To achieve these densities with future scalability, the optimum geometries for laser, detector, modulator, and switch functions are microresonators. The resonance characteristic enables a reduced form factor and, further, it enables WDM to be employed within the chip. In this paper, the microdisk will be evaluated as an absorption and phase modulator in the context of POET (Planar OptoElectronic Technology), a new technology approach for optoelectronic integrated circuits. The modulation is obtained by the blue shift of the absorption edge with the injection of channel charge. The large absorption change provides unique control over the resonator characteristics, whereas the majority of reported microresonator modulators rely mostly on index change. It will be shown that the POET absorption modulator achieves full on-off switching with voltage inputs of 0.3V and an electrically-dominated bandwidth of 50GHz for a 10um diameter disk. Furthermore a row these disks may access the same straight waveguide to achieve WDM with wavelength separations of about 2nm. Using a similar geometry, a row of wavelength selective detectors can be implemented to provide an optimum WDM interface.

8164-12, Session 4

Resonant optoelectronic thyristor switches as elements for optical switching fabrics

G. W. Taylor, Univ. of Connecticut (United States); J. Cai, B. Pile, ODIS, Inc. (United States); Y. Zang, Univ. of Connecticut (United States)

Optical switching fabrics are networks of devices that enable input to output routing of optical packets with arbitrary connectivity, providing that two separate input channels do not require simultaneous connection to the same output port, i.e. a contention. The goal of any fabric is to establish a connection pattern through the network by using the routing code contained in the header. Thus a successful approach must allow OE conversion of the header in real time to resolve contentions. A novel approach is described to implement the fabric with arrays of 2x2 switches where the switches are resonant microdisks coupled to waveguides. The switches have the unique ability to be written with optical inputs which therefore allows the signal pattern to be set up by the first passage of the header through the fabric. Functionally, these switches are OE thyristors and have a storage function which allows the state of the fabric to be set for all subsequent packets until a reset or clear function is applied. The resonant property allows several switches with different wavelengths to share the same waveguide. Thus an N wavelength WDM fabric is enabled with a throughput that is N times the simple fabric. A typical value for N is 5-10 based on the free spectral range of the disk. This paper will discuss the fabric design and progress towards its implementation in POET (Planar OptoElectronic Technology), a new OE technology implementation which integrates the optically resonant devices with complementary transistors for design of control circuits.

8164-13, Session 4

Small form factor optical fiber connector evaluation for harsh environments


For the past decade NASA programs have utilized the Diamond AVIM connector for optical fiber assemblies on space flight instrumentation. These connectors have been used in communications, sensing and LIDAR systems where repeatability and high performance are required. Recently Diamond has released a smaller form factor optical fiber connector called the “Mini-AVIM” which although more compact still includes the tight tolerances and the ratcheting feature of the heritage AVIM. NASA Goddard Space Flight Center Photonics Group in the Parts, Packaging and Assembly Technologies Office has been performing evaluations of this connector to determine how it compares to the performance of the AVIM connector and to assess its feasibility for harsh environmental applications. Vibration and thermal testing was performed on the Mini AVIM with both multimode and singlemode optical fiber using insitu optical transmission monitoring. Random vibration testing was performed using typical launch condition profiles for most NASA missions but extended to 35 Grms which is much higher than most requirements. Thermal testing was performed up to a-55°C to +125°C range. The test results include both unjacketed fiber evaluations and cabled assembly. The results are presented here. The data indicates that the Mini-AVIM provides a viable option for small form factor applications that require a high performance optical fiber connector.

8164-14, Session 4

Fiber optic cables for transmission of high-power laser pulses


High power pulsed lasers are commonly deployed in harsh environments, like space flight and military missions, for a variety of systems such as LIDAR, optical communications over long distances, or optical firing of explosives. Fiber coupling of the laser pulse from the laser to where it is needed can often save size, reduce weight, and lead to a more robust and reliable system. Typical fiber optic termination procedures are not sufficient for injection of these high power laser pulses without catastrophic damage to the fiber endface. In the current study, we will review the causes of fiber damage during high power injection and discuss our new manufacturing procedures that overcome these issues to permit fiber use with high reliability in these applications. A brief review of the design considerations for high peak power laser pulse injection will be presented to familiarize the audience with all the areas that need to be considered during the design phase will be included as an introduction. The majority of the presentation will then focus on the proper polishing methods for high power use with an emphasis on laser polishing of the fibers. Results from recently build fibers will be shown to demonstrate the techniques.
OLTARIS: an efficient web-based tool for analyzing materials exposed to space radiation

T. C. Slaba, NASA Langley Research Ctr. (United States); A. M. McMullen, Rochester Institute of Technology (United States); S. A. Thibeault, C. A. Sandridge, M. S. Clowdseley, S. R. Blattnig, NASA Langley Research Ctr. (United States)

The near Earth space radiation environment includes energetic galactic cosmic rays (GCR), high intensity proton and electron belts, and the potential for solar particle events (SPE). These sources may penetrate shielding materials and deposit significant energy in sensitive electronic devices on-board spacecraft and satellites. Material optimization methods may be used to reduce the exposure and extend the operational lifetime of individual components and/or systems. Since laboratory experiments are expensive and may not cover the range of particles and energies relevant for space applications, such optimization may be done computationally with efficient algorithms that include the various constraints placed on the component, system, or mission. In the present work, the web-based tool OLTARIS (On-Line Tool for the Assessment of Radiation in Space) is presented, and the applicability of the tool for rapidly analyzing exposure levels within either complicated shielding geometries or user-defined material slabs exposed to space radiation is demonstrated. An example approach for material optimization is also presented. Slabs of various advanced multi-functional materials are defined and exposed to several space radiation environments. The materials and thicknesses defining each layer in the slab are then systematically adjusted to arrive at an optimal slab configuration.

Molecular photonics in space environments: a review

J. Pérez-Moreno, Katholieke Univ. Leuven (Belgium)

Although much of the early developments of organic and polymer-based materials were fueled by the research on space materials, most of the optoelectronic applications for usage in space or terrestrial environments are still dominated by semiconductors. In this paper, we review past and present efforts to incorporate organic-based materials into photonic devices that are suitable for applications in space environments, and discuss what are the main challenges that materials based on organics must meet in order to become fully integrated into photonic devices that can operate in space and space-related environments.

Hyper-Rayleigh scattering as a screening tool for the optimization of piezoelectric polymers

J. Pérez-Moreno, K. Clays, Katholieke Univ. Leuven (Belgium)

The use of piezoelectric polymers has been proposed and investigated in different Space-related environments, for example, as ultra-light mirrors in space telescopes or as piezoelectric actuators. Even though some piezoelectric polymers have been shown to be as efficient as the more traditional piezoelectric crystals, no systematic exploration of the different molecular motives available for piezoelectricity has been performed, partly due to experimentally challenging conditions: new structures must be generated in enough quantity to be able to produce thin films, and with measurable piezoelectric response. Consequently, few structure-property relationships have been derived for the piezoelectric performance of polymer based materials. We show how, under certain conditions, the characterization of the second-order nonlinear molecular response through the Hyper-Rayleigh scattering technique, can be used to predict the piezoelectric response of the molecules in a film. In contrast to the piezoelectric characterization, a Hyper-Rayleigh experiment can be performed with minimal amounts of chromophores (~mg) in solution, and is relatively quick. Therefore, we propose to use the Hyper-Rayleigh scattering technique as a screening tool for the search of optimized piezoelectric polymers.
All fiber-based single-frequency Q-switched laser pulses at 2 um for lidar and remote sensing applications

W. Shi, NP Photonics, Inc. (United States); E. Petersen, N. Moor, NP Photonics, Inc. (United States) and Univ. of Arizona (United States); A. Chavez-Pirson, NP Photonics, Inc. (United States); N. Peyghambarian, NP Photonics, Inc. (United States) and Univ. of Arizona (United States)

In this paper, we report an all-fiber-based 2 um pulsed laser for the applications of LIDAR and laser remote sensing. This single-frequency actively Q-switched fiber laser is based on fiber birefringence induced by stress in the short laser fiber cavity. The cavity consists of our proprietary highly Tm doped germanate glass fiber. The highly Tm-doping concentration creates a high unit gain in active fiber, allowing for a short cavity, which creates large longitudinal mode spacing, helping to maintain lasing on a single longitudinal mode. The active fiber is fusion-spliced between two fiber Bragg gratings. In this method, a piezoelectric compressor a fiber creating stress birefringence, and this birefringence acts as a waveplate, changing the polarization state of the light in the fiber and switching the laser between high and low feedback states. The pulse width of this Q-switched fiber laser can be tuned from 10’s ns to sub-ns. The repetition rate can be tuned from 100 Hz to 100’s kHz. The average power is in the mW-level, peak power can reach watt-level, and pulse energy in the range of 10-100 nJ without any amplifier. Moreover, this transform-limited fiber laser pulses in 100’s ns regime has been successfully amplified by using newly developed large core single-mode highly Tm-doped germanate fiber 25/250 um in the power amplifier stage. Based on the monolithic MOPA configuration, > 100 uJ pulse energy has been achieved, which corresponds to a peak power of > 1 kW for transform-limited fiber laser pulses.

