SPIE Optical Systems Design

Co-located with Optical Complex Systems 2011

Technical Summaries

www.spie.org/osd

Conference Dates: 5–8 September 2011
Exhibition Dates: 6–7 September 2011

World Trade Centre/Hotel Mercure
Marseille, France

Connecting minds for global solutions

Contents

SPIE

Conference 8167A: Optical Design and Engineering IV

Tuesday-Thursday 6-8 September 2011

Part of Proceedings of SPIE Vol. 8167A Optical Design and Engineering IV

SPIE Optical Systems Design

8167A-01, Session 1

Optical glass: dispersion in the near infrared

P. Hartmann, SCHOTT AG (Germany)

With deliveries of optical glass lots measurement data are given for the visible range usually from 436 nm (g-line) to 656 nm (C-line). Sometimes the question arises if refractive index values in the near infrared can be calculated from these data. With near infrared we mean the range from the C-line up to 1700 nm in this publication. The reason is that up to 1700 nm most optical glasses have hardly any reduction in their transmission.

On the basis of a large amount of production data obtained over more than ten years with precision v-block refractometers evaluations are possible up to 1014 nm. The precision spectrometer URIS developed by SCHOTT enables to analyze the refative index with measurement uncertainty failry below 10-5 for even longer wavelengths up to 2325 nm, however on a much smaller data basis.

The variability of the IR dispersion is shown for selected glass types. Frequency distributions for the different deviation shapes give information how reliable extrapolations are from the visible range to the near IR. The precision refractometer data were used to simulate such extrapolations employing partial dispersion data from catalog data sheets and to check the consistency of simulated with real data.

For some glass types extrapolations seem to be possible. However, there are also glass types, where the method using catalog partial dispersions leads to significant deviations from reality. So if extrapolations are intended to be done, a general check should be performed if this is justified for the glass type of interest.

8167A-02, Session 1

Method to allocate freeform surfaces in axially asymmetric optical systems

A. Yabe, Consultant (Germany)

Most of optical systems are axially symmetric. But axially asymmetric systems are necessary in some cases, for example, to avoid the vignetting of a mirror surface, or to eliminate the keystone distortion of the tilted object surface. The freeform surface is a surface without the axis of the symmetry. The surface profile is expressed as a function on a 2 dimensional coordinate frame.

The subject of this paper is a construction method of axially asymmetric lenses, which consist of freeform surfaces and spherical surfaces. The fabrication and the alignment of freeform surfaces are much more difficult than those of spherical surfaces. To minimize the fabrication cost, the total number of freeform surfaces should be as few as possible. Freeform surfaces should be used at the most efficient position. The question arises how the optimal position of the freeform surfaces can be found.

One way to find the optimal position of freeform surfaces is to include the surface numbers of freeform surfaces in the independent variables of the optimization. The surface number is the integer. If the surface number is extended to the real number, in other words, if the optical system with the real-number surface numbers is consistently defined, the real-number surface numbers can be treated as ordinary independent variables of the optimization.

In 2005 the author proposed a way to find the optimal position of the aspherics. The idea was to view the aspherics as a sphere plus a thin layer. The same idea can be applied to freeform surfaces. The freeform surface can be viewed as a sphere plus an axially asymmetric layer. By separating the layer from the sphere and putting it between the surfaces, the optical system can be viewed as a state where the surface numbers of the freeform surfaces are between the consecutive integer numbers.

With this formulation the freeform surface can be interpreted as traveling through the optical system. I would like to call it the traveling freeform. The traveling freeform has the entity of the real-number surface number and the surface profile. If the traveling freeform is included in the optical system description, two surfaces per one traveling freeform are inserted in the original optical system with the configuration according to the real-number surface number and the surface profile. The raytrace is performed on this modified optical system with the ordinary procedure. The real-number surface number and the surface profile are used as continuous independent variables of the ordinary optimization method such as the damped least squares.

The example is taken from an objective lens with a mirror. The catadioptic lens with the central obscuration is well known for this purpose. To avoid the obscuration the axially asymmetric system is necessary. The system consists of 1 mirror and 6 lens elements. 4 freeform surfaces are supposed and the optimal surface position is determined through the optimziation. The result shows the method of the traveling freeform is effective to determine the position of the freeform surfaces.

8167A-03, Session 1

Design rules for simple imaging systems

F. de la Barrière, G. Druart, N. Guérineau, ONERA (France); J. Taboury, Institut d'Optique Graduate School (France)

Today, both military and civilian applications require miniaturized and cheap optical systems. To reduce their size and their mass, imaging systems have to be as simple as possible, which means that they have to involve a minimal number of optical elements. The simplest system can be defined as a system which is composed of only three elements: a single optical component, an aperture stop and a detector. However, these elements can be complex if needed: for instance, curved detector, optics with aspheric surfaces or diffractive optical elements, microlens array with a complex shape... This paper aims at presenting the range of optical architectures available for a simple system. Thanks to the formalism of third-order Seidel aberrations, several strategies of simplification and miniaturization of optical systems are examined. This approach leads to a classification of existing miniaturized imaging systems which are described in literature (such as multichannel systems). Figures of merit are also introduced to assess the performance capabilities of such systems, showing the necessary trade-off between simplicity, miniaturization, and optical performance.

8167A-04, Session 1

An opto-mechanical model of the accommodating and aging human eye

K. Frey, M. Palme, T. Peschel, S. Riehemann, G. Notni, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

The objective of this presentation is a new accommodating opto-mechanical model of the aging human eye for simulations of presbyopia. Presbyopia is mainly caused by the rigidification of the crystalline lens, containing the cortex and the nucleus. The mechanical model is based on the Helmholtz theory of accommodation and simulated by a two-dimensional (radial) finite element model using the software system ANSYS, which consists of quadrangular elements with central nodes. The stiffness of the lens interior is assumed to be distributed continuously in the nodes. The reduction of accommodation in the ageing human eye is simulated by the change of stiffness within these nodes. This mechanical model results in physiologically correct parameters for the age dependent accommodation process. The results of this mechanical simulation are used as input for a complete optical eye model, implemented in the software ZEMAX. This model abstracts the real human eye by reducing its parameters to an essential number, e.g. optical surfaces, refractive indices and distances /thicknesses. It uses all available data on these values from literature as a function of age and accommodation, and the parameters of the crystalline lens which have been generated by the FEM calculation. All degrees of freedom within the crystalline lens and the chamber depth are involved in the accommodation process. The resulting combined opto-mechanical eye model is fully working as a function of age and accommodation and simulates the physiological processes in the aging eye. The optical performance of the model in a relaxed and accommodated phase fully corresponds with the examined clinical data. The model is suitable for optical and mechanical simulations, for example, different possible treatments within the crystalline lens such as for presbyopia can be simulated.

8167A-05, Session 2

Discussing the importance of pupil cordinate from the view point of the sine-condition in the presence of spherical aberration

M. Shibuya, Tokyo Polytechnic Univ. (Japan)

As the canonical cordinate proposed by Hopkins, we should take the pupil cordinate as the direction cosin of ray. However Herzberger stated in his paper that we should take the pupil cordinate as the tangent of the angle between the ray and optical axsis.

Although Schwarzschild had already used the direction cosin of ray as the pupil cordinate, its importance might have not been enough understood.

Discussing the sine-condition in the presence of spherical aberration, we can clearly undestand that the pupil cordinate of the direction cosin of ray gives us the correct result. Namely the Marx-Shibuya sine condition is derived by using the Schwarzschild aberration theory.

This subject seems to be resolved. But we do not think so. To discuss and understand the importance of pipil cordinate will be effective to develop novel optics.

8167A-06, Session 2

Freeform lens for an efficient wall washer

R. Wester, Fraunhofer-Institut für Lasertechnik (Germany); A. Bäuerle, RWTH Aachen (Germany) and Fraunhofer-Institut für Lasertechnik (Germany); A. Bruneton, RWTH Aachen (Germany); J. Stollenwerk, P. Loosen, RWTH Aachen (Germany) and Fraunhofer-Institut für Lasertechnik (Germany)

LEDs are a promising alternative to existing illuminants for a wide range of lighting applications. Besides efficiency and high durability, the small light source dimensions open up new possibilities in optical design. In many lighting setups it is desired to realize a prescribed intensity distribution, for example homogeneous irradiance on a given area on a wall or floor. This can be realized using LEDs in combination with specially designed freeform lenses and/or mirrors.

For high efficiency it is necessary to collect at least 70 - 80 degrees half-angle (measured against the z axis) of the light that the LED emits into a 90 degree half-angle. This results in a lens that resembles a hemisphere. The numerical design problem requires a mathematical description that can handle such strongly curved surfaces that have strongly varying surface slopes. Surface parametrization with a rectangular topography, like e.g. Cartesian tensor product B-splines, have severe drawbacks when handling such surfaces.

We report on the use of an alternative surface approximation scheme that uses a triangular mesh. We describe an algorithm that optimizes the two surfaces of a lens for a wall washer that generates homogeneous irradiance on a wall area of 2.8x2.8 m^2 while mounted to the ceiling. The homogeneity is better than 80% and the optical efficiency including Fresnel losses is about 85%. Results from simulations are compared with measurement results obtained from an injection molded sample lens.

8167A-07, Session 2

Design and simulation of diffractive optical components in fast optical imaging systems

A. M. Herkommer, R. M. Reichle, C. Pruss, M. Häfner, Univ. Stuttgart (Germany)

Recent lithographic technologies allow for the fabrication of high period diffractive structures on planar and curved optical surfaces with high precision. Such diffractive surfaces offer the optical designer extra degrees of freedom, which are of special importance for optical systems, where light collection efficiency is important. We illustrate the usage and benefit of diffractive elements within fast optical systems in various applications. For these hybrid design classes it is mandatory to include the realistic as-built performance of the employed diffractive elements into the design phase. Correspondingly we present simulation techniques to include fabrication specific diffraction efficiencies and stray light into the optimization and evaluation process.

8167A-08, Session 2

Analysis of the diffraction efficiency of reflection and transmission holographic gratings by means of a parallel FDTD approach

J. Francés Monllor, S. Bleda, S. Gallego, C. Neipp, A. Márquez, I. Pascual, A. Beléndez, Univ. de Alicante (Spain)

In this work a vectorized and parallel version of the Finite-Difference Time-Domain method (FDTD) is applied to holographic diffraction gratings. More concretely, in this work gratings with a grating period vector forming an arbitrary angle with the perpendicular to the plane of incidence are analyzed. Angular and wavelength selectivity are obtained by means of the normalized diffraction efficiency. These parameters are contrasted and compared with empirical values and also with analytical closed expressions, thus validating our method. Some classical analysis of this type of devices such as the Kogelnik's Coupled Wave Theory (KCWT) assumes only two waves travelling along the grating: the incoming reference wave and the outgoing signal wave; moreover infinite plane wavefronts are also assumed. These assumptions cannot be easily considered in a classical finite grid simulation by the FDTD method, even for small values of the refractive index modulation the existence of high-order diffracted waves inside the phase gratings cannot be ignored. For that reason it has been considered the simulation of a wide grid that permits a large number of periods of the grating. On the other hand, a time domain method such as the FDTD method permits to visualize the interaction between the electromagnetic fields with the whole structure providing reliable information about the formation of the hologram. Furthermore, analysis of the performance of the parallel method is shown obtaining a severe improvement respect to the classical version of the FDTD method. This improvement of the algorithm provides a feasible and accurate scheme for simulating a wide range of optical devices.

8167A-09, Session 2

The use of the Zernike polynomials in optical systems design

S. N. Bezdidko, Open Joint-Stock Co. Research-and-Production Corp. (Russian Federation); E. I. Morosova, House of Optics Scientific Ctr. (Russian Federation)

Requirements to the designed optical systems are approaching the maximum achievable image quality at high value of lens speed and angular field of view and minimum overall weight and dimensions characteristics. In this connection the special importance have works on the development of effective techniques of optical systems design. Considerable importance in the development of efficient techniques for the lens design and effective solution of the various problems of Applied Optics has Zernike polynomials.

In this paper we present the most effective ways of using Zernike polynomials in lens design and optical engineering, including the use of Zernike polynomials in creating optimization programs, some methods of determination of the limit potential image quality of optical systems of various complexities, analysis of the aberration properties of optical systems and the choice of the starting point and others. The numerical examples of use of offered techniques are presented.

8167A-10, Session 3

Modeling highly aspherical optical surfaces using a new polynomial formalism into Zemax

S. Vivès, S. Pascal, Observatoire Astronomique de Marseille-Provence (France); A. Secroun, Univ. Paris 13 (France); M. Gray, D. Le Mignant, J. Cuby, M. Ferrari, Observatoire Astronomique de Marseille-Provence (France)

We developed a new mathematical formalism to model highly aspherical optical surfaces opening the possibility to explore innovative optical designs. This formalism is based on the Bernstein polynomials allowing to describe from low to high order deformations of the optical surface. This formalism has been implemented into Zemax making use of the User-Defined Surface (UDS-DLL) Zemax capability. In this case, the mathematical definition of the surface is imported into Zemax thus allowing to apply classical optimization and analysis functionalities. This paper presents the UDS-DLL tool based on the Bernstein polynomials together with the optical analysis performed to evaluate the gain in using such new formalism.

8167A-11, Session 3

Parametrical synthesis of three-mirrors optical systems

I. L. Livshits, V. N. Vasilyev, V. A. Zverev, National Research Univ. of Information Technologies, Mechanics and Optics (Russian Federation)

In starting point selection for mirror systems we differ structural and parametrical synthesis of optical schemes. When we decided the structure of the system: in our case, as a three mirror system, we go to the next step of design process - estimation of the system's parameters, which we call parametrical synthesis. Usually there always exist few approaches to solve this problem. In case of mirror systems we advise to use an artificial method of replacement reflecting surfaces by thin "mirror" lenses, which gives us easy understanding and the opportunity to create analytical equations as the base for subsequent parametrical synthesis of optical system consisting from two reflecting surfaces and more.

In this case interconnection of "lens" components' optical powers are determined by required field curvature of the image and the ratio of back focal length and the distance between the components which is considered as a parameter.

If the third reflecting surface is located away from the two-mirror systems axis, the F-number of such three-mirrors system is determining the optical power for the third component and the parameters of the whole optical system.

To get the parametrical model, which describes all possible constructions of three-mirrors systems, we estimated the optical powers of the two first mirror-components as a function of optical power of the third component, and then used the ratio of distances between components and back focal length to the distance between second and third components as constructing parameters.

In one particular case we get a variant of three-mirrors system with acceptable aberration correction when one mirror has a spherical shape.

If we add an aberration-free and an optical power-free flat dummy surface to any reflecting surface (spherical or aspherical shape), we receive a system of thin mirror components which has an optical power of the first (depending on beams propagation) reflecting surface.

Replacing of reflecting surfaces by provisional thin "mirror-lenses" allows us to get analytical equations. For convenience we scale the total optical power of the system to scale factor 1, and estimate the parameters of two-mirror optical system.

In the publication we are going to show that the distance between the first and the second components is equal to the ratio of the coefficient of central obscuration by a pupil diameter to the back focal distance divided into the distance between the components.

Field curvature in case of zero astigmatism is determined by the coefficient which is equal to the sum of optical powers of the separate components. As a result we get a second order equation in dependence on the coefficient of central obscuration by a pupil diameter. It is easy to show that in case of off-axis location of the third reflecting surface F-number of three-mirror system determines an optical power of the third thin component calculated in accordance of scale factor of optical power of two-mirror system. Solving this equation we receive values of construction parameters of the whole system. On the base of this approach we proposed different variant of composition of both on-axis and off-axis three-mirrors systems, which we are going to present in our publication.

In case of off-axis three-mirrors systems we consider that optical powers of all three components are different. It is convenient to describe the connection of construction parameters of this system by a set of coefficients estimated as a ratio of values of the corresponding parameters. As a result, we receive an equation describing the variety of all possible scheme solutions, including both spherical and aspherical shapes of surfaces of the components.

8167A-12, Session 3

Distortion properties and correction abilities of axis-symmetric aspherical surfaces of arbitrary shape

B. A. Hristov, Institute of Optical Materials and Technology BAS (Bulgaria)

The real (all orders) aberration properties and correction abilities of optical aspherical surfaces of arbitrary shape are insufficiently investigated because of lack of exact aberration theory.

Here we derive and investigate an exact analytical distortion function for axis-symmetric aspherical surfaces with arbitrary shape that describes correctly image distortion for the whole object space without any approximations. We prove that in the object and image spaces of every aspherical surface for fixed stop position there is in the common case one orthoscopic object surface and one conjugate image surface. In addition we offer formulae for determination of object and image orthoscopic surface coordinates in every refracting or reflecting axis-symmetric aspherical surface with known coordinates and continuous first derivative on the whole profile.

To verify the distortion correction we use the commercial program OSLO. The differences between our results and these obtained by OSLO are less than 1X10-8 mm.

Using these exact formulae we investigate the real shape and location of the orthoscopic object and image surfaces as a function of stop position in different reflecting and refracting aspherics.

The investigations of distortion correction ability are presented in a number of figures. The results can be used by optical designers in the process of synthesis of orthoscopic optical systems.

8167A-13, Session 3

Development of optical design algorithms on the base of the exact (all orders) geometrical aberration theory

B. A. Hristov, Institute of Optical Materials and Technology BAS (Bulgaria)

Optical design is to a great extent systematic implementation of a cut-and-try process due to lack of suitable and exact aberration theory. In the paper we propose such a theory for the case of centered systems. It allows for correction of one or more aberrations by solving one equation or a system of equations.

Correction of spherical and paraxial chromatic aberration and fulfillment of Abbe Sine Condition demand solving one linear equation for each of them. Astigmatism elimination, sagittal curvature removal and tangential curvature correction involve solution of the second order equation for each of them. Field curvature correction and tangential coma elimination separately require solution of the third order equation.

To verify the correction of every single aberration we use the commercial program OSLO. The differences between our and OSLO

results for each aberration (except for the tangential coma) are less than 1X10-8mm.

Simultaneous correction of spherical and paraxial chromatic aberration, as well as simultaneous removal of spherical aberration and Abbe Sine Condition fulfillment entail consecutive solution of one quadratic and one linear equation.

Simultaneous elimination of astigmatism and field curvature demands to solve consecutively one seventh order polynomial and one quadratic equation.

The more aberrations undergo simultaneous correction, the higher polynomial order is.

In addition we show variety of interesting and "impossible" examples of optical systems design.

8167A-14, Session 4

The role of aberration analysis in modern optical design (Tutorial)

J. Bentley, Univ. of Rochester (United States)

Prior to the existence of modern ray tracing programs, aberration theory was an essential tool in the design of optical systems. However, the field of optical design has changed considerably in the past few decades. Now with easy-to-use software one does not need to be an expert in understanding aberrations to find solutions to many different optical design problems. With global optimization algorithms one can often find many solutions to a single problem quickly. Furthermore, modern software has the ability to take an object and show you what the resulting image looks like in real time (skipping any sort of aberration analysis/understanding). As a result, aberrations are sometimes ignored by new designers and the ability to determine the limiting aberrations through transverse ray aberration plots may be in danger of becoming a lost art. However, aberration theory and aberration analysis still have a role to play in modern optical design. For example, how do you know what to change to make the system better? Which solution is the best solution for manufacturing? Is the design as good as it can get? Aberrations can help you answer all these questions by providing insight into design limitations, tolerance sensitivity, and the manufacturability of the underlying design form. This becomes extremely useful when searching for cost-effective solutions.

In this tutorial an overview of aberrations, aberration balancing, and reading transverse ray error diagrams will be given. Since most modern optical systems have high resolution, large bandwith, and large field requirements, the tutorial will focus on more than just the standard textbook third order Seidel aberrations but include examples of higher order and induced aberrations (e.g. spherochromatism, oblique spherical aberration, and elliptical coma) using real lens systems where multiple aberrations are present and tend to balance each other for best performance. Then optical systems such as simple UV, visible, and IR refractive lenses; more complicated refractive systems requiring Petzval correction; and complex broadband zoom lenses are used to illustrate how the application of aberration theory can improve the entire lens design process.

8167A-15, Session 5

Monolithical optical freeform element for an IR line camera

S. Riehemann, M. Palme, R. Steinkopf, P. Munzert, G. Notni, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); J. Krieg, Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung (Germany)

Actually, for infrared (line) cameras as well as for cameras in other spectral ranges mostly optics (objectives) consisting of multiple lenses or mirrors are used. Within this paper, we present a novel approach for an optical system for a near infrared (IR) line camera, which exists of only one monolithical optical element with 3 optical free form surfaces. The element was optimized by optical design process, manufactured by diamond turning free form fabrication, and finally (partially) coated by a reflective metal.

The optical design was performed with respect to the following requirements given by the application: wavelength range 0.9 µm to 1.7 µm, field angle 75° x 2°, angle resolution 0.5°. Within the design process two of the three optical surfaces are formed biconic, one is real-ized as cylindrical surface. Tolerancing of the monolithical component was performed to enable the fabrication of all 3 optical free form surfaces of the element within one fabrication process by diamond turning Ultra Precision (UP) treatment.

The calculated component was realized as PMMA element by means of diamond turning UP treatment. Within a next fabrication step two of the optical surfaces were gold coated to work as mirrors for the above mentioned spectral range. Due to the specific problems that are connected with the deposition of well-adherent coatings on PMMA, an adhesion-promoting layer had to be applied. While this NIR-transparent layer was vapour-deposited, the gold reflector was subsequently coated by magnetron sputtering.

The realized element was optically characterized. The measured optical performance was compared with the calculated values resulting from the design process. The values are in good accordance.

8167A-16, Session 5

Freeform Fresnel RXI-RR Köhler design with spectrum-splitting for photovoltaics

M. Buljan, Univ. Politécnica de Madrid (Spain); P. Benítez, Light Prescriptions Innovators, LLC (United States); R. Mohedano, Light Prescriptions Innovators Europe, S. L. (Spain); J. C. Miñano Dominguez, Light Prescriptions Innovators Europe, S. L. (United States)

Development of a novel, practical, high-concentration PV optics using four-junctions (4J) of existing high-efficiency solar cells via spectrum splitting is presented. The novel HCPV Fresnel RXI-RR Köhler concentrator concept uses the combination of a commercial concentration GaInP/GaInAs/Ge 3J cell and a Back-Point-Contact (BPC) concentration silicon cell for efficient spectral utilization, and external confinement techniques for recovering the multijunction cell's reflection. The design targets an equivalent cell efficiency greater than 45%, and CPV module efficiency greater than 38%, achieved at a concentration level larger than 500X and wide acceptance angle (±1º).

The primary optical element (POE) is a flat Fresnel-Köhler lens, and the secondary optical element (SOE), a monolithic free-form Köhler RXI-RR concentrator, with an embedded cost-effective high-performance band-pass filter that reflects or refracts the light rays while crossing the device. In the RXI-RR SOE concentrator, the RR illuminates the BPC silicon cell, while the RXI illuminates the 3J cell. This last illumination is asymmetric from one hemisphere, allowing the use of an confining cavity in the other hemisphere to efficiently collect the light reflected by the grid lines and the semiconductor surface of the triple junction cell. RXI-RR free-form surfaces are calculated using an iterative process in three dimensions. The Köhler integration guarantees a uniform illumination of the two cells, free from spatial chromatic aberration.

A first proof-of concept prototype has been manufactured, and preliminary measurements show an efficiency increase over the 3J cell greater 10% under real sun operation, results that will be shown at the conference.

8167A-17, Session 5

Evaluation and analysis of chromatic aberrations in images

V. Blahnik, D. Gängler, J. P. Kaltenbach, Carl Zeiss AG (Germany)

Optical designers typically use aberration diagrams based on ray tracing to analyze the chromatic aberration performance of their optical system. However to evaluate the impact of chromatic aberrations on color fringes in images optical imaging simulations are necessary including the effect of spectral response of the sensor or film, exposure time, Gamma corrections, etc. We have analyzed the correspondence of classical chromatic aberration measures versus analysis based on image simulations. We propose a metric directly linked to color fringes

SPIE Optical Systems Design

in images which can be used to constrain and specify the chromatic aberration performance of an optical system.

8167A-18, Session 6

Design of a compact objective for SWIR applications

J. M. Infante Herrero, Indra Sistemas, S.A. (Spain); W. Lin, J. C. Miñano Dominguez, P. Benítez, Univ. Politécnica de Madrid (Spain); M. C. de la Fuente, Indra Sistemas, S.A. (Spain); G. Biot, H. Ahmadpanahi, Univ. Politécnica de Madrid (Spain); A. F. Cifuentes, SECPhO (Spain)

Lately the short-wave infrared (SWIR) has become very important due to the recent appearance on the market of the small detectors with a large focal plane array. Military applications for SWIR cameras include handheld and airborne systems with long range detection requirements, but where volume and weight restrictions must be considered. In this paper we present three different designs of telephoto objectives that have been designed according to three different methods. Firstly the conventional method where the starting point of the design comes from the first order approximation. Secondly the simultaneous multiple surfaces (SMS) method, where the starting point is the input wavefronts that we choose. And lastly the multichannel configuration, a new method which enables us to obtain ultra compact designs. The designs are compared in terms of optical performance, volume, weight and manufacturability. Because the objectives have been designed for the SWIR waveband, the color correction has important implications in the choice of glass that will be discussed in detail.

8167A-19, Session 6

Imaging systems application of multichannel configurations

J. M. Infante Herrero, Indra Sistemas, S.A. (Spain); J. C. Miñano Dominguez, P. Benítez, G. Biot, H. Ahmadpanahi, W. Lin, J. Liu, Univ. Politécnica de Madrid (Spain); J. C. Chaves, Light Prescriptions Innovators Europe, S. L. (Spain); M. C. de la Fuente, Indra Sistemas, S.A. (Spain)

While multichannel configurations are well established for non-imaging applications they have not been used yet for imaging applications. In this paper we present for the first time a battery of multichannel designs for imaging systems. The multichannel comprises discontinuous optical sections which are called channels. The phase-space representation of the bundle of rays going from the object to the image is discontinuous between channels. This phase-space ray-bundle flow is divided in as many paths as channels there are but it is a single wavefront both at the source and the target. Typically, these multichannel systems are at least formed by three optical surfaces: two of them have discontinuities (either in the shape or in the shape derivative) while the last is a smooth one. Optical surfaces discontinuities cause at the phase space the wavefront split in separate paths. The number of discontinuities is the same in the two first surfaces: Each channel is defined by the smooth surfaces in between discontinuities, so the surfaces forming each separate channel are all smooth. Aplanatic multichannel designs are also shown and used to explain in detail the design procedure. The diffraction analisys is presented as well as the effects of the straight light.

8167A-20, Session 6

Advances in SMS design method for imaging optics

W. Lin, P. Benítez, J. C. Miñano Dominguez, J. M. 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[1]. 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 [2]. More recently the extension to up to four aspherics was developed [3][4]. 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 800mm focal length, f/8 and 1.170 diagonal field of view. With this catadioptric lens structure we have achieved designs with excellent performance (RMS spot size <14 um), with total system length less than 50 mm, and the results obtained with the different algorithms will be presented.

[1] Chapter 8 in R.Winston, J.C. Miñano, P. P. Benítez, with contributions of N. Shatz, J. Bortz, “Nonimaging Optics”, Academic Press Elsevier, 2004

[2] P. Benítez and J. C. Miñano, “Ultra high-numerical-aperture imaging concentrator,” J. Opt. Soc. Am. A , Vol 14, 1997

[3] J. C. Miñano, P. Benítez, Wang Lin, José Infante, Fernando Muñoz, Asunción Santamaría, “An application of the SMS method for imaging designs,” Optical Express, Vol 17, No. 26, p. 24036, 2009

8167A-21, Session 6

Portable virtual display system design with a wide eye motion box for a Motor vehicle

S. C. Shin, Y. Chi, T. Ahn, S. S. Jeong, S. Lee, K. Choi, LG Electronics Inc. (Korea, Republic of)

We have succeeded in designing a portable virtual display system based on a virtual projected optical design with a MD panel. We have optimized the optical performance using the 2D optical multi zoom so that we should obtain comfortable the eye motion box area. and then, when we consider with different height head position, It is designed to mechanically adjust the system tilting angle. also It is able to display the full color Navi map and DMB using RGB 3in1 LED sources. We belive that it has been developed as an alternative to conventional built-in type HUD system targeting the high volume aftermarket with an affordable price.

8167A-22, Session 7

Solid catadioptric telephoto lens design with SMS method

L. Wang, Univ. Politécnica de Madrid (Spain); P. Benítez, J. C. Miñano Dominguez, Univ. Politécnica de Madrid (Spain) and LPI-LLC (United States); J. M. Infante Herrero, Univ. Politécnica de Madrid (Spain); M. C. de la Fuente, Indra Sistemas, S.A. (Spain); G. Biot, Univ. Politécnica de Madrid (Spain)

The Simultaneous Multiple Surfaces (SMS) was developed as a design method in Nonimaging Optics during the 90s[1]. 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 [2]. More recently the extension to up to four aspherics was developed [3]. 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 800mm focal length, f/8 (aperture diameter 100 mm) and 1.170 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 <14 umm), with total system length less than 50 mm. Compared to traditional designs, the solid lens designs are much more compact, easy to assemble and thus cost-saving.

[1] Chapter 8 in R.Winston, J.C. Miñano, P. P. Benítez, with contributions of N. Shatz, J. Bortz, “Nonimaging Optics”, Academic Press Elsevier, 2004

[2] P. Benítez and J. C. Miñano, “Ultra high-numerical-aperture imaging concentrator,” J. Opt. Soc. Am. A , Vol 14, 1997

[3] J. C. Miñano, P. Benítez, Wang Lin, José Infante, Fernando Muñoz, Asunción Santamaría, “An application of the SMS method for imaging designs,” Optical Express, Vol 17, No. 26, p. 24036, 2009

8167A-23, Session 7

Recent developments in wafer-level fabrication of micro-optical multi-aperture imaging systems

R. Leitel, P. Dannberg, A. Brückner, A. Bräuer, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Micro-optical systems, that utilize multiple channels for imaging instead of a single one, are frequently discussed for ultra-compact applications such as digital cameras. The strategy of their fabrication differs due to different concepts of image formation. Illustrated by recently implemented systems for multi-aperture imaging, typical steps of wafer-level fabrication are discussed in detail. In turn, the made progress may allow for adapted degrees of freedom in optical design. Pressing ahead with very short overall lengths and multiple diaphragm array layers, results in the use of extremely thin glass substrates down to 100 microns in thickness. The desire for a wide field of view for imaging has led to chirped arrays of microlenses and diaphragms. Focusing on imaging quality, aberrations were corrected by introducing toroidal lenslets and elliptical apertures. Such lenslets had been generated by thermal reflow of lithographic patterned photoresist and subsequent molding. Where useful, the system’s performance can be further increased by applying aspheric microlenses from reactive ion etching (RIE) transfer or by achromatic doublets from superimposing two moldings with different polymers. Multiple diaphragm arrays prevent channel crosstalk. But using simple metal layers may lead to multiple reflections and an increased appearance of ghost images. A way out are low reflecting black matrix polymers that can be directly patterned by lithography. But in case of environmental stability and high resolution, organic coatings should be replaced by patterned metal coatings that exhibit matched antireflective layers like the prominent black chromium. The mentioned components give an insight into the fabrication process of multi-aperture imaging systems. Finally, the competence in each step decides on the overall image quality.

8167A-24, Session 7

Metrology system based on bidirectional microdisplays

C. Grossmann, F. Perske, S. Zwick, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); J. Baumgarten, Fraunhofer-Institut für Photonische Mikrosysteme (Germany); B. Richter, S. Riehemann, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); U. Vogel, Fraunhofer-Institut für Photonische Mikrosysteme (Germany); G. Notni, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); A. Tünnermann, Friedrich-Schiller-Univ. Jena (Germany)

Expanding requirements on manufacturing technology increase the requirements on neces-sary non-contact metrology.

Several optical metrology systems are based on a separated observance (e.g. camera unit) and image emitting unit (e.g. projection unit). This fact limits the miniaturization of the sen-sor.

The image emitting unit consists of a light source with an illumination lens and an image generating device like a reflective microdisplay. A first step towards the miniaturization of this unit is the application of self-image-emitting microdisplays. Such image generating el-ements (active matrix OLED microdisplay) enable to eliminate additional light source and illumination optics which are normally used for the illumination of the reflective microdis-plays like DMD (Digital Micromirror Device) or LCoS (Liquid Crystal on Silicon) display. Com-pared to this technique the OLED microdisplays allow an easy and small system design. OLED microdisplays are actually state of the art and are used in a wide range of applications, e.g. multimedia, medical and metrology applications.

We present a compact, highly integrated optical distance and inclination sensor applying the inverse confocal principle using a bidirectional OLED-microdisplay developed by Fraunhofer IPMS. This microdisplay combines light emitting devices called OLED-microdisplay (projection unit) and light detectors called photo diodes (camera unit) on one single chip realized by the OLEDs-on-CMOS-technology. This technology gives the opportunity for a further miniaturization of optical metrology systems.