Low-noise laser at 2 micron wavelength with FM modulation

L. S. Watkins, B. Xu, R. Van Leeuwen, C. Ghosh, Princeton Optonics, Inc. (United States); E. W. Taylor, International Photonics Consultants, Inc. (United States)

We have developed a laser in the 1550nm wavelength band with very low intensity and phase noise, and are currently extending this technology to develop lasers with very similar characteristics in the 2 micron wavelength band. The 1550nm laser is a diode pumped solid-state laser using Yb:Er doped high phosphate glass for the gain medium. Both Tm doped YAP and Tm doped YAG are being investigated in a very similar laser configuration to produce lasers in the 2 micron wavelength band. Experiments are underway to investigate ionizing radiation and other effects on the lasers’ properties.

The laser power will be in the 20-100mW range and be single frequency with linear polarization output into a PM fiber. The laser design applies frequency feedback control using an internal high finesse locker to stabilize the wavelength and reduce the phase noise. The laser uses piezoelectric tuning with which we have demonstrated up to 5GHz FM modulation depth in both sinusoidal and ramp profiles at up to 1kHz rates. This has applications in Doppler LIDAR and other sensor applications.

The talk will review the overall laser design including FM modulation approaches. Latest results including radiation tests for the 2 micron laser will be given.

Recent developments in polycrystalline oxide fiber laser materials

H. Lee, K. A. Keller, B. M. Sirn, UES, Inc. (United States); M. Cheng, F. K. Hopkins, Air Force Research Lab. (United States); T. A. Parthasarathy, UES, Inc. (United States)

Laser quality, polycrystalline oxide fibers are critical to the optimization of high energy and high power lasers. Advanced ceramic processing technology, along with a novel powder production process, make it possible to produce various oxide fibers with an outstanding optical quality for use in the fiber laser applications. The production of contaminant-free green fibers with a high packing density, as well as uniform packing distribution, is a key factor in obtaining laser-quality fibers. High quality green fibers are dependent on the powder quality combined with the appropriate slurry formulation. These two fundamental technologies were successfully developed at UES, and used to produce Yb-doped yttrium aluminum garnet (YAG) fibers’ with high optical quality, high chemical purity, and suitable core diameters down to 20 microns. Current progress in developing polycrystalline oxide fibers for high energy laser applications will be reviewed.

Strategic photonic sensors: technology needs and challenges

S. Forbes, Air Force Research Lab. (United States)

No abstract available

Planar hybrid integration for the development of cost effective interferometric fiber optic gyroscopes (IFOG)

W. K. Bischel, M. A. Kouchmir, Gener8, Inc. (United States); M. Bitter, Gemfire Corp. (United States); R. Yahalom, Infiber Technology, Inc. (United States); E. W. Taylor, International Photonics Consultants, Inc. (United States)

The need for cost effective interferometric fiber optic gyroscopes (IFOG) for DoD and commercial applications requires that new approaches to the design and manufacturing of IFOG systems be developed. Monolithic integration has been demonstrated and commercialized for some optical integration applications (e.g. InP PIC optical chips), but this approach is unable to provide a complete solution for the integration of the discrete IFOG optical components. We have developed a new technology platform for IFOG optical systems based on the concept of hybrid integration. Hybrid integration enables the use of the best materials for the specific application and enables higher yields at low volumes due to the ability to yield at the individual chip level before integration. The most cost effective approach for optical integration is to leverage the more than 30 years of learning from the planar wafer-based semiconductor industry into the manufacturing of optical components.

A waveguide technology platform has been developed that includes several different processes and optical sub-components that effectively implement planar hybrid integration as a manufacturing strategy for advanced optical components. We will discuss the development of a practical set of device designs and processes that have been integrated into the first 4-channel IFOG optical engine planar waveguide hybrid chip. These include: (1)Passive waveguide platform for integration (PLC), (2)Out-of-plane mirrors and detector arrays, (3)Integration of light source arrays into a PLC chip, (4)Waveguide isolator array design and integration, (5)Chip-to-chip coupling techniques for fiberless interconnects, and (6)Lithium-niobate-PLC hybrid integration.
We will present the test results for the IFOG optical engine hybrid chip in an IFOG test bed and compare the result to the typical published results for an IFOG system fabricated from discrete optical components. We will also present the results of radiation testing of the IFOG optical engine as a first step toward qualification for space based applications. A sample set will be irradiated by Co-60 gamma-rays at a nominal room temperature to determine if any permanent induced effects result from the ionizing radiation dose.

8164-26, Session 7

Radiation effects on multiple DOF MEMS inertial sensors

B. Dillard, V. Trent, M. Greene, Archangel Systems, Inc. (United States); E. W. Taylor, International Photonics Consultants, Inc. (United States)

A novel 5 degree-of-freedom MEMS sensor called the MEMS Annular Rotating Sensor (MARS) with navigation-grade accuracy is being developed. MARS has a spinning mass gyroscope heritage but provides triaxial accelerations and dual rate outputs. The MARS rotor is suspended electrostatic in vacuum, isolating the silicon mass from bulk material noise and fatigue effects. Program expectations are gyro bias stability of 0.01°/hr, angular random walk of 0.001°/rt-hr, gyro scal e factor stability of 50 ppm and a bandwidth of 300 Hz. Evaluation prototypes are slated for Q4, 2011 release will have SWAP budgets of 3 cubic inches, 125 grams and 1 W for the MEMS sensor and all support hardware.

While the body of work in radiation effects on electronics is expansive, the same is not true for MEMS sensors. In this work, a set of MARS sensors are fully characterized, irradiated by Co-60 gamma rays under passive conditions and examined for total dose effects. Post-radiation comparative performance results will be presented at the conference.

8164-28, Session 8

Performance of long-wave infrared InAs/GaSb strained layer superlattice detectors

E. Plis, N. Gautam, M. N. Kutty, S. A. Myers, B. Klein, T. Schuler-Sandy, M. Naydenkov, S. Krishna, The Univ. of New Mexico (United States)

Photodetectors operating in the long-wave infrared (LWIR, 8-14 m and beyond) spectral band could be potentially useful for a wide variety of applications such as meteorology, satellite based surveillance, terrestrial pollution monitoring, and space-based astronomy. The technologies currently dominating those applications in this wavelength range are based on interband Mercury-Cadmium-Telluride (MCT) and extrinsic silicon blocked impurity band (BIB) MCT detectors are characterized by low operation temperatures due to a low electron effective mass resulting in excessive leakage current. Moreover, they are sensitive to small changes in the alloy composition ratio during the epitaxial process, making the spatial non-uniformity a challenging problem for large format focal plane arrays (FPAs). BIB detectors are limited to even lower operation temperatures due to high thermal ionization rates.

The basic material properties of type-II InAs/GaSb strained layer superlattices (SLs) provide a prospective benefit in the realization of photodetectors with cut-off wavelengths in LWIR range. Suppressed Auger recombination rates and larger effective mass in SLS leads to a reduction of tunneling currents and improved temperature limits of spectral detectivities compared with MCT detectors of the same bandgap. High degree of uniformity for III-V growth and processing over a large area also offers advantage for the InAs/GaSb SLS technology.

During the presentation, our efforts on fabrication of high-performance LWIR and VLWIR SLS single element detectors and FPAs will be presented. Implementation of novel nBn and pBiBn design concepts to SLS detectors, as well as multispectral operation of nBn detectors will be also discussed.

8164-29, Session 8

Thermoluminescence properties of Eu3+-doped CaSiO3-(SO4) nano phosphor

C. Rayappa, Vivekananda Degree College (India); K. P. Ramesh, Indian Institute of Science (India); B. M. Nagabhushana, M S Ramaiah Institute of Technology (India)

Porous materials are of significant interest due to their wide applications in catalysis, separation, light weight structural materials and biomaterials. Calciumsulphosilicate biomaterial doped with europium (Ca1-xEux SiO3-(SO4); x = 0.0 to 0.05) were synthesized by low-temperature solution combustion reaction. Solution combustion technique is a versatile process leading to synthesize single phase, composites, solid solutions as well as complex compound silicate phases in homogeneous form. Powder X-ray diffraction, scanning electron microscopy, Transmission electron microscope (TEM) and Fourier Transform Infrared spectroscopic techniques were used for the characterization of the synthesized products. The thermoluminescence (TL) and some of the dosimetric characteristics of Eu3+-activated (Ca1-xEux SiO3-(SO4) were reported. The TL glow curve is composed of only one peak located at about 156 °C between room temperature and 500 °C. The optimum Eu3+ concentration is 0.003 mol % to obtain the highest TL intensity. The TL kinetic parameters of (Ca1-xEux SiO3-(SO4) were studied by the peak shape method. The TL dose response is linear in the protection dose ranging from 1 to 80 Gy. The maximum temperature, the integral and the full width at half maximum of the thermoluminescence glow - peak as a function of the heating rate were studied in the range 2 to 25 oC/s.

8164-30, Session 8

Advances in nonlinear materials for space applications

E. W. Taylor, International Photonics Consultants, Inc. (United States)

No abstract available
8165A-01, Session 1

Optimal prediction and correction of optical wavefronts in an adaptive optics experiment

J. Tesch, J. S. Gibson, Univ. of California, Los Angeles (United States)

This paper discusses the use of a linear time invariant controller based on optimal wavefront prediction in an adaptive optics experiment. The minimum variance predictor, which has state space form, is identified from a measured wavefront sequence by a subspace system identification method. Experimental results show the improved performance of the optimal predictor/controller as compared to a classical adaptive optics loop. In the experiment, a membrane deformable mirror adds wavefront disturbance to a laser beam, representing the effect of turbulence. A second membrane deformable mirror, with different geometry, is driven by the control loops to correct the wavefront error. A Shack-Hartmann sensor measures the wavefront error for feedback.

8165A-03, Session 1

Impact of branch points in adaptive optics compensation of thermal blooming and turbulence

M. F. Spencer, S. J. Cusumano, Air Force Institute of Technology (United States)

Adaptive optics (AO) can be used to mitigate turbulence; however, when a single deformable mirror is used for phase-only compensation of thermal blooming, analysis predicts the possibility of instability. This instability is appropriately termed phase compensation instability (PCI) and arises with the time-dependent development of spatial perturbations found within the high-energy laser (HEL) beam. These spatial perturbations act as local hot spots that produce negative-lens-like optical effects in the atmosphere. An AO system corrects for the hot spots by applying positive-lens-like phase compensations. In turn, this increases the strength of the thermal blooming and leads to a runaway condition, i.e., positive feedback, in the AO control loop. This study uses computational wave-optics simulations to model horizontal propagation with the effects of thermal blooming and turbulence for a focused Gaussian HEL beam. A point-source beacon and nominal AO system are used for phase compensation. Results show that a high number of branch points limit the development of PCI for phase compensation of only thermal blooming. For phase compensation of thermal blooming and turbulence, the number of branch points decreases and system performance is reduced. A series of computational wave-optics experiments are presented which explore the possibility for PCI.

8165A-04, Session 1

Characterization and closed-loop AO performance of a liquid deformable mirror

E. S. ten Have, Technische Univ. Delft (Netherlands); G. V. Vdovin, Flexible Optical B.V. (Netherlands) and Technische Univ. Delft (Netherlands)

A liquid deformable mirror based on total internal reflection (TIR) applying an electrostatically deformed liquid-air interface was used to perform closed-loop adaptive optical correction on a collimated beam of a HeNe-laser that was aberrated by a rotating phase disk.

The properties of the mirror and the AO system performance were observed. Characterization of the mirror included frequency and step-function responses depending on the properties of the liquids used (water and glycerol) and the influence of liquid surface motion in absence of external optical aberrations. The performance of the AO system was determined for static and dynamic aberrations for various sets of system parameters.

The frequency response of the glycerol-air interface shows a drop of 22 dB for the amplitude at a frequency of 350 Hz with respect to the DC value. Our investigation shows that the motion of the liquid surface due to vibrations of the building etc. primarily results in the lateral movement of the beam which can be significantly decreased by engaging the AO feedback. While using the phase disk AO system performance showed an improvement of the wavefront of a factor of 3 - 4 in terms of residual rms error for correction of dynamic aberrations and of a factor of 4 - 12 in terms of residual rms error and of 50 - 1800 in terms of Strehl number for static aberrations.

The successful application of the liquid mirror opens new ways for applying very large numbers of actuators in adaptive optics for e.g. astronomical observatories.

8165A-05, Session 1

Using of Hermite-Gaussian antisymmetric mode for intracavity fiber array beam combining

S. A. Dimakov, A. A. Mak, S.I. Vavilov State Optical Institute (Russian Federation)

The report introduces the results of experimental studies of intracavity fiber array beam combining. For the first time it was experimentally demonstrated generation of Hermite-Gaussian anti-symmetric mode TEM30 in stable super resonator for coherent combination of beams of four fiber amplifiers. Behind the output mirror of a super resonator a super-mode was corrected by static phase corrector to receive quasi-plane wave. Maximum number of phasing fiber channels by means of suggested method has been discussed.

8165A-06, Session 1

Response analysis and experimental results of holography-based modal Zernike wavefront sensor

S. Dong, T. Haist, W. Osten, T. Ruppel, O. Sawodny, Univ. Stuttgart (Germany)

Holography based modal wavefront sensing (HMWS) employs diffractive optical elements to detect directly the amplitude of Zernike components of an aberrated wavefront. The sensor has a good linearity for single mode or multiple modes with small amplitudes. However, the crosstalk problem inherent in HMWS becomes more severe with increasing aberrations, that finally result in degrading the sensor accuracy. In this paper the working principle of HMWS is theoretically described and the cause of crosstalk is further revealed. It is found that the intermodal crosstalk due to the complexity of an input wavefront dominates the sensor performance. In order to extend the use of HMWS for simultaneous detection of multiple and large size Zernike modes (which is essential in atmospheric aberration correction), the response of HMWS is examined statistically with random aberrations created in accordance to the atmosphere turbulence model. The simulation results show that the behavior of sensor response changes randomly according to different incident beams. It is also demonstrated that the response curve trends to
approach the “theoretical curve” as aberration size decreases (close-loop case). Using this analysis, an optimization process with system parameters like pinhole size and encoded phase bias is implemented considering the turbulence strength. The sensitivity and accuracy of the sensor is further improved by using calibrated response curves. The final results show that the number of iterations needed for obtaining a residual wavefront error of 0.1λ in RMS is reduced from 18 to 3. First preliminary experimental results are shown for validating the method.

8165A-07, Session 2

High-resolution lens-free on-chip microscopy using holographic multiframe pixel super-resolution

W. Bishara, T. Su, A. F. Coskun, H. Zhu, Univ. of California, Los Angeles (United States); A. Ozcan, Univ. of California, Los Angeles (United States) and California NanoSystems Institute (United States)

We present lensfree holographic on-chip microscopy with ~0.6µm resolution over 24mm² field-of-view (FOV). This is achieved by a partially-coherent in-line holographic imaging set-up that employs a Pixel Super-Resolution algorithm to effectively increase the space-bandwidth product of a sensor-array by synthesizing higher resolution images from multiple shifted low-resolution ones. Lensfree hologram shifting is implemented by mechanically shifting the source (e.g., an LED filtered by a ~0.1mm pinhole) by relatively large distances of ~0.1nm. We have also implemented the use multiple LEDs to achieve pixel super-resolution without the use of any mechanical scanning. Furthermore, we have also demonstrated opto-fluidic implementation of the same scheme, where the fluidic-motion of the objects within a micro-fluidic channel is used to synthesize high-resolution lensfree holographic images. In all of these implementations, multiple shifted in-line holograms of the same object scene are acquired and processed to generate a single high-resolution hologram with a much smaller effective pixel size, which is then processed with an iterative phase-retrieval algorithm to recover complex-valued microscopic images of the objects.