According to conventional confocal sensors, the object is shifted through the focal plane (± z) and the back-scattered light is collected via special designed optics and detected by photo diodes. The detected photocurrent depends on z. In contrary to the confocal sensor, our inverse confocal sensor detects a minimum of back-scattered light if the object is positioned in the focal plane.

Further the inclination and the parallel alignment of the object can be investigated by the point-wise scanning at the display matrix structure without moving the sensor or the object. The presented sensor can work as a sequential multi-point sensor which can be used to measure distances and inclinations with a high precision positioning accuracy.

8167A-25, Session 7

A study of optical design for optics of high-contrast projector

C. Yen, National Formosa Univ. (Taiwan); Y. Fang, C. Tsai, National Kaohsiung First Univ. of Science and Technology (Taiwan)

A new optical design inclusive of zoom optics and optical engine system is proposed in this paper. Traditionally, There are trade-off between F-number of projection optics and contrast, which seems that super high-contrast image from commercial projector was simply a dream. Some ideas of adaptive optics were announced before for the improvement of high contrast. However, few reach success or cost will be high. Traditionally, there is nothing to do with optics of projector and optical engine of projector if lens meets the specification. In this paper, a new optical design for optics and optical engine is studied with liquid optics arrays. Thanks to advanced optical design and LED light luminance, simulation results show that 50% improvement for image contrast could be made without sacrifice of volumetric size.

8167A-26, Session 8

Design of a handheld confocal fluorescence microscope for clinical dermatologic applications

C. Bechtel, Technische Univ. Dresden (Germany); J. Knobbe, H. Grüger, H. K. Lakner, Fraunhofer-Institut für Photonische Mikrosysteme (Germany)

Although skin is easily accessible to optical methodologies, biopsies are at present a widly used procedure in dermatologic diagnostics. However fluorescence confocal laser scanning microscopy (LSM) is a noninvasive imaging technique that allows depth resolved investigations of inflammatory and neoplastic skin disorders in vivo and

at high resolution. By applying substances onto or into the epidermis LSM is well suited to obtain information regarding the morphological structures of the skin down to a hundred mircometers below the skin surface. Compared to conventional light microscopy of hisological sections this optical method has a clear advantage in the case of kinetic measurements. To this end, we have designed a portable confocal fluorescent microscope for future dermatologic studies, offering a field of view of 600um. Based on a dual-axis MEMS mirror (Fraunhofer IPMS, Germany) the confocal character of the system resides in the use of the same path for illumination and detection with spatial filtering of the signal collected from the subsurface analysis plane. Illumination is provided by a 488nm laser and the backscattered fluorescence light is separated from the illumination light by a filter, before being detected behind the pinhole. To reconstruct the image the measured intensity and position information is correlated. The ability to perform cross-sectional imaging in the skin will be given by an integrated z-shifter.

Based on the usage of the dual axis MEMS mirror certain implication are associated. Besides the figures of merit for the MEMS-scanner performance as there is for example the   D-product which directly translates to the maximum number of resolvable spots, the integration is accompanied with a range of further requirements on the optical elements included in the design and therefore considerably affects the overall system layout. These correlated restrictions and chances of the system layout are discussed in detail.

8167A-27, Session 8

Design of an integrated micro-optical femtosecond pulse shaper

M. Bohling, J. Jahns, FernUniv. in Hagen (Germany)

Ultrashort laser pulses are of increasing importance in many fields of science and technology. In these fields there often exists a demand to shape or filter the pulses. This can be realized by means of an appropriate pulse shaper. Conventional techniques for the filtering and shaping for fs-pulses are based on spectral filtering and the use of grating interferometers. In the usual discrete implementation, however, these setups are critical with respect to alignment and dispersion.

In order to provide a device that is stable with respect to mechanical and thermal influence, we have recently demonstrated an integrated microoptical pulse shaper. A folded optical axis allows for a co-planar configuration: one plane contains microlenses - used in reflection - another contains diffraction gratings - also used in reflection - and modulators in the spectral plane. The two functional planes are implemented on two physical micro-structured substrates between which the light signal travels in air. The reflective implemention completely eliminates material dispersion. Modal dispersion, which may occur due to the folded axis, is eliminated by cascading two 4f-setups.

The design task for building an integrated pulse shaper includes two main aspects: optical and technological. The optical design is first done for an ideal system. We first investigate the properties of the ideal system in terms of the space-bandwidth product of the system. Then we take into account aberrations that occur due to the fabrication of the lenses and due to tolerances in the system. The lenses are fabricated by ultraprecision micromachining. Different techniques for the fabrication can be identified by the aberrations that occur. The analysis is performed by ray-tracing simulations in combination with using the results from wavefront measurements for the characterization of the lenses. Finally, the results of the simulations are compared with experiments.

8167A-28, Session 8

Zoom-chirped DOW interference system for micro- and nano-lithography

M. Wang, INO (Canada)

The field of optical materials has been rapidly developing in recent years, promising to deliver new materials with exotic properties generally unattainable in nature with the existing and conventional materials. As scientific quests and engineering applications reach down to a nanometer scale, there is a strong need to fabricate three-dimensional (3-D) nanostructures with regularity and controllability in their pattern, size, and shape, including chirped pitch. These well-defined large-area nanostructures opened new application possibilities in areas beyond nanoelectronics, such as nanomaterials for energy, micro fluidics, and biomaterials. It is really a challenge to make the nanostructures over a large area with good regularity and uniformity at reasonable cost with the current manufacturing methods such as e-beam lithography and nano-imprinted.

Interference lithography is considered to be the most efficient way to make submicron-scale periodic patterns over a large area with superior control of pattern regularity. In order to make a chirped nano-patterning with interference lithography technology, we propose a zoom-chirped interferometer as a novel manufacturing tool with more flexibility for 3-D nano-patterning fabrication. The optical concept of this novel zoom-chirped interferometer is based on the Fresnel Division-of-Wavefront (DOW) interference combined with a pair of semi-anamorphic zoom lenses located in front of a Fresnel 900-mirror to control the chirped rate and pitch for nano-patterning. The collimated beam will be used as the incident beam for the interferometer in the UV or DUV wavelength region. The center period on the nano-pattern can be adjusted by rotating the Fresnel 900-mirror, and the variation of the required chirped rate will be controlled by moving one anamorphic lens, along the direction of optical axis, with respect to another lens in the system. This novel zoom-chirped interferometer is more flexible and stable than conventional interferometric configuration for micro and nanolithography. A linear chirped rate is fully achieved, and the chirped rate can be varied from a few nm/cm to dozens nm/cm, depending on the requirements, with this novel concept for large wafer nano-patterning. In this concept, it uses simple and relatively inexpensive optics to generate uniform interference patterns such as lines and dots with only one beam for excellent stability of the interference fringe, which is very important in micro and nanolithography, especially for mass-volume manufacturing environment. Both analytical and numerical solutions with this concept have been shown for good agreement, which will be given in the paper with more details.

This novel optical concept is very promising for advanced interference lithography with the large-area of 3-D nano-patterning and nanofabrication. We believe that this novel zoom-chirped DOW interferometer will be a more flexible and powerful optical system for micro and nano-patterning to adapt different ranges and requirements in future micro and nanolithography with or without chirped pitch and shape. Evidently, it is a low cost solution for mass-volume manufacturing in microlithography industry.

8167A-29, Session 8

Simulation tools for advanced mask aligner lithography

A. Bramati, U. Vogler, SUSS MicroOptics SA (Switzerland); B. Meliorisz, GenISys GmbH (Germany); K. Motzek, Fraunhofer-Institut für Integrierte System und Bauelementetechnologie (Germany); M. Hornung, SUSS MicroTec Lithography GmbH (Germany); R. Voelkel, SUSS MicroOptics SA (Switzerland)

Contact/proximity lithography in a Mask Aligner is a very cost effective technique for photolithography, as it provides a high throughput and very stable mature processes for critical dimensions of typically some microns. For shadow lithography the printing quality depends much on the proximity gap and the optical properties of the illumination light.

SUSS MicroOptics has recently introduced a novel illumination optics referred as MO Exposure Optics for all SUSS Mask Aligners. MO Exposure Optics provides excellent uniformity of the illumination light, telecentric illumination and a full freedom to shape the angular spectrum of the mask illuminating light precisely. This allows to fully simulate Mask Aligner Lithography from the light source to the final pattern in photoresist after development. The commercially available software LayoutLab allows to optimize Mask Aligner Lithography beyond its limits by both shaping the illumination light (Customized Illumination) and the photomask pattern (Optical Proximity Correction). Results from simulation and experiment will be presented.

8167A-30, Session 8

Refractive x-ray condenser optics for use in microscopes with x-ray tube sources

H. Vogt, M. Simon, V. P. Nazmov, A. Last, J. Mohr, Karlsruher Institut für Technologie (Germany)

Refractive X-ray optics are produced at the Institute of Microstructure Technology (IMT) at Karlsruhe Institute of Technology (KIT). These optics are going to be used as condensers in X-ray microscopes with X-ray tube sources for energies above 8 keV. To achieve large apertures with low absorption we follow a new approach for lens fabrication. The lenses are produced out of a thin structured foil with equidistant ribs of triangular cross-section. The foil is cut in an appropriate shape and wound around a glass fibre core [1]. Simulation and first tests approve the working principle however the overall performance of the produced lenses is still behind their theoretical limits. The reasons for this deficit were investigated and the lenses are now undergoing an optimisation procedure. One important property of the lenses is the correct shape of the wound structure. This adverts to the width of the foil layer in a certain distance to the optical axis to provide enough prisms in a row to refract a ray into the desired focal position and to the shape of the layer itself which should be bent and not parallel to the optical axis of the lens. If the layer is parallel to the optical a fraction of the incoming radiation leaves the layer it entered and is lost. If an X-ray tube is used the expansion of the source gets important because it also influences the required shape of the whole lens. The rolling process itself is also revised to produce lenses with small cores with diameters below 100 µm and bent foil layers while preserving a tight fitting foil layer bundle. The lenses are tested by characterizing their transmission properties at different energies and types of X-ray tubes as well as synchrotron sources to obtain additional information about the internal structure like the quality of the lens after the rolling process. In the talk we will describe the new lens concept and the fabrication process. We will also present results on the lens performance.

[1] Simon M., Reznikova E., Nazmov V., Grund T., Last A., “A New Type of X-ray Condenser Lenses with Large Apertures Fabricated by Rolling of Structured Films”, AIP Conference Proceedings, 1221, 85-90, 2010

8167A-31, Session 9

Compact optical design solutions using focus tunable lenses

M. Blum, M. Büeler, É. Labaume, Optotune AG (Switzerland)

Several approaches have been demonstrated to build focus tunable lenses. The additional degree of freedom enables the design of elegant, compact optical systems, typically with less mechanics. We present a new range of electrically and mechanically focus tunable lenses of different sizes and tuning ranges and discuss their characteristics. Our lenses are based on an elastic polymer film and liquid combination, whereas the curvature of the lens is varied by changing the pressure in the liquid. We show how tunable lenses can be used to improve optical designs for auto-focus and zoom in terms of size, quality and speed. Furthermore we present an LED-based spot light with variable illumination angle, which shows optimal performance in terms of spot quality and optical efficiency.

8167A-32, Session 9

Integral imaging system with 33 mega-pixel imaging devices using the pixel-offset method

J. Arai, M. Kawakita, T. Yamashita, F. Okano, NHK Science & Technical Research Labs. (Japan); Y. Haino, M. Sato, JVC KENWOOD Holdings, Inc. (Japan); M. Okui, NHK Science & Technical Research Labs. (Japan)

We believe that a practical system able to present three-dimensional (3D) motion video in real time will be an important means of conveying information. Integral photography (IP), first proposed by Lippmann, is a technique for capturing 3D photographic images. IP allows viewing of 3D images that change depending on the viewing position without the use of special viewing glasses and using natural light. These conditions are very close to how we observe the real world. Because of these advantages, we are advancing development of Integral 3D television system based on IP and able to capture and display 3D motion video in real time. To present a high-quality 3D image, Integral 3D television requires huge amounts of information. Earlier, we built an Integral 3D television using Super Hi-Vision (SHV) technology, with 7680 pixels horizontally and 4320 pixels vertically. Here we report on an improvement of image quality by developing a new video system with an equivalent of 8000 scan lines and using this for Integral 3D television.

To date, no video systems capable of presenting motion video at resolutions higher than full-resolution SHV have been reported. Accordingly, we used existing 33 mega-pixel imaging devices and the pixel-offset method to construct a camera with an equivalent resolution of 8000 effective scan lines. The light from the photographic subject enters the camera lens and is split using a four-panel color separation prism assembly into two green (G1, G2), a red (R), and a blue (B) channel. The separated channels are each captured by 33 mega-pixel CMOS sensors. The green channels contribute the most to the image’s luminance component, so it is possible to increase the effective resolution of the luminance signal of the imaging system using fewer pixels. The image capture equipment consists of this camera, with 8000 effective scan lines, and a lens array composed of 400 lenses horizontally and 250 lenses vertically.

For the display device, we constructed a projector with an effective resolution of 8000 effective scan lines using three 33-megapixel reflective liquid crystal panels and the complementary field-offset method. With the complementary field-offset method, the green signals are displayed diagonally offset from each other by half a pixel on even and odd fields. The display equipment consists of this 8000 scan-line equivalent resolution projector and a lens array composed of 400 lenses horizontally and 250 lenses vertically.

We conducted experiments to evaluate the resolution of 3D images using this prototype equipment and were able to show that by using the pixel-offset method we have eliminated aliasing that was produced by the full-resolution SHV video equipment. As a result, we confirmed that the new prototype is able to generate 3D images with a depth range approximately twice that of Integral 3D television using the full-resolution SHV.

8167A-33, Session 9

Optical designing method to shorten the nearest object distance and its application for head-mount 3D display

S. Hase, M. Shibuya, K. Maehara, M. Oka, S. Nakadate, Tokyo Polytechnic Univ. (Japan)

When the object distance is changed, intrinsic aberration is fundamentally caused. Therefore the nearest object distance is finite. In order to overcome this phenomenon, one can apply the inner focus system. However since this method is complicated, this cannot be applied to small camera installed on cellular phone.

Therefore we have theoretically developed a novel method without using inner focus system. First, we have confirmed that the main important aberration is image curvature. Also the coma aberration has a little effect and aspherical aberration has little effect. Since we obtain the image on solid state sensor, image distortion can be easily corrected by computer. Second, by considering the focusing of small pencil of ray both on axis and on off-axes points and comparing them, we have derive the condition which make the caused image curvature small. We have found out that by introducing the proper distortion the caused image curvature will be suppressed. Also we have confirmed this condition from the viewpoint of 3-rd order aberration theory. Third, by applying the 3-rd order aberration theory, we have derived the condition which suppresses the coma aberration caused by the change of image distance. We have found out this aberration will be suppressed by using curved image. We also explain this condition intuitively.

In addition, we confirm our proposed condition by practical lens designing. Also in order to obtain natural 3-D, we applied this method to 3-D display system using head mount display. Our proposed will be useful for small optics like the camera installed on cellular phone.

8167A-78, Session 9

Designing with Phi-polynomial surfaces

K. H. Fuerschbach, Univ. of Rochester (United States)

No abstract available

8167A-48, Poster Session

A new software tool is developed to evaluate the measured/simulated transmission characteristics of optical multilexers/demultiplexers

D. Seyringer, P. Schmid, Fachhochschule Vorarlberg (Austria)

A new software tool to evaluate the simulated/measured transmission characteristics of optical multiplexers/demultiplexers based on arrayed waveguide gratings (AWG) is presented. The reason for this work is the fact that when defining the performance of an AWG and also determining its suitability for a particular application, a set of parameters (so called AWG transmission parameters) must be considered [1]. These parameters are extracted by analyzing AWG transmission characteristics - the simulated/measured AWG spectral response for both the transverse electric (TE) and the transverse magnetic (TM) polarization states. While the measurement method adhered by most AWG vendors is the deployment of Mueller Matrix method [2] the way that vendors specify the performance of a device from the measured curves differs widely. Additionally to this, it is also important to note that the output from all commercially available AWG design tools is the simulated transmission characteristics only and none of them supports the AWG parameter calculation.

In our new developed software tool (“AWG analyser”) the input for the calculation is the simulated/measured optical transmission characteristics of AWG. The output of the calculation is a set of the transmission parameters like: non-uniformity, adjacent crosstalk, non-adjacent crosstalk, background crosstalk, insertion loss, Polarisation Dependent Loss (PDL), etc. calculated for each output channel first and then for the whole AWG - the worst-case value of each parameter over all the output channels. This set of parameters is then taken as the AWG specification. All parameters are calculated for a particular Channel Bandwidth (also known as the Channel Passband or ITU Passband), that is also an input parameter for the calculations. Additionally, the developed software tool, having a user friendly interface, offers the help where all calculated transmission parameters are explained and exactly defined. The tool also includes a brief overview about AWG functionality with a small animation and the information about various AWG types (CWDM and DWDM AWGs, Colourless AWGs).

[1] A. Rahman: “AWG parameters definition and discussion”, http://home.comcast.net/~dwdm2/awg_characterization.html

[2] W. A. Shurcliff, “Polarized Light: Production and Use,” Harvard University Press, Cambridge, MA, 1966; Dennis Derickson, “Fiber Optic Test and Measurement,” Prentice Hall, Upper Saddle River, NJ, 1998.

8167A-49, Poster Session

An all-spheric unobstructed optical terminal for free-space quantum communication

C. Pernechele, Istituto Nazionale di Astrofisica (Italy); F. Tamburini, Univ. degli Studi di Padova (Italy); T. Jennewein, Univ. of Waterloo (Canada); A. Zeilinger, Univ. Wien (Austria)

We design and built a novel optical terminal specifically designed for free-space communication operating at light levels at the quantum limit, such as in quantum communication. Our system is particularly well suited for this task, as it is based on an all-spheric catadioptric design, which allows for large and un-obstructed apertures. This design offers an easier and cheaper approach to building high-quality optical terminals with large apertures than schemes based on off-axis parabolic mirrors. We utilized an off-axis version of the original Schwarzschild concentric design, and correct the spherical aberration by substituting the original on-axis secondary spherical mirror with an off-axis catadioptric secondary mirror. A prototype of the optical terminal was realized and tested and it meet the expected performance.

8167A-50, Poster Session

Compact holographic optical interconnections using nematic liquid crystal spatial light modulators

T. Lu, N. Collings, Univ. of Cambridge (United Kingdom)

In a fibre-optic communication network, the wavelength-division multiplexing (WDM) technique enables an expansion of the data-carrying capacity of optical fibres. This can be achieved by transmitting different channels on a single fibre, with each channel modulating a different wavelength. In order to access and manipulate these signals at a node of the network, a compact holographic optical add-drop multiplexer is modelled, designed, and constructed in this project.

The structure of such a multiplexer consists in a series of optical components which are used to collimate the beam from the input, demultiplex each individual wavelength into separated channels, manipulate the separated channels, and reshape the beam to the output. A gradient-index (GRIN) lens controls diffraction in the system as well as eliminating the aberrations caused by a traditional spherical lens. A GRIN lens is used to collimate the diverging input beam from a single mode fibre. The beam is then incident on a high-dispersion diffraction grating, where the individual wavelengths are angularly demultiplexed.

A spatial light modulator (SLM) is a crucial system component, offering control and flexibility at the signal manipulation stage, and providing the ability to redirect light into thedesired output fibre. This is achieved by the use of a 2-D analogue phase computer generated hologram (CGH) based on liquid crystal on silicon (LCOS) technology. Future work will be done to reduce the crosstalk and improve the steering efficiency of the optical system.

8167A-51, Poster Session

The study of toxic and hazardous gas(Methane)effects on human life through monitoring with chirped fiber Bragg grating

J. Singh, A. Khare, Univ. Institute of Technology, RGPV (India)

Since global warming is the phenomenon of increasing temperature on earth due to heat generated by the green house gases includes methane and carbon dia oxide etc.. The excessive quantity of green house gases negatively affects the temperature of earth. Too many gases will trap excessive heat and the climate will increase respectively. Sensitive crops will be damaged and in turn there will be less food to support life.Through the help of Optical fiber Bragg grating based gas sensor we can monitor the exact value of gas concentration.The design gas sensor will worked on the algorithm of Chirped Optical Fiber Bragg Grating.We will develop this algorithm through the simulation software MATLAB.

Out of many hazardous gases, we are focusing only to methane because it is a major cause of global warming as it can produce heat when it reacts with oxygen. The presence of Methane in the Earth’s atmosphere in 1998 was 1745 parts per billion (ppb), which had stayed mostly flat upto 2008 and had risen to 1,800 ppb.By 2010Properties of methane are as follows:-

1. Methane is a colorless, odorless and highly toxic gas in nature.

2. At room temperature, it is a gas less dense than air

3.It melts at -183°C and boils at -164°C.

4. It is not very soluble in water.

5. Its Methane is combustible, and mixtures of about 5 to 15 percent in air are explosive.

6. Methane is not toxic when inhaled, but it can produce suffocation by reducing the concentration of oxygen inhaled.

7. When methane react with oxygen in environment, it generate the heat and increase the temperature

$CH_4(g) + 2\,O_2(g) \rightarrow CO_2(g) + 2\,H_2O(l)$ + 891 kJ/mol

Due to combustion, CO_2 generate and oxygen depletes. which causes suffocation to living being. If the concentration of methane increases in such a manner then temperature of environment rises and deficiency of oxygen occurs.

8167A-52, Poster Session

The optimization design of broadband mid-IR grating

S. Fan, L. Bai, Xi’an Jiaotong Univ. (China)

The broadband mid-IR grating is required in the infrared spectrophotometer to keep the instrument compact. In this paper the optimization design of a type of broadband grating is studied by the rigorous diffraction grating electromagnetic theory. As a differential vector method, the rigorous coupled wave analysis (RCWA) has been widely used for the analysis and the design of diffractive structures. In this paper, firstly, the diffraction efficiency properties of the traditional broadband dual-blaze grating were analyzed by RCWA. Then a simple structure grating with broadband spectrum can be obtained to the dual-blaze grating. It is interesting that the designed grating only had one blazed angle which is more easily to made compared to dual-blaze grating. The optimization grating structure parameters were given. According to our design example of broadband, mid-IR metal grating, the grating with grating period 10.0μm and blazed angle 22 can obtain more than 80% diffraction efficiency within the whole broadest spectrum 8 18μm. The optimization design result demonstrates this simple structure grating is with broadband spectrum and more easily to produce than the dual-blaze gratings.

8167A-53, Poster Session

Experimental validation of opto-thermo-elastic modelling in Oofelie MultiPhysics

A. Mazzoli, Univ. de Liège (Belgium); P. Saint-Georges, Open Engineering S.A. (Belgium); A. Orban, Univ. de Liège (Belgium); J. Ruess, GDTech S.A. (Belgium); C. Barbier, Y. Stockman, M. Georges, Univ. de Liège (Belgium); P. Nachtergaele, S. Paquay, P. De Vincenzo, Open Engineering S.A. (Belgium)

The objective of this work is to demonstrate the correlation between a simple laboratory test bench case and the predictions of the Oofelie MultiPhysics software in order to deduce modelling guidelines and improvements. For that purpose two optical systems have been analysed. The first one is a spherical lens fixed in an aluminium barrel, which is the simplest structure found in an optomechanical system. In this study, material characteristics are assumed to be well known: BK7 and aluminium have been retained. Temperature variations between 0 and +60°C from ambient have been applied to the samples. The second system is a YAG laser bar heated by means of a dedicated oven.

For the two test benches thermo-elastic distortions have been measured using a Fizeau interferometer. This sensor measures wavefront error in the range of 20 nm to 1 µm without physical contact with the optomechanical system. For the YAG bar birefringence and polarization measurements have also been performed using a polarimetric bench.

The tests results have been compared to the predictions obtained by Oofelie MultiPhysics which is a multiphysics toolkit treating coupled problems of optics, mechanics, thermal physics, electricity, electromagnetism, acoustics and hydrodynamics. From this comparison modelling guidelines have been issued with the aim of improving the accuracy of computed thermo-elastic distortions and their impact on the optical performances.

8167A-54, Poster Session

The alignment of the optical corrector for DECam

M. L. Antonik, Univ. College London (United Kingdom); J. L. Bailey, Argonne National Lab. (United States); R. A. Bernstein, Lick Observatory (United States); D. Brooks, Univ. College London (United Kingdom); D. L. DePoy, Texas A&M Univ. (United States); P. Doel, Univ. College London (United Kingdom); B. L. Flaugher, G. Gutierrez, A. Stefanik, Fermi National Accelerator Lab. (United States); S. P. Worswick, Optical Design Consultant (United Kingdom)

The Dark Energy Survey (DES) will image 5000 square degrees of sky in five photometric bands and aims determine the dark energy equation of state parameter to better than 5%. A new wide-field camera for the survey, the Dark Energy Camera (DECam), is in the final construction stage. The optical corrector contains five lenses ranging in diameter from 0.54 to 0.98 meters, held to tight tolerance limits to meet the scientific requirements. This paper describes the process used to align the large lenses as well as reporting the alignment precision achieved.

8167A-56, Poster Session

Novel optimized spatial filter collimator for laser indicators and range finders

J. Chen, Chung-Hua Univ. (Taiwan)

A novel and optimized spatial filter collimator is developed for the laser indication and laser range finding application. The commercial available mass produced, inexpensive, red and blue semiconductor laser modular can easily be optimized as fine line laser indicator source as well as high accuracy cross line target indicating laser ranger finder transmitter source. We have theoretically investigated the results, simulated the designs, measure the laser beam spots and the laser fine lines. The spatial filter collimator has been designed and optimized for practical used and the results are very satisfactory.

8167A-57, Poster Session

Active optics: vase form multimode deformable mirror for in-flight aberrations correction

M. Laslandes, M. Ferrari, E. Hugot, G. R. Lemaître, Observatoire Astronomique de Marseille-Provence (France)

Vase form Multimode Deformable Mirrors have been developed by observing a similarity between the Clebsch-Jordan polynomials, describing the deformation of a circular plate, and the Zernike polynomials, describing the wave-fronts. It is used to correct off-axis aberrations with a limited number of actuators. In this paper, we present the possibility to insert this kind of correcting active system in the next generation of space instruments. Indeed, the need for both high quality images and light structures is a constant concern in the conception of space telescopes. But, having lightweight primary mirrors, space telescopes will be sensitive to the environment variations (thermal dilatation and weightless conditions in space with respect to the AIT conditions on ground), inducing optical aberrations in the instrument.

We highlight here the steps in the active Deformable Mirror design: a Finite Element Analysis is performed to characterize the system. The geometrical characteristics are optimized not only to correct the first Zernike polynomials with a high precision but also to suit flight constraints (weight, volume, power consumption and mechanical strength). The key element is the use of the system’s influence functions (deformations resulting to the unit command on one actuator): the decomposition of phase maps on this characteristic base allows the determination of the mirror correction capacity. With this method, we have computed the expected precision of correction for the optical aberrations expected in a telescope: a Vase form Multimode

Deformable Mirror is an efficient active correcting system.

To finish, we will present the test bench designed in order to demonstrate the equipped mirror performances and to validate such a concept.

8167A-58, Poster Session

Telescope for lidar system implementing holographic optical elements

O. Asmolova, P. A. Molchanov, Ampac Inc. (United States)

The purpose of the current research is to fabricate telescope for LIDAR receiver with specific parameters such as bandwidth, angular selectivity, off-band rejection, implementing holographic techniques. Fabricated holographic filter also works as a mirror of special shape, allowing to use it instead of secondary mirror in telescope without any prior beam manipulation. The bandwidth of holographic filter is several nanometers and diffraction efficiency is up to 90 %. Using this filter in telescope makes it more simple, lightweight, low cost.

For testing and analysis there are several arrays of single and multiplexed reflection holograms were recorded on a single layer of holographic materials using different setups and development regimes. The characterization and comparison of all fabricated elements has been done.

8167A-59, Poster Session

Athermalization of catadioptric infrared camera under uniform thermal distribution

R. Khoei, Islamic Azad Univ. (Iran, Islamic Republic of)

Optical systems are designed, optimized and fabricated under normal enviromental circumistances, 20 degrees and 1 Atm. peressure. But, there is no guarantee that normal circumistances are stable in all enviroments and the temperature will chang in any operationa session. It leads to change in index of refraction for optical componetnts which in result, changes the whole system focal length. A defocus aberration will happen.It is obvious that such effect is harmful for system operational goals.

To avoid such effects,optical designer should aethermalize optical system.In this process, the effect of temperature change on optical components and mechanical parts of the system is studied. Then, by choosing proper optical materials and suitable materials for mechanical parts, the system will be athermalized. It is athermalized, because length increase for one mechanical part, must be neutralized by length decrease for another mechanical part.

In this paper,a ctadioptric infrared camera is used for athermalization process.Using optomechanical format of the system, we know the material of all lenses used in design and dimensions of mounts,holders and other mechanical parts. choosing suitable the material for mounts, the system will be athermalized.

Temperature change is not only changes the material index, but also affects the radiuses of the optical components. Thus, the component characteristics change is also very important and should be considere.

After starting analysis, we cameo conclusion that changing the radiuses and distances between mirrors, has the worst effect on image quality.By results from calculation, we could choose the material for mirrors and the holder of two mirrors.

Also we concluded that the distance change between lenses is not very effective onimage quality.

By optomechanical analysis, we chose the material for detector holder and the form of the mounts for lens junction to primary mirror.

By this method, the optical system is athermalized for long temperature range from -40 degrees to +60 degrees under uniform thermal distribution.

8167A-60, Poster Session

The research of optical window used in aircraft sensor systems

L. Yan, Z. Feng, Beijing Institute of Space Mechanics and Electricity (China)

The optical windows using in aircraft protect optical systems from the environmental effects. The sensor is placed behind an optical window through which it views the scene. Considering the requirement of imaging quality, the flat surface type is used in the conventional optical windows. For aircraft operating at high speeds, the optical windows should be relatively aerodynamic, but the flat optical windows may introduce unacceptably high drag to the vehicles. When a flat optical window is at front of a scanning infrared sensor and vertical to the optical axis, the narcissus effect is serious. Some optical windows with aspherical shape may introduce relatively less drag in the airflow, but the aspherical optical windows may introduce wavefront aberrations which affect the imaging performance. In this paper, the properties including the aerodynamic performance, the wavefront aberrations and the narcissus effect of a flat optical window and an aspherical optical window that are using at front of a scanning IR optical system are researched and compared. The optical windows with torus surfaces type are demonstrated suitable for use in sensor system of high-speed aircraft. The regular wavefront aberrations introduced by the torus optical window can be compensated by an optical corrector placed between the optical window and the sensor.

8167A-62, Poster Session

Optical characterization of proton irradiated diamond

A. Sytchkova, ENEA (Italy); S. Lagomarsino, Univ. degli Studi di Firenze (Italy) and Istituto Nazionale di Fisica Nucleare di Firenze (Italy); M. M. Vannoni, Istituto Nazionale di Ottica (Italy); S. Calusi, Univ. degli Studi di Firenze (Italy); P. Olivero, Univ. degli Studi di Torino (Italy) and Istituto Nazionale di Fisica Nucleare di Torino (Italy)

The manufacturing of miniaturized photonic devices based on diamond technology is possible by implanting the pristine material with highly energetic particles. Theoretically the optical constants of irradiated material may vary from the values typical for pristine diamond to those of graphite, however only precise knowledge of the optical constants allows calculation of performance of the novel photonic micro- and nano-devices like e.g. diamond-based waveguiding structures.

The geometry of the damaged zones represents the principal obstacle for their characterization. Their lateral dimensions, in fact, render hardly possible implementation of commercial spectrophotometers, while on the other hand an adequate modeling is necessary to describe variation of optical constants within the specimen depth. The refractive index of proton-implanted zones in CVD-grown diamond have been estimated recently at 632.8 nm from interferometric measurements of optical path difference (OPD) and a model has been developed for description of the in-depth damaged material as a stack of stratified media composing an inhomogeneity profile. Here we further develop the argument and report on the spectral characterization of the optical constants of proton-damaged diamond. Absorption of the irradiated zones was estimated in the UV-vis-NIR from direct transmittance measurement using a dedicated setup with enhanced spatial resolution. The OPD data providing an estimation of the thickness of the damaged area and its depth profile, have allowed then evaluation of the extinction coefficient from the transmission measurements. Simultaneous variation of dispersive optical constants makes the modeling significantly more complicated compared to the above cited monochromatic study.