The performance of this approach has been validated by imaging patterned substrates, blood samples, C. elegans and Giardia lamblia parasites. This lensfree holographic imaging modality could enable the first experimental demonstration of the cylindrical hyperlens and other hyperlens design, all the experimental demonstrations of hyperlens so far were limited to the one dimensional magnification and ultra-violet wavelengths, hindering any practical imaging applications. Here, we present a spherical hyperlens for two-dimensional sub-diffraction limited real-time imaging at visible frequencies without the need of optical scanning or image reconstruction. Designing a spherical hyperlens with flat hydrophobic dispersion supporting wave propagations with very large spatial frequency, and yet same phase speed, we are able to resolve sub-diffractional features down to 160nm, much smaller than the diffraction limit at visible wavelength of 410nm. Such a hyperlens can readily be integrated in conventional microscopes, critically expanding their capabilities beyond the diffraction limit and opening a new realm in real-time nanoscopic optical imaging of biological machineries.

8165A-08, Session 2

Metamaterials-based 2D hyperlens imaging beyond the diffraction limit at visible frequencies

J. S. Rho, Z. Ye, Y. Xiong, Univ. of California, Berkeley (United States); X. Yin, Univ. of California, Berkeley (United States) and Lawrence Berkeley National Lab. (United States); Z. Liu, Univ. of California, San Diego (United States) and Univ. of California, Berkeley (United States); H. Choi, G. Bartal, Univ. of California, Berkeley (United States); X. Zhang, Univ. of California, Berkeley (United States) and Lawrence Berkeley National Lab. (United States)

Hyperlens has excited much interest, not only because of the intriguing physics also for its ability of real-time imaging sub-diffraction-limited objects into the far-field. The major breakthrough emerged with the concept of optical hyperlens, showing the first proof-of-principle for magnifying sub-diffractional images to the far-field as propagating waves.
system is limited to about half of the working wavelength \( \lambda/2 \). Various metamaterial based superlenses that can achieve deep subwavelength scale resolution have been proposed and demonstrated within the last decade. Although these superlenses can achieve super resolution, they cannot focus a plane wave to a spot and thus behave differently from conventional lenses. By applying phase compensation mechanisms to metamaterials, we have recently demonstrated the plane wave focusing capability, i.e., the Fourier transform function, in the metamaterial immersion lens (MIL) and the metalens. In this work, we show a new imaging paradigm in negative refraction based lenses if a focal length can be defined, using the hyperbolic metalens as an example. In contrast to conventional lenses, a hyperbolic metalens works as a converging lens from one side but a diverging lens from the other. This distinctive focusing behavior leads to extraordinary imaging properties that are not available in common lenses. These extraordinary imaging properties significantly expand the horizon of imaging optics and optical system design.

8165A-11, Session 2

Ultrasound-modulated fluorescent contrast agent for optical imaging through turbid media

C. E. Schutt, M. J. Benchimol, Univ. of California, San Diego (United States); M. J. Hsu, Ziva Corp. (United States); S. C. Esener, Univ. of California, San Diego (United States)

Optical imaging in a highly scattering media is effective only at very shallow depths which limits its use as a diagnostic tool in biomedical imaging. By combining optical and acoustic modalities, high-contrast, physiologically-relevant optical information at higher spatial resolutions can be achieved. Hybrid imaging modalities such as acousto-optic and photoacoustic imaging improve resolution over conventional optical imaging, but tissue scattering results in poor signal-to-background ratios especially in deeper tissues. To overcome these challenges, we have developed a novel microbubble (MB) contrast agent surface-loaded with a self-quenching fluorophore. In response to ultrasound, the MB expands and contracts, generating changes in the fluorophore surface density. The changes in physical separation between fluorophores modulate the quenching efficiency and produce a fluorescence intensity modulation. To our knowledge, this is the first experimental demonstration of ultrasound modulation of fluorescence using a self-quenching MB scheme. The modulation is spatially localized to the ultrasound focal zone where the pressure is the greatest and the largest MB oscillations are induced. The modulating signal can be extracted from a large constant light background, increasing detection sensitivity. This technique can enable sensitive optical imaging with ultrasound-scale sub-millimeter spatial resolution, overcoming some challenges of optical imaging in turbid media. The MBs were prepared with a shell of phospholipid and lipophilic self-quenching fluorophore. MB ultrasound response was studied in a custom setup which monitored fluorescence emitted from an insonified sample. Fluorescence signals displayed clearly modulated intensity and the FFT of these signals showed a strong component at the ultrasound driving frequency.

8165A-12, Session 3

Optical Janus lens and its extraordinary imaging properties

Z. Liu, Univ. of California, San Diego (United States)

Optical lenses are pervasive in various areas of sciences and technologies. The lens imaging properties have been well established for centuries since the first elaboration by Kepler in 1611. It is also well known that the resolving power of a lens and thus optical systems is limited by the diffraction of light. Recently, various plasmonics and metamaterials based superlenses have been emerging to achieve super resolution and exotic imaging properties. In this talk I will introduce an optical “Janus Lens” based on phase compensated negative refraction in metamaterials. The Janus lens performs as either converging lens or diverging lens depending upon the illumination directions. Extraordinary imaging equations and properties that are different from those of all the existing optical lenses will also be presented. These new imaging properties, along with the super resolving power, significantly expand the horizon of imaging optics and optical system design.

8165A-13, Session 3

Compressive hyperspectral acquisition and unmixing

T. Sun, C. Li, Y. Zhang, K. F. Kelly, Rice Univ. (United States)

Hyperspectral hardware can be complex and the associated data processing typically demands enormous computational resources. In this paper, we investigate a low complexity scheme for hyperspectral data acquisition, compression and reconstruction. In this scheme, compressed hyperspectral data are acquired directly by a spectrometer variation of the single-pixel camera based on the principle of compressive sensing. To decode the compressed data, we propose a numerical procedure to directly compute the unmixed abundance fractions of given endmembers, completely bypassing high-complexity tasks involving the hyperspectral data cube itself. Experimental and computational evidences obtained from this study indicate that the proposed scheme has a high potential in real-world applications.

8165A-14, Session 3

Compressive echelle spectroscopy

L. Xu, K. F. Kelly, Rice Univ. (United States)

We have constructed an echelle spectrometer based on the principles of compressive sensing. While our current system operates in the visible part of the spectra, our CS method is especially beneficial when you move into the infrared and two-dimensional focal plane arrays where costs can skyrocket from $50 for a 5 megapixel silicon sensor to tens of thousands of dollars for less than a megapixel. In addition, we will introduce a new design for the system that replaces the complicated and somewhat optically limited digital micromirror device with a simpler and more robust architecture.

8165A-15, Session 3

Experimental demonstration of compressive sensing-based Raman microscopy

M. A. Turner, K. F. Kelly, Rice Univ. (United States)

We demonstrate the experimental realization of compressive sensing applied to Raman microscopy. The theory of compressive sensing (CS) is now well-known among statistics, signal processing, and information theory fields. Certain applications were immediately apparent, such as in analog-to-digital conversion, but CS principles are proving useful in a wide range of other situations including imaging. CS guides one to sample natural signals at a rate closer to the information rate than the traditional Shannon sampling rate. Thus, CS measurement systems generally should be preferred for science and engineering problems wherever more efficient sampling would result in reduction of cost or acquisition time. In our setup we expand a laser beam to fill the active area of a digital micromirror device (DMD) from Texas Instruments, which consists of 13,6 micron-pitch mirrors that can flip +/- 12 degrees to normal incidence. This structured illumination then travels to an objective lens that focuses the light down onto a roughly 10 square-micron area. Scattered light from the illuminated sections is then analyzed in a spectrometer. We reconstruct a hyperspectral data cube where the “wavelength” dimension...
now contains Raman spectra from various points in the sample. This will be broadly useful in fields such as semiconductor metrology, cancer detection and imaging, and nanomaterials characterization. By example of Raman imaging of graphene on SiO2, we demonstrate that for only ~20% of the acquisition time required by state-of-the-art micro-Raman systems we achieve identical performance.

8165A-16, Session 3

**Single-molecule super-resolution imaging of surface enhancement hotspots**

H. Cang, Univ. of California, Berkeley (United States) and Lawrence Berkeley National Lab. (United States); A. Labno, C. Lu, X. Yin, M. Liu, C. W. Gladden, Y. Liu, X. Zhang, Univ. of California, Berkeley (United States)

The invention of single molecule super-resolution imaging has allowed optical microscopy to reach electron microscopy-level resolution. We apply this new technique to probe surface enhancement hotspots. These hotspots appear on rough metallic surfaces under optical illumination where the local electromagnetic field is concentrated, giving rise to the famous surface enhancement effect. Current optical instruments’ limited resolution has made it difficult to characterize hotspots, and their size is unknown. Using the Brownian motion of single fluorescent molecules enables us to probe the inside of single hotspots for the first time. We found that light is strongly confined with an exponential profile. A hotspot is as small as 15nm in width, less than 1/30 the wavelength of light.