8167A-64, Poster Session

Monochromatic and chromatic aberrations of thin refractive variable-focus lens

A. Miks, J. Novák, P. Novak, Czech Technical Univ. in Prague

(Czech Republic)

Conventional lenses made from optical glass or plastics have fixed optical parameters that depend on the index of refraction and geometrical parameters of the lens. Recently, several types of refractive tunable lenses with a variable focal length were developed. The advantage of these active lenses is their capability to change continuously the focal length within a certain range. Aberrations are essential factors which affect the image quality of the lens. Thus, it is important for designing optical systems composed of tunable-focus lenses to analyze paraxial imaging properties and aberrations of such lenses. We present a possible theoretical approach for the calculation of fundamental paraxial properties and the analysis of the third order monochromatic and chromatic aberrations of thin refractive liquid lenses with a variable focal length. We perform a detailed theoretical description of lenses composed of two immiscible liquids with an interface of a variable curvature. A detailed theoretical analysis is performed for a simple variable-focus lens and formulas are derived for an optical design of such lenses. Aberration coefficients of the third order of the variable-focus lens can be completely characterized by three parameters which depend only on refractive indices of fluids forming the variable-focus lens. The calculations are provided for Varioptic lens Arctic-416. Potential applications for a primary optical design of modern liquid lens-based optical systems are emphasized. The provided analysis may serve for understanding aberration and imaging properties of the refractive tunable-focus lenses and for the initial design of non-conventional optical systems using refractive tunable-focus lenses, whose parameters can be used for their further optimization using optical design software.

8167A-65, Poster Session

The thermal baffling of SPHERE IFS

R. G. Gratton, R. U. Claudi, E. Giro, U. Anselmi, D. Mesa, L. Lessio, INAF - Osservatorio Astronomico di Padova (Italy); V. De Caprio, E. Mattaini, S. Incorvaia, E. Santambrogio, INAF-IASF Milano (Italy); S. Scuderi, INAF - Osservatorio Astrofisico di Catania (Italy); J. L. Beuzit, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); K. Dohlen, Lab. d'Astrophysique de Marseille (France); P. Puget, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); J. L. Lizon, R. J. Dorn, M. Kasper, European Southern Observatory (Germany)

IFS is one of the scientific ouptuts of SPHERE, the new high contrast imager for the ESO VLT telescope. IFS is an integral field spectrograph for the near IR (up to 1.65 micron), using an Hawaii II detector. To simplify opto-mechanical design, IFS has no cold pupil. To reduce thermal background, a cold filter fabricated by JDSU has been placed about 30 mm in fron of the detector. This filter allows to reduce thermal background by more than a factor 1e4. We describe the design and implementation of the baffling required for proper use of this system: this includes a combination of a cold and a warm baffles, and appropriate choices of the coatings of the surfaces. We present the laboratory results obtained, which show that this system allows to reduce thermal background below 10 e-/s/pixels in the SPHERE working conditions.

8167A-66, Poster Session

The S4I prototype: a beam-slicer dedicated to the new-generation multichannel subtractive double pass for EST imaging spectropolarimetry

F. N. Sayède, P. Mein, J. Amans, J. Moity, Observatoire de Paris à Meudon (France)

For the future European Solar Telescope (EST) the Observatoire de Paris proposes a new generation of MSDP: an imaging spectro-polarimetry instrument. To validate this new generation, we develop a beam slicer prototype that will be tested and validated on an optical bench and on existing telescopes.

The prototype called S4I (Spectral Sampling with Slicer for Solar Instrumentation) is under construction and test at the Observatoire de Paris. It validates the opto-mechanical feasibility of the new beam slicer. After a complete description of the system, we evaluate the performances of the prototype and compare them to the requirements for the beam-slicer dedicated to the future EST.

8167A-67, Poster Session

Optical design and test of the BIGRE-based IFS of SPHERE

R. U. Claudi, E. Giro, U. Anselmi, J. Antichi, R. G. Gratton, S. Desidera, INAF - Osservatorio Astronomico di Padova (Italy); V. De Caprio, INAF - IASF Milano (Italy); L. Lessio, INAF - Osservatorio Astronomico di Padova (Italy); S. Scuderi, P. Bruno, INAF - Osservatorio Astrofisico di Catania (Italy); D. Fantinel, B. Salasnich, INAF - Osservatorio Astronomico di Padova (Italy); E. Cascone, INAF - Osservatorio Astronomico di Capodimonte (Italy); J. L. Beuzit, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); K. Dohlen, Lab. d'Astrophysique de Marseille (France); P. Puget, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); M. Kasper, European Southern Observatory (Germany)

During the last months IFS, is the Integral Field Spectrograph for SPHERE, devoted to the search of exoplanets has been integrated in the clean room of Padova Observatory. The design of IFS is based on a new concept of double microlens array sampling the focal plane. This device named BIGRE consists of a system made of two microlens arrays with different focal lengths and thickness equal to the sum of them and precisely aligned each other. Moreover a mask has been deposited on the first array to produce a field stop for each lenslet. After a previous prototipization of the BIGRE in the visible range, now the first measurements of the performances of the device in the IR range has been obtained on the instrument that will be mounted at the VLT telescope. These tests confirmed that specifications and properties of the prototype are met by state of the art on optics microlens manufacturing.

8167A-68, Poster Session

A compact and portable catadioptric telescope with all spherical optics

R. Sperotto, Quasar di Sperotto & Dal Grande srl (Italy); C. Pernechele, S. Poppi, INAF - Osservatorio Astronomico di Cagliari (Italy)

A dismountable and portable telescope with a primary mirror of 250 mm in diameter and a numerical aperture of 5.6, is presented. The telescope has a all-spheric catadioptric optical design, consisting of a spherical primary and a group of spherical lenses, where the last surface is aluminized, as a secondary mirror.

The group of lenses corrects all the optical aberrations, including the spherical introduced by the primary and the chromatic ones. The telescope has a very compact design, with a physical length of 600mm. This fact, joint with the all- spherical design, make it a ligth portable and easy to align instrument: when dismounted it can be contained in a suitcase sizing 580x440x140 mm and the spherical surface for all the mirrors and lenses makes easy the final alignment of the optical train.

We discuss here in detail the optical design and the realized prototype and will show the results, both in terms of theoretical and effective performances.

8167A-69, Poster Session

Ghost images determination for the stereoscopic imaging channel of SIMBIOSYS for the BepiColombo ESA Mssion

V. Da Deppo, Consiglio Nazionale delle Ricerche (Italy); G. Cremonese, INAF - Osservatorio Astronomico di Padova (Italy); G. Naletto, Univ. degli Studi di Padova (Italy)

BepiColombo is the fifth cornerstone mission of the European Space Agency (ESA) foreseen to be launched in August 2014 with the aim of studying in great detail the Mercury planet.

One of the BepiColombo instruments is the STereoscopic imaging Channel (STC), which is part of the Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem (SIMBIOSYS) suite: an integrated system for imaging and spectroscopic investigation of the Mercury surface. STC is a stereo camera consisting of two sub-channels, which are looking at +/-20° from nadir direction, that share the detector and some of the optical components.

The main scientific camera objective is the 3D global mapping of the entire surface of Mercury with a scale factor of 50 m per pixel at periherm. Five different spectral bands are foreseen, a panchromatic and four intermediate bands, in the range between 410 and 930 nm.

To avoid mechanisms, the technical solution chosen for wavelength selection is the single substrate stripe-butted filter in which different glass pieces, with different transmission properties, are glue together. This peculiar choice for the filter architecture, coupled with the fact that the filter is mounted very close to the detector, creates multiple ghosts which can affect seriously the quality of the images.

The intensity and the position of the ghost images generated by each filter strip are discussed. An analysis of the ghosts impact on the imaging performance and the solution adopted to limit the degradation are presented.

8167A-70, Poster Session

Parallel hardware-oriented relaxation method for colving the inverse aim

I. V. Musiichuk, N. I. Zabolotna, Vinnytsia National Technical Univ. (Ukraine)

In the paper it is considered such perspective medical diagnosis method as optical tomography including diffuse tomography. Developed diffusion tomogram algorithms have relatively high resolution (0.5 cm), but they are not as fast as required for real time diagnosis. It is likely that the best designed systems for early detection of breast abnormalities should combine various methods of parallel measurements with promising quick measured data processing methods.

In such conditions new approach role increases, oriented on application of parallel optical-electronic computer structures conception, in which together with traditional procedures and algorithms mathematical apparatus way of input information massives (vectors or matrices) transformation and processing oriented on natural parallelism.

It is shown the necessity of development of mathematical apparatus for tomography "inverse" aim that should satisfy such modern optical tomography systems demands as algebraic image reconstruction effective parallel methods elaboration necessity for an application of optoelectronic computing system based upon quantum-dimensional structures in diffuse tomography systems.

It is also considered parallel interpretation of relaxation method, its mathematical model is shown and it is made a conclusion that suggested parallel interpretation of relaxation method has advantages over the parallel interpretation of Gauss-Jordan method because unlike it, relaxation method in its parallel interpretation ensures the independence of operation performance time and the N input matrix and vector dimensions and thus provides the best time characteristics under multiple scattering conditions.

8167A-71, Poster Session

Optimizing the APPROXv1 algorithm for coping with diffraction effects in protein-based volumetric memories

D. Trinca, S. Rajasekaran, Univ. of Connecticut (United States)

Much of the current research effort in biological nanotechnology is directed toward self-assembled monolayers and thin films, biosensors, and protein-based photonic devices. Although a number of proteins have been explored for device applications, bacteriorhodopsin has received the most attention. This protein, with its unique light-activated photocycle, nanoscale size, cyclicity (> 10^7), and natural resistance to harsh environmental conditions, provides for protein-based memories that have a comparative advantage over magnetic and optical data storage devices. In addition, bacteriorhodopsin protein memory devices exhibit increased thermal, chemical and photochromic stability, and have the advantage of being portable, radiation-hardened, waterproof, and EMP-resistant. Such devices are capable of storing large amounts of data in a small volume. However, the construction of protein-based memories has been severely limited by fundamental issues that exist with such devices, such as unwanted diffraction effects. Algorithms that maintain the number of 0's equal to the number of 1's would eliminate the diffraction effects, as discussed in previous work (Proc. of IEEE NANO 2008, pp. 397-400). One way of ensuring an equal number of 0's and 1's is to replace a 0 with 01 and a 1 with 10. However, this would reduce the available memory by a factor of 2 (which means that the utility factor would be 50% in this case). Recently, we have proposed some methods that provide utility factors of more than 50%. However, for completely random data, the best utility factor provided by previously proposed algorithms is about 99.9%, which can be obtained by using the APPROXv1 algorithm that we have recently proposed (Proc. of IEEE NANO 2010, pp. 802-805), and which works as follows. Let I be the input data, and bI the binary representation of I. Suppose that bI doesn't have an equal number of 0's and 1's. If I is of length L, then bI is of length 8L. Scan the binary string bI from left to right, bit by bit. For each position i in this scanning, 1 =(i-Zs[i]) or Zs[i] =(i-Zs[i]), then we check to see if Zs[i]-(i-Zs[i])=(NofZs-NofOs)/2. If

yes, then the scanning stops, and the output of the algorithm is xc_{1:q}bI_{q+1:8L}, where q is this current position in the scanning. Otherwise, if Zs[i]-(i-Zs[i])!=(NofZs-NofOs)/2, then the next position in the scanning is i+(NofZs-NofOs)/2-(Zs[i]-(i-Zs[i])). If Zs[i]<(i-Zs[i]), then the next position in the scanning is i+(NofZs-NofOs)/2+((i-Zs[i])-Zs[i]). Denote this improved version of APPROXv1 by APPROXv2. Results of our implementations show that APPROXv2 is significantly faster than APPROXv1.

8167A-72, Poster Session

Common path optical design for 2D inspection system with the capability of autofocusing

W. C. Wang, C. Wang, S. Kuo, L. Chang, H. Wang, Industrial Technology Research Institute (Taiwan)

This paper provided a method and system for focusing, which modulated a broadband light into a dispersive light having a higher dispersion characteristic and a lower dispersion characteristic, and the dispersion light was projected onto an object so as to form an object light. By means of the filtering and dividing procedure, a first optical spectrum of the dispersion light with respect to the higher dispersion characteristic was utilized to detect a height information of the surface profile of the object. Then, according to the height information, a second optical spectrum of the dispersion light with respect to the lower dispersion characteristic was adjusted to focus onto the object so that an imaging sensing device is capable of sensing the object light with respect to the lower dispersion characteristic, and thereby obtaining a clear and focusing image corresponding to the surface of the object.

8167A-73, Poster Session

High-range laser bandwidth tuning for focus drilling

A. Andryzhyieuskaya, J. van Keulen, T. van der Hoeff, J. J. H. M. Linders, B. Smits, M. van Veen, P. Gabolde, ASML Netherlands B.V. (Netherlands); T. Kumazaki, S. Tanaka, H. Tanaka, J. Fujimoto, Gigaphoton Inc. (Japan)

193nm ArF immersion microlithography has been used widely in high-volume manufacturing, and it is considered to be the main solution below 32nm node until extreme ultraviolet (EUV) lithography becomes ready. Laser systems are now enlarging its function and capability to meet various applications. In this paper, we report a newly developed solution for focus drilling technique applied to increase the depth of focus (DOF) for patterning contacts, vias or trenches. The laser light is stabilized at any E95 in the range from 0.3 pm to 2.5 pm, where E95 is defined as the width of the spectral range that contains 95% of the integrated spectral intensity. The high-range bandwidth is realized by introducing a newly developed line narrowing module (LNM) in the oscillator resonator. The bandwidth is measured with the on-board Fabry-Perot etalon, an E95 based bandwidth analysis module of high accuracy, and controlled by a combination of the LNM and E95 Variable Front Mirror at each side of the oscillator resonator. This technique is easy upgradable to Gigaphoton latest GT62A-1SxE with the flexible output power (60W - 90W) and stabilized spectrum (E95=0.3pm).

In comparison to another focus drilling technique where the large DoF is achieved by tilting a wafer stage during scan, the increase of the bandwidth of light source has much smaller impact on the required performance of the scanner such as productivity, overlay and critical dimension uniformity (CDU). In the paper we present the data that indicate the increases in DoF with broadening of the laser spectrum and imaging results obtained at high bandwidth.

8167A-74, Poster Session

Multiplex coding for real-time optical image processing

S. Elwardi, SUP'COM (Tunisia) and Telecom SudParis (France); B. Benkelfat, TELECOM SudParis (France); M. Zghal, SUP'COM (Tunisia)

The latest developments in optical image processing for security, compression and cryptography require parallel real time processing and multiplexing. Coherence modulation of broadband light source has found many applications in the last decade including optical communications and optical sensing. In this paper, we propose a new architecture based on the use of coherence modulation of light for real-time encoding and decoding of images which can be useful for the above-mentioned applications. The proposed technique utilizes the coherence properties of broadband sources for encoding signals onto light beams. One major asset of the architecture, compared to other conventional optical modulation methods, is an original multiplex coding of several signals through a single light beam. The proposed architecture has been theoretically and numerically investigated and validated. We achieve simultaneous real-time all optical image processing of analog two-dimensional signals. The signals to be processed are encoded by two-dimensional spatial coherence modulators (SCM's) set in cascade and illuminated by a single light beam with a short coherence length. Each SCM, which consists of a liquid crystal spatial light modulator and a birefringent plate placed between two polarizers, introduces an optical path difference (OPD) greater than the coherence length (Lc) of the light source. This OPD is determined to minimize the channel cross talk. The decoding module is formed by a birefringent plate set between two polarizers. Finally we suggest a set of new criteria, based on mean square error, signal to noise ratio and peak to peak signal to noise, to improve the quality of the decoding image as function of the optical path difference and the coherence length of the source.

8167A-75, Poster Session

A Novel Structure Design and Angle Algorithm of Imaging Polarization Sensor for Navigation

K. Zhao, Z. You, Tsinghua Univ. (China)

Navigation sensor plays a key role in exploration, emergency, precision-guided weapons, ship and aircraft navigation and satellites positioning system. The hot issues of current research of navigation technology include: optimization of single navigation sensor performance, multiple sensors information fusion, novel principle navigation sensor exploitation. The perfect navigational capabilities of some insects afford us plenty of technology reference on novel navigation sensor research. Inspired by the polarization sensitivity mechanism for navigation of desert ants (Cataglyphis), a novel imaging polarization navigation sensor system is designed. The work principle of bionic imaging polarization sensor for navigation is discussed in detail. A novel heading solution algorithm for imaging polarization navigation is designed, which implements precise navigation angle extraction by means of main polarization direction selection, polarization direction line character detection and polarization direction image center checkout. The new heading angle solution method can improve sensor polarization sensitivity, spatial solution and navigation performance robustness effectively. Based on the work principle of the new imaging polarization sensor, the prototype machine which integrates CMOS image detector and tri-tier thin film micro polarizer array is built up. Due to this function architecture design, the volume and power consumption of navigation sensor is decreased greatly, and the overall navigation performance is enhanced obviously. The imaging polarization sensor character is calibrated in the dark field and uniform non-polarization light field, and several possible sensor error causes are analyzed. Polarization grating photo response and polarization image direction detection experiment indicates the function structure design and angle algorithm of the novel polarization navigation sensor is feasible and effective.

8167A-76, Poster Session

Simulation of 3D LADAR imaging system using fast target response generation approach

A. A. Al-Temeemy, J. W. Spencer, Univ. of Liverpool (United Kingdom)

Ladar systems have unique capability to give intensity and full 3-D images of an object. These systems have many civilian and military applications. Consequently, simulations for these systems have become a valuable tool for developing LADAR systems and their recognition algorithms. In order to simulate these systems, it's required to generate the target response for each laser pulse transmitted towards its parts. This response can be generated by obtaining the intersection points of the laser rays that represent the laser beam footprint samples with the triangles faces that represent the model surface. To obtain these intersection points, the intersection point algorithms must be applied between every laser ray and all model's triangles. But in spite of the fact that this normal approach is simple and straightforward, extensive calculations are required to do it, make it very slow, especially when the model consists of a large number of triangles or when a large number of laser footprint samples are required.

To overcome on these limitations, a new approach is proposed. This approach is fast and able to deal with high scanning requirements and complex target models. This leads to a more efficient LADAR simulator and opens up the possibility for simulating more complex scenes LADAR images. The approach is to derived the target angular ranges algorithms in order to directly select the target's parts that lie in the laser field and calculate the intersection points from them, instead of checking the whole target as it's done by the normal approach. The performances of these two approaches are compared for a variety of conditions. The comparison of results shows that the proposed approach is faster than the normal when the model consist of a large number of triangles or when the laser footprint contains large number of samples.

8167A-77, Poster Session

Three-dimensional LADAR imaging system using AR-4000LV laser range-finder

A. A. Al-Temeemy, J. W. Spencer, Univ. of Liverpool (United Kingdom)

Laser Detection and Ranging (LADAR) is a three-dimensional (3-D) spatial measurement tool that used in many applications, including precision distance measurements, target detection, precise aircraft navigation, and medical applications.

The high prices for these devices make their use very limited in the research field. Therefore a new LADAR prototype system has been designed and implemented in order to make these systems more affordable and usable in this field. The cost for this system is approximately equal to 5K (GBP) and it is designed to have a high sampling rate and scanning resolution, where both the scanning field of view and the resolution are selectable by the user. The system have a large field of view and it can reach up to +=<0x100000>159o in the pan direction and <0x100000>47o to +31o in the tilt direction, and it is able to scan objects with an angular resolution of 0:0265o at a scanning speed equal to 714 angular positions per second (in both pan and tilt directions). The technical aspects of the LADAR design are presented, which include hardware components (AccuRange 4000-LV laser distance sensor and the computer controlled Pan-Tilt Unit D46-17) and both the mathematical model and the controlling software that are required for reconstructing the resultant LADAR images from the scanning measurements. The new prototype system is tested, by scanning different objects. The resultant scanning images for the this system show the effectiveness of the mathematical model for producing these images in different formats (spherical and Cartesian). The results also show that, combining both the AccuRange 4000-LV and D46-17 with specific parameters producing clear and high resolution images at minimum cost.

8167A-79, Poster Session

Design of the coronagraph with large FOV and the stray light suppressing

H. Zhang, Z. Lu, H. Liu, Changchun Institute of Optics, Fine Mechanics and Physics (China)

The coronagraph with large field of view is designed, in which, the FOV is ±20° (sun in the center), the resolution is 1.2 arc min, the aperture is 5.6 mm, the focal length is 38mm, and the total length is 1080mm. With the help of large FOV(sun in the center), the 8R -72R coronagraph can be detected when the satellite is at the 1AU; and 24R -215R at the 1AU. The stray light level requirement is better than 3×10−15, in this paper, the stray light is divided into three orders. The first order stray light is the direct solar radiation, the second order stray light is mainly including the diffractive light from the edge of entrance window, aperture stop, outer occulter, and the scattering light from object lens, the second order stray light is 10-5, the third order stray light is mainly including the diffractive light from the edge of field stop, inner occulter, and the inner reflection in the object lens, the third order stray light is 10-10. And the key technologies to suppress the three stray light orders are introduced respectively.

8167A-34, Session 10

Cryogenic lens design for astronomical and space applications

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. To explain the most advance design concept and technique, I will present a particular case study. The Gemini Planet Imager (GPI) 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 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, glass selection (cryogenic temperature model) to the final cryogenic system for both optical and mechanical design. I also discussed the assembly procedure (room temperature vs cryogenic compensation), the test support equipment and finally the laboratory optical performances over the field of view.

8167A-36, Session 10

Development status of the telescope for the Ingenio/SEOSAT mission primary payload

C. Miravet, SENER Ingeniería y Sistemas S.A. (Spain); D. Zorita, J. I. Bueno, L. Pascual, SENER Ingenería y Sistemas S.A. (Spain); A. E. Marini, European Space Research and Technology Ctr. (Netherlands)

The Ingenio/SEOSAT mission is the flagship mission for the Spanish National Space Program. Ingenio/SEOSAT is a high performance satellite for Earth Remote Sensing, designed to provide imagery for applications in land zoning, urban and rural planning, cartography, emergency support, water resources management, agriculture, environment, etc. This is a novel scenario, as for first time an industrial Spanish consortium is fully responsible of the design, development and in-orbit operation of a satellite of this characteristics.

The primary users, composed of several Spanish Governmental Organizations and Scientific Institutions, have defined the requirements of the mission, encompassing state-of-the-art image quality and radiometric performances. In order to fulfill these requirements, it has been defined a high performance instrument, facing several challenges on the design and manufacturing from the engineering point of view.

The instrument is based on two Korsh telescopes with a 55 Km swath, with a 2.5m resolution on the panchromatic channel and 10m on the multispectral channel, with a high SNR>100 on all bands, and a demanding MTF value at Nyquist frequency.

The main features of the instrument are:

- Concept based of a reflexive optics, free of chromatic aberration in the large operational spectral band (blue-NIR)
- Telescope limited by the diffraction in the complete Field of View
- Telescope designed to have very low degradation by thermo-elastic effects
- 7-stage TDI detector for the PAN band, to enhance radiometric performance
- Very high SNR in comparatively narrow spectral bands
- Very large dynamic range for dark and bright observations
- High quality MTF both in PAN and MS at level 0 in the complete field of view
- High value on the MTF * SNR parameter which assures high quality on the post-processing (de-convolution) on ground
- Distortion on the edge of the field of view lower than 2%
- Possibility of having observations on the border of very bright elements as clouds, due to the excellent stray-light rejection factor of the telescope

The article summarizes the development status of the instrument telescope, which the main components (detectors, mirrors, filters, structural elements) being currently manufactured, and integration of an Engineering Qualification Model scheduled to start in the following months.

In the article will be addressed the main challenges faced in the design of the system (optical quality, direct light and stray-light control, SNR, tight tolerances in the M1-M2 axial direction, etc) and the engineered solutions to these problems, that have to be tackled in any telescope design based on the Korsch concept. Finally, an overview of the integration and verification steps with main associated optical set-ups will be provided.

8167A-37, Session 10

Integrated optical and IR Earth albedo monitor design and laboratory performance measurement

S. Seong, S. Kim, Yonsei Univ. (Korea, Republic of); M. Lockwood, Univ. of Reading (United Kingdom)

It is well known that annual trend of Earth albedo anomaly shows clear discrepancy among observational data (e.g. CERES instrument and Big Bear Solar Observatory measurement) and the climate model prediction (e.g. Had3CM). One of the methods to clarify such discrepancy is to measure incoming solar and Earth reflected SW (Short Wave, λ<4μm) radiation simultaneously. We report a new optical and IR space instrument incorporating novel measurement concept of aforementioned solar and Earth radiations and the trial laboratory performance measurement of the technology demonstrator (i.e. "breadboard") instrument. The measurement concept is to rotate the instrument aperture while being positioned around the L1 (Lagrange 1) halo orbit so that the same instrument looks at the Sun and Earth alternately. This approach tends to remove the need for complex inter-calibration among separate measurement instruments. The proposed optical system has two observing apertures (Sun- and Earth-observation) and two sub-instruments (Energy and Visible instruments). The radiation from the target (i.e. the Sun and Earth) passing through the instrument aperture is divided into two parts. One travels to the energy instrument and the other to the visible instrument. The incoming Sun and Earth lights are attenuated by neutral density filters so that the energy and visible instrument detectors receive signals within the detector dynamic ranges. The energy channel is to measure the incident solar and Earth reflected SW radiation, producing Earth reflectance data. The Earth reflectance is derived from the irradiance ratio of Earthlight and Sunlight obtained from the energy channel detector output signals. The ratio is to be 0.3% in relative uncertainty during signal integration. The energy instrument consists of two folding mirrors, optical chopper, CPC (Compound Parabolic Concentrator), and pyroelectric detector. The folding mirrors direct incident lights from the Sun- and Earth-observing apertures towards the CPC. The rays arriving at the CPC entry aperture are modulated by the optical chopper and concentrated into the exit aperture. They are then absorbed by the pyroelectric detector element. In the mean time, the visible instrument is to support the energy instrument while ensuring that the Earth and Sun images fall within the instrument field of view (±2°) over the sufficient exposure time. The visible instrument is a modified Cassegrain system with parabolic primary and spherical secondary mirrors, and 4 correcting lenses. The breadboard instrument has sub-systems including imaging and energy optical elements, detector assembly and their support structure. The standard light source assembly was aligned together with the breadboard instrument on an optical bench for laboratory performance test. Initially, the uncertainties in the energy instrument detector output signal and in optical system radiative transfer efficiency were then measured while the light source beam power and direction remain stationary. The test results demonstrate that the optical system satisfies the measurement uncertainty requirement. The technical details of optical system design, breadboard instrument construction, laboratory performance measurement results are presented together with future performance test plan.

8167A-38, Session 11

Optical aberrations compensation with active deformable mirrors: applications to space instruments

M. Laslandes, E. Hugot, M. Ferrari, Observatoire Astronomique de Marseille-Provence (France)

Wave-front correction in optical instruments is often needed, either to compensate Optical Path Differences, off-axis aberrations or mirrors' deformations. Active optics techniques are developed to allow efficient corrections with relatively simple systems, with a deformable mirror as the key element. In this paper, we will present the conception of particular deformation systems which could be used in space telescopes and instruments in order to improve their performances while allowing the specifications relaxation on the others components.

Firstly, we will focus on the design and performances of an active mirror to compensate large lightweight primary mirrors' deformations. With 24 actuators, the system is able to correct precisely the optical aberrations expected to appear in a space telescope because of the thermal variations and the weightless conditions. The equipped active mirror presented here considers the space constraints (such as compactness, weight, reliability and mechanical behavior). Its expected performances are really encouraging for a use as a correcting element of future space telescopes. Indeed the primary mirror deformations could be compensated with a precision better than 10 nm rms.

Secondly we will introduce some optimization techniques to minimize the number of actuators in active systems. On the one hand, if the aberrations to be corrected and their evolutions are known in advance, an optimal system geometry, with only one actuator, can be determined thanks to the elasticity theory and Finite Element Analysis. On the other hand, the actuator configuration itself can be optimized: a least square minimization algorithm will allow the determination of the best actuator number and the corresponding actuator's positions to correct given phases. Both techniques require a precise knowledge of the correction needs in an instrument but they allow a significant gain in simplicity and performances.

Active optics is an efficient technique which has various applications; it can improve the optical performance of an instrument but also simplify some optical designs. The active concepts presented in this paper are developed within the framework of a space application so a significant effort is done on the systems' simplification. The deformable mirrors are designed and optimized with Finite Element Analysis which allows us to characterize the expected performances and mechanical behavior. Then the different concepts will be validated with the realization of demonstrators.

8167A-39, Session 11

Membrane photon sieve telescope

G. P. Andersen, U.S. Air Force Academy (United States)

We have developed diffractive primaries in flat membranes for ultra-large apertures (>20m) for space-based imagery. They are an attractive approach in that they are much simple to fabricate, launch and deploy compared to conventional three-dimensional optical structures. In this talk we highlight the design of a photon sieve which consists of a large number of holes in an otherwise opaque substrate. We present both theoretical and experimental results from small-scale prototypes and key solutions to issues of limited bandwidth and efficiency that have been addressed. Our current efforts are being directed towards an on-orbit 0.2m solar observatory demonstration deployed from a 3U CubeSat bus.

A photon sieve is essentially a large number of holes located according to an underlying Fresnel Zone Plate (FZP) geometry. The advantages over the FZP are that there are no support struts required which lead to diffraction spikes in the far-field and an asymmetric tensioning that can cause wrinkling of the substrate. Furthermore, with modifications in hole size and distribution we can achieve improved resolution and contrast over conventional optics. Photon sieve patterns are very simple to generate and fabricate using standard lithographic techniques.

The trade-offs in using diffractive optics for imaging are the large amounts of dispersion and decreased efficiency. Our work has led to several solutions to these limitations which will be detailed here. Also presented are studies conducted into the materials aspects in order to optimize performance and achieve a scalable solution to an on-orbit demonstrator. These include understanding the substrate flatness and uniformity requirements as well as the deployment and tensioning methods.

We have addressed these issues and present a design for a primary optic optimized for solar imaging at the H-alpha wavelength of 656nm. The deployed membrane primary and tensioning structure as well as secondary optics, filters and imaging camera are all configured to fit within half the volume of a standard 3U CubeSat (30cmx10cmx10cm). Details of the mission will be given in this talk as well as details on future directions for this technology.

8167A-40, Session 11

Design and first results of a Fourier transform imaging spectrometer in the 3-5 µm range

N. Matallah, H. Sauer, J. Taboury, P. H. Chavel, F. Goudail, Institut d'Optique Graduate School (France); J. L. Fontanella, Thales Optronique S.A. (France); Y. Ferrec, ONERA (France)

An imaging spectrometer in the 3-5 µm wavelength range is presented. This wavelength range reveals important information about scenes such as gas or landmine detection, but the amount of light is usually low and signal to noise ratio is a real issue. That is why we selected a Fourier transform (FT) spectrometry design, since such systems are known to provide a better signal to noise ratio than classical dispersive devices when detector noise dominates.

The interferometric part of the system consists in a Michelson interferometer with its mirrors replaced by twin mirrors arranged at right angles in an hollow roof, providing nearly straight fringes localised at infinity, i.e. a linear path difference variation over the interference field. Since in FT-based spectral imagers, the interferogram is acquired over the whole field of the camera while the scene of interest scans the path difference range, the radiometric response should be constant over the field. It is thus necessary to avoid any vignetting while keeping the size of the interferometer semi-reflecting plate and roof prisms as small as possible for manufacturability and cost reasons. The key point for that purpose is to put the (aerial) entrance pupil of the imaging lens inside the interferometer. This implies a customized imaging lens matching the entrance pupil and the detector cold shield and careful trade-offs between lens F number and angular field of view.

The resulting system has a spectral resolution of about 25cm-1 that fulfils the requirement for most targeted applications. Examples of absorption bands detection will be shown.

8167A-41, Session 11

Optical design of the VLT/MUSE instrument

J. Kosmalski, Observatoire de Lyon (France); L. Parès, Institut de Recherche en Astrophysique et Planétologie (France); W. Seifert, Landessternwarte Heidelberg (Germany); W. Xu, Optical System Engineering (Germany); J. Olaya, Astrophysikalisches Institut Potsdam (Germany); B. Delabre, European Southern Observatory (Germany)

MUSE (Multi Unit Spectroscopic Explorer) is a second generation VLT panoramic integral field spectrograph developed for the European Southern Observatory (ESO), operating in the visible and Near Infrared wavelength range (0.465-0.93 µm) with a 1 arcmin square FoV sampled at 0.2arcsec. It is composed of a Calibration unit, a fore-optic and splitting and relay system that feeds 24 identical Integral Field Units (IFU); each one incorporates an advanced image slicer associated with a classical spectrograph.

This article will present the optical design choices that have been done to optimize the costs, size and performances of the instrument as well as a detailed ghost images analysis of the whole instrument using ZEMAX non sequential mode and it's impact on the design.

8167A-42, Session 11

Optical architecture of the MICROCARB spectrometer

J. Loesel, C. Buil, Ctr. National d'Études Spatiales (France)

The CO2 global monitoring from space is an important concern those last years. Several projects exist to reach this goal among which the MICRCARB spectrometer from the CNES (the French Space Agency).

As planned for this project, an accurate CO2 measurement leads to an instrument with 3 different spectral bands (0.76 µm, 1.57µm and 2.05 µm), with a spectral resolution around 25000 to 30000 and a high signal to noise ratio.

The CNES as developed a patented new optical design able to reach this goal, while being sufficiently compact to fit in a microsatellite.

This article will describe this new optical architecture.

8167A-43, Session 12

Design of a hybrid-integrated MEMS scanning grating spectrometer

H. Grüger, T. Pügner, J. Knobbe, H. Schenk, Fraunhofer-Institut für Photonische Mikrosysteme (Germany)

Spectroscopy is one of the most frequently used qualitative and quantitative analyzing techniques. The near infrared (NIR) spectral region, i.e. 780nm - 2500nm, provides access to molecular transitions of organic compounds. In combination with the typical penetration depth of several millimetres, NIR spectroscopy is a very important tool for food quality sensing, water monitoring, biological and medical analysis and many other applications.

Grating spectrometers have been designed for more than 150 years in different configurations, mostly for scientific and laboratory environment. Today potential high volume applications ask for extremely miniaturized and ultra low cost systems. The availability of integrated detector arrays in combination with concave gratings led to the invention of miniaturized spectroscopic systems. For the visible range, standard CMOS based detector arrays can be used and hybrid systems with about thumb size were realized.

For the NIR range still more sophisticated detector materials are necessary that are a decisive cost factor. By a MEMS (micro electro mechanical systems) based monochromator system approach a less expensive single detector can replace the NIR detector array. The design of a hybrid integrated MEMS scanning grating spectrometer has been drawn. Several planar substrates are stacked by sophisticated mounting technologies. Is has to be considered that normally the grating plane has to be turned widely off axis to address a suitable wavelength range. For planar substrates this is not feasible, thus the placement of slits, mirrors and grating has to be adjusted to the new optical design.

Finally the optical bench will have 17mm x 12mm x 16mm size for a spectrometer working in the 950nm - 1900nm range with 9nm resolution. Grating and slits are fabricated in one single MEMS chip. This chip is mounted on a small circuit board together with the detector and than stacked with spacer and mirror substrate.

8167A-44, Session 12

Stray light measurements of immersed gratings for high resolution spectroscopy in the Near Infra-red

J. A. Fernandez-Saldivar, I. Bhatti, D. R. Lobb, Surrey Satellite Technology Ltd. (United Kingdom); B. J. Guldimann, European Space Agency (Netherlands)

New immersed grating technology is needed particularly for use in imaging spectrometers that will be used in sensing the atmosphere O2A spectral band (750nm - 775 nm) at spectral resolution in the order of 0.1 nm whilst keeping a high efficiency and low stray light.

In this work, an Ion-beam etched grating in a fused-silica substrate of 100 mm 100mm immersed on a prism of the same material is designed to obtain dispersions > 0.24°/nm-1 and 70% efficiency. The optical performance of the immersed grating is modelled and methods to measure its efficiency and scattered radiance are described.

The optical setup allows the measurement of an 80mm beam diameter to derive Bidirectional Scatter Density Function (BSDF) from the immersed grating from a minimum angle of 0.1° from the diffracted beam with angular resolution of 0.05°. This paper will describe the status of the work being undertaken in this programme.

8167A-45, Session 12

Design and development of the high-resolution spectrograph HERMES and the unique volume phase holographic gratings

J. Heijmans, Australian Astronomical Observatory (Australia)

The AAO is developing a High Efficiency and Resolution Multi Element Spectrograph, (HERMES) for the Australian Astronomical Observatory. The final design has been approved in December 2010 and current activities involve the manufacturing of the optics and the mechanics, testing of the cryogenic detectors, assembly of the fibre cable and prototyping of the VPH gratings. The spectrograph will make use of four large (500 x 200mm clear aperture) VPH gratings that have an extreme angle of 68.1 degrees to achieve a resolution of 30,000 with an efficiency of 50% minimally. A high resolution mode of 50,000 is provided by masking the entrance slit accepting a light loss of 47%.

The required high resolution demands the steep angle of diffraction of 68.1 degrees and a high line density ranging between 2400 and 3800 lines per mm. It also requires a high optical quality of both the grating and optics to create the required point spread function (PSF) on the detector. The glass substrates for the gratings are 280 x 600mm in size. The anti reflection coating has to allow for a high transmissivity of both the S and P polarization states as both polarizations are diffracted in the grating.

This grating development is pushing the VPH grating process to its limits. An overview is given on the challenges that had to be overcome and the current developments.

The HERMES spectrograph operates over between a wavelength range from 370nm up to 1000nm.

8167A-46, Session 12

MUSE splitting and relay optics: a fan-shaped bridge for 24 spectrographs

W. Xu, Optical System Engineering (Germany); H. E. Nicklas, Georg-August-Univ. Göttingen (Germany); W. Seifert, Landessternwarte Heidelberg (Germany); H. Anwand, Georg-August-Univ. Göttingen (Germany)

The Multi Unit Spectroscopic Explorer (MUSE) is a second generation instrument in development for the Very Large Telescope (VLT) of the European Southern Observatory (ESO). The MUSE splitting and relay optics splits the corresponding telescope 1'x1' adaptive optics corrected field of view into 24 sub-fields and feeds each sub-field into a spectrograph. The design and the prototype of the field splitter and separator are described in detail in this paper. The relay optics with two fold mirrors builds a 24-channel fan-shaped bridge between the sub-fields and the corresponding spectrographs. The alignment procedure is shortly described.

8167A-47, Session 12

Optical properties and thermal performance of 100-mm space telescope

K. Ahn, Yonsei Univ. (Korea, Republic of); S. Jeong, Ewha Womans Univ. (Korea, Republic of); S. Kim, Yonsei Univ. (Korea, Republic of); J. Nam, I. H. Park, Ewha Womans Univ. (Korea, Republic of)

The UFFO (Ultra-Fast Flash Observatory) pathfinder is a space instrument onboard the Lomonosov satellite scheduled to be launched in November 2011. It is designed for extremely fast observation of optical counterpart of Gamma Ray Burst (GRB). UFFO has two subsystems; i) UBAT (UFFO Burst Alert & Trigger Telescope) and ii) SMT (Slewing Mirror Telescope). This study is concerned with SMT opto-mechanical subsystem design and optical performance test. SMT is a F/11.4 Ritchey-Chretien type telescope benefited from compact design with a very short optical tube assembly for the given focal length of 1,140 mm. SMT is designed to operate over a wide range of wavelength between 200 nm and 650 nm and has 17 arcmin FOV (Field of View), providing 4arcsec in detector pixel resolution. The main detector is 256 x 256 ICCD (Intensified Charge-Coupled Device) of 22.2μm in pixel size. This SMT design offers good imaging performance including MTF of 0.77 at 22.52 /mm nyquist frequency and 2.7 μm in RMS spot radius. The SMT subsystem is to be subjected to the temperature variation ranging from -10 degrees and to +40 degrees. Using FEM thermal analysis, the design solution is to have the primary mirror (M1) supported by three Bi-pods, ensuring that the M1 RMS surface error falls below 1/30 waves in aforementioned temperature variation. The SMT structure is designed to satisfy stronger than 2 in safety factor for 60g in static gravity loading. The 1st natural frequency mode of the telescope structure was estimated as 178Hz that proves the structural stiffness sufficient to survive the launch stress. Both primary (M1) and secondary (M2) mirror are hyperbolic surfaces and were manufactured within 1/50 waves (He-Ne, 632.8nm) in RMS surface error. After completion of the initial integration, the SMT opto-mechanical subsystem reached to the system wavefront error better than 1/10 waves in room temperature. We then tested the optical performance under thermal cycling and vibration. In this study, we report the SMT subsystem design solution and integration together with thermal and vibration test results.

Conference 8167B: Detectors and Associated Signal Processing IV

SPIE Optical Systems Design

Monday 5 September 2011

Part of Proceedings of SPIE Vol. 8167B Detectors and Associated Signal Processing IV

8167B-80, Session 13

Improvements in NDIR multiple gas monitoring within the same gas chamber

J. C. Martinez-Anton, M. Silva Lopez, Univ. Complutense de Madrid (Spain)

Non-dispersive infrared (NDIR) is a well known technique for gas concentration monitoring. Lead salt photoconductors and thermopile detectors are typically used. Together with gas filter correlation (GFC) they are the basis for a reference standard in environmental gas monitoring like carbon monoxide determination and other gas species. To increase gas sensitivity, a multi-pass optical cavity is often used. In this contribution we re-analyze the limits and possibilities of this technique under the frame of recent commercial developments in infrared detector and emitter technologies. More relevant, we propose some improvements in optical and radiometric design and explore its final performance, especially for the simultaneous determination of the concentration of multiple gases within the same optical cavity.

8167B-81, Session 13

DUVEX a versatile EUV-X detector

A. Jean-Michel, K. Le Guen, P. Jonnard, Univ. Pierre et Marie Curie (France); Y. Menesguen, Ctr. National de la Recherche Scientifique (France)

Efficient photon counting system at relatively low-cost remains a challenging problem in the soft-x-ray and extreme UV domains. Indeed because of window absorption, standard x-ray Geiger-Muller counters are unefficient and other systems such as Si diodes or channeltrons suffer from parasitic influences such as visible light or electrons coming from the radiation sources. To try to overcome these difficulties, a detector system, called DUVEX, has been developed for the soft-x-ray and E-UV domain. It consists in a YAG:Ce scintillator coupled to a photomultiplier module working under vacuum in counting mode. The design and the performances of this detector (response, noise, stability and efficiency) are reported. Spectra in the soft x-ray range of different elements (W, Ag, Al, Mg, Cu, N, C, B) obtained in WDS mode using this detector are presented. DUVEX appears as a competitive detection tool in terms of cost and easiness of implementation.

8167B-82, Session 13

A multispectral, high-speed, low-cost, single-element detector in the UV-MWIR spectral range

T. Svensson, R. Lindell, Swedish Defence Research Agency (Sweden)

This paper presents the design and performance of a multispectral, high-speed, low-cost, single element detector device. It is composed of six separate single element detectors covering the spectral range from UV to MWIR. Due to the wide spectral ranges of the detectors, these are used in conjunction with spectral filters.

The device is a tool to spectrally and temporally dissolve large field of view angularly integrated signatures from very fast events and get a total amplitude measure. It has been used to determine the maximal amplitude signal in muzzle flashes. Since the pulse width of a muzzle flash is in the rising order of 1 ms, a sensor with a frame rate significantly higher than 1000 Hz is needed to dissolve the flash. This is beyond the frame rate of an infrared imaging sensor. Examples from experimental trials are given.

8167B-83, Session 13

A new design of the laser range finding system using the synchronized single photon counting (SSPC) method

M. Lee, S. Baeg, Korea Institute of Industrial Technology (Korea, Republic of); J. Jang, Gwangju Institute of Science and Technology (Korea, Republic of)

Range measurement method with a high resolution and accuracy for the FPA (Focal Plane Array) is the most important element to determine the whole system structure to sense the unknown target information from remote places accurately. There are many existing optical ranging measurement methods based on pulsed TOF(Time Of Fight), interferometry and triangulation.

However, these are not proper to use in FPA, which a few tens of pixels. Especially, in case of pulsed TOF FPA, we cannot integrate the TDCs(Time to Digital Convertor) in every pixel. Moreover, these method have limitations for requirements such as a few cm of accuracy, cm or less resolution, a few hundreds of distance range, lots of data points per sec, simple architecture and miniaturization for applications of manufacturing, 3D motion imaging and autonomous navigation. The proposed method in this thesis is using a single photon detector built-in the single photon avalanche diode (SPAD) operated in Geiger mode, quenching circuit and thermoelectric cooler.

It features the maximum count rate (20MHz), dead time (50ns), photon detection probability (22% at 660nm), timing resolution(60ps), dark count rate (< 1cps) and output pulse width (10ns). The continuous wave modulation laser is utilized for active illumination source, which characterizes such as the 660nm wavelength, up to 50mW power, 50MHz bandwidth (-3dB point) and illumination field of view(2 degree). This algorithm based on statistically synchronized photon counting with 4-Tap (C0,C1,C2,C3) or more taps which is originated from lock-in-pixels CCD in SR series 3D CAMERA(MESA) is possible to calculate using the DFT (Discrete Fourier Transform) on the phase difference between emitted and incident sinusoidal illumination wave from the target. The period is divided into a number of 2(n+2) taps (n: zero +integer) which is in time domain region. To put it shortly, it can be statistically demodulates the phase difference using photon counted taps in synch with emitted CW laser signal. In this thesis, we will designate it as the “Synchronized Single Photon Counting (SSPC) method”. Range finding performance is approved with prototype of SSPC LRF. The SSPC system is theoretically and experimentally demonstrated within 7.5m and tested using the white target. Experimental results well shows that the maximum mean nonlinearity error (μError) is 2.58cm within 7.5m and 1δ repeatability error is 3.09cm at 2m with average of 2500 measurements during the integration time of 2ms. We focused on theoretical analysis of ranging performance dependent on SSPC systemic parameters such as harmonic distortion, optical power budget, photon counting rate, external noise source and so on. In conclusion, the proposed SSPC laser range finder features the fully digital with simple architecture, cost effective (Needless Time to Digital Convertor) and high sensitive. Most of all, we think this method can be effectively used for readout circuits for the FPA of Geiger-Mode APDs to demodulate a continuous wave. Therefore, the pixel-level high speed processing can be realized without any TDC. As a final result of this research, the demodulation method based on the SSPC could be a one of core algorithm in 3D imaging camera in the near future.

8167B-84, Session 13

Velocity and size estimation of nanoparticles down to 75nm with nano-LDA

L. Vámos, Research Institute for Solid State Physics and Optics (Hungary); P. Jani, Reserach Institute for Solid State Physics and Optics (Hungary)

Laser Doppler anemometry offers a non-intrusive in-situ flow

measurement method, that's why it is commonly used both in scientific and industrial environments, especially in extreme conditions. Compared to the commercial LDA systems Nano-LDA device was developed for simultaneous flow measurement, particle counting and sizing down to the nanometer size range. The high detection sensitivity of Nano-LDA is reached by high numerical aperture collecting optics, increased illumination power density and applying single photon avalanche diodes. The FPGA controlled data acquisition system records the single count events with 10ns accuracy and transfer the time series of single count events to a PC. This single photon-by-photon detection requires photon correlation technique and special techniques for particle counting (burst selecting) and individual burst signal processing. The model-based algorithms help the burst selecting in case of nanoparticles with low signal-to-noise ratio, simplifies the calibration process and refines the sizing based on amplitude technique. Three changeable neutral density filters assures ca. 11 order of magnitude dynamic range of the photon rate in counts per second. It means a wide dynamic range from 1micron down to about 50nm.

The velocity and size estimator algorithms were tested on simulated raw data earlier. In this paper verifying measurements are performed with Palas 2.0 iP aerosol generator and differential mobility analyzer down to 75nm paraffin particles, which is in accord with the lower size limit of the generator. The velocity is calculated from the power spectral density function generated by the fast Fourier transform of the autocorrelation function. In case of individual particle velocity estimations the low SNR signal requires special prepare of the autocorrelation function such as unfolding, zero padding and windowing. The parabolic interpolation of the power spectral density first maximum results refined velocity estimation. A detailed discussion is shown for the role of the different techniques in velocity estimation.

The amplitude technique in the particle sizing requires a calibration process to determine the intensity loss of the system. The model-based algorithm supports the calibration by the complete simulation of the measurement process and light scattering. By this way a single calibration measurement for one kind of monodisperse particles can be enough. The model-based algorithm is tested by measurements with monodisperse particles of different sizes set by the DMA.

8167B-85, Session 13

Multispectral MCT detectors for THz/sub-THz region

F. F. Sizov, V. Zabudsky, Z. Tsybrii, V. Lashkaryov Institute of Semiconductor Physics (Ukraine); N. Mikhailov, V. Varavin, A.V. Rzhanov Institute of Semiconductor Physics (Russian Federation)

MCT is a base material for IR detectors with ultimate performance. Here bipolar narrow-gap MCT was used for creation of semiconductor THz/sub-THz bolometers. The response of MCT warm-electron bolometers was measured in 0.037-1.54 THz frequency range at T = 68-300 K. The theoretical model for the bolometer of this kind was developed in [1]. Theoretical model developed qualitatively explains the behavior of response with account of several components of output signal: Dember effect, thermoelectromotive force contribution and free carrier concentration changes. Experimental results confirm main conclusions of the model.

Another type of detector is based on embedded p-n-junction and is more sensitive in comparison with ordinary MCT bolometer. As the base material, thin (near 2 microns) p-type epitaxial layers of CdxHg1-xTe (x=0.22) grown by MBE method on GaAs substrates were used. The planar p-n-junction serve as active element of detector, the metallic contacts to n- and p-areas simultaneously play a role of receiving antenna. The voltage sensitivity dependence on bias current of p-n-structure were measured. In this kind of structures the sensitivity can be one order higher as compared with bolometric structures early developed. Their differential resistances (R ~ 10^3÷10^4 Ohm and, depending on design, in some sensitive elements up to R ~ 10^6 Ohm) depend on the applied bias but become lower and closer to the antenna impedance at a direct bias of diode I-V characteristic where a maximum output voltage is observed. The measured S/N-ratios were 0.76 mV/2.8 μV at zero bias and 18.5 mV/15 μV at 0.45 mA bias, respectively for the 1-Hz bandwidth.

1. V. Dobrovolski, F. Sizov. THz/sub-THz bolometer based on electron heating in a semiconductor waveguide," Optoelectr Rev 18, 250-258 (2010).

8167B-86, Session 14

Specifications of an analog-to-digital converter for uncooled infrared readout circuits

P. Robert, ULIS (France)

This paper presents how to specify an ADC to digitalize the analog video of the uncooled infrared readout circuit. In a first part the main features will be discussed to select the right resolution, SNR, THD and ENOB of the converter. In a second part the characteristics more specifically sensitive for an ADC integrated in the readout circuit will be presented: architecture, power consumption, electrical dynamic range, crosstalk issues. Indeed, the increasing demand for integrated functions in uncooled readout circuits leads to on-chip ADC design as interface between the internal analog core and the digital processing electronic. This IP could be seen as an inescapable link to integrate also NUC, BPR or all other processing functions on-chip). However specifying an on-chip ADC dedicated to focal plane array raises many questions about its architecture and its performance requirements. We show two architectures approaches are needed to cover the different sensor features in term of array size and frame speed. Finally we will conclude with a trade-off between external or internal approach taking into account the application of the camera, the cost and the ADC state of art.

8167B-87, Session 14

Object detection system using SPAD proximity detectors

L. Stark, The Univ. of Edinburgh (United Kingdom) and STMicroelectronics (R&D) Ltd. (United Kingdom); J. M. Raynor, STMicroelectronics (R&D) Ltd. (United Kingdom); R. K. Henderson, The Univ. of Edinburgh (United Kingdom)

This paper presents an object detection system based upon the use of multiple single photon avalanche diode (SPAD) proximity sensors operating upon the time-of-flight (ToF) principle, whereby the co-ordinates of a target object in a co-ordinate system relative to the assembly are calculated. The system is similar to a touch screen system in assembly and operation except that the lack of requirement of a physical sensing surface provides a novel advantage over touch screen systems. The sensors are controlled by FPGA-based firmware and each proximity sensor in the system measures the range from the sensor to the target object. A software algorithm is implemented to calculate the x-y co-ordinates of the target object based on the distance measurements from at least two separate sensors and the known relative positions of these sensors. Existing proximity sensors were capable of determining the distance to an object with centimetric accuracy and were modified to obtain a wide field of view in the x-y axes with low beam angle in z in order to provide a detection area as large as possible. Design and implementation of the firmware, software, electronic hardware, mechanics and optics are covered in the paper. Possible future work would include characterisation with alternative designs of proximity sensors, as this is the component which determines the highest achievable accuracy of the system.

8167B-88, Session 14

The PLATO Mission Instrument Control Unit's digital signal processing

M. Focardi, M. Pancrazzi, E. Pace, Univ. degli Studi di Firenze (Italy); R. Cosentino, Fundación Galileo Galilei - INAF (Spain); S. Pezzuto, A. Di Giorgio, Istituto di Fisica dello Spazio Interplanetario (Italy); R. Ottensamer, A. Luntzer, Univ. Wien (Austria)

PLATO is an M-class mission candidate of the European Space Agency's Science programme Cosmic Vision 2015-2025 foreseen to be launched by the end of 2018. "PLAnetary Transits and Oscillations of stars" aims to characterise exoplanetary systems by detecting planetary transits and conducting asteroseismology of their parent stars.

The instrument Control Unit (ICU) is the electronics devoted to process and compress digital data coming from 18 front-end electronics, collecting analog data from 34 FPAs hosting each one 4 CCDs. ICU will be also in charge of managing telemetry and telecommands to and from the Service Module and to collect the payload's housekeepings. This paper will discuss the ICU HW architecture and functionalities in order to illustrate the full addressing of the Mission Science requirements.

8167B-89, Session 14

The Solar Orbiter METIS Coronagraph data signal processing chain

M. Pancrazzi, M. Focardi, Univ. degli Studi di Firenze (Italy); G. Nicolini, INAF - Osservatorio Astronomico di Torino (Italy); E. Magli, Politecnico di Torino (Italy); L. Abbo, INAF - Osservatorio Astronomico di Torino (Italy); M. Romoli, Univ. degli Studi di Firenze (Italy)

METIS, the Multi Element Telescope for Imaging and Spectroscopy, is one of the instruments selected in 2009 by ESA to be part of the payload of the Solar Orbiter mission. The instrument design has been conceived to perform both multiband imaging and UV spectroscopy of the solar corona.

The two sensors of the detecting system will produce images in visible light and in two narrow UV bands, at 121.6 and 30.4 nm.

The instrument is constituted by several subunits that have to be properly controlled and syncronized in order to provide the expected performances. Moreover, the huge amount of data collected by METIS, has to be processed by the on board electronics to reduce the data volume to be delivered to ground by telemetry.

These functionalities will be realized by an on-board dedicated electronics, the Main Power and Processing Unit (MPPU).

This paper will describe the METIS data processing chain from the detectors output and the proximity electronics to the digital front-end electronics and will report the data management and processing performed by the MPPU.

8167B-90, Poster Session

Dual cavity refractive index sensor based on a photonic crystals 90° waveguide splitter

M. De Laurentis, A. Irace, G. Breglio, Univ. degli Studi di Napoli Federico II (Italy)

In this paper we present an integrated double branch Bragg Grating Fabry-Perot cavities refractive index sensor calibrated in temperature and integrated in each of the branches of a 90 waveguide splitter. The studied configuration allows to realize a very compact device with only one interrogation channel, since the monitored signals are the cavities reflected signals. The sensitive elements used are the modulation of the cavities linewidth due to temperature and refractive index change, measured by means of the cavities detuning. The appeal of such type of devices, respect to the corresponding ones in optical fibers, is the possibility to expand the configuration to create on the same chip the detector and the requested signal processing devices. The reability of the proposed configuration is related to the interrogation technique, based on the radio-frequency phase modulation of the inpinging laser ligth. This thecniques was widely demonstrated in the last years [2] [3] and initially borrowed by the cavity frequency stabilization and locking Pound-Drever-Hall methods [1].

The sensor is constituted by a 90 bends photonic crystals waveguide splitter, where the two cavities are positioned on one of the branch of the splitter so that a modulated laser ligth can inpinge and can be reflected by both the cavities. The latest are designed so that the linewidth of the one is double of the linewidth of the other cavity (γ2 2γ1). In this way choosing a suitable modulation frequency for the incoming signal (Ωmod ~ γ1) and modulation depth so that the second harmonics of the modulation signal are not suppressed (the sidebands at ±2Ωmod) we monitor on a single channel simultaneously the detuning of both cavities.

In fact, since passing through a phase modulator driven at frequency Ωmod, the incoming laser light will present a carrier at the laser frequency ν and two sidebands at frequency ν – Ωmod and ν + Ωmod, plus the second harmonics at frequency ν – 2Ωmod and ν + 2Ωmod respectively, being the modulation frequency of the order of the cavity 1 linewidth, depending on the cavity detuning the reflected sidebands at frequency Ωmod will experience a very different phase shift while at cavity resonance they are completely out of the phase. On the other hand being smaller than linewidth of the cavity 2, they will negligibly phase shifted by this cavityViceversa the harmonics at ±2Ω will experience a phase shift of +π and 1 –π by reflection on cavity 1, being enough out-side of its linewidth but will experience an appreciable phase shift by reflection on cavity 2.

In this way, demodulating the signal detected by the photodiode at frequency Ωmod we extrat information only on the detuning of the cavity 1; while demodulating the same signal at frequency 2Ωmod we can drow out the detuning of the cavity 2.

This scheme allows to design a refractive index sensor calibrated in temperature and interrogating on only one channel. Two possible con-figuration are investigated, one with a 2D photonic crystals Fabry-Perot cavities and a second one with Bragg Reflectors cavities. The sensibility and capabilities of both configuration are investigated and compared by means of the cavities theory and by finite difference beam propagation methods.

8167B-91, Poster Session

Nanosecond large aperture optical shutter for one-pixel and imaging systems

P. A. Molchanov, Ampac Inc. (United States); V. M. Contarino, R Cubed Inc. (United States); O. Asmolova, Ampac Inc. (United States)

Optical shutter is providing protection for the high-sensitivity detectors from overexposures which can cause permanent damage or short term detectors sensitivity changes. The nanosecond optical shutter with aperture 2 square inches demonstrated of 86% transmission and 30 dB switching contrast in visible light range. Application of low molecular weight polymer dispersed liquid crystal (PDLC) material and application of high-voltage (200-500V) pulses allows to decrease switching time up to 20-100 nsec. Applied pulse electric field was about 10 V/μm. For applied PDLC the delay time approaches a constant value at higher electric fields, >10 V m-1. Transition and delay times decrease with increasing temperature. The proposed optical shutter technique can replace for electrical gating, such as dynode gating within PMTs, currently incorporated into LIDAR and gated imaging systems. Optical shutter can eliminate signal distortion caused by mixing of gate and signal pulses in current LIDAR one-pixel or imaging systems. Proposed optical shutter universal and could be integrated into any standard one-pixel or imaging telescope design for all visible range.

8167B-92, Poster Session

Hardware implementation of fuzzy logic for image stabilization

E. Koohestani, Safir Informatics (Iran, Islamic Republic of)

The most important issue in the image stabilization case is to purpose a real-time strategy to achieve the global motion of the whole image. We designed an applicable method to extract the sub-image motions from the detected edge intensity of nine areas thanks to a general convolution algorithm. After that, an innovative tagging criterion helps us to validate the possibility of the correctness of the extracted motion in every window by considering a managed variance sub-convolution. This criterion gave a meaningful instrument to score the validity of the nine motions in a fuzzy environment to make a globally average motion. Next, the desired motion should be regarded by a PID filter to smooth the effect. The hardware and purposed software can be employed in tracking systems properly because of the calculated overhead on a TriMedia family CPU.

Conference 8168: Advances in Optical Thin Films IV

SPIE Optical Systems Design

Monday-Wednesday 5-7 September 2011

Part of Proceedings of SPIE Vol. 8168 Advances in Optical Thin Films IV

8168-01, Session 1

Progress in optical coatings

H. A. Macleod, Thin Film Center, Inc. (United States)

No abstract available

8168-02, Session 2

Ultra-low-reflectance, high-uniformity, multilayer-antireflection coatings on large substrates deposited using an ion-beam sputtering system with a customized planetary rotation stage

S. Dligatch, M. Gross, A. Chtanov, Commonwealth Scientific and Industrial Research Organisation (Australia)

A customized planetary rotation stage has been fitted to a commercial ion beam sputter coater in order to enable the deposition of high uniformity, multilayer optical coatings on large substrates without the use of masks.

Uniformity is this system achieved by sequentially depositing each layer of the coating in two fixed locations in the sputtered particle plume where the geometry of the natural thickness distributions on a rotating substrate in these locations are of complementary shape and add to produce an overall uniform layer. The modified planetary stage allows substrate rotation about its own axis at any fixed position of the substrate centre about the axis of the planetary system. Uniformities over a diameter of more than 300 mm of better than +/-0.5% (peak-to-valley) have been found to be readily obtainable on most materials without the use of any masking to modify the source plume distribution. The suitable locations in the plume of each material that allow maximum uniformity are found by trial and error refinement of locations obtained by modelling of the plume distribution and expected thickness distributions. Ellipsometric monitoring of the thickness of the layer in each fixed position is used to determine the precise ratio of thicknesses in each location needed to obtain the correct total layer thickness simultaneously with high uniformity.

The system has thus far enabled single wavelength antireflection coatings of less than 0.002% reflectance to be fabricated over 300 mm diameter substrates. This requires the film uniformity on all layers to be less than +/-0.4%. In addition, 4-layer, dual wavelength antireflection coatings have been fabricated with less than 0.01% reflectance on both wavelengths over similar substrate dimensions.

8168-03, Session 2

Protective infrared antireflection coating based on sputtered Germanium carbide

D. R. Gibson, E. M. Waddell, Thin Film Solutions Ltd. (United Kingdom); F. Placido, Univ. of the West of Scotland (United Kingdom)

This paper describes optical, durability and environmental performance of a germanium carbide based durable anti-reflection coating. The coating has been demonstrated on germanium infra-red material however is applicable to other materials such as zinc sulphide and zinc selenide. Applications include low cost thermal imaging systems and multi-band thermal systems.

Traditionally germanium carbide is deposited using plasma enhanced chemical vapour deposition (PECVD), however substrate temperatures in excess of 300ºC are required and film stress limits film thickness. Moreover, PECVD deposition is low throughput and not practical for production usage.

In this paper the material is deposited using a novel reactive closed field magnetron (CFM) sputtering technique, offering significant advantages over conventional evaporation processes for germanium carbide, such as plasma enhanced chemical vapour deposition. The sputtering process is "cold", making it suitable for use on a wide range of substrates. More efficient loading for high throughput production is achieved through a rotating drum format.

Magnetron sputtering has developed rapidly over the last decade to the point where it has become established as the process of choice for the deposition of a wide range of applications. CFM sputtering is an exceptionally versatile technique, suitable for the depositon of high quality, well adhered films of a wide range of materials at commercially useful deposition rates.

The use of the closed field and unbalanced magnetrons creates a magnetic confinement that extends the electron mean free path, leading to high ion current densities. The combination of high current densities with ion energies in the range ~30eV creates optimum thin film growth conditions. As a result the films are dense, spectrally stable, supersmooth and low stress. Films incorporate low hydrogen content resulting in minimal C-H absorption bands within critical infra-red passbands such as 3 to 5um and 8 to 12um.

Tuning of germanium carbide (Ge(1-x)Cx) film refractive index from pure germanium (refractive index 4) to pure germanium carbide (refractive index 1.8) will be demonstrated. Use of film grading to achieve single and dual band anti-reflection performance will be shown.

The paper will describe in detail optical performance in the near, mid and thermal infra-red, demonstrating useable spectral range from 1 up to 15um. Also film stress, mechanical and durability performance and single and dual band anti-reflection performance on germanium substrates.

Film stress was evaluated from measured substrate curvature before and after film deposition. Stress measurements indicate a factor of eight reduction in CFM deposited films as compared with conventional PECVD methods.

CFM sputtering has been used for many years to produce highest quality tribological coatings. This paper demonstrates the same basic process produces transparent carbide coatings with outstanding optical, durability and environmental properties. Also the process is capable of producing low stress, dense, super-smooth coatings with low optical scatter. These properties are all derived from the fundamental advantage of the closed field strategy inherent in the combination of high ion current density combined with low ion energy.

8168-04, Session 2

Comparison of different deposition technologies for the post-coating of commercial CCD detectors

C. Hecquet, S. Sorce, C. Koc, M. Lequime, Institut Fresnel (France)

The ability to deposit optical thin films at the surface of commercial CCD detectors provides a possibility to improve their performance by decreasing the amount of reflected light (antireflective coatings) or to customize their spectral response by adding specialized filtering functions (bandpass, for instance).

The scope of our study is to evaluate the compatibility of different physical vapour deposition techniques (e-beam deposition with and without ion assistance, ion beam sputtering with and without ion assistance) with the post-coating of such commercial CCD arrays and to identify the impact of such post-coating operation on their performance (especially dark current and sensitivity). The dielectric materials selected for this study are Ta_2O_5 and SiO_2.

In this presentation, we will give a complete description of our experimental methodology including the optical bench we have developed for this purpose. The achieved results will be summarized and analyzed with respect to future potential applications.

8168-05, Session 2

Design and development of broadband antireflection coatings on silicon and GaAs substrates for solar cell applications

N. R. Kolli, V. Tamilselvan, Indian Institute of Science (India); N. Raghu, M. Sudhakar, ISRO Satellite Ctr. (India)

Triple-junction solar cells (InGaP/GaAs/Ge) are popular for space applications because of their higher efficiency of conversion. As these devices have spectral response over a wide wavelength region (300-1600nm), high performances anti-reflection coatings (ARC) are required. Several methods have been reported for reducing the reflections from semiconductor surfaces [1-6]. Dielectric material such as TiO2, Al2O3, SiO2, ZnS, Si3N4 and MgF2 are widely used for this purpose. However, the oxide films are more stable and durable and hence they are preferred. Aiken [6] has studied the step down interference coating structure namely ns>nh>nm>nl>no. where nS and n0 are the substrate, incident medium refractive indices respectively. The optimum index for nh , nm, nl were found to be 2.67, 2.15 and 1.65 respectively and all are having quarter wave thickness. There is no practical material which has this high index and high transparence in the wavelength region of interest. Hence there is an ample scope for the design and development of the broad band antireflection coatings for this kind of application. The refractive index of the conventional materials is further improved either by depositing the films at elevated temperatures or by adopting ion beam deposition technique [7]. In this work, an attempt has been made on the design and development of broad band antireflection coatings on Silicon and GaAs substrates for solar cells. Studies were made on single layer films of TiO2, Al2O3 and SiO2 deposited by electron beam evaporation at elevated temperatures 200-350oC and estimated the refractive indices of the films using both spectrophotometer and ellipsometer. Double and triple layer antireflection coatings were studied using TiO2, Al2O3 and SiO2on Silicon and GaAs substrates. The average reflectance of 2 layer and 3 layer ARC's was observed to be less than 2.3 and 2.9 % respectively in the region 400 - 1600 nm.