8165A-17, Session 4

**Power requirements for polarimetric SAR image imaging**

S. C. Cain, Air Force Institute of Technology (United States)

Polarimetric SAR is a method for collecting images using non-imaged laser speckle returns. This approach allows reflected laser radiation to be captured incoherently over a large area and then used to reconstruct a facsimile of the illuminated target via an image synthesis algorithm. The use of incoherent detection combined with dual channel polarization measurements allows an image to be reconstructed with an effective aperture much larger than what could be achieved via traditional monochromatic imaging systems. Although phase information is lost in the detection process, the dual polarization architecture captures the additional information needed to aid in the regularization of the image reconstruction problem from intensity measurements. It is the goal of this research to quantify the laser power and aperture size requirements as related to the achievable spatial resolution of the polarimetric SAR imaging system. The study is carried out via Monte-Carlo simulations which are used to infer simple relationships between laser power, aperture size, range to target and achievable spatial resolution.

8165A-18, Session 4

**Imaging performance of long-range laser scanning through atmospheric turbulence**

D. G. Voelz, M. S. Nairat, New Mexico State Univ. (United States)

Active laser scanning to form an image through atmospheric turbulence is studied in terms of the Optical Transfer Function (OTF). The concept considered is the illumination of a two-dimensional target by a focused laser beam that propagates through turbulence. As the beam scans the target, a record of the reflected flux versus expected beam centroid position is collected at the receiver and used to reconstruct an image. The distance between the illuminator and target is assumed to be in the Fresnel region. Spatial resolution and cut-off frequency are considered as a function of turbulence strength and exposure time. Beam wander is included in the investigation and an OTF expression is developed to specifically describe this effect. Wave optics simulations are performed to illustrate emphasizes the performance of the scanning method and image results are compared with the theoretical model.

8165A-19, Session 4

**Discrimination of multiple ranges per pixel in 3D flash ladar to enhance spatial resolution**

B. J. Neff, S. C. Cain, Air Force Institute of Technology (United States)

Laser Radar imagers known as FLASH LADAR sensors can be designed to provide 2-D and 3-D images of a scene in a single pulse. For 3-D sensors, the benefit of having a range for every pixel in the image is obvious. Unfortunately, the added manufacturing complexity for 3-D sensors has restricted the spatial resolution to much lower values than 2-D sensors. Based on this limitation, it is possible that the field of view for an individual pixel will observe the pulse reflections from multiple surfaces. Fortunately, the narrow pulse width of 3-D FLASH LADAR allows us to accurately determine range to multiple surfaces close together with accuracy on the order of feet. However, the spatial mixing effects cause ambiguity as to the presence of these surfaces. The goal of this work is to develop an algorithm to enhance the utility of 3-D sensors using accurate ranging to multiple surfaces per image pixel. Using an algorithm that determines the precise range to multiple surfaces per pixel, it will be possible to observe numerous enhancements. Among these enhancements, the following will be demonstrated. First, based on the statistical nature of the target being imaged, the relationship of each surface will be used to enhance the spatial resolution of an image. Second, the task of detecting obscured targets with a single pulse will be possible. Finally, edge detection will be enhanced which provides many benefits to include enhanced registration among an ensemble of images.

8165A-20, Session 4

**Phase errors analysis and speckle reduction in synthetic aperture imaging ladar demonstration system**

Y. Zhou, J. Sun, Y. Zhi, Y. Wu, N. Xu, A. Yan, L. Wang, Z. Luan, L. Liu, Shanghai Institute of Optics and Fine Mechanics (China)

A demonstrator of synthetic aperture imaging ladar (SAIL) is constructed to study the feasibility under random disturbance. Where the transmitting and receiving system are based on the free-space optics to give changeable wave font, and the local optical channel is based on fiber delay line having the nearly the same optical distance with signal optical channel to reduce the demands on the linewidth and the initial optical frequency synchronism of the each chirped laser pulse. By applying several reference dots and optical fiber loop, several kinds of phase errors, including nonsynchronous initial optical frequency, platform vibration, air turbulence, and the autologous phase disturbance of fiber delay line are extracted to study theirs effects on SAIL imaging. After mitigating all these timely phase errors, a well-focused two-dimensional SAIL image can be given, but apparent speckle effect also can be observed. The speckle effect comes from the spatial random distribution of target dots, which induce different effect on SAIL imaging from the effect by the timely phase errors. Apart from multilook processing method, sliding spotlight imaging mode is also used to try to reduce the speckle noise.
Multiframe blind deconvolution for imaging in daylight and strong turbulence conditions


We describe new computational techniques to extend the reach of large ground-based optical telescopes, enabling high resolution imaging of satellites under daylight conditions. Current state-of-the-art systems, even those employing adaptive optics, dramatically underperform in such conditions because of strong turbulence generated by diurnal solar heating of the atmosphere. Our approach extends previous advances in multi-frame blind deconvolution (MFBD) by exploiting a priori physical constraints on the imaging process that have hitherto not been incorporated or not fully exploited in MFBD algorithms. We describe early results with a new algorithm which may be used with seeing-limited image data or as an adjunct to partial compensation with adaptive optics to restore imaging to the diffraction limit even under the extreme observing conditions found in daylight.

Experiments on speckle imaging using projection methods

M. Y. Loktev, G. V. Vdovin, O. A. Soloviev, S. Savenko, Flexible Optical B.V. (Netherlands)

Adaptive optics based on phase conjugation has been commonly used to compensate image blur due to atmospheric turbulence in astronomy. However, the adaptive optics is not directly applicable for extended scene imaging in turbulent conditions on horizontal paths due to strong anisoplanatism of the aberrated field. Besides, in many practical cases the wavefront information cannot be obtained and/or used. Therefore, a cost-effective approach, with or without the use of adaptive optics, is required to obtain high resolution with extended field in conditions of strong blur. Speckle imaging methods based on deconvolution of a series of images, each with its own point-spread function (PSF), are promising for implementation of such an approach.

In this paper we present some experimental results of speckle imaging applied to ground-based scenery and astronomical objects. The method of alternating projections onto convex sets is used for iterative PSF reconstruction, combined with Wiener filtering for deconvolution and several pre-processing techniques. Modifications of the optical system with variable aperture size and multiple apertures are considered. The results of imaging on a horizontal path are reported and compared with time averaged, best frame and median filtered images, under different turbulence conditions. Resolution improvement is demonstrated in a field much wider than the isoplanatic patch size.

Scene-based blind deconvolution in the presence of anisoplanatism

D. C. Dayton, Applied Technology Associates (United States)

Most non-conventional approaches to image restoration of objects observed over long atmospheric paths require multiple frames of short exposure images taken with low noise focal plane arrays. Multi-frame blind deconvolution is such an approach. In most cases the object is assumed to extend only over a single isoplanatic patch. However, when one is observing scenes over a near horizontal or downward looking path, and the isoplanatic patch size is small due to extended atmospheric turbulence over the entire slant path, and the scene usually extends over many isoplanatic patches. In addition base motion jitter in an airborne observing platform introduces a frame-to-frame linear shift that must be compensated for in order for the multi-frame restoration to be successful.

In this paper we describe a maximum a-posteriori parameter estimation approach to the simultaneous estimation of the frame-to-frame shifts and non-isoplanatic point spread functions. This approach can be incorporated into an iterative algorithm. We present a brief derivation of the algorithm as well as its application to actual image data collected from airborne and ground based platforms.
8165A-26, Session 5

Blind deconvolution of long exposure lens-based chromotomographic spectrometer data

S. V. Mantravadi, Air Force Office of Scientific Research (United States); S. C. Cain, Air Force Institute of Technology (United States)

Projection-based chromotomographic spectrometers are sensors that collect both spatial and spectral information with fairly simple optical as well as electronic hardware. Efforts to utilize them for remote sensing applications have met with obstacles primarily due to the fact that the impulse response of the imaging system as a function of wavelength must be known in order to reconstruct the spatial/spectral content of the scene under study. This paper reports a blind deconvolution algorithm specifically designed to reconstruct the spectrum of the scene under study as well as an estimate of the wavelength dependent atmospheric transfer function of the system. The approach uses a bayesian framework for determining the spectral image of the scene. The seeing parameter of the atmosphere is estimated using algorithm convergence criteria. The iterative algorithm derived in this paper converges when the estimated noise variance is equal to the predicted value based on the assumption that the measurements are Poisson. The lowest value of the seeing parameter for which the algorithm converges is chosen as the seeing parameter estimate. The method is tested using simulated data with realistic turbulence and noise factors in order to demonstrate its effectiveness.

8165A-27, Session 6

Detailed comparison of a Michelson interferometer and intensity interferometer SNR for GEO stationary satellites imaging


Geo-stationary satellites (GEO) represent a very difficult imaging problem due to their distance from the Earth and apparent dimension from the observers. This is not that different than some of the more challenging astronomical imaging problems. In order to attain the required resolution in order to form a high fidelity image one needs fairly large telescopes with diameters ranging in the several tens of meters. Several projects are attempting to develop such telescopes but there are several problems. One solution would be to use existing long baseline optical interferometers or develop a new facility along these lines. When dealing with Long Baseline there are two main approaches, the Michelson interferometer and the intensity interferometer. Arguments favoring either of these approaches have been made. It is the aim of this paper to present a complete comparison between these two techniques in terms of technical challenges, possible costs and overall signal-to-noise-ratio (SNR) etc. The comparison will be analytic and quantitative as much as possible.

8165A-28, Session 6

A study of image reconstruction algorithms for hybrid intensity interferometers

P. N. Crabtree, J. Murray-Krezan, R. H. Picard, P. J. McNicholl, Air Force Research Lab. (United States)

Intensity interferometry holds tremendous potential for remote sensing of space objects. Unlike traditional earth-based observatories which are typically limited by both the size of the primary mirror and atmospheric effects, Intensity Interferometers (IIs) are relatively unaffected by atmospheric distortions and their effective apertures can be substantially larger than is practical for traditional observatories. Hybrid Intensity Interferometers (HIIs) are explored for their potential to improve the imagery produced by IIs, which historically have labored under SNR and fill factor challenges. Concepts for HIIs include the use of additional information furnished by partially resolved imagery from a traditional telescope, or use of phase and amplitude information from amplitude interferometers. As phase retrieval algorithms are typically used for image reconstruction from interferometric information, methods for incorporating additional information into an integrated phase retrieval process are explored. We investigate image reconstruction techniques with suitable image quality metrics.

8165A-29, Session 6

Simulated optical interferometric observations of geostationary satellites

H. R. Schmitt, U.S. Naval Research Lab. (United States); D. Mozurkewich, Seabrook Engineering (United States); S. R. Restaino, J. T. Armstrong, R. B. Hindsley, U.S. Naval Research Lab. (United States); A. M. Jorgensen, New Mexico Institute of Mining and Technology (United States)

We simulate observations of geostationary satellites using different optical interferometer configurations. We test several array designs, including the typical Y shaped array, similar to the Navy Prototype Optical Interferometer, an elliptical array, and telescopes mounted on a linear movable boom. We use aperture synthesis techniques to reconstruct images from the simulated observations and determine which configuration produces the most accurate images relative to the original ones. These simulations also take into consideration the number of telescopes needed to achieve the best results, and their separations.

8165A-30, Session 6

Laser testing of an Iris AO dielectric-coated, segmented MEMS DM

M. A. Helmbrecht, Iris AO, Inc. (United States); A. P. Norton, Univ. of California, Santa Cruz (United States); D. T. Gavel, Univ. of California Observatories (United States)

Iris AO has been developing dielectric-coated segmented MEMS DMs for use in laser applications. In order to produce high-quality (λ/20 rms or better) mirrors with the relatively thick and high-stress coatings, stress-compensation coatings have been deposited onto the underside of the mirror segments.

Deformable mirrors have been fabricated with compensation coatings targeted for 355 nm, 1064 nm and 1540 nm. The mirror segments for these DMs are 50 µm to better accommodate run-to-run stress variations, variations in stress as a result of humidity changes, and different target wavelengths.

Deformable mirrors were coated with 532 nm dielectric coatings. Preliminary measurements show that the coatings have survived exposure from a 2 W, 50 µm FWHM 532 nm CW beam onto a single segment for 30 minutes. This is approximately 100 kW/cm². A 2W beam onto a single segment is equivalent to an average power handling of 630 W/cm² for the segment. At 2 W incident laser power, the segment heats up approximately 10-15 ºC above ambient temperature and peak-to-valley deformations of the segment are less than 15 nm. The DM segments can operate at temperatures exceeding 120ºC. Thus we expect the power handling could be many kW/cm². This paper will describe in detail more comprehensive laser testing.
1. G. Vdovin, O. Soloviev, A. Samokhin, and M. Loktev, “Correction of low-real-life scenarios. Experimental results on both configurations are reported for different and 1 kHz bandwidth for correction of all 3-rd order Zernike aberrations. With integrated tip-tilt stage, featuring 250 Hz bandwidth for the tip-tilt, turbulence, we have developed a low-order membrane deformable mirror that does not produce any hot spots in the beam. In astronomical systems, and as a high-power laser deformable mirror, reported configuration has certain advantages as a high-quality woofer correction of all 3-rd order aberrations, except spherical, addition of some interesting design solutions. [1]. Application of these rules to the design of a deformable mirror should be satisfied for high quality of correction, certain formal restrictions on the geometry of actuators in the deformable mirrors should be achieved. To achieve a very smooth, high quality correction of low-order aberrations, we have developed a 18-ch (38-ch as an ultra-smooth option) piezoelectric deformable mirror featuring zero actuator count under the beam footprint. We have demonstrated a very high quality correction of all 3-rd order aberrations, except spherical, addition of the 19-th central actuator allows for correction of spherical aberration. Reported configuration has certain advantages as a high-quality woofer in astronomical systems, and as a high-power laser deformable mirror that does not produce any hot spots in the beam. To achieve a very low-cost high-quality correction of atmospheric turbulence, we have developed a low-order membrane deformable mirror with integrated tip-tilt stage, featuring 250 Hz bandwidth for the tip-tilt, and 1 kHz bandwidth for correction of all 3-rd order Zernike aberrations. Experimental results on both configurations are reported for different real-life scenarios. 1. G. Vdovin, O. Soloviev, A. Samokhin, and M. Loktev, “Correction of low order aberrations using continuous deformable mirrors,” Opt. Express 16, 2859-2866 (2008).
Michelson interferometry, in which light beams are brought together and the interference pattern is measured, is significantly more difficult, requiring precision optics and precise pathlength control, but it has a great advantage in sensitivity. To measure a magnitude 5 star with a squared correlation (squared fringe visibility) of 0.3 requires ~5 hours to reach SNR = 5 with an intensity interferometer (two 10 m telescopes, 100 MHz detection bandwidth), but requires a few milliseconds with a Michelson interferometer (two 1 m telescopes, 300 nm bandpass). However, for interferometry with a large number of array elements, the sensitivity of Michelson interferometry suffers from the fact that the light beams must be shared among many correlations, thereby reducing the sensitivity of each measurement. We explore these and other influences on the relative sensitivities of these techniques to determine under what circumstances, if any, their sensitivities become comparable.