References:

1. P.A Lles ."Anti reflection coatings for solar cells" J. Vac. Sci.Technol., 14(5), 1100- (1977).

2. N.D.Arora, J.R..Houser, "Anti reflection layer for GaAs solar cells:" J. Appl. Phys. 53, 8839-8846 (1982).

3. P..Nubile "Analytical design of antireflection coatings for silicon photovoltaic devices", Thin Solid Films,342, 257- 261 (1999).

4. D.Bouhafs, A.Moussi, A.Chikouche, J.M.Ruiz, "Design and simulation of antireflection coating systems for optoelectronic devices: Application to Silicon solar cells" Solar Energy Mat & Solar cells. 52, 79-93(1998).

5. Cid, N.Stem, C.Brunetti, A.F.Beloto, C.A.S.Ramos, "Improvement in anti- reflection coatings for high-efficiency Silicon solar cells" Surface and Coatings Technology, 106, 117-120 (1998).

6. D.J.Aiken, "High performance anti reflection coating for broad band multi junction solar cells" Solar Energy Mat & Solar cells, 64, 293-296 (2000).

7. K.Narashimha Rao, " Influence of deposition parameter on optical properties of TiO2 films" Opt.Eng.41,2357-(2002).

8168-06, Session 2

Design and fabrication of low-polarization antireflection coating at 248nm

Y. Li, X. Liu, W. Shen, Zhejiang Univ. (China)

Until presently, the researches on deep ultraviolet coating which is employed in lithography system and illuminated with excimer laser only focus on the coating material itself. However, many optical elements with large curvature utilized in lithography system produce relatively larger incident angle. In this situation, coating induced polarization state variation cannot be neglected, and can be controlled through reasonable design of optical coating and optimized technical parameters. In this paper, LaF3 and MgF2 are chosen as high and low index material because of their bulky band gaps. Thermal evaporation and electron beam evaporation were employed to fabricate MgF2 and LaF3.Through several experiments on the two monolayer coating, the optimized technology parameters for designing the low absorption fluoride multilayer coating have been found. With the optical constants calculated from the experiments above, one low polarization (LP) and one common AR coating at 248nm were designed and fabricated to compare their polarization properties. The LP was thicker than the common AR one. The measured spectrums of the two coating matched the theoretical predication on the whole: the transmittance of the LP is comparatively lower than that of the common one at 248nm, which were 98.6% and 99.1%, respectively. On the other hand, the transmittance shift between P and S polarized direction induced by the LP changed limitedly with the increase of the incident angle, but absolutely different for the common one. When the incident angle was 60 degree, the transmittance shift between P and S polarized direction induced by the LP was about 3%, which was much smaller than 15% caused by the common one. Moreover, coating induced stress might induce birefringence of the substrate, and caused polarization state variation. Thus, reducing residual stress of the coating also played an important role in controlling polarization state. With and without the low polarization one, the Peak and Valley (PV) values of the substrate were 1.457 and 1.572λ(λ=632.8nm), respectively, which meant the coating induced stress was well controlled. Thus, with the technical parameters we adopted, polarization state variation induced by substrate birefringence has also been limited.

8168-07, Session 3

Giant field over-intensity in optical coatings under total internal reflection

C. Amra, Institut Fresnel (France)

No abstract available

8168-08, Session 3

Design of multilayer coatings containing metal island films

T. V. Amochkina, Lomonosov Moscow State Univ. (Russian Federation); J. Sancho-Parramon, V. Janicki, Institut Ruder Bo?kovic (Croatia); M. K. Trubetskov, Lomonosov Moscow State Univ. (Russian Federation); H. Zorc, Institut Ruder Bo?kovic (Croatia); A. V. Tikhonravov, Lomonosov Moscow State Univ. (Russian Federation)

Thin metal films exhibit unique optical properties and possess a high potential in design and fabrication of multilayer coatings with sophisticated spectral performances over wide wavelength and angular ranges. Within the manufacturing contest at OIC Conference in 2004 it has been demonstrated that there were design problems benefiting from using metal layers. It is known from the theory that there exist design problems that cannot be solved without the use of absorbing layers. An example of such design problem was considered as a part of manufacturing contest at OIC Conference in 2007.

The main difficulty in the designing metal-dielectric coatings is that the optical constants of metal layers are strongly dependent not only on the wavelength but also on the film thickness and on the deposition conditions. It means that, in order to design and produce metal-dielectric coatings with desired spectral characteristics, two main requirements must be satisfied. At first it is necessary to know the wavelength and thickness dependencies of optical constants of thin metal films. Secondly, these dependencies are required to be taken into account during the design process. In our recent publication we reported a new general approach for characterization of thin metal films. Applying this approach it is possible to find wavelength and thickness dependencies of metal island films with a high accuracy.

In the present study we propose an approach aimed at designing multilayer structures containing thin metal island layers with optical properties depending on thickness. As an example we designed a coating with different colors reflected from the front and back sides and having average transmittance not less than 45%. Additionally, the reflected colors do not change when the incidence angle is varying from 0 to 45 degrees. In the design process we used optical constants

of Ag metal island films, that were carefully determined based on our characterization approach.

8168-09, Session 3

Investigation of manufacturing processes by numerical sensitivity analysis

O. Vasseur, ONERA (France); M. Cathelinaud, Ctr. National de la Recherche Scientifique (France)

During the manufacturing of optical coatings, errors in refractive index values or in thickness values of each layer of the coating can induce dramatic consequences on the desired optical properties. Global numerical sensitivity analyses using space filling designs and metamodels were applied in the case of the influence study of refractive index errors on optical filter characteristics to determine the most critical interactions of layers. In this case, the interactions highlighted the simultaneous effect of independent error values on the spectral properties of the optical coating.

We propose to use space filling designs to assess by computer experiments the sensitivity of optical filters to the simultaneous errors in the refractive index values and thickness values. In this study, the principal characteristics of space filling designs are presented and are compared to random designs. This comparison allows us to identify the best types of space filling designs to conduct sensitivity analysis with few computer runs.

We will present the first results concerning the global sensitivity analysis of bandpass and mirror coatings in the case of simultaneous errors in refractive index values and in thickness values. We consider for this study two monitoring techniques : a quartz monitoring, which implies independent error in refractive and thickness values, and an optical monitoring, which implies correlated error in refractive and thickness values. By this way, we will highlight the influence of correlated errors on the most critical interactions classification and give a different perspective to these monitoring techniques.

In conclusion, this computational study gives clues to the understanding of error propagation in manufacturing processes and points out the most critical interactions in coatings to improve the robustness of optical coatings and reduce the production costs.

8168-10, Session 3

Application of global optimization algorithms for optical thin film index determination from spectro-photometric analysis

L. Gao, F. Lemarchand, M. Lequime, Institut Fresnel (France)

The determination of the complex refractive index of thin films is of great importance, since its accuracy directly impacts the performance of a thin film filter.

Spectro-photometric methods consist in analysing Reflectance and/or Transmittance on a given spectral domain, under one or several incidences with controlled polarization. Although, in general, it is possible to accurately estimate the indices of transparent or weakly absorbing materials, strongly absorbing materials are much more difficult, because a large number of parameters is needed to correctly describe their optical dispersion laws. The widely used nonlinear least-squares method becomes inefficient. So there is a strong demand for a global optimization method suitable for the determination of thin film indices. We here propose to investigate and compare different global optimization algorithms including Simulated Annealing, Genetic Algorithm and Clustering Global Optimization. The efficiency, sensitivity to noise and the initial input conditions, final solutions, and merit functions are used as different performance criteria. This comparison is carried out through simulated and experimental investigations on different kind of materials.

8168-11, Session 3

Effect of substrate index of refraction on the design of antireflection coatings

R. R. Willey, Willey Optical, Consultants (United States)

Broad band antireflection coatings have been studied and modeled extensively by several authors over several decades. The effects of the index of refraction of the substrate have mostly been ignored and have appeared to be very minor. This work has been undertaken to make a systematic investigation of where the effects of substrate index of refraction might be important, and where they can justifiably be neglected. The range of practical non-dispersive substrate indices from a minimum to a maximum were varied, a similar range of coating materials were varied, and a range of overall thicknesses were varied for optimized designs from narrow to very broad spectral ranges for antireflection coatings. From past studies, it is known that very broadband antireflection coatings tend toward optima that are quantized in overall thickness, and also that there is some minimal overall thickness that needs to be satisfied to achieve a near-optimal result. From this past practical experience, this investigation was confined to a range of overall thicknesses from the aforementioned minimum to three times that value. Design of experiments methodology was used to select the parameter points within the ranges to be designed. The many designs were then optimized. The results of the average reflectance in the specified bands versus the indices of the substrates, the indices of the coating materials, the antireflection bandwidth, and the overall thickness of the coating were then processed by the design of experiments software to provide formulae which have satisfactory statistical fits to the data generated. The conclusions of where the index of refraction of the substrate is and is not a significant factor in the design of an antireflection coating are presented.

8168-12, Session 3

Angular and spectral light scattering from complex multidielectric coatings

C. M. Grèzes-Besset, D. Torricini, H. T. Krol, CILAS (France); M. Zerrad, M. Lequime, C. Amra, Institut Fresnel (France)

Due to the improvement of deposition technologies and polishing techniques, light scattering has been considerably reduced in optical coatings these last decades, with the result of high quality dense optical filters with minimal losses. However such improvements coupled with modern monitoring techniques have also allowed to design and produce more complex coatings with layer numbers exceeding several hundred in some situations. Within this framework light scattering must again be revisited and analyzed in detail, including global loss levels together with angular and spectral analysis.

This paper is devoted to the optical balance of sophisticated components for Earth Observation, where the same scene is observed simultaneously in several adjacent wavebands. Self-blocking multilayer stacks are involved to eliminate out-of band harmonics in the instrument but the filter performances are degraded due to an increase of cross talk originating from light scattering. To address this problem we use the theories of light scattering from surface roughness and bulk heterogeneity, which allows to quantity cross-talk levels and choose more adequate filters. A special emphasis is given to the case of hyperspectral filters assemblies located in the focal plane for image filtering.

“Etude de la diaphonie d’un système de démultiplexage par filtres interférentiels. Conséquences de la diffusion de la lumière par les irrégularités des surfaces optiques,” C.Grèzes-Besset, C.Amra, B.Cousin, G.Otrio, E.Pelletier, R.Richier, Ann. Télécommun., 43, 135-141 (1988)

“Relationship of the total integrated scattering from multilayer-coated optics to angle of incidence, polarization, correlation length, and roughness cross-correlation properties,” J. M. Elson, J. P. Rahn, and J. M. Bennett, Appl. Opt. 22, 3207-3219 (1983)

“Comparison of surface and bulk scattering in optical multilayers,” Claude Amra, C. Grèzes-Besset, and L. Bruel, Appl. Opt. 32, 5492-5503 (1993)

"Performance Results for the Landsat OLI Spectral Filters", J.W. Figoskia, N.Zauna, T.Mooneyb, Proc. of SPIE Vol. 7452, 74520T (2009)

8168-13, Session 3

Design and production of robust dispersive mirrors

V. Pervak, Ludwig-Maximilians-Univ. München (Germany); M. K. Trubetskov, A. V. Tikhonravov, Lomonosov Moscow State Univ. (Russian Federation)

We develop and apply a new robust synthesis method to the design of dispersive multilayer dielectric coatings. The robust synthesis is based on a simultaneous optimization of spectral characteristics of multiple designs located in a small neighborhood of a so-called pivotal design. The advantage of this method consists in the ability to design a dispersive mirror with a low sensitivity to manufacturing errors without using any specific starting design. As a result, we designed and manufactured dispersive mirrors that were impossible to design and then produce with acceptable accuracy using conventional needle optimization technique. We performed experimental depositions of robust synthesis design and conventional design with our magnetron-sputtering coating machine in order to show the efficiency of the robust design technique in practice. The Group Delay Dispersion (GDD) measurements of fabricated mirrors performed by white light interferometry show that the robust design has superior performance in comparison to the conventional design. The fabricated dispersive mirror covers 690-890 nm wavelength range and provides the dispersion of -300 fs2 at 800 nm.

The level of GDD oscillations is an order of magnitude lower for the robust design compared to the conventional design. Also the robust design demonstrates a good manufacturability, providing very similar GDD in repeated deposition runs. In addition, the robust design provides lower intensities of electric field inside a coating and therefore higher laser damage threshold values can be expected.

8168-14, Session 4

Optical coatings in space

D. Wernham, European Space Research and Technology Ctr. (Netherlands)

No abstract available

8168-15, Session 4

Colour control and selectivity in TiAIN solar-thermal absorbers

S. Zhao, Uppsala Univ. (Sweden); D. Shu, Hefei Univ. of Technology (China); C. G. Ribbing, Uppsala Univ. (Sweden)

Solar-thermal absorbers should absorb as much as possible of the incoming, short-wave radiation in the interval 0.5-2.5 µm. Zero reflectance in this interval implies that the appearance should be black for optimum performance, since the visible range 0.36 - 0.78 µm is part of the solar spectrum. In this contribution we demonstrate - with calculations and experimental results for reactively sputtered TiAIN-surfaces - that the loss in radiative efficiency can be small for dark nuances of red, blue, gold and green. The significance of these results is that some colour would make solar absorbers on building aesthetically acceptable and yet permit high radiative efficiency.

Optical constants for simulations were obtained by R- and T-measurements on TiAIN thin films deposited on Corning 7059 glass. The model parameterized free carrier effects and an inter-band excitation. The calculations demonstrated that the colour effects are due to interference and inter-band absorption around 500 nm in a single layer coating. The peak shifts with the thickness of the thin film which gives a simple way to obtain different colours.

Solar absorptance of 86 % can be reached already for a single TiAIN-film on an Al substrate.

To achieve higher solar absorptance, double and triple layers were sputtered with gradient composition. The measured solar aborptance for an anti-reflected TiAION/TiAIN surface with a dark red hue was 0.95.

8168-16, Session 4

Research on low-polarizing x-plate for LED projector using green phosphors

M. Li, C. Kuo, National Central Univ. (Taiwan); J. Huang, Delta Electronics, Inc. (Taiwan); C. Lee, National Central Univ. (Taiwan)

We have designed and fabricated the low-polarizing X-plate to increase the luminous throughput for LED projector. This projector uses the green fluorescent powder to replace the Green LED to enhance the intensity of the green light. Using blue LED to excite the green fluorescent powder its spectral range wide than a green LED, the wavelength shift at 45 ° ± 8 °degree of X-plate must be less than 20 nm to enhance the effect. For the low-polarizing X-plate, we discuss the possibility of different material and design to decrease the wavelength shift. We calculate reflectivity characteristic of X-plate as a function of the wavelength at different angles of incidence from air of unpolarized light. A new way to design filter to control the title effect of thin film filters. Wavelength shift of the new design for reflecting red filter and reflecting blue filter at 45 ° ± 8 °degree is 16 nm and 14 nm compared to commercial filter, respectively.

8168-17, Session 4

Optical filters with controlled porosity for security and gas sensing applications

B. Baloukas, R. Vernhes, Ecole Polytechnique de Montréal (Canada); J. Houska, Univ. of West Bohemia (Czech Republic); J. E. Klemberg-Sapieha, L. Martinu, Ecole Polytechnique de Montréal (Canada)

The range of applications of optical coatings (OC) continuously broadens, especially thanks to the development of new structurally controlled thin film materials with specific multifunctional properties. In order to assess and predict their performance, it is necessary to develop a detailed understanding of the structure-property relationships, and to optimize their characteristics, including stability.

This presentation provides two specific examples of situations benefiting from the presence of controlled porosity of OC grown under alternating energetic conditions involving ion-bombardment-modulated film growth by magnetron sputtering, and by plasma enhanced chemical vapor deposition. In Example A, Electrochromic Interference Filters (EIF) formed by porous/dense multilayer stacks of tungsten oxide (WO3) simultaneously exhibit electrochromic as well as angle-dependent coloration effects in a single system. Such filters are considered for anticounterfeiting devices offering two levels of protection. In Example B, we propose gas sensing based on Fabry-Perot filters using dense/porous multilayer stacks of silicon nitride (SiN).

The optical performance of such structures is related to the packing density and the size of the pores that are in turn controlled by the energy of bombarding ions. The size of the pores and the density in such mesoporous and microporous structures is determined by spectroscopic ellipsometry-porosimetry and gas absorption isotherm measurements, and modeled by molecular dynamic simulations. Finally, we discuss performance of such devices, fabrication flexibility and tolerances, and the film mechanical integrity and functional stability.

8168-18, Session 4

Coatings for thin disk laser systems

S. Günster, D. Ristau, Laser Zentrum Hannover e.V. (Germany); B. Weichelt, A. Voss, Univ. Stuttgart (Germany)

The operation of thin-disk laser (TDL) systems relies on diode pumping

of thin disks of laser active material. The thickness of such laser disks ranges between about 50 and 300 micrometers depending on the absorption coefficient and the number of pump passes. High performance optical coatings deposited on the front and back surface of the disks are essential for efficient TDL operation. Two types of coatings are necessary: On the rear surface, a high finesse HR coating is required to reflect both laser and pumping radiation. On the front surface, a low loss antireflective coating allows to transmit the laser radiation under (near) normal incidence and the pumping radiation under oblique incident angles. Besides the optical properties, the coating system on the TDL substrate has to fulfil specific mechanical and, especially for the HR coating, thermal requirements.

At the Laser Zentrum Hannover, a cluster deposition tool has been developed to deposit coatings for TDL systems. This cluster deposition tool consists of a substrate load lock system for inspection and in-situ pre-treatment of the substrates, a second chamber for the deposition of low loss dielectric coatings with Ion Beam Sputtering technique, and a third section for the deposition of metal layers, which can be employed as reflective layers or for soldering purposes. The dielectric deposition chamber is equipped with an RF ion source for the deposition of discrete materials or material mixtures. Thus, discrete high low stacks or rugate filter systems can be deposited. The process is controlled via an optical broad band monitor. Moreover, an in situ stress measurement system allows for an estimation of the mechanical stress in the material on the basis of an online bending measurement system. The set-up of the deposition system will be explained in detail and the properties of the produced coatings will be presented.

8168-19, Session 5

Atomic layer deposition of optical thin films

A. V. Szeghalmi, Friedrich-Schiller-Univ. Jena (Germany); M. Arnold, Technische Univ. Chemnitz (Germany); A. Berger, M. Knez, Max-Planck-Institut für Mikrostrukturphysik (Germany); E. B. Kley, Friedrich-Schiller-Univ. Jena (Germany); D. R. T. Zahn, Technische Univ. Chemnitz (Germany); A. Tünnermann, Friedrich-Schiller-Univ. Jena (Germany)

First atomic layer deposition (ALD) thin films were already realized in the late seventies, but their application for optical elements is still not established. This paper will present advances in the deposition of dielectric and metallic thin films for specialty optics. The optical properties and morphology of iridium metallic layers and Ir / alumina nanolaminate composites will be discussed in more detail. Iridium has been deposited using iridium acetylacetonate and oxygen as precursors. The iridium growth rate is ca. 0.5 Å/ cycle. Alumina has been processed using trimethylaluminum and H2O at a growth rate of ca. 1 Å/ cycle. High resolution transmission electron microscopy and energy-dispersive X-ray spectroscopy measurements show sharp interfaces and pure Ir layers in the nanolaminates. Four point probe measurements of the resistivity of metallic and composite systems have been performed and proved conductive layers with an Ir film thickness of 5 nm.

Excellent thickness control, high uniformity and low roughness of ALD films are demonstrated. The ALD capability to deposit conformal coatings on complex nanostructured substrates with high aspect ratio is a great advantage for new strategies in the development of specialty optics such as mirrors, filters, photonic crystals, guided mode resonance sensors, polarizers, etc.

8168-20, Session 5

Plasma and optical thin film technologies

N. Kaiser, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); P. Awakowicz, R. P. Brinkmann, Ruhr-Univ. Bochum (Germany); T. Frauenheim, Univ. Bremen (Germany); A. Ohl, INP Greifswald e.V. (Germany); D. Ristau, Laser Zentrum Hannover e.V. (Germany); O. Stenzel, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

The PluTO project is aimed at combining thin-film and plasma technologies. Accordingly, the consortium comprises experts in optical coating (Laser Zentrum Hannover, Fraunhofer IOF) and such in plasma technology (INP Greifswald, Ruhr University of Bochum RUB). The process plasmas available, especially the sheath layers, will be thoroughly characterized by means of special probes, so that the types, numbers and energies of the particles participating in the coating formation processes can be determined comprehensively in every detail for the first time. The data thus obtained will provide a basis for a numerical modelling of layer growth at atomic scale (Bremen Center of Computational Material Sciences). The results are expected to deepen the understanding of the physical mechanisms responsible for the influence of plasma action on the layer properties. In parallel, suitable tools for process monitoring will be identified and made available. Some first results have already been achieved which prove the viability of the approach.

8168-21, Session 5

Systems and processes for producing low-loss interference coatings

H. Hagedorn, W. Lehnert, J. Pistner, H. Reus, M. Scherer, A. Zoeller, Leybold Optics GmbH (Germany)

Mass production is required to satisfy the increasing demand for complex interference filters with low losses. High transmittance or reflectance bands with steep edges require a high number of layers and complex layer thickness structures. It is more and more important to keep scattering and absorption losses on a low level. In addition in case of high transmittance bands the residual reflectance has to be controlled on a low level. Only by minimizing all three loss channels simultaneously, good results can by achieved.

Plasma ion assisted deposition (PIAD) and Plasma assisted reactive magnetron sputtering (PARMS) are widely used in the production of thin film filters. For both technologies the capabilities will be demonstrated on selected examples from the UV to NIR. The PIAD results were achieved in a large box coater with a 300mm RF-source. For the PARMS applications a high throughput sputtering system was used. 12 Substrates with 200mm diameter are deposited in one batch. Direct optical monitoring on the rotating substrate holder was used for both technologies.

8168-22, Session 5

Optical and thin film properties of mixed oxides deposited by pulsed reactive magnetron sputtering

S. Bruns, M. Vergöhl, Fraunhofer-Institut für Schicht- und Oberflächentechnik (Germany)

Reactive magnetron sputtering was used to deposit optical thin films. In order to obtain high deposition rates, metallic targets were used. For the creation of mixed oxides bipolar pulsed sputtering was applied to two different targets. A new process control setup was developed to monitor the oxidation state of both targets individually. Two different elemental targets are co-sputtered in oxygen-argon atmosphere within the lambda-probe stabilized transition mode. The composition is controlled by optical emission spectroscopy. Thus different mixtures are accessible without changing target material.

Varied mixtures in the system hafnia-silica and hafnia-alumina have been prepared. The optical properties (refractive indices, absorption, surface roughness, density) as well as mechanical behavior (film stress, hardness) of the mixtures are compared to pure oxide materials. By mixing the oxides thin film quality can be improved beyond the properties of the single materials.

8168-23, Session 5

New sputtering concept for optical precision coatings

D. Rademacher, G. Bräuer, M. Vergöhl, B. Fritz, T. Zickenrott, Fraunhofer-Institut für Schicht- und Oberflächentechnik (Germany)

The deposition of optical precision coatings on glass by magnetron sputtering is still a challenging problem regarding particle density and long term stability of coating plants due to target material erosion. A novel approach to increase process stability and reduce drifts is the usage of cylindrical cathodes. These cathodes allow a particle free deposition process as they have virtually no redeposition zones that can lead to destruction of coatings by arcing caused by surface charges. In the present paper optical single layers (SiO2, Nb2O5, Ta2O5) as well as multilayer coatings were sputtered by means of reactive magnetron sputtering using a double cylindrical cathode setup. The magnetrons are attached to a rotating disc coater in a sputter-up configuration. The process was stabilized by means of oxygen partial pressure control. Optical properties like refractive index, absorption, stress, morphology, particle density and optical shift where investigated in different sputtering conditions (i.e. power, pressure, magnetic field arrangement).

8168-24, Session 5

PACA2M: magnetron sputtering for 2-meter optics

G. Chauveau, D. Torricini, C. M. Grèzes-Besset, CILAS (France); D. Stojcevski, M. Lequime, Institut Fresnel (France)

In this paper, we present in detail the new deposition magnetron sputtering machine so-called PACA2M, that CILAS has implemented for coating large optics up to 2 meters, within a dedicated consortium, with the financial support of the French Department of Industry and of the local administrations, and with the help and the expertise of the French OPTITEC optical cluster.

Our innovative large size deposition machine is equipped with 2.5 meters-long planar magnetrons (seven cathodes), to ensure uniform coating on large optical components, up to 2 meters by 2 meters, 40 centimetres thick and to 1.5 ton weight. Some magnetrons are adapted to a DC, Mid Frequency (MF) or Radio Frequency (RF) operation, which allows the deposition of metals and also dielectric oxides under reactive atmosphere.

Moreover, PACA2M is equipped with a powerful broadband optical monitoring system that permits to reach sophisticated spectral specifications and a good agreement with theory, which will be presented in detail in another paper of the conference.

As the magnetron sputtering technique leads to very dense layers close to bulk material, it is particularly well suited for applications that require environmental resistance, as for example the LMJ (Laser MegaJoule) French laser fusion program in which CILAS is in charge of the metallic mirrors on large complex-shaped reflectors for laser chains amplifiers.

Numerous experimental results are presented here such as protected and enhanced metallic mirrors, metal-dielectric absorbing coatings or multi-dielectric coatings, deposited on different kinds of substrates, for which qualification tests have been done.

8168-25, Session 6

Organic small molecule-based optical coatings

U. Schulz, N. Kaiser, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

A small molecule is a low molecular weight organic compound which is by definition not a polymer. Therefore, physical vapor deposition by evaporation as common for inorganic oxides is possible. Organic layers can be useful as components of interference stacks for different functions. A number of organic compounds have interesting UV absorption characteristics and can be used to protect UV-sensitive polymers such as polycarbonate. In addition, organic layers can be applied to generate nanostructured thin films with a very low effective refractive index, as shown recently for polymers. A structured organic single layer may act as an antireflective (AR) coating or as polarizing element. Etched organic layers as the top layers of a stack are especially promising for achieving good AR performance without colored edges on strongly curved optical lenses. The applicability of several small molecule compounds will be discussed.

8168-26, Session 6

Tailored TCOs

A. Bingel, K. Füchsel, Friedrich-Schiller-Univ. Jena (Germany); N. Kaiser, A. Tünnermann, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Transparent conductive oxides (TCOs) combine electrical conductivity with a high transparency in the visible spectral region. These unique material properties lead to a broad spectrum of applications, such as transparent electrodes for solar cells, flat panel displays or electric lightening (OLED). Due to the presence of free charge carriers, the electrical conductivity of TCOs is attended by a high reflectance in the infrared spectral region. Therefore an application as low-e films in architecture glass is also in use. All these fields require tailored properties that have to be optimized in each individual case.

In general, a high conductivity and low absorption in the visible spectral range is realized by high substrate temperatures. But there are applications with limited process temperatures, e.g. the fabrication of OLEDs or coating of thermally unstable substrates. In such cases the manufacturing process has to be optimized for low temperature deposition. Furthermore specifications in terms of reflectance or transmittance of the TCO film for defined wavelengths can occur. In the field of conductive films with high near infrared transmittance a low doping concentration is necessary to shift the plasma resonance of the free carriers. On the other hand TCOs can be used in ultraviolet transparent applications. In this range the fundamental absorption of the material is the limiting factor for achievable transmittance values. Again, the correlation between electrical an optical properties can be used to tailor the TCO properties by enhancing the doping concentration of the TCOs. Hence the band edge can be moved to the UV as a consequence of the Moss-Burstein-Shift.

8168-27, Session 6

Spectral density analysis of the optical properties of Ni-Al_2O_3 nano-composite films

G. A. Niklasson, Uppsala Univ. (Sweden); T. K. Boström, Norut Teknologi (Norway); E. Tuncer, GE Global Research Ctr. (United States)

Thin films consisting of transition metal nanoparticles in an insulating oxide exhibit a high solar absorptance together with a low thermal emittance. Such films are often applied as spectrally selective surface coatings on solar collector panels. In order to optimise the nanocomposites for this application a more detailed understanding of their optical properties is needed. The optical properties of nanoparticle composites are well understood in the cases of a dilute mixture of one component in the other. The situation is more complicated for non-dilute composites, because of the sensitivity of the optical properties to the actual nano-structure. In principle, the spectral density formalism gives a rigorous description of the dielectric permittivity of two-component composites, where the influence of the nano-structure is described by a spectral density function (SDF), and can be separated from the optical properties of the constituents. Here we use a highly efficient recently developed numerical method to extract the spectral density function of nickel-aluminum oxide (Ni-Al2O3) composites from experimental data on the dielectric permittivity in the optical and near-infrared wavelength ranges. Thin layers of Ni-Al2O3 were produced by a sol-gel technique. Reflectance and transmittance spectra were measured by spectrophotometry in the wavelength range 300 to 2500 nm for films with thicknesses in the range 50 to 100 nm. The effective dielectric permittivity of the nanocomposite films was extracted by inversion of the experimental transmittance and reflectance data. Transmission electron microscopy showed crystalline Ni particles with sizes in the 3 to 10 nm range. The SDF shows a multi-peak structure with two or three peaks clearly visible. The peaks are due to particle shape as well as particle-particle interactions giving rise to structural resonances in the response of the composite to an electromagnetic field. The peak structure of the SDF is reminiscent of the behavior of fractal equivalent circuit models of optical properties of percolating composites.

8168-28, Session 6

Organic materials for the use in optical layer systems

T. Neubert, A. Gaida, W. Huwer, M. Vergöhl, Fraunhofer-Institut für Schicht- und Oberflächentechnik (Germany)

Ceramic materials such as SiO2 or Ta2O5 are widely used for optical interference coatings. These materials have a high hardness and mostly offer excellent optical properties. However, there is a growing demand not only for good optical properties and a high stability, but also for coatings with a high elasticity. Especially coatings on polymer substrates need layers with improved elasticity since cracks in the layers occur easily when the coated substrates were mechanically deformed. For such applications flexible layer materials using organics or even polymers are very promising. These may be used as pure organic layers of with organic-inorganic composites. Unfortunately the chemical reactions to form polymers layers are more complex than the reactions to form oxides. Thus the deposition techniques for polymer layers are much more varying. Another important issues are the deposition rate stability and the optical properties of the polymer layers like haze, refractive and absorption index. In this paper we compare different ways for the deposition of organic and polymer layers in the gas phase at low pressures. The methods used were: evaporation, sputtering, PECVD and thermal CVD techniques. The optical parameters (refractive index, absorption and haze) and some mechanical parameters (adhesion, crack onset strain) of the different polymer layers were characterized. It will be shown that excellent organic film properties can be obtained by the use of a suitable organic material and deposition process. Also shown will be results on composite materials to modify the optical properties.

8168-29, Session 6

Machinable thick silicon coatings for the manufacture of ultra-precise optical components

M. Schürmann, P. J. Jobst, N. Kaiser, S. Müller, A. Kolbmüller, A. Gebhardt, S. Risse, R. Eberhardt, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

A limiting factor in the manufacturing of ultra-precise optical components is the surface quality of machined optical surfaces. Apart from conventional metal substrates silicon can be polished well and very smooth surfaces can be achieved. However, crystalline silicon is very hard and causes a large wear of the tools, which makes the ultra-precise machining of silicon substrates difficult and expensive. Substrate materials like Al or AlSi-alloys are much easier to machine, however, they cannot be polished to very low surface roughness based on the crystalline microstructure. For reflective optics the state of the art is to overcome these limitations by chemical deposition of amorphous NiP onto machined Al-substrates. The NiP-layer can be polished much better than the machined Al-surface and a roughness below 1nm rms can be achieved. In this paper a new approach is described: Si-films with thicknesses of several microns are deposited onto the surface of ultra precise machined AlSi- or Si-substrates.

It is well known, that silicon films deposited by magnetron sputtering have an amorphous microstructure. In this work such films with thicknesses of several microns are deposited onto surfaces of ultra-precision machined AlSi or Si substrates. They can be polished to a roughness lower than 1 nm rms using established polishing techniques. In this contribution the influence of important deposition parameters on the microstructure of several microns thick Si films will be shown. Further, the applicability of several microns thick Si-films for the manufacture of transmitting optical components for the NIR and MIR spectral range will be discussed.