8165A-36, Poster Session

**Laboratory demonstration of Fresnel telescope imaging ladar**

E. Dai, L. Liu, A. Yan, J. Sun, Y. Wu, Y. Zhou, Y. Zhi, Shanghai Institute of Optics and Fine Mechanics (China)

In this paper, we present a laboratory demonstration of Fresnel telescope imaging ladar system, whose name is derived from the Fourier telescope, for imaging the faraway objects with high resolution. Two concentric and coaxial quadratic wavefront laser beams with orthogonal polarization are used as scanning beams of the target. The scattered signal light from the target is split into two beams by a polarized beamsplitter (PBS). One beam acts as the reference beam and pass through a quarter waveplate to convert linear to circular polarization, the other beam acts as the signal beam and pass through a half waveplate to rotate the polarization by 45 degree. Then these two beams are heterodyne detected by a 90 degree 2×4 optical hybrid with two balanced detectors. To stable target, the image can be constructed by the digital processing of the outputs of the two balanced detectors by two dimensional scanning and only one dimensional scanning is needed for a moving target. The imaging resolution is higher than that of the diffraction limited optical system. Since both reference and signal beam pass through the same optical track, it may minimize the influence of the atmosphere.
An adaptive coded aperture imager: building, testing and trialling a superresolving terrestrial demonstrator

C. W. Slinger, Malvern Innovations (United Kingdom); H. Bennett, K. Gilholm, N. Gordon, D. Huckridge, M. E. McNie, R. Penney, QinetiQ Ltd. (United Kingdom); K. Rice, Goodrich Corp. (United States); K. Ridley, L. Russell, G. de Villiers, P. Watson, QinetiQ Ltd. (United Kingdom)

Adaptive coded aperture imaging (ACAI) is one of a new wave of computational imaging techniques beginning to be applied to meet a variety of challenging commercial, security and military needs. ACAI promises orders of magnitude performance improvements in some of these applications. In contrast to the conventional (classical) approach of focusing an image of a scene onto a detector array, ACAI encodes the incoming light prior to detection. The detected pattern is then decoded using a variety of algorithms and digital signal processing hardware to yield desired information from the scene. The patterns used to code the light can be changed with time to yield additional system benefits.

This paper describes the principles of ACAI, the practical considerations needed when applied to its use in the mid wave infrared (MWIR), and the design methods used for the construction of a large, wide cone-angle terrestrial demonstrator. The construction, calibration and results from laboratory and field trials of this demonstrator are then described. Tracking and imaging performance measurements are compared to the predictions of a multiphysics system model.

Intelligence supportability analysis and intelligence systems

J. Morrison, U.S. Air Force (United States)

No abstract available

Adaptive coded aperture imaging: progress and potential future applications

S. R. Gottesman, A. Isser, G. W. Giglioli, Jr., Northrop Grumman Electronic Systems (United States)

Interest in Adaptive Coded Aperture Imaging (ACAI) continues to grow as the optical and systems engineering community becomes increasingly aware of ACAI’s potential benefits in the design and performance of both imaging and non-imaging systems, such as good angular resolution (IFOV), wide distortion-free field of view (FOV), excellent image quality, and light weight construct. In this presentation we first review the accomplishments made over the past five years, then expand on previously published work to show how replacement of conventional imaging optics with coded apertures can lead to a reduction in system size, weight, and power (SWAP). We also present a trade space analysis of key design parameters of coded apertures and review potential applications as replacement to traditional imaging optics. Results will be presented, based on last year’s work of our continuing investigation into the trade space of IFOV, resolution, effective focal length, and wavelength of incident radiation for coded aperture architectures. Finally we will discuss the potential application of coded apertures for replacing objective lenses of night vision goggles (NVGs).
Multidimensional TOMBO imaging and its applications

R. Horisaki, J. Tanida, Osaka Univ. (Japan)

We present a framework of multi-dimensional compound-eye imaging with the thin observation module by bound optics (TOMBO) and its applications. In conventional multi-dimensional optical data acquisition, the object information is observed with two-dimensional detector array by sacrificing the observation time to scan along the axial direction or the spatial resolution to arrange filters on the detectors or the compactness of the hardware to increase the number of the detectors. The proposed framework can alleviate the problems. The advantages of TOMBO are the thinness of the compound-eye optics and the flexibility of the system design. In the proposed multi-dimensional TOMBO imaging system, each of the sub-optics equips optical coding elements to shear or to weight the multi-dimensional object information along the axial direction. The encoded information is integrated onto the detectors in the sub-optics. This system is ill-posed. The object is reconstructed by a compressive sensing algorithm. Compressive sensing solves ill-posed linear problems by employing a sparsity constraint. The framework can be applied to various optical information acquisitions. For example, in spectral imaging, the spectral datacube can be sheared by dispersive elements and weighted by color filters in the units. In polarization imaging, the polarized datacube can be sheared by birefringence elements and weighted by polarization plate. Those applications can be combined easily for higher-dimensional data acquisitions with compact hardware. We will show some numerical demonstrations.

Control of optical aberrations with coded apertures

A. R. Harvey, Heriot-Watt Univ. (United Kingdom)

This presentation will describe the design of amplitude masking functions for the apparently disparate fields of imaging through aberrations and x-ray imaging with increased depth of field. The two modalities are quite different; shadow casting is the dominant process in formation of x-ray images, whilst conventional imaging is an interferometric process. The mathematical descriptions of the two imaging processes have significant commonality however and offer similar approaches to mitigation of optical aberrations.

There has been considerable progress in recent years in the use of phase techniques for the correction of aberrations in optical imaging. Adaptive optics phase correction enables the real-time correction of phase aberrations and high contrast imaging at the detector. Hybrid imaging techniques, using pupil-plane phase coding of the point-spread function, yields reduced-contrast imaging at the detector, but when used with digital image recovery enables high contrast imaging with reduced sensitivity to optical aberrations, but optimal mitigation of dynamic aberrations is difficult, particularly at infrared wavelengths.

We report here the design of coded aperture functions that, when combined with digital recovery, provide a route to mitigating optical aberrations using agile amplitude masks: the technique is thus applicable to a wide range of wavelengths as a low-cost alternative to phase-based adaptive optics. The optimisation process fundamentally aims to reduce destructive interference effects in the optical-transfer function. For imaging with hard x-rays, modulation of the source intensity function offers a mathematically similar technique for mitigating the image blur associated with extended sources.

Image exploitation from encoded measurements

D. Bottisti, R. Muise, Lockheed Martin Corp. (United States)

We consider a coded aperture imaging system which collects far fewer measurements than the underlying resolution of the scene we wish to exploit. Our sensing model considers an imaging system which subsamples pixels intensities with an SLM device. The theory of compressive imaging has been studied in the context of rebuilding high resolution imagery from a smaller set of image measurements. Thus it is ideal for our application. We present a compressive imaging model to our proposed image measurement system and simulate image reconstruction performance. The compressive imaging sensing and reconstruction models are then modified to incorporate an exploitation task into the sensing and reconstruction process. The results being twofold: A more structured encoding for the measurement process, and an algorithm capable of reconstructing the processed imagery with the same computations as reconstructing the image itself. Essentially, we get exploitation for free. The equations are generated for an arbitrary linear filtering exploitation algorithm and we present some results based upon a quadratic correlation filtering target detection algorithm.

Compressive light field imaging with hybrid measurement basis

A. Ashok, M. A. Neifeld, The Univ. of Arizona (United States)

Light field/Integral imaging refers to the measurement of spatio-angular information of a scene. Traditional light field imaging architectures, such as the plenoptic camera and the integral imager, map the four dimensional spatio-angular scene information directly onto a two dimensional detector array and typically suffer from spatio-angular resolution trade offs. Compressive light field imaging exploits the sparsity/compressibility of natural scenes to make fewer photon efficient compressive measurements that alleviate the spatio-angular resolution trade off. Recent work in the area of compressive light field imaging has investigated the performance of various compressive measurement bases, ranging from the purely random basis to the Karhunen-Loève (KL) basis. While the random basis relies solely on the scene sparsity prior, without assuming knowledge of a particular sparsity basis, the KL basis relies on the second-order statistics estimated from a representative set of scenes. In this work, we describe a hybrid measurement basis design that optimally combines a purely random basis with a known sparsity basis, such as the Wavelet basis, to improve the reconstruction performance of a compressive light field imager. The particular compressive imager architecture considered here makes compressive measurements only along the spatial dimensions of the four dimensional light field. We use a simulation study to quantify the performance of the spatial compressive light field imager for the random and hybrid bases. The simulation results show a significant performance improvement in terms of reconstruction error for the hybrid basis compared to the purely random basis.

Comparison of frequency-based and spatial subdivision mask sets for passive detection and target tracking with a single photodetector

S. M. Klein, R. K. Ragade, R. W. Cohn, Univ. of Louisville (United States)

Detection and tracking of self-luminous point sources and small targets is implemented using a single, low noise photodetector together with
a programmable micromirror array. The scene is imaged onto the array and then through focusing, the product of the scene and mask pattern is integrated onto the detector. There are various approaches to designing the mirror array mask sets to query the scene for the location of the target. Two general approaches are compared in this report and their performance depends in different ways on the dynamics of the target motion. The first method derives target location as an n-bit binary number, where each bit corresponds to the spatial periodicity of the mask pattern (either a single checkerboard, or successive frames of vertical and horizontal stripes). In the second method, the mirror array is partitioned into multiple regions, each modulated at a different temporal frequency. This modulates different portions of the scene into different frequency bins that are continuously monitored. The frequency regions, together with a track-gate or guard band, can be adaptively shifted and scaled in extent as the target moves and grows/shrinks in apparent size. The spatial subdivision method proves more effective at tracking slow moving, point-like targets, while the frequency based method is more effective at tracking and maintaining a spatially extended target within the track gate. These two methods are combined in both experiments (with a 1400x1050 pixel TI DLP micromirror array) and simulation, and performance curves of their individual and combined performance are presented.