8168-30, Session 6

An investigation into the effects of Ar/O_2 ratio and annealing on the crystalline phase and electrochromism of niobia sputtered from metal and conductive oxide targets

M. K. Neeves, F. Placido, Univ. of the West of Scotland (United Kingdom)

Electrochromic materials have generated much interest and investigation due to their significant potential in many devices, including smart windows and optics which are able to modulate the transmittance of visible light and solar radiation. This ability presents itself to a number of potential applications aimed toward the conservation of energy, providing aesthetic function and display devices. The transition metal oxides form one of the most important groups of electrochromic materials, with cathodically colouring niobium oxide (Nb2O5, commonly known as Niobia) being a material of growing interest due to its colouration ability and tunability making it a possible rival to the highly researched tungsten oxide (WO3) [1, 2, 3], albeit requiring higher potentials for colouration and suffering slower reaction kinetics [3]. So far the vast majority of existing work on niobium oxide focuses itself upon those films deposited by the sol-gel technique [2, 4].

Niobium oxide may exist in one of at least twelve different phases of crystalline phases [1], with the phase achieved through deposition being highly dependent upon the deposition conditions [1]. Previous studies have indicated that the pseudo-hexagonal TT phase may possibly be preferential for the production of electrochromic devices [1].

In this investigation, thin films of niobium oxide are prepared upon conductive indium tin oxide (ITO) coated glass microslide, plain glass microslide and amorphous silica disc substrates by pulsed DC sputtering using both metal and conductive non-stoichiometric oxide targets. Films produced from both targets are then annealed at various temperatures. The crystalline structures of the resultant films are then analysed through the use of x-ray diffraction (XRD) studies to determine the relationship between the deposition condition(s) and phase produced. Then, through the use of in-situ spectroscopic testing of the electrochromic function within the visible range, the films are tested to deduce the effects of both the phase, and deposition target employed, have on the electrochromic function of the film. This in-turn allows for optimisation of the deposition and annealing conditions to produce the optimum phase required when producing electrochromic devices, and a consideration to the target material to be employed.

[1] R. Romero, E.A. Dalchiele, F. Martin, D. Leinen, J.R. Ramos-Barrado, Electrochromic behaviour of NB2O5 thin films with different morphologies obtained by spray pyrolysis, Solar Energy Materials & Solar Cells, 93, 222-229, 2009

[2] N. Özer, M.D. Rubin, C.M. Lampert, Optical and electrochemical characteristics of niobium oxide films prepared by sol-gel process and magnetron sputtering A comparison, Solar Energy Materials & Solar Cells, 40, 285-296, 1996

[3] J.P. Cronin, T.J. Gudgel, S.R. Kennedy, A. Agrawal, D.R. Uhlmann, Electrochromic Glazing (Review Article), Materials Research Vol 2, 1, 1-9, 1999

[4] M. Ma ek, B. Orel, Electrochromism of Sol-gel Derives Niobium Oxide Films, Tr. Journal of Chemistry, 22, 67-72, 1998

8168-31, Session 6

Experimental research on the surface morphology analysis and light scattering properties of ZnO/TiO_2 composite thin films

J. Cui, L. Jiang, H. Fu, Y. Liu, A. He, Nanjing Univ. of Science & Technology (China)

In this paper, we prepared ZnO/TiO2 composite films at different annealing temperatures by electron beam evaporation method. We have measured the morphology and analyze statistical laws of the film surface by atomic force microscopy. The results show that, there are fluctuations and roughness that are smaller than the order of

visible light wavelength on the surface of ZnO/TiO2 composite films at different annealing temperatures by electron beam evaporation method. Thus it can be considered to be weak scattering random surface with different roughness. Annealing temperatures affect the roughness, particle size and the fractal features a lot. With the increasing of the annealing temperature, the roughness decreased, the distribution of particles tended to be regular and the fractal features obvious. However, when the annealing temperature increased to a certain extent, hole-burning phenomena occurred, the roughness degree began to increase, the distribution of particles tended to be irregular and the fractal features fuzzy. All things considered, the best annealing temperature should be among the range of 500° to 600°. Good control of annealing temperature is very important for the preparation of films with good features.

We built the experimental optical path based on rotating wave plate method, and did the laser scattering experiments with the wavelength of 632.8 to different film samples. The result showed that, the reflection intensity and the polarization of different samples have different angle responding characteristics. When the incident light is S polarized, the reflection intensity decreased with the incident angle increasing, while the depolarization phenomena is very weak. At the same incident angle, the reflection intensity of rougher surface is relatively small and so is the value of polarization. When the incident light is P polarized, there exists a Brewster phenomenon with the incident angle increasing. The depolarization is significant. The best depolarization incident angle is corresponding to the effective Brewster angle. We explained the light scattering properties above reasonably combined with the statistical laws of the film surface.

The study on the properties of film surface takes benefit of the understanding of the grain growth mechanism and the improvement of film preparation. It has some value to improve the quality of the film surface. The fractal theory, as an effective method to study film surface, gets more and more attention in the academia. The applied research of film fractals in this paper can provide the reference of methods and engineering applications for researchers in related fields. In addition, by light scattering experiments, this paper also shows that ZnO/TiO2 weak scattering random rough surface has the function of selecting polarization and angle depolarization. It has some value of guidance on laser communication and other fields.

8168-32, Session 7

IRDIS filters: from design to qualification

H. T. Krol, N. Valette, D. Torricini, C. M. Grèzes-Besset, CILAS (France); K. Dohlen, D. Le Mignant, M. Saïsse, G. Moreaux, M. P. Langlois, C. Moutou, A. Vigan, Observatoire Astronomique de Marseille-Provence (France); F. Lemarquis, Institut Fresnel (France)

IRDIS (Infra Red Dual Imager and Spectrograph) is one of the scientific sub-systems for the SPHERE (Spectro-Polarimetric High-contrast Exoplanet REsearch) instrument, to be mounted on one of the four VLT 8-m telescopes in Paranal (Chile) in 2012. IRDIS and two other scientific sub systems will analyze the resulting high-contrast image with the aim of direct detection of extrasolar planets. IRDIS covers the near infrared bands Y, J, H and Ks (950-2300nm) and works at cryogenic temperature. The main observational mode of IRDIS is Dual Band Imaging, where the same object is observed simultaneously in two adjacent wavebands. For this mode, differential aberrations between the two channels are critical and filter optical quality is crucial.

In this paper, we focus on the design, production and tests of the IRDIS filters. The deposition technique involves DIBS (Dual Ion Beam Sputtering) and leads to very compact coatings, with material properties close to those of bulk material, making these filters well suited for cryogenic applications. The use of an in-situ optical monitoring system in visible and near infrared range (up to 2500nm) permits to reach the demanding spectral filter specifications (bandwidth, rise and fall widths, peak transmission, wide band blocking) and to have a good agreement with the theoretical design. Spectral measurements at ambient and cryogenic temperatures are then presented. In addition, the laboratory test results of the IRDIS camera, including the validation of the optical performance, are presented in a parallel paper session of this conference.

8168-33, Session 7

Exclusive examples of high-performance thin-film optical filters for fluorescence spectroscopy made by plasma-assisted reactive magnetron sputtering

M. Lappschies, U. B. Schallenberg, S. Jakobs, Optics Balzers Jena GmbH (Germany)

Since more than four decades band-pass filters are important components of microscopes used for the fluorescence spectroscopy. During all the time this special field of application has been one of the main drivers for research and development in thin-film optics, particularly for the thin-film design software and the coating technology. With a shortwave pass filter, a multi-notch filter, and a classical band-pass filter as examples of such filters provided for the latest generation of fluorescence microscopes we present the state-of-the-art in coating design and technology. Manufacturing these filters is a great challenge because the required spectral characteristics need necessarily multilayers with up to 300 layers and overall thicknesses up to 30 µm. In addition, the designs require also 3 to 5 nm as thinnest layers and all the layers are completely of non-quarterwave type. The filter were manufactured in a rapid-prototyping regime by a Leybold Helios plant using plasma-assisted reactive magnetron sputtering of thin films of different metal oxides. Designed and real spectra are compared and differences are discussed. Measurement results of other optical and non-optical characteristics as film stress, total integrated scattering, and micro roughness are presented.

8168-34, Session 7

Manufacturing and characterizing of all-dielectric band-pass filters for the short-wave infrared region

T. Bauer, M. Lappschies, U. B. Schallenberg, Optics Balzers Jena GmbH (Germany)

Besides the typical channels in the visible and near infrared spectrum, optical remote sensing of the earth from air and space utilizes also several channels in the short-wave infrared spectrum from 1000 nm to 3000 nm. Thin-film optical filters are applied to select these channels, but the application of classical multiple-cavity band-pass filters is impossible. Because of their additional blocking elements they are disallowed due to geometrical or other non-optical reasons. Within the sensitivity region of an MCT detector as typical detector device, the selection and blocking of radiation by the filter has to be provided by a single multilayer system. The spectral region of the SWIR as well as blocking width and depth require necessarily designs with overall thicknesses of more than 20 µm, with layer numbers up to 100. SiO2 and TiO2 were used as thin-film materials deposited with reactive e-beam evaporation under ion assistance in a Leybold SyrusPro box coater. A special challenge was the thickness measurement of the thin films by an optical broadband monitoring device in the visible range. The results of manufacturing and characterizing of such filters are presented by three examples for the center wavelengths of 1375 nm, 1610 nm, and 2190 nm.

8168-35, Session 7

The challenges of 3D-NTT Fabry Perot plates coating

D. Torricini, G. Chauveau, C. M. Grèzes-Besset, CILAS (France); D. Stojcevski, L. Abel-Tibérini, F. Lemarchand, M. Lequime, Institut Fresnel (France); J. Gach, M. Marcelin, Observatoire Astronomique de Marseille-Provence (France)

The 3D-NTT instrument is a spectro-imager offering two modes: a low resolution mode (300-6000) with a Tunable Filter, and a high resolution mode (10 000 - 40 000) with a standard scanning Fabry-Perot. This instrument developed by the Astrophysics Laboratory of Marseille requires the production of very complex multi-dielectric coatings which

CILAS has been in charge of, under Institut Fresnel's expertise.

A broadband reflective multi-dielectric stack that reaches a given value of reflectivity as flat as possible over a wide [370 nm -800 nm] spectral range is required on the front face and a broadband antireflection coating with less than 1% reflectivity on the rear face.

Moreover, the finesse resolution that the instrument intends to be reached requires high quality flatness of the final coated components.

In order to obtain such demanding performances, complex multidielectric coatings have been designed that involve non-quarter wave layers. The production of such coatings requires the use of a perfectly mastered dense technology for production and an in-situ optical broad-band monitoring system in order to reach a good agreement with the theoretical design.

We show in this presentation the coatings solutions that have been designed for the project to satisfy the optical properties and how prediction and compensation of flatness degradation introduced by the coatings can be obtained.

Then, we present the experimental results that we have obtained with our large magnetron sputtering machine on which the 3D-NTT coatings have been implemented. We will also present technical results on in-situ and ex-situ refractive index characterization, which is a guarantee of the success of the final spectral response.

Our so-called PACA2M coating machine (2 meters by 2 meters), which can deposit various dielectric and metallic layers will be presented in detail in two other presentations of the present conference, as well for its impressive characteristics of process quality as for its innovative optical monitoring system.

8168-36, Session 7

Development of infrared polarizing beam-splitters for the 7 to 13mm spectral region

L. Li, National Research Council Canada (Canada); J. Thériault, Defence Research and Development Canada (Canada); Y. Guo, National Research Council Canada (Canada)

For infrared imaging applications, there is a need to use broadband and wide-angle polarizing beam-splitters (PBS) to separate images with two orthogonal polarizations. Such polarized images often provide important information about the properties of the imaged objects that can not be detected with un-polarized light. Existing infrared polarizers or polarizing beam-splitters are often made of metal wire grids on transparent plate substrates. They are not suitable for imaging purpose because the tilted plates introduce aberrations that are very difficult to correct.

In this paper, we propose to develop infrared thin film polarizing beam-splitters that are based on light interference and frustrated total internal reflection. The PBS coatings consist of high and low index layers of germanium and fluorites and are to be deposited onto ZnSe prism substrates. The coated substrates are bonded by optical contacting. Compared to conventional thin film PBS designs, these PBSs not only have much better performance but also consist of fewer layers.

Similar polarizing beam-splitters have been successfully made for the visible spectral region; however, it is more challenging to make such PBSs in the infrared region from 7-13 m. First of all, there are limited choices of transparent coating materials available in the IR region, especially for the low index materials. Second, the low energy e-beam evaporation process has to be used to deposit the coatings and it produces relatively poor quality coatings that can be difficult to bond later by optical contacting. Third, the optical constants of the coating materials are not well investigated and have to be characterized very accurately by a spectrophotometer and an infrared ellipsometer. Forth, both the optical constants as well as layer thicknesses of the infrared PBS coatings have to be controlled well enough to meet the performance requirement.

At the conference, we will present the calculated performance and some experiment results of the infrared polarizing beam-splitter.

8168-37, Session 7

Design, manufacturing, and characterization of an 8-channel optical chip for low cost and fine color measurement

S. Tisserand, M. Hubert, S. Gautier, A. Faiola, J. Ganne, V. Sauget, T. Berthou, L. Roux, Silios Technologies (France)

Color measurement is used in many scientific and industrial applications for material control, detection and characterization. In the industrial field, fast and low cost measurement methods are often preferred. The color of products has to be measured on line (agro-food, environment, chemicals ...). Standard visible spectrometers allow rigorous measurements of color but are often too expensive and slow. Lower cost RGB colorimeters are widely used despite of lack of accuracy and reliable color information.

We developed a new color measurement system based on 8 band-pass filter chip, called DVF (Discrete Variable Filter) to perform finer color measurements than RGB system ones. The chip is composed of 8 adjacent cells, each one filtering a 20 to 30nm-wide spectral band. These 8 channels are centered over the visible range from 400nm to 700nm. We take benefit from micro-technology collective manufacturing methods to produce low cost optical chips. Thin film deposition methods and micro-etching processes are combined to obtain adequate spectral filtering functions. Accurate film measurements have been developed to control the oxide thickness with an accuracy of +/- 1nm.

Some wafers of 8 channel DVF chips have already been manufactured with success. The filter's spectral responses have been measured. Some chips have been mounted onto 1D CMOS detectors leading to very compact 8 channel spectrometers. In this paper are presented the manufacturing process of the chips, the chip's characteristics and the color measurement performances obtained. We show that the 8 channel DVF allows to probe a larger gamut than the RGB's one.

8168-38, Session 8

Mechanical and tribological properties of optical coatings

J. E. Klemberg-Sapieha, Ecole Polytechnique de Montréal (Canada)

No abstract available

8168-39, Session 8

Optical performance of narrow-band transmittance filters under low- and high-energy proton irradiation

A. M. Piegari, I. Di Sarcina, M. L. Grilli, S. Scaglione, A. Sytchkova, ENEA (Italy)

Very narrow band filters having a transmittance bandwidth of 3-4 nm are under development for an imaging instrument to be loaded on the METEOSAT III mission of the European Space Agency.

These filters must transmit the Oxygen line triplet in the range 777.19-777.54 nm, under illumination within a cone angle of +/- 5.5 degrees and reject the background radiation. Moreover they should withstand the space environmental conditions expected for this mission, in particular they should maintain their optical performance under gamma rays and protons bombardment.

In this work the behaviour of interference optical filters under low- and high-energy proton irradiation has been investigated. Low energy protons are expected to be necessary to prove the effects on the coating, whereas the high energy proton tests shall verify mainly the substrate susceptibility to induced damage. The expected interaction of protons with coating and substrate was simulated by the TRIM software, to identify the most appropriate conditions for the irradiation experiments.

Two different accelerator facilities have been used for low- and high-energy protons: at the Rudjer Boskovic Institute, Croatia, for 60 KeV protons with an integrated fluence of 10^12 p+/cm2 and at the INFN-LNS (National Institute of Nuclear Physics, National South Laboratory) Italy, for 30 MeV protons with an integrated fluence of 10^8 p+/cm2.

The analysed filters were obtained with an alternate TiO2 - SiO2 multilayer coating deposited by ion beam sputtering on fused silica and have a transmittance peak centred at 770 nm with a bandwidth of about 5 nm. Uncoated substrates were also irradiated.

The spectral transmittance of the filters was measured before and after irradiation by a Perkin-Elmer Lambda 950 spectrophotometer. According to simulations, no significant effects were detected in the visible-near infrared spectrum, while some variations appeared in the ultraviolet range at low-energy irradiation.

8168-40, Session 8

Study of the laser matter interaction in femtosecond regime: application to the analysis of the laser damage phenomena in optical thin films

B. Mangote, X. Fu, L. Gallais, M. Zerrad, M. Commandré, L. Gao, F. Lemarchand, M. Lequime, Institut Fresnel (France); A. Melninkaitis, J. Mirauskas, M. Jeskevic, V. Sirutkaitis, Vilnius Univ. (Lithuania); M. Mende, L. O. Jensen, H. Ehlers, D. Ristau, Laser Zentrum Hannover e.V. (Germany)

The damage of dielectric material by femtosecond laser has been studied in detail by the scientific community, thus providing the basis of mechanisms involved in this interaction. At the femtosecond scale only electronic processes can be excited by the electric field and contribute to the absorption of energy from the laser pulse. Moreover, this absorption occurs at a time scale very short compared to heat transfer time. It is possible to uncouple and treat separately the mechanism of absorption, energy transfer to the structure, and physical degradation of the material.

Despite common characteristics with bulk materials, the laser damage of dielectric thin films has peculiarities that need to be studied. Dielectric thin films have specific optical, mechanical, thermal and electronic properties, affecting the resistance of components under laser exposition. Indeed, a strong dependence of damage threshold with the deposition parameters used was observed in nanosecond regime. An investigation into femtosecond regime is therefore necessary to update the influence of various physical parameters such as deposition technique, the nature of the material used or the thickness.

Advanced metrological tools have been developed to better understand these different aspects. Laser benches for pico/femtosecond laser interaction have been developed at the Institut Fresnel and Laser Research Center, offering the possibility to accurately measure damage thresholds. Also the special properties of optical thin films have motivated the development of a dedicated model. It is based on the coupling of the determination of the electron density during the pulse and the resulting change of the complex index of the material with the calculation of the electromagnetic field in the stack. The model highlights the transient effects on the electric field distribution within the layer during the pulse. The ability of this model to interpret data from damage tests has been shown by various experiments. In particular, for a material and a fixed deposition technique, the variation of coating thickness leads to different thresholds that can be explained by the model developed.

The impact of the material nature and deposition technique on the laser resistance has been explored for different pure dielectric materials and mixtures (SiO2, HfO2, Ta2O5, Nb2O5, SiO2/Nb2O5, SiO2/ZrO2 and SiO2/HfO2). The results obtained on pure dielectric materials have confirmed a direct link between bandgap and damage threshold. A complete characterization of the mixtures was realized and the damage thresholds in nanosecond (12ns) and sub-picosecond (500fs) were measured and compared with results obtained on the pure materials.

8168-42, Session 8

Using monodisperse SiO_2 spheres to study laser-induced damage of nodules in HfO_2/SiO_2 high reflectors

X. Cheng, Z. Shen, H. Jiao, J. Zhang, B. Ma, T. Ding, W. He, X. Ye, Z. Wang, Tongji Univ. (China)

Nodules have been proved to play an important role in the activation of laser damage in 1.064 um HfO2/SiO2 high reflectors. However, some damage test results revealed that the ejection fluences of some big nodules with height around 1 um were abnormally high. To find the correlation between the surface dimensions of nodules and their susceptibility to nano-second pulsed laser radiation, monodisperse SiO2 spheres with five different sizes were used to create engineered nodules in 1.064 um HfO2/SiO2 high reflectors. The defect density of nodules created from SiO2 spheres was purposely controlled to be around 20/mm2 and special cares were taken to minimize clusters of SiO2 spheres as less as possible. This enabled us to take a large area raster scan test and to get the statistical value of ejection fluences of these engineered nodules. Prior to laser illumination, the height and width dimensions of the engineered nodules were measured using Atomic Force Microscope and Scanning Electron Microscope, especially the discontinuity of nodular boundary was revealed by cross-sectioning of nodular defects using a focused ion-beam milling instrument. Based on the above information, the damage test results were interpreted using electric field enhancement model and mechanical stability of nodular structures.

8168-43, Session 9

Design, deposition and characterization of multilayer mirrors for ultrashort pulses in the attosecond domain

S. de Rossi, Lab. Charles Fabry, Institut d'Optique (France)

No abstract available

8168-44, Session 9

Optical, chemical, depth, and magnetic characterization of Mg/co-based nanometric periodic multilayers

K. Le Guen, M. Hu, J. André, P. Jonnard, Univ. Pierre et Marie Curie (France); S. Zhou, H. Li, J. Zhu, Z. Wang, Tongji Univ. (China); N. Mahne, A. Giglia, S. Nannarone, A. Verna, Lab. Nazionale TASC (Italy); C. Meny, Institut de Physique et Chimie des Matériaux de Strasbourg (France); A. Galtayries, Ecole Nationale Supérieure de Chimie de Paris (France); M. Walls, Univ. Paris-Sud 11 (France)

We have recently elaborated Mg/Co-based nanometric periodic multilayers to develop efficient mirrors for applications in the extreme ultraviolet (EUV) spectral range.

For s-polarized light, the peak reflectivity of as-deposited Mg/Co is measured at 42.6 % at 25.1 nm and 45 ° of grazing incidence. Both X-ray emission spectroscopy and nuclear magnetic resonance (NMR) measurements indicate that there is no noticeable interdiffusion at the interfaces between successive layers [1]. Scanning transmission electronic microscopy images also attest the high structural quality of the stack. X-ray reflectivity (XRR) curves in the hard x-ray and EUV ranges confirm this description and indicate a weak interfacial roughness of the order of 0.5 nm.

Scanning electron microscopy images and XRR curves give evidence of the thermal stability of Mg/Co up to 300 °C. From that value, a strong change in the sample morphology occurs: the delamination of the multilayer from the substrate is even observed. This should be responsible for the drastic reflectivity drop observed above this temperature.

Starting from the Mg/Co structure, we have inserted a Zr layer at one or at the other interface or at both interfaces to estimate the effect of the introduction of a third material within the period. We have measured that Mg/Co/Zr is more efficient (50 % of reflectivity) than Mg/Zr/Co and Mg/Zr/Co/Zr (~ 40 %). Through time-of-flight secondary ion mass spectrometry (ToF-SIMS) depth profiling and NMR measurements, we have assigned this difference to an intermixing process when Co layers are deposited onto Zr layers [2].

Taking the advantage of the magnetic character of Co, we plan to perform resonant magnetic reflectivity to determine the magnetization profile of the Co layers within the Co/Mg multilayer. This will be done by measuring the reflectivity as a function of the incident photon energy around the absorption edge of the Co atom for opposite circularly polarized radiations. The obtained profiles will allow us to refine the data extracted from the above mentioned ToF-SIMS and NMR data, allowing the detection of a transition layer with an expected resolution of one monolayer.

References

[1] K. Le Guen, M.-H. Hu, J.-M. André, P. Jonnard, S. K. Zhou, H. Ch. Li, J. T. Zhu, Z. S. Wang and C. Meny, J. Phys. Chem. C, 114, 6484 (2010)

[2] K. Le Guen, M.-H. Hu, J.-M. André, P. Jonnard, S. K. Zhou, H. Ch. Li, J. T. Zhu, Z. S. Wang, N. Mahne, A. Giglia and S. Nannarone, Appl. Phys. A 102, 69 (2011)

8168-45, Session 9

EUV reflectivity and stability of tri-component Al-based multilayers

E. Meltchakov, A. Ziani, S. De Rossi, C. Bourassin-Bouchet, F. Bridou, A. Jérôme, F. Choueikani, F. Varnière, Institut d'Optique Graduate School (France); F. Auchère, X. Zhang, Institut d'Astrophysique Spatiale (France); M. Roulliay, L'Institut des Sciences Moléculaires d'Orsay (France); F. Delmotte, Institut d'Optique Graduate School (France)

Extreme ultra-violet (EUV) is the range of increasing interest for various applications such as solar physics, high-order harmonic generation or synchrotron radiation. A need for optical elements with specific spectral characteristics and enhanced temporal, thermal and radiation stability requires a new approach to the multilayer design by using often more than two materials and optimization of deposition process including an interface and capping engineering. Some aspects of the multilayer design, fabrication and characterization as well as recent results will be presented and discussed.

We will report on further development of multilayer coatings made with a use of aluminum for various EUV applications. The optical performance of Al-based multilayer mirrors will be discussed with regard to promising reflectivity and selectivity characteristics and problems of stability and large interfacial roughness for this type of multilayers.

It was found that the introduction of refractory metal in Al-based periodic stack helps to reduce significantly an interfacial roughness and provides for a higher theoretical reflectance in the spectral range from 17 to 35 nm [1]. The multilayer mirrors Al/Mo/SiC and Al/Mo/B4C of various periods have been fabricated by magnetron sputtering and characterized with x-rays and synchrotron radiation. The structure of tri-component systems with protective capping layers has been calculated according to EUV reflectivity simulations in order to obtain the peak reflectance for each wavelength within the spectral range. A certain improvement of the multilayer characteristics was achieved via optimization of the deposition process.

The EUV and X-ray reflectivity measurements have shown a significant advance in the optical performance and a rather good temporal and thermal stability of tri-component Al-based multilayer mirrors. At near-normal incidence, the reflectance more than 50 % in the range from 17 to 21 nm and more than 40 % around 30 nm was measured with these new systems. The multilayer parameters did not change during heating until 350°C.

[1] E. Meltchakov, C. Hecquet, M. Roulliay, S. De Rossi, Y. Menesguen, A. Jérome, F. Bridou, F. Varniere, M.-F. Ravet-Krill and F. Delmotte: Appl. Phys. A., 98 (2010), 111

8168-46, Session 9

Interface-engineered multilayer mirrors with enhanced reflectivity

V. V. Nesterenko, S. A. Yulin, T. Feigl, N. Kaiser, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

The development of high performance multilayer mirrors for the spectral range of 2-50 nm is a challenge for modern technology because of very small individual layer thicknesses (< 15 nm) and strong influence of interface roughness and intermixing on the mirror optical performance. It was shown that the interface performance of the structures can be considerably improved by interface-engineered design with the application of diffusion barriers with layer thickness < 1 nm and transition from conventional two-layer to interface engineered three- or four-layer design.

The reflectivity improvements from 48.7 % to 56.6 % at 45.0 nm, from 68.8 % to 69.6 % at 13.5 nm, and from 2.8 % to 5.2 % at 2.45 nm were achieved by interface engineering technology. It was also demonstrated that multilayer mirrors with diffusion barriers have enhanced thermal stability and can be used under high thermal loads.

8168-47, Session 9

Coating development for the far- and extreme-ultraviolet based on material characterization

J. I. Larruquert, L. Rodríguez-de Marcos, S. García-Cortés, M. Vidal-Dasilva, A. P. Pérez-Marín, J. A. Aznárez, J. A. Méndez, Consejo Superior de Investigaciones Científicas (Spain)

Observations for astronomy and solar physics in the far and extreme ultraviolet (FUV: 100-200 nm; EUV is defined here as 50-100 nm) require the development of new coatings. The performance of the available coatings is limited by the fact that all materials in the EUV, and most materials in the FUV, absorb radiation. This absorption becomes a major difficulty for the preparation of efficient EUV-FUV coatings below ~140 nm. The latter range makes often use of single-layer coatings (sometimes coated with a protective layer) because little radiation intensity penetrates deeper than the outer layer. Absorption severely limits the performance of coatings and it has impeded the development of efficient coatings for specific applications.

A challenging situation for a coating development is present when a weak EUV-FUV radiation of interest is masked with a much more intense parasitic radiation, particularly at a longer wavelength. One example is the observation of solar H Lyman beta (102.6 nm) immersed in a more intense H Lyman alpha (121.6 nm) background. Another example is the imaging of any FUV-EUV spectral line with a CCD; the problem for FUV-EUV imaging is that these cameras are not solar blind and in fact they have a larger sensibility to the visible-near UV-near IR. This behavior, along with the often larger intensity of the long-wavelength spectrum, turns it challenging to develop coatings that enable the use of CCD cameras for FUV-EUV imaging.

GOLD's efforts are devoted to develop novel coatings with improved performance in the difficult spectral range of the FUV-EUV, particularly to solve specific problems as those mentioned above. Our efforts start with the search and characterization of new materials. Our progress in material characterization and the development of novel FUV-EUV coatings will be presented.

8168-48, Session 9

Mg-based multilayers and their thermal stabilities for EUV range

J. Zhu, S. Zhou, H. Li, Q. Huang, L. Jiang, Z. Wang, Tongji Univ. (China)

In the past decades, multilayer mirrors have been successfully used in extreme ultraviolet (EUV) lithography, synchrotron radiation and EUV astronomy. At the wavelengths longer than Mg L-edge at 25.2nm, Mg-based multilayers provide higher theoretical reflectivity than Mo/

Si. In this paper, some Mg-based multilayers including Co/Mg, SiC/Mg and Zr/Mg were studied. All these multilayers were fabricated by direct current magnetron sputtering. As Mg is an active element with rather low melting point, the stability of Mg-based multilayers should be investigated. A serial of annealing experiments were performed in vacuum for one hour at different temperatures from 200° to 500°. Before and after annealing, the multilayers were characterized by grazing incidence X-ray reflectance and near-normal incidence EUV reflectance to evaluate their thermal stabilities. SiC/Mg and Co/Mg are stable up to 200° and the reflectivity decreases drastically with the increase of temperature, while the reflectivity of Zr/Mg keeps constant during annealing at 300° and falls slowly as the temperature increases. Up to 550°, Bragg peaks of Zr/Mg multilayer are still sharp in X-ray reflectivity curve, and EUV reflectivity is 25% at 26.2nm at 30 degree incidence. The measured results also indicate Zr/Mg multilayer encounters two critical temperatures when annealing from room temperature to 550°. First change is observed between 300° and 400° and the second is between 500° and 550°. These results suggest that Co/Mg and SiC/Mg should be applied below 200°, while Zr/Mg can be used in practical application requiring optics with better heat resistance.

8168-49, Session 10

Broadband monitoring simulation with massively parallel processors

M. K. Trubetskov, T. V. Amochkina, A. V. Tikhonravov, Lomonosov Moscow State Univ. (Russian Federation)

Modern extremely efficient optimization techniques, namely needle optimization and gradual evolution, enable one to design optical coatings of any type. Even more, these techniques allow obtaining multiple solutions with very close spectral characteristics. Therefore it is important to develop software tools that can allow one to choose a practically optimal solution from a wide variety of possible theoretical designs. A practically optimal solution provides highest production yield when optical coating is manufactured. A computer simulation of production runs (computational manufacturing) is a low-cost tool for choosing a practically optimal solution.

The theory of probability predicts that reliable production yield estimations require many hundreds or even thousands of computational manufacturing experiments. Broadband monitoring systems typically provide spectral data at approximately thousand spectral points. With several dozens of layers in a theoretical design a reliable estimation of the production yield may require too much time to complete.

The most time-consuming operation is calculation of a discrepancy function value. It consists of a sum of terms over wavelength grid, and every grid point can be computed simultaneously in different threads of computations. This opens great opportunities to parallelization of computations. Multi-core and multi-processor systems can provide accelerations up to several times.

Additional potential for further acceleration of computations is connected with Graphics Processing Units (GPU) utilization. A modern GPU consists of hundreds of massively parallel processors and is capable to perform floating-point operations very efficiently. The main problem in implementation of efficient algorithms at GPU is to provide enough task to all massively parallel processors in order to utilize all computing power efficiently. We developed a specialized version of the discrepancy function computations, which uses two-dimensional grid of threads. One dimension is responsible for processing of spectral grid points, while another dimension works with special reduction-type algorithm performing layer characteristics matrix computations and multiplications.

8168-50, Session 10

Online re-optimization as a powerful part of enhanced strategies in optical broadband monitoring

S. Schlichting, C. Schmitz, H. Ehlers, D. Ristau, Laser Zentrum Hannover e.V. (Germany)

Enhanced strategies in optical broadband monitoring allow for thin film deposition under rapid production conditions with very high process stability. Recent developments in the field include simulation techniques with virtual deposition systems, to enable a pre-selection of different multilayer designs, and hybrid process control strategies which combine optical monitoring with quartz crystal monitoring. In particular, automated online error re-calculation and design re-optimization are presently in the focus of research to improve the efficiency of deposition plants. In this contribution a developed re-optimization module is presented, and the resulting increase in production yield of complicated multilayer designs is demonstrated by deposition examples. Besides automated design changes directly initiated by the recalculation software, the presented approach also considers supervising functions that stop the deposition run when critical errors are detected.