8165B-48, Session 9

Code aperture optimization for spectrally agile compressive imaging
G. Arce, H. Arguello, Univ. of Delaware (United States)

Coded aperture spectral imaging (CASSI) provides a mechanism to capture a 3D spectral cube with a single shot 2D measurement. In many applications, selective spectral imaging is sought since relevant information often lies within a subset of spectral bands. Capturing and reconstructing all the spectral bands in the observed image cube, to then throw away a large portion of this data is inefficient. This paper extends the concept of CASSI to a system admitting multiple shot measurements which leads not only to higher quality of reconstruction, but also to spectrally adaptive imaging when the sequence of code aperture patterns are optimized. The aperture code optimization problem is shown to be analogous to the optimization of a constrained, multichannel filter bank. The optimal code apertures allow the decomposition of the CASSI measurement into several subsets, each having information from only a few selected spectral bands. The rich theory of compressive sensing is used to effectively reconstruct selected filter bank spectral bands of interest from the measurements.

8165B-49, Session 9

Adaptive coded apertures for occlusion detection and motion estimation
R. M. Willett, Duke Univ. (United States)

No abstract available

8165B-50, Session 10

Establishing a MOEMS process to realise microshutters for coded aperture imaging applications
M. E. McNie, R. R. Davies, A. Johnson, QinetiQ Ltd. (United Kingdom); B. Hardy, G. Harnes, D. Monk, MEMSCAP Inc. (United States); S. Rogers, Air Force Research Lab. (United States)

Coded aperture imaging has been used for astronomical applications for several years. Typical implementations used a fixed mask pattern and are designed to operate in the X-Ray or gamma ray bands. Recently applications have emerged in the visible and infra red bands for low cost lens-less imaging systems and system studies have shown that considerable advantages in image resolution may accrue from the use of multiple different images of the same scene - requiring a reconfigurable mask. Previously reported work focused on realising such a mask in the mid-IR based on polysilicon micro-opto-electro-mechanical-systems (MOEMS) technology and its integration with ASIC drive electronics using a tiled approach to scale to large format masks. The MOEMS chips employ interference effects to modulate incident light - achieved by tuning a large array of asymmetric Fabry-Perot optical cavities via an applied voltage using row/column addressing.

In this paper we report on establishing the manufacturing process for such MOEMS microshutter chips in a commercial MEMS foundry, MEMSCAP - including the associated challenges in moving the technology out of the development laboratory and the technical hurdles along the way.

Small scale (7.3 x 7.3mm) and full size (22 x 22mm) MOEMS chips have been produced and their performance tested. The results are compared with reference devices.

8165B-51, Session 10

A new photonics technology platform and its applicability for coded aperture techniques
S. R. Davis, S. D. Rommel, S. Johnson, S. Selewyn, G. Farca, M. Anderson, Vescnt Photonics Inc. (United States)

An emergent electro-optic technology platform, liquid crystal (LC) waveguides, will be presented with a focus on performance attributes that may be relevant to coded aperture approaches. As a low cost and low SWaP alternative to more traditional approaches (e.g. galvos, MEMs, traditional EO techniques, etc.), LC-Waveguides provide a new technique for switching, phase shifting, steering, focusing, and generally controlling light. LC-waveguides provide tremendous continuous voltage control over optical phase delays (>2mm demonstrated), with very low loss (one million pm/Volts) while circumventing their historic limitations; speeds can be in the microseconds and LC scattering losses can be reduced by orders of magnitude from conventional LC optics. This enables a new class of photonic devices: very wide analog non-mechanical beamsteerers (270° demonstrated), chip-scale widely tunable lasers (50 nm demonstrated), chip-scale Fourier transform spectrometers (<5 microWatts optical time delay devices (12 nsecs demonstrated) for phased array antennas, and many more. Both the limitations and the opportunity provided by this technology for use in coded aperture schemes will be discussed.

8165B-52, Session 10

Memristor-based imaging architecture opportunities for adaptive coded aperture imaging applications
T. M. Taha, C. Yakopcic, G. Subramanyam, Univ. of Dayton (United States); S. Rogers, Air Force Research Lab. (United States)

This paper explores memristor based computing architecture opportunities for imaging algorithms geared towards potential Adaptive Coded Aperture imaging applications. Memristors are a new class of devices that inherently have nonvolatile memory properties. Systems based on these devices can typically utilize fewer resources than traditional computing platforms. This allows a chip of a given area to have stronger information processing capabilities, thus reducing overall chip counts.

In this paper we describe novel memristor based computing components such memory arrays and their interactions with processors for high
performance imaging computations. Additionally, we present calculations for the chip areas consumed by the components described.

8165B-53, Session 10

**Nanoparticle dispersed metamaterial sensors for adaptive coded aperture imaging applications**

P. Banerjee, G. T. Nehmetallah, R. Aylo, Univ. of Dayton (United States); S. Rogers, Air Force Research Lab. (United States)

Nanoparticle dispersed metamaterials have been researched due to their flexibility in operating frequency, electronic tunability, ease of fabrication, and low cost. We propose binary/core-shell polaritonic/plasmonic nanoparticles in a suitable host as candidates for metamaterials, which can be used either in a single-layer or a multi-layer configuration for Adaptive Coded Aperture Imaging (ACAI) applications ranging from visible to terahertz. We demonstrate the use of this approach to enhance the functionality of (a) pressure and temperature sensors, (b) microbolometers in thermal infrared cameras, (c) directed energy transfer. Properties of the nanoparticle dispersed metamaterial are determined using effective medium theory. Tunability can be achieved through changing the nature, sizes and filling fractions of the nanoparticles, as well as electronically through changing the biasing of the host. In microbolometer application, a single layer structure can be designed to give zero reflection, thereby allowing maximum transmission to the detector. Using multilayer structures with alternating positive and negative index materials, one can design temperature and pressure sensors with minimal crosstalk by employing the additional zero-index bandgap, characteristic of such structures. Finally, by incorporating a defect layer in such multilayer structures one can realize tunable radiation patterns with specific directivities with possible applications to spectroscopy and free-space communications.

8165B-54, Session 10

**Adaptive phase change metamaterials for infrared aperture control**

D. H. Werner, T. S. Mayer, The Pennsylvania State Univ. (United States); C. Rivero-Baleine, Lockheed Martin Missile and Fire Control (United States); N. J. Podraza, The Pennsylvania State Univ. (United States); K. A. Richardson, Clemson Univ. (United States); J. P. Turpin, A. V. Pogrebnyakov, The Pennsylvania State Univ. (United States); J. D. Musgraves, Clemson Univ. (United States); J. A. Bossard, The Pennsylvania State Univ. (United States); S. Rogers, J. D. Johnson, Air Force Research Lab. (United States)

This talk will discuss the use of chalcogenide phase change materials to create tunable metamaterials that can be applied to aperture control in the infrared. Phase change materials exhibit large and reversible changes in optical properties (n, k) when switched between the amorphous and crystalline phases. Thermally-induced phase transitions from the insulating amorphous to the conductive crystalline state can be controlled through external means, facilitating the design of reconfigurable metamaterial devices that operate with ultrafast response times. In this work, robust global stochastic optimization algorithms were combined with full-wave electromagnetic simulation tools to design periodic subwavelength chalcogenide nanostructure arrays to meet the specified device performance goals in each phase. The measured optical properties of deposited chalcogenide thin films and nanofabrication constraints were incorporated into the optimization algorithm to guarantee that the designed nanostructures could be manufactured. By choosing the appropriate cost functions, adaptive metamaterials were designed to switch between transmissive and reflective, transmissive and absorptive, and reflective and absorptive states. The measured optical response of a nanofabricated metamaterial device, which was optimized to switch from the highly transmissive to the highly absorptive state in the near infrared, met the specified performance goals and agreed well with the theoretically predicted performance. This demonstration of the successful design, fabrication, and characterization of a reconfigurable phase change device represents a powerful step in the development of adaptive infrared metamaterials.