8168-51, Session 10

From independent thickness monitoring to adaptive manufacturing: advanced deposition control of complex optical coatings

H. Ehlers, S. Schlichting, C. Schmitz, D. Ristau, Laser Zentrum Hannover e.V. (Germany)

Ever increasing demands in the field of optical coating systems with highest complexity impose new challenges on the development of advanced deposition techniques with increased stability, and especially on the corresponding precise thickness monitoring strategies. Most of the classical thickness monitoring concepts employed in industrial production, which are based on quartz crystal or optical monitoring, are presently operated near to their precision limits. However, resulting from extensive research activities, monitoring concepts could be significantly extended during the last years. On the one hand, newly developed hybrid process control algorithms combine the information of the optical and non-optical sensors to achieve a higher precision and fault-tolerance. On the other hand, independent thickness monitors are integrated in flexible manufacturing concepts which include adapted computational manufacturing tools as well as specific re-calculation and design re-optimization modules. Computational manufacturing is based on numerical simulations applying virtual deposition plants and has been demonstrated for optical broadband, single-wavelength, and quartz-crystal monitoring. It allows for a design pre-selection prior to deposition with essentially improved certainty which could not be achieved with classical error analysis until now. In contrast, the re-calculation and re-optimization modules are on-line tools that monitor the running deposition process. In case of critical deviations, a fully automated modification of the residual design assures a successful achievement of specifications under the chosen monitoring technique. The present study gives a review on selected monitoring strategies that integrate optical and non-optical measurement techniques in adaptive manufacturing concepts for highest precision and yield.

8168-52, Session 10

Broadband optical monitoring for a 2-meter optics magnetron sputtering deposition machine

D. Stojcevski, M. Lequime, Institut Fresnel (France); D. Torricini, G. Chauveau, C. M. Grèzes-Besset, CILAS (France)

In the field of optical coatings production, in situ determination of thin films properties during deposition process is a key point for the achievement of high performance filters. Using a spectral measurement over a wide range is a way to improve the robustness of the reverse engineering methods implemented for the monitoring of thin film thickness and the in-situ determination of material refractive index.

In the framework of the development of a magnetron sputtering deposition machine for 2-meter optics driven by CILAS, the Optical Thin-Film Research group of Institut Fresnel has designed and qualified a dedicated Broadband Optical Monitoring (BOM) covering the visible and near infrared spectral range from 280 nm to 2 200 nm, with a 3 nm spectral resolution in the visible part of the spectrum and about 16 nm in the infrared. An all-fibered system, well adapted to the extremely large size of the machine, is used to select the location of the measurement point inside the vacuum chamber (among 9 possible). Moreover, this system allows to achieve uniformity studies at the surface of large size substrates along a straight line perpendicular to the cathode main axis with the help of the motorized displacement system of the substrate in front of the magnetron cathodes,. At last, with this monitoring system, it is possible to switch between transmission and reflection measurements in a very short time (less than one second). A real-time monitoring of the physical thickness is thus done offering possibilities for automatic deposition process and in-line design re-optimization.

During our oral presentation, we will give a complete description of this new set-up and an illustration of its capabilities through various types of coatings (monolayer, dual layers, bandpass filter, broadband dielectric mirrors ...).

8168-53, Session 10

Optimization of ion-assisted ITO films by design of experiment

S. Schwyn Thöny, J. Buchholz, Evatec Ltd. (Switzerland)

Design of Experiment (DOE) is a methodology, which is widely used e.g. in semiconductor manufacturing in order to optimize processes and assess the influence of changes in process parameters. However, in optical thin film deposition industry the use of this powerful method is not wide spread. ITO is of particular interest in many very diverse applications since this material shows the unique combination of high optical transparency and good electrical conductivity. ITO films can be deposited by electron beam evaporation at high temperature (T>240°C). However, for many applications there is a temperature limit of 130-150°C. This limitation can be overcome by using an ion-assisted process. We will show in this work how the methodology of DOE can be used for the development of ion-assisted ITO films deposited at low temperatures. The DOE optimization procedure allows us to identify the most important process parameters, which yield films with high transmittance and low resistivity. The parameters investigated were the mean ion energy, the gas mixture, the deposition rate and the temperature. From the transmittance data the dispersion of the refractive index and extinction coefficient will be determined. In ITO there is a trade-off between transmittance and sheet resistance. Virtually absorption free films could be obtained with a resistivity of 3.7 μΩm, whereas the lowest resistivity (3.1 μΩm) yielded a transmittance, which was reduced by some few percent. For many applications the surface roughness is of interest as well, some applications require smooth surfaces, others high roughness. Therefore, the report will include an investigation of the surface roughness by AFM.

8168-54, Session 10

Modelling and optimization of film thickness variation for plasma-enhanced chemical vapour deposition processes

D. R. Gibson, E. M. Waddell, Thin Film Solutions Ltd. (United Kingdom); X. Fu, Changchun Univ. of Science and Technology (China)

This paper describes a modelling method for film thickness variation within plasma enhanced chemical vapour deposition (PECVD) processes. The model enables identification and optimization of deposition process sensitivities to electrode configuration, deposition system design and gas flow distribution.

The model specifically quantifies electric field distribution, plasma density, temperature profile and gas flow and relationship with film deposition rate and thickness variation across electrode geometry. The relevant modeled parameters assume radial symmetry inline with deposition system configuration. The flow characteristic, electric potential and temperature distributions are all modeled as each contribute to the process.

Model capability also includes three dimensional substrate structures through import from standard coMputer aided design packages. Modelling of electric field, gas flow and temperature are included for three dimensional substrate structures.

The paper describes relative contribution of each parameter to overall film thickness variation across both flat and three dimensional parts.

Comparison between theory and experiment is provided for PECVD of diamond-like-carbon (DLC) deposition onto flat and curved substrate geometries. The process utilizes butane reactive feedstock with an argon carrier gas. Radio-frequency (RF) plasma is used.

The PECVD deposition system is based on co-planar 300mm diameter electrodes with separate RF power matching to each electrode. The system has capability to adjust geometry such as electrode separation and a wide range of other process parameters to optimize uniformity. Accurate control of electrode temperature up to 350ºC is achievable with an accuracy of < ±5 ºC.

The system is also equipped with dry pumps capable of working with aggressive feedstocks and with closed loop process pressure control using a butterfly fly valve, in conjunction with a high accuracy baratron, to vary the pump speed. Modelling capability also confirms importance of pressure control and necessary control tolerances to achieve high performance (<±1%) thickness uniformity.

Deposited film thickness sensitivities to electrode geometry, plasma power density, pressure and gas flow distribution are demonstrated. In addition to film thickness uniformity, optical, durability and environmental performance of resulting DLC on germanium substrate material is reported.

Use of modelling to optimise film thickness uniformity is demonstrated for planar and curved geometries. Results show DLC uniformity <±1% over a 300 mm flat electrode diameter is achieved.

Use of the modelling method for PECVD using metal-organic feedstock is demonstrated, specifically for deposition of silica films using metal-organic tetraethoxy-silane. Film optical and durability/ environmental performance is described.

The relevant parameters modelled assuming radial symmetry as the system displays this. The flow characteristic, electric potential and temperature distributions are all modeled as they each play a part in the process and the three dimensional structure can be important.

The model is used to explore scalability and geometry issues of PECVD processes, optimization of film thickness uniformity as well as issues associated with edge effects. Such edge effects can be eliminated through an understanding of electric field configuration and appropriate design of substrate holder.

Comparison is made between a series of experiments to compare the influence of a range of process parameters with modeled predictions. Modelling applicability to other PECVD processes is described.

8168-55, Session 10

Testglass changer for direct optical monitoring

A. Zoeller, H. Hagedorn, W. Weinrich, E. Wirth, Leybold Optics GmbH (Germany)

For the production of high performance multilayer systems with tight specifications and large numbers of layers optical monitoring is essential. Substantial progress was achieved by the introduction of direct monitoring on the rotating substrate holder. Pre production analysis by computer simulation of coating processes helps to optimise monitoring strategies and reduces the effort for expensive and time consuming test runs significantly. However not in any case we can find error compensating monitoring strategies. Also we have to deal with error accumulation effects especially with multi layer systems with large number of layers. Changing the monitor glass after the layer stack is deposited partly is a useful method to discontinue accumulation effects.

A testglass changer which helps to suppress error accumulation was developed and automised. The testglasses are located on the rotating substrate holder which may be a calotte or a plane substrate holder. It combines the advantages of direct monitoring with the flexibility to change testglasses in a fully automatic process. The basic principle will be described. Results of multilayer systems demonstrate the benefits of the newly developed testglass changer.

8168-56, Session 11

New phenomena in plasmonics and metamaterials

M. Qiu, KTH Royal Institute of Technology (Sweden)

No abstract available

8168-57, Session 11

Omnidirectional bandgaps in ternary and quaternary 1D photonic crystals

G. V. Morozov, F. Placido, Univ. of the West of Scotland (United Kingdom)

One-dimensional (1D) photonic crystals are 1D periodic dielectric or metallo-dielectric structures with a period comparable to the wavelength of light. In practice, they are simply constructed as periodic stacks of thin films. Their critical feature is a possible existence of omnidirectional bandgaps where both transverse electric (electric field perpendicular to the plane of incidence) and transverse magnetic (magnetic field perpendicular to the plane of incidence) polarizations of impinging light are totally reflected for any incident angle. As a result, omnidirectional reflectors have potential applications in improving characteristics of filters, mirrors, waveguides, and laser cavities.

In this paper, allowed (pass) and forbidden (bandgaps) bands of one-dimensional photonic crystals with three (ternary) and four (quaternary) layers in the unit cell (period) are investigated. The results show that omnidirectional bandgaps of a conventional binary 1D photonic crystal might be significantly increased. The analysis is based on the Transfer Matrix Method and Floquet-Bloch formalism. At the first step, the dispersion equation for the Bloch phase for both ternary and quaternary crystals is derived. Those equations are analysed using a perturbative expansion on parameters which remain small around the band edges of physically realisable crystals. The transmission and reflection amplitudes for the whole crystal are expressed in terms of single-period amplitudes and the Bloch Phase.

8168-58, Session 11

Re-definition of effective refractive index of thin film buried quantum dots

Y. Chen, C. Lee, National Central Univ. (Taiwan)

In this article, we predicted the optical properties of the thin film buried quantum dots according to the mathematical mode which is based on the quantum theory. The method consists of two parts. The first one is the classical explanation for the interaction between light and matters. It takes care of the interaction as dipoles and electromagnetic wave and describes clearly the profile of spectrum. Another part is the transition of quantized energy, absorption and spontaneous emission which exhibits singular valleys or peaks in spectrum. For the reason of quantum theory, we have to verify Bohr radius of each crystallized material to make sure that the particle size is small enough to present quantum effect. After constructing the spectrum, the data significantly presents optical properties of matters, we try to re-define the effective refractive index of the thin film including quantum dots by the spectrum which is the result of light affected by matters.

8168-59, Session 11

Nanostructures versus thin films in the design of antireflection coatings

U. B. Schallenberg, Optics Balzers Jena GmbH (Germany)

It is shown how the discussion about antireflection coatings for the visible and near infrared region has been changed dramatically with recent experimental applications of nano structures that realize media with effective refractive indices less than the ‘magic border’ of 1.3. Using the so-called binary optics as an example, a glass-like nano structure similar to the moth-eye structure is theoretically designed as antireflection coating for the visible and near infrared region. In a straightforward way this structure is combined and modified with thin films of silica and tantala. With the aim of this example and considering only known design principles of thin-film optics, a connection between nano structures and thin films regarding their alternative or combined application as antireflection coatings is presented. As summary regarding the nano structures vs. thin film discussion, a map is presented that arranges different types of antireflection coatings presented in the past 70 years with respect to their applications, designs, and deposition technologies.

8168-60, Session 11

Zero dispersive narrowband pass filter design using negative refraction index materials

S. Chen, J. Tsai, C. Lee, National Central Univ. (Taiwan)

Normally, the phase of optical thin film is increased when the thickness of optical thin film is increased. However, the phase of negative refraction index material (NIM) is decreased as the thickness of the film is increased to affect the whole phase decreased. In other words, the whole phase is compensated. The result affects the spectra of the thin films have less sensitivity in wavelength and incident angle. If the narrow band pass filters are designed with normal thin-film materials mixed NIMs, the angle dispersion of the central wavelength can be designed. In this research, a narrow band pass filter was designed as a wavelength-non-shift filter with incident angle based on the relationship of incident angle and central wavelength. The wavelengths shifting in P and S-polarization are less than 0.1 nm within 10 degree of incident angle and in S-polarization is only 0.4 nm within 18 degree of incident angle.

8168-61, Session 11

Two waves interaction in layered photonic structure at big phase mismatching

V. A. Trofimov, T. M. Lysak, Lomonosov Moscow State Univ. (Russian Federation)

Recently we have found out the possibility of a realization of strong self-focuusing mode for axial-symmetric laser beam propagation in medium with quadratic nonlinear response. Maximum intensity of optical radiation at the axis of beam and in the centre of pulse increases hundred times in comparison with its input intensity. The base of this phenomenon is the well-known effect: cascading second harmonic generation. In this report we investigate the possibililty of realization of the similar mode at a laser pulse propogation in layered nonlinear structure.

It is necessary to stress that the predicted mode of strog self-focusing in homogeneous medium gives us opportunity to realize the regime similar to Kerr-lens mode locking, but for laser systems generating optical radiation with duration from microsecond to picosecond duration. For layered photonic structure such mode of laser beam interaction can lead to breakdown of photonic crystal, for example.

8168-62, Poster Session

Thickness uniformity improvements on large diameter for the advanced gravitational waves interferometers

B. Sassolas, R. Flaminio, D. Forest, A. Lacoudre, C. Michel, J. Montorio, N. Morgado, L. Pinard, Institut National de Physique Nucléaire et de Physique des Particules (France)

Gravitational wave detectors such as LIGO and Virgo use long-baseline Michelson interferometers with high finesse Fabry-Perrot cavity in the arms. The symmetry of these cavities is essential to prevent the interferometer from sensitivity to laser fluctuations. For this purpose

the difference between the transmissions of the two input mirrors has to be minimized.

Advanced LIGO, the upgrade of LIGO, plans a transmission matching between the two input mirrors as high as 99%. A small deviation in the process fabrication from run to run might induce transmission mismatch larger than 1%. Consequently, the two input mirrors have to be coated during the same coating run. That requires ability to deposit the reflective coating, based on a stack of titanium doped tantala (Ti:Ta2O5) layers and silica layers, uniformly over a 800 mm diameter aperture.

We propose to present our work to improve the transmission uniformity over an 800mm diameter aperture. The method is based on iterative corrective masks to improve layer thickness uniformity. The mask shape is a radial function computed from a thickness profile obtained with or without mask. One key point is the thickness measurement precision that can be achieved. For Ti:Ta2O5, a simple monolayer is deposited and the thickness is directly extracted from the transmission spectrum using an enhanced envelope method. About silica thickness it is not possible to get accurate information from the same method as Ti:Ta2O5 and an important effort has been dedicated to the silica. A silica wave layer was deposited onto a thin Ti:Ta2O5 layer. In this case, the transmission spectrum is fairly independent of the tantala layer properties but in contrast the extrema positions are linearly dependent on the silica layer thickness. The silica layer thickness uniformity was deduced from relative extrema position. Finally thickness uniformity for both materials about 0.2% rms was achieved.

8168-63, Poster Session

Magnetron sputtered multilayer mirrors for x-rays and EUV

F. Delmotte, F. Choueikani, A. Ziani, C. Bourassin-Bouchet, E. Meltchakov, S. de Rossi, F. Bridou, A. Jérôme, F. Varnière, Lab. Charles Fabry (France)

One of the pioneers in coatings for optics in the extreme ultraviolet (EUV) spectral range (typically 10 to 60 nm), the “X-UV Optics” team of Laboratoire Charles Fabry de l’Institut d’Optique (LCFIO) study and optimize interferential mirrors based on multilayers for several applications since more than 25 years. Today, the main applications are related to the observation of the solar corona in astrophysics, optics for new x-ray sources (X-ray lasers, High Harmonics Generation Sources, Free Electron Lasers), optics for ultrashort pulses (attosecond science) or diagnostics of hot plasmas.

In a first part, we will present an overview of physico-chemical and optical properties of thin films and multilayers deposited by magnetron sputtering. Several materials, including Mo, Si, B4C, Sc, Al, SiO2 and Si3N4 have been deposited by using RF or DC sputtering and characterized by a combination of different techniques: RBS, TEM, XES, AFM, SIMS, X-ray and EUV reflectometry.

In a second part, we will focus on the design of multilayer mirrors for x-ray and EUV with three typical cases : narrowband mirror made of a periodic stack, dual-band mirror made of multi-periodic stack and broadband mirror made of aperiodic stack.

Finally, we will show some examples of recent realizations and compare these experimental results with theoretical ones, taking into account the physico-chemical properties of materials and interfaces.

8168-64, Poster Session

Multilayers systems-based aluminum synthesized by ion beam sputtering for extreme UV

A. Ziani, Institut d’Optique Graduate School (France) and Ctr. National d’Études Spatiales (France); F. Delmotte, Institut d’Optique Graduate School (France); C. Le Paven-Thivet, Institut d’Electronique et Télécommunications de Rennes (France); E. Meltchakov, F. Bridou, A. Jérôme, Institut d’Optique Graduate School (France); M. Roulliay, L’Institut des Sciences Moléculaires d’Orsay (France); K. Gasc, Ctr. National d’Études Spatiales (France)

Most of conventional multilayer mirrors for EUV range [10 nm - 40 nm] are made with a use of silicon [1]. For this study, we have chosen to move towards the development of Al-based multilayer mirrors for the spectral range [17 nm - 34 nm]. The replacement of silicon by aluminum is motivated by lower absorption of aluminum in this spectral region which provides for a better theoretical reflectivity. Major technological problems that arise during the deposition of aluminum layers are due to a tendency of aluminum to crystallize easily and a high reactivity of aluminum with oxygen, which could cause a high interfacial roughness. Recently, Al-based multilayer mirrors made by magnetron sputtering (MS) have shown more than 50% reflectivity near 17 nm [2]. Usually, the multilayers deposited by ion beam sputtering (IBS) have fewer defects compared to the MS due to a lower gas pressure. The purpose of this presented study consisted in optimizing the deposition of Al-based multilayers by IBS technique according to several parameters such as an ion beam current and an angle of inclination of targets which allowed us to vary the energy of ad-atoms deposited onto a substrate. We expect to achieve good reflectivity values for both bi- and tri-material stacks: aluminum/molybdenum [Al/Mo] and aluminum/molybdenum/silicon carbide [Al/Mo/SiC]. We have undertaken a series of structural (XRD / TEM) and chemical (RBS) analysis of these systems. We will present their optical characteristics in the EUV range.

1. M-F. Ravet et al. Proceedings of SPIE St Etienne (2003) 5250-12
2. E. Meltchakov et al. Appl Phys A (2010) 98: 111-117

8168-65, Poster Session

Frequency selected optical feedback CRD technique for high-reflectivity measurement

Z. Qu, B. Li, Institute of Optics and Electronics (China)

The frequency selected optical feedback cavity ring-down (FSOF-CRD) technique is investigated for measuring the high reflectivity of ultra-high reflective mirrors. A broadband continuous Fabry-Perot (FP) diode laser is employed as the light source. The retro-reflection of the ring-down cavity (RDC) is re-injected into the oscillator cavity of the diode laser and causes the spectral fluctuation. According to the correlation of the bandwidth of the light source and the coupling efficiency of the optical power into the RDC, the bandwidth reduction of each longitudinal mode can be calculated althought the overall spectrum of the diode laser is broadened. Due to the optical feedback induced spectral fluctuation, the coupling efficiency of the optical power into the RDC is enhanced. The CRD output signals with large amplitude are employed for high reflectivity measurement of optical mirrors at 1064nm. The results show that the present FSOF-CRD technique is highly sensitive and reproducible for ultra-high reflectivity measurement.

8168-66, Poster Session

Energy logistics in an all-optical binary adder based on a 1D porous silicon photonic crystal

E. Y. Glushko, V. Lashkaryov Institute of Semiconductor Physics (Ukraine)

The ideology of a photonic crystal resonator covered with optically nonlinear layer was discussed in previous works [1-3] where two all-optical signal processing schemes were proposed for binary adder and logic gates of various kinds. The way the all-optical binary adder transforms a physical sequence of added signals to the logical sequence with corresponding shift of digital units is based on the nonlinear band shift effect. A key problem of the binary adder range precip by rejected part of light beams was discussed and some ways to solve the problem by the use of special precip appendixes were proposed.

In this work, the electromagnetic field structure for optically linear 1D porous silicon PhCr containing nonlinear inclusions is investigated. The optical parameters of a 1D PhCr resonator built on layered porous silicon covered with a nonlinear layer are calculated for various nonlinear materials. An approximate design of a 64-bit binary adder based on 1D porous silicon resonator is considered. The binary adder heating by powered optical pulses and energy distribution inside the device are analyzed. The heat sink ways and geometry of the binary adder design are discussed. It was found that from a point of view of heating the R-scheme of signal processing in the binary adder is more optimal.

1. E.Ya. Glushko, All-optical signal processing in photonic structures with nonlinearity, Opt.Commun. vol.247, 4-6, 275-280 (2005).

2. E.Ya. Glushko, A.E. Glushko, V.N.Evteev, A.N. Stepanyuk, All-optical signal processing based on trapped modes of a photonic crystal resonator, Proc. SPIE Vol. 7354, Nonlinear Optics and Applications III, Mario Bertolotti, Editor, 73540L-73540L-11 (2009).

3. E.Ya. Glushko, Logical gates on trapped modes in photonic crystals with nonlinear coating ," Proc. SPIE Vol. 6903, 69030G -69030G-10 (2008).

8168-67, Poster Session

Interface plasmonic properties of silver coated by ultrathin metal oxides

A. Sytchkova, D. Zola, A. M. Piegari, ENEA (Italy); M. Fang, H. He, J. Shao, Shanghai Institute of Optics and Fine Mechanics (China)

Many fields of high technology take advantage of conductor-dielectric interfaces properties. Deeper knowledge of physical processes that determine the optical response of the structures containing metal-dielectric interfaces is important for improving the performance of thin film devices containing such materials.

Here we present a study on optical properties of several ultrathin metal oxides deposited over thin silver layers. Some widely used materials (Al2O3, TiO2, SiO2) were selected for deposition by r.f. sputtering, and the created metal-dielectric structures were investigated using attenuated total reflectance (ATR) technique and by variable-angle spectroscopic ellipsometry (VASE). A home-made set-up operational in Otto configuration with a fine-positioning sample holder has been implemented for angle-resolved ATR measurements. VASE was performed with a help of a commercial ellipsometer (WVASE by J.A.Woolam Co) at various incident angles and in a wide spectral range. Simultaneous analysis of data obtained by these two independent techniques allows elaboration of a representative model for plasmonic-related phenomena at metal-dielectric interface. The optical constants of both metal and ultrathin oxide layers are shown to be influenced by surface plasmon propagation. A series of oxides chosen for this study allows a comparative analysis aimed for selection of the most appropriate materials for different applications.

8168-68, Poster Session

Optical and mechanical properties of oxide UV coatings, prepared by PVD techniques

O. Stenzel, M. Schürmann, S. Wilbrandt, N. Kaiser, A. Tünnermann, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); M. Mende, H. Ehlers, D. Ristau, Laser Zentrum Hannover e.V. (Germany); S. Bruns, M. Vergöhl, Fraunhofer-Institut für Schicht- und Oberflächentechnik (Germany); W. Riggers, Laseroptik GmbH (Germany); M. Bischoff, Qioptiq Photonics GmbH & Co. KG (Germany); M. Held, Bte Bedampfungstechnik GmbH (Germany)

Oxide Materials are widely used in optical coating technology today. They are applied as coating materials from the infrared via the visible up to the UV spectral ranges. As the performance of weakly absorbing optical interference coatings is crucially dependent on the refractive index contrast between the individual coating materials, in the past much effort has been devoted to optimizing the properties of typical high and low index coating materials. Particularly with respect to the visible spectral range, TiO2, Nb2O5 and Ta2O5 are often used high index materials, while SiO2 is a standard low index oxide material. Most practically relevant optical coating specifications in the VIS can be satisfied using these few materials.

The picture changes for UV specifications, because the previously mentioned high index materials show significant absorption in the UV. HfO2 or Al2O3, which may act as mid-index materials in the VIS, are still transparent in parts of the UV and are therefore in use as UV high index materials.

The present study is focused on the optimization of hafnia and alumina coatings with respect to applications in the UV. We present experimental data obtained from coatings deposited by evaporation and sputtering techniques. Emphasis is placed on optical properties, particularly on the relation between UV refractive index and absorption edge. The shift of the coatings is investigated as well as the mechanical stress. The results are discussed with respect to the mutual correlation between optical and mechanical properties, and are compared to literature data from competing deposition techniques.

8168-69, Poster Session

Coating technology for the deposition of structurable chromium films with reduced reflection

P. J. Jobst, M. Schürmann, N. Kaiser, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); F. Luck, B. Beier, M. Thaut, POG Präzisionsoptik Gera GmbH (Germany)

Due to its advantageous properties chromium is commonly applied in structurable coatings for the fabrication of optical microstructures. Numerous applications of such microstructures demand a reduced reflectivity of these chromium films. Chromium oxide based coatings are commonly applied to fulfill this demand. The optical properties of chromium oxide make it suitable to efficiently reduce the reflection of an underlying chromium layer and its chemical properties are compatible with the structuring processes used for chromium layers. However, the etching rates of chromium oxide coatings differ significantly from chromium etching rates, leading to technological problems especially for chromium oxide/chromium-coatings containing several chromium oxide layers or chromium oxide layers thicker than 100 nm. It will be shown that these can be overcome by a tuning of the etching properties of chromium and /or chromium oxide layers by a modified deposition process.

The etching properties of chromium oxide can be modified by the addition of nitrogen to the reactive sputter deposition process. It was found that the amount of incorporated nitrogen has a strong influence on the etching rates of chromium oxinitride. On the other hands, small amounts of incorporated nitrogen have only a small effect on the optical properties of chromium oxinitride. Chromium layers can be modified by the addition of small amounts of other metals during the deposition process. The possibility of using these technologies to adjust the etching properties of chromium oxinitride layers to the properties of chromium films will be discussed.

8168-70, Poster Session

Band-pass and OH-suppression filters for the E-ELT: design and prototyping

S. Günster, D. Ristau, Laser Zentrum Hannover e.V. (Germany); R. I. Davies, Max-Planck-Institut für extraterrestrische Physik (Germany)

Optical filters are used for a variety of purposes at astronomical telescopes. In the near infrared region, from 1 to 2.5 µm, bandpass and edge filters are used to separate the different astronomical channels, such as the J, H, and K bands. However, in the same wavelength range light emission generated in the earth's atmosphere is superimposed on the stellar radiation. Therefore, ground based astronomical instruments measure, in addition to the stellar light, also unwanted contributions from the earth's atmosphere. The characteristic lines of this OH emission are extremely narrow and distributed over the complete NIR spectral range.

The sensitivity of future telescopes, like the European Extreme Large Telescope (E-ELT) which is currently being designed by ESO, can be dramatically improved if the atmospheric emission lines are effectively suppressed while the stellar radiation is efficiently transferred to the detector systems. For this task, new types of optical filters have to be developed. In this framework new design concepts and algorithms must be used, combining the measurement needs with practical restrictions. Certainly, the selected deposition process plays the key role in the manufacturing process. Precise and highly stable deposition systems are necessary to realise such filter systems with an appropriate homogeneity. Moreover, the production control techniques must be adapted to match the high level of precision required in the NIR range. Finally, the characterisation set-ups for such filters systems have to be provided. The manufacturing of such a filter system for a feasibility study of an E-ELT instrument is presented. The design development, the deposition with adapted Ion Beam Sputtering deposition plants, and the characterisation of such filters in the J-Band is described.

8168-71, Poster Session

Investigation of the optical property and structure of WO3 thin films with different sputtering depositions

H. Chen, C. Chen, National Yunlin Univ. of Science and Technology (Taiwan); D. Jan, Institute of Nuclear Energy Research (Taiwan); K. Huang, Y. Lo, National Yunlin Univ. of Science and Technology (Taiwan); S. Chen, National Central Univ. (Taiwan)

The purpose of this research was to invesgate the optical properties and structure of tungsten oxide (WO3) thin films that was deposited by different sputtering depositions. WO3 thin films were deposited by three methods: radio frequency (RF) magnetron sputtering, direct current (DC) magnetron sputtering, and pulsed DC sputtering. A 99.99% WO3 target was used as the starting material for these depositions. The deposition energy would be changed from 70W, 100W and 150W for the 3-inch gun at different deposition methods. These WO3 thin films were deposited on the ITO glass, PET and silicon substrate with different gas ratios of oxygen and argon. The gas ratio of oxygen and argon would be changed from 1:1, 1:2, 1:3, 1:4 and 1:5. A double beam shadow moiré interferometer was used to measure and analyze the residual stress of WO3 films on PET. Then the residual stress could calculate by the Stoney correction formula for the flexible electronics. Anyway, the film deposited by RF magnetron sputtering had the large residual stress than the films deposited by other method for the PET substrate. A Raman spectrum could exhibit the phase of oxidation of WO3 thin films with different depositions. At the gas ratio of oxygen and argon of 1:1, the WO3 thin films had the best oxidation phase than other films with different gas ratios. An optical spectrumeter of Hitachi (U-3900) could be used to measure the transmittance spectra of WO3 thin films deposited by different methods. It was important at the change of the transmittance (ΔT = Tbleached - Tcolored) between the coloring and bleaching for the electrochromic films. Then, WO3 thin film had the large variation of transmittance between the coloring and bleaching at the gas ratio of 1:1 for oxygen and argon. It is well know that the variation of transmittance (ΔT) could be impacted by the deep of the loose and tense of WO3 thin films. In these different deposition processes, the DC magnetron could get the looser WO3 thin film for the high change of the transmittance than other films deposited by different depositions. An atomic force microscopy (AFM) would be used to investigate the surface profile of these WO3 thin films with different depositions. It would be found the films deposited by the RF magnetron sputtering had larger surface roughness and boundary size than the films deposited by other methods. The phenomenons also explain the WO3 thin films had the dense films at RF magnetron sputtering.

8168-72, Poster Session

Residual stress analysis for oxide thin film deposition on flexible substrate using finite element method

H. Chen, C. Huang, S. Lin, National Yunlin Univ. of Science and Technology (Taiwan); S. Chen, National Central Univ. (Taiwan)

Good adhesion, hardness and stress are basic requirements for optical thin film. Residual stress is one of the deposition parameter needed to be considered because it affects the optical properties of the film especially for the dense wavelength division multiplexer (DWDM), which play an important role in the application of optical fiber. Interference filter that divided the light into multi-channel in DWDM requires high stability of optics and humidity, and it may be damaged and caused central wavelength shift by film-stress. Residual stress is developed due to non-uniform material properties, coefficient of thermal expansion, and nucleation growth during the processing and cool down to operating or room temperatures. Unlike evaporated films, generalizations with respect to stress are difficult to make for sputtered films because of the complexity of the plasma environment and deposition process; so that the residual stress analysis for thin-film structures could not be performed using analytical methods. Such residual or internal stresses directly affect a variety of phenomena including adhesion, generation of crystalline defects, perfection of epitaxial layers and formation of film surface growths such as hillocks and whiskers. Since they tend to increase with thickness, so they promote film peeling. Tensile stresses which are greater than the cohesive strength of the coating lead to cracks and excessive levels of compressive stresses result in buckling phenomena. Sputtering oxide films with high density promote high compressive stress, and it offers researchers a reference if the magnitude of residual stress could be analyzed directly. Therefore, with the development of computing technology, more researchers are using numerical methods. The finite element method (FEM) is a very powerful technique to model thin-film structures and to carry out processing, static, and dynamic analyses. Recently, an equivalent-reference-temperature (ERT) technique had been proposed and used to model and evaluate the intrinsic strains of layered structures. ERT technique is based on the residual stress of an experimental referenced sample combined with thermal stress and intrinsic stress of simulation by iteration, and then the value of ERT that responded to the intrinsic stress could be determined. But the only drawback of this technique is that it can't analyze the residual stress for thin film that has not been deposited. In this paper, we take advantage of ERT on the residual stress analyze for each other. The residual stress can consist of thermal stress and intrinsic stress, both of them are calculated by Stoney's equation for glass substrate, and by correcting form for flexible substrate in this experiment.The experimental and numerical study of residual stress for the TiO2 thin film sputtered on glass substrate and flexible substrate are investigated. Numerical calculations of residual stress that connect to the lattice parameter based on the finite element method were performed, and we generalized that the results are found to be in good agreement over 70% with the experimental findings.

8168-73, Poster Session

Laser-induced damage of pure and mixture material high reflectors for 355-nm and 1064-nm wavelength

M. Mende, L. O. Jensen, H. Blaschke, H. Ehlers, Laser Zentrum Hannover e.V. (Germany); W. Riggers, Laseroptik GmbH (Germany); D. Ristau, Laser Zentrum Hannover e.V. (Germany) and Ctr. of Quantum Engineering and Space-Time Research (Germany)

High reflecting multilayer coatings play a key role for many applications of pulsed Nd:YAG high power lasers in industry and science. In the present contribution, improvements in the optical properties and the radiation resistance of high reflectors for 355nm and 1064nm wavelength on the basis of mixture materials are discussed. Within a cooperation between the LASEROPTIK GmbH and the Laser Zentrum Hannover e.V., several deposition processes including Ion Beam Sputtering (IBS), Magnetron Sputtering, and Electron Beam Evaporation could be addressed for this study. The selected material combinations HfO2+ZrO2/SiO2, HfO2+Al2O3/SiO2, HfO2+SiO2/SiO2 and HfO2/SiO2 were deposited using a zone target assembly for the IBS technique or defined material mixtures for the evaporation process. Single layers of the applied mixtures were analyzed by UV/Vis/NIR spectroscopy to correlate the optical constants with the atomic compositions quantified by energy dispersive X-ray spectroscopy (EDX) and X-ray photoelectron spectroscopy (XPS). In addition to

pure material reference mirrors and reflecting multilayer coatings with high index material mixtures, also interference coatings consisting of nanolaminates as well as multilayer systems with refractive index profiles were produced. The laser induced damage thresholds at 1064nm wavelength for nanosecond pulse durations were measured in a 1000on1 experiment complying with the standard ISO11254. For the 355nm high reflectors, the radiation resistance was determined in a 10000on1 procedure, furthermore, the radiation-induced absorption was measured by laser calorimetry according to ISO11551. Finally, the layer interfaces and the amorphous microstructure of selected multilayers were analyzed by Transmission Electron Microscopy (TEM) to obtain detailed information about possible partial crystallinity. The results are interpreted in the context of former investigations on the power handling capability of coating systems involving material mixtures.

8168-74, Poster Session

Resonances determination in microstructured films embedded in multilayered stacks

B. Vial, Institut Fresnel (France) and Silios Technologies (France); F. Zolla, A. Nicolet, M. Commandré, Institut Fresnel (France); S. Tisserand, Silios Technologies (France)

The field of application of diffraction gratings has been extended over the past decades. They are commonly used in various industrial and scientific domains, such as integrated optics, acousto-optics or spectroscopy. For instance, they proved to be particularly efficient as anti-reflective surfaces, beam shapers, waveguide couplersor spectral filters. More than a dozen of numerical methods (coupled-wave approach, C method, differential method, integral method, OAGSM method, FDTD method FEM, MFS, . . .) have already been developed as an answer to this strong need of conceiving and optimizing gratings.

Since the famous study of R. Wood,it is well known that electromagnetic effects can play a key role in the diffraction behavior of gratings. Fano was the first to propose that some anomalies could be explained by surface waves (called plasmons later).

In 1997, Ebbesen et al. observed an enhanced transmission through a metallic film pierced with periodically arranged holes. Although the holes introduce a channel for light propagation more efficient than the simple tunneling through the continuous film, the enhanced transmission is predominantly due to the plasmon excitation on one or both film surfaces, so that the effect could also be observed at corrugated surfaces having a constant thickness.

Our approach consist in finding the eigenmodes and the complex eigenfrequencies of stuctures using the finite element method (FEM). If the frequency of the incident light is close to the real part of one eigenvalue, there will be a resonance of the electromagnetic field, attenuated by a damping ratio corresponding to the imaginary part of this eigenvalue. The FEM allows us to study mono or bi periodic gratings with complex shaped patterns, with anisotropic and graded index material, under oblique incidence and arbitrary polarization, enbedded in a multilayered dielectric stack. To deal with each infinite issue arising with gratings problems, we only model one period and apply pseudo-periodic conditions in the direction(s) of periodicity, and we truncate the substrate and superstrate by using Perfectly Matched Layers (PML). A previous work at Fresnel Institute based on a new formulation of the FEM for the diffraction problem of similar structures give us the diffraction efficiencies, the losses, and thus the energy balance at a given wavelength.

In order to validate our method, we illustrate an example of a 3 layer dielectric slab, and compare the results with an original method called « tetrachotomy » (based on complex analysis results) that gives us numerically, thanks to a robust algorithm, the poles of the reflexion coefficient (that correspond to the eigenfrequencies of the structure).

We also study a one dimensional grating of slits engraved in a chromium film deposited on a glass substrate, and show that the dispersion diagram obtained by solving the eigenvalue problem is in good agrement with the loci of the extremas of transmission.

8168-75, Poster Session

Design and properties of dispersion compensation mirrors for ultra-fast lasers

H. Niu, Y. Zhang, W. Shen, Zhejiang Univ. (China)

Designs and properties of 2 types of dielectric chirped mirrors manufactured by DIBS (Double Ion Beam Sputtering) system is discussed. The first type includes mirrors providing negative GDD (Group Delay Dispersion) and high reflectance in a wavelength range 600nm-1000 nm.Double chirp method is selected for designing the initial structure of the chirped mirrors.In order to compress the nonlinear oscillation of the diepersion curve,we deeply analysis the impact of the number of double chirped layers and modulation index to the properties of the mirror.Based on this,we also establish the best combination value of the two parameters and the resulted residual ripples of the average GDD of the chirped mirror pairs is less than 20fs2 which is smooth enough for application. The actual reflectivity and GDD of such a mirror pair are measured by a spectrophometer and a home-made white light interferometry system.The results are well consistent with the designs. Use of these mirrors in a Ti:sapphire laser leads to a good clamping result.Finally a14.5fs ultra-short pulse is generated directly from the laser.

The second type of mirror is for pulse compression of the Yb-doped photonic crystal fiber laser systems.It has a much higher reflectivity which is more than 99.9% and an average TOD(Third-Order Dispersion) of about -8000fs3 in the wavelength range of 1020nm-1060nm.The GDD value of this mirror linearly increases from -200fs2 to 200fs2 in the designed band,thus,its TOD is almost a contant in this band.The film structure of such a mirror is relatively simpler than the mirrors above and its robustness also improves.When small manufacturing errors are encountered the mirror's performance can also completely success to satisfy specifications.We measured the reflectivity as well as group delay dispersion of the manufactured mirror.It is eventually used in the extracavity pulse compression for the Yb-doped photonic crystal fiber laser systems.An obvious compression effect can be seen from the intensity autocorrelation trace of the pulse.

8168-76, Poster Session

Study on advanced process control and development of high-precision optics with adaptive manufacturing

C. Schmitz, H. Ehlers, S. Schlichting, D. Ristau, Laser Zentrum Hannover e.V. (Germany)

Due to higher requirements to optical coatings, new analyzing methods and correction algorithms on the basis of an optical broadband monitor (BBM) were developed. With two adequate anti reflection coatings the possibilities of the advanced adaptive manufacturing are shown.

Both designs were simulated with computational manufacturing software to test their feasibility and error tolerance. Slight differences could be observed, which were evaluated on the basis of real deposition runs. Afterwards, to refine e.g. the index of refraction, it has been tried successfully to reproduce the real coating with the virtual deposition machine. This is done by varying different error parameters until the simulator shows the best approximation to the real coating. With corrected dispersion data the accuracy of the real coating has been improved, but still slight thickness deviations occurred. To reduce error accumulation during deposition even more, an automated re-calculation and re-optimization tool was added to the optical monitoring system. It re-calculates the thickness of each layer within the deposited layer stack after each determined layer. The re-optimization is programmed to intervene and refine the remaining layer thicknesses when defined tolerance values are exceeded. Additionally, a quartz crystal micro balance is used for the enhanced error control. Therewith it is possible to assist the optical monitoring system in situations that are critical for an optical thickness monitor (e.g. large error accumulation).

SPIE Optical Systems Design

8168-77, Poster Session

Investigation and correlations of ion beam and coating material properties vs. layer properties

M. Jupé, D. Scharrenbach, S. Malobabic, Laser Zentrum Hannover e.V. (Germany); H. Steffen, INP Greifswald e.V. (Germany); D. Ristau, Laser Zentrum Hannover e.V. (Germany)

Ion beam sputtering (IBS) is considered as a coating process which creates layer system with lowest losses and high precision. However, the absorption losses in the bulk materials are still orders of magnitudes lower than in the corresponding coatings deposited with IBS indicating that a further optimization of the process may be possible. Such an improvement in quality requires a more detailed knowledge of the process properties for an extending field of process parameters.

The present paper reports on a preliminary study parameterization strategy for IBS processes. In the first step, the ion beam propagation properties are analyzed in detail. In these investigations, both, the total dissipation of energy and the specific argon ion distribution of the beam was measured and interpreted. The second part of the investigation was focused on the sputtered material. With respect to the construction of a phase separating IBS process, the energy distribution and the charge of the material particles have been investigated. The physical properties of the adatoms are related to the losses of the deposited dielectric layers.

Conference 8169:
Optical Fabrication, Testing, and Metrology IV

Wednesday-Thursday 7-8 September 2011

Part of Proceedings of SPIE Vol. 8169 Optical Fabrication, Testing, and Metrology IV

8169-01, Session 1

MRF with adjustable pH

S. D. Jacobs, Univ. of Rochester (United States)

Deterministic final polishing of high precision optics using sub-aperture processing with magnetorheological finishing (MRF) is an accepted practice throughout the world. A wide variety of materials can be successfully worked with aqueous (pH 10), MR fluids, based upon magnetic carbonyl iron (CI) and either ceria or nanodiamond nonmagnetic abrasives. Polycrystalline materials like zinc sulfide and zinc selenide are difficult to polish at pH 10 with MRF, due to their grain size and the relatively low stiffness of the MR fluid lap. If microns of material are removed, the grain structure of the material begins to appear. In 2005, Kozhinova et al. (Appl. Opt. 44 4671-4677) demonstrated that lowering pH could improve MRF of ZnS. However, magnetic CI particle corrosion rendered their low pH approach unstable and unsuitable for commercial implementation.

In 2009, Shafrir et al. described a sol-gel coating process for manufacturing a zirconia-coated CI particle that protects the magnetic core from aqueous corrosion (Appl. Opt .48 6797-6810). The coating process produces free nanozirconia polishing abrasives during the coating procedure, thereby creating an MR polishing powder that is "self-charged" with the polishing abrasive. By simply adding water, it was possible to polish with good stability at pH 8 for three weeks. The development of a corrosion resistant, MR polishing powder, opens up the possibility for polishing a wide variety of materials, wherein the pH may be adjusted to optimize effectiveness. In this paper we describe the CI coating process, the characterization of the coated powder, and procedures for making stable MR fluids with adjustable pH, giving polishing results for a variety of optical glasses and crystals.

8169-02, Session 1

Stress polishing of ELT segments at LAM: full-scale demonstrator status

E. Hugot, M. Ferrari, G. R. Lemaître, J. Floriot, M. Laslandes, Observatoire Astronomique de Marseille-Provence (France)

The Laboratoire d'Astrophysique of Marseille is involved in the prototyping of a full scale demonstrator for stress polishing of segments for the European Extremely Large Telescope. Stress polishing methods are developed at LAM since more than 40 years, and these mature technologies have been used with success for VLT instruments. They are now considered as a promising manufacturing method for mass production of large off axis mirrors, specifically for ELT segments. This powerful method, based on elasticity theory, allows the generation of super-smooth off-axis aspherics exempt of high spatial frequency ripples by spherically polishing a warped blank with a full-sized tool. Thanks to the simple spherical polishing, the operation time can be strongly reduced compared to the time-consuming sub-aperture tool methods of grinding and polishing. The goal is to rapidly converge to a 1 micron RMS optical quality on a circular blank, that will be finally cut hexagonally and corrected using Ion Beam Finishing.

In this paper we will present the status of the demonstrator and the design of the prototype warping harness that must be able to precisely warp the circular blank. We will also present some parallel developments pursued in order to reduce the complexity and allowing reducing the number of actuators needed for the warping.

8169-03, Session 1

Manufacturing and testing of large lenses for dark energy survey (DES)at SESO

D. Fappani, Société Européenne de Systèmes Optiques (France); P. Doel, D. Brooks, Univ. College London (United Kingdom); B. L. Flaugher, Fermi National Accelerator Lab. (United States)

After a brief introduction of what is the Dark Energy Survey (DES) project and which optical imaging system will be used, the presentation will be mainly focused onto the optical production of the large lenses (up to 1m diameter) constituting the DES Camera (DECAM) located at the focal plane of the main observing telescope. Special emphasis will be made onto the optical manufacturing issues and the interferometric testing solutions which have been carried out by SESO during this project. In particular, we will detail how we have produced and tested the biggest entrance lens named C1 (=very challenging CV/CX meniscus) including the compensation of refractive index inhomogeneities of the glass substrate (Silica) and the management of the distorsion vs.gravity of the optical surfaces under test when they are tested individually, by reflection, as mirror surfaces. We will comment the corresponding different test set-up and show several pictures of the finished lenses. Through several examples of typical past realizations or future possible ones for different astronomical projects requiring 1m-class optics, the presentation will conclude by a brief over review of the corresponding existing "state of the art" at SESO for these technologies.

8169-04, Session 1

Sagem contribution to ALOS-3 multispectral and hyperspectral imagers

R. Geyl, J. F. Rodolfo, Sagem SA (France)

In 2009, Sagem-REOSC has been awarded by Nec Toshiba Space for the manufacturing of the optical components for the Hyperspectral and Multispectral sensors on board of japanese ALOS-3 mission.

The systems are of Three Mirror Anastigmat type with 30 cm aperture and 5° field of view with diffraction limited peformance specified. Light weight mirrors are made from Zerodur material and Silicon carbide material, two technologies well mastered at Sagem-REOSC.

We will report the significant achievements made during the execution of this work with some focusing on the alignment and global performance verification work done prior shipment of the components.

8169-05, Session 1

Fused silica long-term stability: case studies

M. Vannoni, A. Sordini, G. Molesini, Istituto Nazionale di Ottica (Italy)

Fused silica is the material of choice for optical elements when long term mechanical stability is required. It is commonly used to build high quality reference standards, but also for other applications as gravitational wave detectors, space borne experiments and high finesse optical cavities. In the case of planarity assessment in dimensional metrology, we start from primary standards made of fused silica flats and transfer the calibration to other samples, using interferometric methods to reach a nanometric level of accuracy. The original calibration of the fused silica flats can be verified using an absolute measurement method, in which three such flats are compared interferometrically and the results are mathematically elaborated, to retrieve the absolute figure of each flat.

In our laboratory, we maintain calibrated flatness standards using a modified method of the three-flat test: the calibration involves an average of 40000 different measurements and it is repeated every year; the accuracy reached for the peak-to-valley of the absolute maps is less than 1 nm. Recently, we have reported a long-term deformation of one flat, explained in terms of plastic deformation (permanent bending) caused by gravity; the phenomenon occurs at room temperature, and was ever observed before.[1]

Here we report some additional cases of fused silica optics in which we noticed a long term deformation of the shape, computing the pertaining time constant and making a calculation of the corresponding viscosity at room temperature. The study of these long term effects could be fundamental to understand the behavior of fused silica as a reference material and to calculate the expected influences to high end applications in which the mechanical and shape stability is crucial.

[1] Vannoni M., Sordini A. and Molesini G., "Long-term deformation at room temperature observed in fused silica," Optics Express, Vol. 18, Issue 5, pp. 5114-5123 (2010).

8169-06, Session 2

Metrology for an imaging Fourier transform spectrometer working in the far-UV (IFTSUV)

C. Ruiz de Galarreta Fanjul, A. Philippon, J. Vial, Univ. Paris-Sud 11 (France); J. Maillard, Institut d'Astrophysique de Paris (France); T. Appourchaux, Univ. Paris-Sud 11 (France)

An Imaging Fourier Transform Spectrometer in the far-UV (IFTSUV) is an attractive instrumental solution to answer the many unsolved problems concerning the physics of the solar outer atmosphere. The far UV spectral domain introduces a fundamental constraint on the design of the instrument: as there are no transmitting optics below 140 nm, an all reflection system imposes itself. Such a system can be accomplished by replacing the traditional beam-splitter with two reflection gratings working at normal incidence on the ±1 orders to split and recombine the analyzed input source. Unfortunately, this is neither the only nor the main technical challenge related to the UV range. Due to the short wavelength, to preserve IFTSUV spectral precision and Signal to Noise Ratio (SNR) demands high optical surface quality and very accurate (linear and angular) metrology.

The whole set of specifications in terms of SNR will be reviewed. We will pay special attention to the different effects that degrade scanning of the optical path difference by the moving mirror. Then, we will discuss the many possible solutions to maintain the performances of IFTSUV. Fast scan (consistent with the observation of solar dynamics) will mitigate the effects of environmental vibrations. The Jacquinot's (or Etendue) advantage gives us some flexibility to enlarge the aperture, which will improve the signal.

As far as metrology is also concerned, we present a "back-to-back" servo-system that will allow us to maintain the optical path difference during the entire scanning process by: (i) dynamic alignment for tip/tilt compensation (ii) optical path difference sampling trigger. It consists of a classical homodyne Michelson interferometer whose DC output feeds the input of a deflectometer. Both systems are aligned to the same optical axis, and share a collimated He-Ne laser beam reference source (λ=632.8nm). A quadrature phase detection system enables fringe counting and optical path difference determination thanks to the synchronous homodyne Michelson interferometer sub-system. The deflectometer sub-system lies on a Quadrant Photodiode Detector (QPD) to measure tip/tilt misalignment and two adaptative piezo-actuators for a feed-back control. To reach the required angular and linear precision the scanning mirror is set to a multi-reflection configuration. When the resonance condition is satisfied, angular and linear resolutions of the system are increased by a factor N, N being the number of reflections on the moving mirror. This kind of system has already being demonstrated obtaining excellent results with accuracies down to the nano-scale over either middle or long travel ranges.

8169-08, Session 2

Static gradient and birefringence error detection and removal in the interferometric measurements of large optical surfaces

D. A. Pearson II, Engineering Synthesis Design, Inc. (United States)

The measurement of large optical surfaces, over long optical path lengths, presents multiple metrology challenges. Due to the size and complexity of the required test scenarios, these types of measurements are largely made with simultaneous phase-shifting, vibration insensitive interferometers. In making long optical path length measurements, one immediate concern is the stability of the atmosphere over the path length of the measurement. Static gradients, the change of the index of refraction in the atmosphere, in the measurement path will induce measurement errors. Additionally, all simultaneous phase-shifting interferometers utilize two orthogonally polarized beams, test and reference, to simultaneously acquire multiple, phase-shifted interferograms. Over a long optical path, there may be additional optical surfaces, and elements, which alter the polarization state of the test or reference beams. This change, or slight rotation of polarization of the test or reference beams, with respect to one another, will induce measurement errors. Additionally, any optics utilized in the test set-up, both internal and external to the interferometer, including reference optics, may induce a birefringence error. Using a simultaneous phase-shifting, Fizeau interferometer (H2000), we shall demonstrate the existence and effects of static gradient, polarization state, and birefringence errors in the measurement of large optical surfaces. We shall provide a quantitative characterization of their magnitude and their influence on the measurement results. Additionally, we shall demonstrate the elimination of these errors through the use of simultaneous phase-shifting measurement techniques.

8169-09, Session 2

Experimental Determination of Aberration in Lithographic lens by Aerial Image

L. Duan, Shanghai Micro Electronics Equipment Co., Ltd. (China); X. Wang, B. Peng, Shanghai Institute of Optics and Fine Mechanics (China); A. Bourov, Shanghai Micro Electronics Equipment Co., Ltd. (China)

In this paper, we propose a method to extract aberration using aerial image measurement and present its measurement results on lithographic tools. Based on physical simulation and statistical analysis, linear or quadratic regression matrix is obtained between principal component coefficients of a specific aerial image and aberrations, and then aberrations are solved by the regression matrix. An engineering model is established based on an extension of theoretical model that incorporates all the significant systematic errors. The performance of the engineering model applied on a 0.75 NA ArF scanner is reported. In the experiment, measurement marks oriented in orthogonal directions are used and aerial images on 11 field points are measured, under small sigma conventional illumination, large sigma conventional illumination and annular illumination respectively. To verify the repeatability of this technique, every point is measured for 20 times. By inputting the aerial images in the engineering model, Zernike coefficients are solved and the results are analyzed. The results are compared with the technique using photoresist exposure. The comparison shows the proposed technique offers reliable aberration measurement with satisfied repeatability.

8169-10, Session 3

Wavefront reconstruction and piston measurement using Ronchi test

D. H. Penalver, F. Granados-Agustin, D. L. Romero-Antequera, Instituto Nacional de Astrofísica, Óptica y Electrónica (Mexico)

Ronchi test represents an economical alternative, with ease of implementation and uncertainties in the order of wavelength, to measure the piston between the elements of a segmented mirror. The current trend to use segmented surfaces to emulate monolithic surfaces is one of the major challenges in adaptive optics. The control of diferent segments of a mirror to produce a desired image, represents the mechanism by which is possible control the aberrations for segmented mirror.

The classical Ronchi test has proved to be suitable for determine the geometric shape of monolithic concave surfaces, the goal of this paper is to prove its applicability for segmented mirrors. This will open the field for the development of new wavefront sensors that would retrieve information allowing an optimal disposition of the segments to form an image with minimum of optical aberration. We have developed a computer software that determine the distance between the mirrors and the light source using a non-linear optimization algorithm. It is capable to determine changes on the intensity profilefunctions for each surface of the ronchigrams mirror, and detect the regions that contain the points with maximun intensity and therefore the shape and position

of the Ronchi fringes. Using a geometrical relation determined by Dr. Malacara, which relates the locus of the fringes with experimental parameters such as the period of the grating,the separation between source and griding ,the shape of the surface, the center of curvature and others, different images were analyzed. The defocus by each segment were determined and compared.

Finally, we made a first attempt of improving the method, we use a combined non-linear optimization and least square algorithm to study high-order wavefront deformations which are related to the aberrations of the system.

8169-11, Session 3

The difficult material processing by using an exotic quasiparticles from laser-produced plasma

V. A. Skvortsov, Moscow Institute for Physics and Technology (Russian Federation); N. I. Vogel, Technische Univ. Chemnitz (Germany)

The diamond bundles [1,2] as well as other difficult material processing are considered in present work by using an exotic quasiparticles [3] which in turn had been generated in result of influence an intense picosecond Nd YAG-laser beams on metallic target in vacuum and gases. In parallel with experimental results the results of computer simulations (based on RMHD code) of considered systems are represented too.

1.Skvortsov V.A., Vogel N.I. The diamond bundle for memory from an exotic quasiparticle. Proc. 37 Int. Conf. on Plasma Physics and Confinement Synthesis. Zvenigorod, 8-12 Febr. 2010, p.321.

2. Skvortsov V.A., Vogel N.I. “The bundle for memory” from an exotic quasiparticle. Proc. 14 th Lomonosov Conf. on Elementary Particle Physics. Moscow, 19-25 Aug., 2009. World Scientific. Singapore, 2010, pp.429-434.

3. Skvortsov V.A.,Vogel N.I. The generation of exotic quasiparticles. Proc. 11th Lomonosov Conference on Elementary Particle Physics.. Moscow, 25-29 Aug.2003. In book: “Particle Physics in Laboratory. Space and Universe. Ed. by A.I. Studenikin. World Scientific. Singapore. 2005, pp. 373-382.

8169-12, Session 4

Wafer-level micro-optics: trends in manufacturing, testing, and packaging

R. Voelkel, K. J. Weible, M. Eisner, SUSS MicroOptics SA (Switzerland)

Micro-optics is an indispensible Key Enabling Technology (KET) for many applications today. The important role of micro-optical components is based on three different motivations: miniaturization, high functionality and packaging aspects. It is obvious that a miniaturized systems requires micro-optics for light focusing, shaping and imaging. More important for industrial applications is the high functionality of micro-optics allowing to combine these different functions in one element. In DUV Lithography Steppers and Scanners an extremely precise beam shaping of the Excimer laser profile is required. High-precision diffractive optical elements are well suited for this task. For Wafer-Level Cameras (WLC) and fiber optical systems the packaging aspects are more important. Wafer-Level Micro-Optics allows to manufacture and packaging some thousands of sub-components in parallel. We report on the state of the art in wafer-based manufacturing, testing and packaging.

8169-13, Session 4

Fabrication and testing of highly efficient resonance domain diffractive optical elements

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

Structuring of optical surfaces with surface-relief diffractive optical elements (DOEs) becomes nowadays an integral part of optical design and fabrication. Fringes or diffractive zones in commonly exploited computer generated DOEs have large local periods, relative to the light wavelength. This is customary for scalar Fourier optics, but restricts available changes in light direction to less than few degrees and NA of diffractive lenses to less than~0.05, substantially underperforming to optically recorded volume holograms.

This lecture deals with “resonance domain” DOEs which have local periods, exceeding the subwavelength limit but staying near to the wavelength. Even though the resonance domain DOEs are surface relief structures, they provide Bragg effects and nearly 100% diffraction efficiency, usually attributed to volume optical holograms. Fabrication technology challenges include (a) deep grooves with high aspect ratio1.5-2.5; (b) small periods of about 300nm-800nm for the visible region of spectrum; (c) slant of the grooves; (d) complexity of deep and dense profile measurements. Based on our analysis, we came up with the following fabrication procedure: direct e-beam writing on fused silica wafers, Al lift-off procedure, oblique reactive ion etching (RIE), coating of Al layer at an oblique angle of about 45° and repeating RIE.

We developed an arrangement for characterization of the resonance domain DOEs by measurements of their diffraction efficiency and polarization state of the diffracted laser light. Restoration of the groove depth and slant from measurements is performed by the effective grating theory for the resonance domain diffractive structures, which generalizes effective index approach of subwavelength structures.

Experimental results of fabrication, SEM and AFM profile measurements will be presented for a deep fused silica grating with period 520 nm, designed for the green 532 nm laser light. Applications of gradually varying resonance domain DOEs in aberration correction, beam shaping and parallel multifunctional performance are discussed.

8169-14, Session 5

Method for the characterization of Fresnel lens flux transfer performance

J. C. Martinez-Anton, D. Vazquez Molini, A. A. Fernandez-Balbuena, J. Muñoz de Luna, J. A. Gomez Pedrero, Univ. Complutense de Madrid (Spain)

Fresnel lenses and other faceted or micro-optic devices are increasingly used in multiple applications like solar light concentrators and illumination devices, just to name the more representative. However, it seems to be a certain lack of adequate techniques for the assessment of the performance of final fabricated devices. As applications are more exigent this characterization is a must. We provide a technique to characterize the performance of Fresnel lenses, as light collection devices. The basis for the method is a configuration where a camera images the Fresnel lens aperture through a small mask situated at the conjugate of the desired source. A detailed map of the performance of the lens is obtained and correlated with irradiance at target. Finally these data may be compared with simulation or expected results. Several experimental cases are presented.

8169-16, Session 5

Fabrication and analysis of self-organized nano-channel array

C. Chen, S. Chen, National Central Univ. (Taiwan)

Recently, nano-channel structures have been applied to several optical devices such as DSSC solar cell, and carbon nano-tube, field emission display. The fabrication and analysis of the periodic nano-channel structure have been a big problem. In our study, anodic aluminum oxide (AAO) method has been used to fabricate the periodic nano-channel structures. And Fast Fourier Transform (FFT) method has been applied to analyze the quality of the structure. Self-organized nano-channel array grew on aluminum foil surface by five-step AAO method with bias voltage of 80-160 V. We dipped aluminum foil in the 10wt% H_3PO_4 electrolyte at 3 . The bias voltage of 80~160 V was applied for 30 min to grow AAO structure. Then, the AAO structure was removed by NaOH (1.0M) to form the periodic aluminum structures. In order to increase the regularity of the nano-channel array, it is necessary to repeat the steps for five times. Based on the process the nano-channel structures with 150-380-nm interpores can be controlled accurately by different bias voltage. To analyze the interpore quality of nano-channels, the SEM images of the structures was processed to analyze the circularity and the regularity. The results show the higher bias voltage can form the more circular interpores. The average periods of nano-channel array were calculated using FFT and the periods was 168.4 nm to 412.88 nm with bias voltage of 80-160 V, respectively. In conclusion, the self-organized nano-channel array has been fabricated by five-step AAO process with accurate period by controlling bias voltage. And the interpore quality of the structure can be figured out by the SEM image processing to analyze the circularity and the regularity successfully.

8169-17, Session 5

Manufacturing, testing, and metrology of axi-symmetric circular phase masks for stellar coronagraphy

M. N'Diaye, K. Dohlen, Observatoire Astronomique de Marseille-Provence (France); S. Tisserand, Silios Technologies (France); K. El Hadi, G. Moreaux, Observatoire Astronomique de Marseille-Provence (France); R. Soummer, Space Telescope Science Institute (United States); S. Cuevas, C. A. Sánchez Pérez, Univ. Nacional Autónoma de México (Mexico)

Stellar coronagraphs using circular phase masks are promising concepts dedicated to the image suppression of an observed bright star in order to enhance the substellar mass companions present in its vicinity, typically 2lambda/D angular separation. These concepts include a focal plane phase mask which introduces a phase delay on a part of the stellar image. With an adequate choice of the mask parameters (thickness, diameter), the light going through the mask and the light going outside the mask will interfere destructively inside the geometric pupil in the following pupil plane. The light rejected outside this re-imaged pupil will be blocked by a Lyot stop.

Typically, the mask physical size is about lambda F, where F denotes the f-number of the optical system, and the mask thickness depends on the required phase shifting. The contrast provided by these concepts is highly related to the quality of thickness profile of the phase mask and therefore, severe manufacturing tolerances are necessary to reach the theoretical performance of the corresponding coronagraphic system. In 2007, we designed a Roddier & Roddier phase mask with a 65um diameter and ordered it to GEPI of Paris Observatory which manufactured it using ion etching process. A roughness of 0.8 nm rms and a transition width of 1% of the mask diameter were measured with a profilometer for this mask showing the good quality of the mask.

We pursue our efforts to design and manufacture high quality masks in collaboration with SILIOS. Several tests of manufacturing procedures are currently realized to reach the best trade-off between mask roughness and mask transition width. These values, measured in our laboratory with a profilometer, allow us to determine the best configuration for fabrication. In addition, knowing the mask profile allows us to estimate theoretically the performance that can be reached.

8169-18, Session 5

Fabrication of bilayer wire-grid polarizer using replicated polymer nanograting

S. Kim, E. Byeon, J. Kim, Chung-Ang Univ. (Korea, Republic of)

The polarizer is an essential device for modulating the light in the liquid crystal display (LCD). In the conventional LCD, only 2% of light from the source is used for display the information. The main reason of the low efficiency lies on the absorption of the un-polarized light in the polarizer film. To improve the efficiency of LCD, a brightness enhancement films have been used for high-end LCD and mobile LCD. A reflective polarizer, such as metal wire grid polarizer (WGP), can be an alternative solution for improving the efficiency of LCD. Ahn, et. al, successfully demonstrated 50nm half-pitch WGP by etching of deposited aluminium layer using the nano imprinted polymer grating barrier [1]. Although they used nano imprinting technology for low cost patterning process, the fabrication process of WGP was still complex and expensive due to the etching processes for removal of residual layer and aluminium layer. A bilayer wire grid polarizer (B-WGP) composed of phororesist nanograting structure and deposited metal layer was proposed for the simpler and less costlier fabrication method for reflective polarizer [2]. In this study, we fabricated B-WGP based on a UV-nanoreplication process, which is regarded as the most suitable method to fabricate sub-wavelength optical grating pattern because of its low lateral shrinkage and high replication quality. An electroformed nickel mold was fabricated using a lithographed photo resist master pattern with a pitch of 80nm, a line width of 50nm, and a height of grating of 100nm. A UV-curable polymer was coated on the nickel mold and glass substrate was covered on it. After the UV-curing process, an aluminium layer with a thickness of 50nm was deposited. The SEM images and AFM surface profiles of master pattern, mold and replica were measured and compared for characterizing the geometrical properties of each fabrication process. To examine the performance of the fabricated B-WGP structure, the transmission spectra of p- and s- polarized light, and the extinction ratio spectra (s-transmittance / p-transmittance) were measured and compared with the simulated spectra. A rigorous coupled wave analysis (RCWA) was conducted using commercial software (DiffractMOD, R-SOFT, USA) to calculate the transmission spectrum for both s- and p-polarized broad band light sources. The measured transmittance and extinction ratio of the fabricated B-WGP were ~ 40% and ~ 1000 in whole visible range, respectively, and the difference between measured and simulated results was due to the side wall deposition in E-beam evaporation process and low dynamic range of the measurement setup used in this study. The development of a method to simulate the performance of B-WGP considering the fabrication errors for the structure optimization is the subject of our on-going research.

8169-19, Session 5

Nonlinear-optical spatially periodic structures for micro-optics

V. A. Smirnov, L. I. Vostrikova, A.V. Rzhanov Institute of Semiconductor Physics (Russian Federation)

Optical poling is so called an induction in medium the long lived space periodic electrostatic polarization by influence of the multi-chromatic inter-coherent radiation that leads to a formation of the nonlinear-optical spatially-periodic structures of second-order polarizability photo-integrated in amorphous materials. It is a method for creation of a reversible change of the symmetry by local range transforming of the isotropic medium into an optically uniaxial material inside which nonlinear tree-wave interactions become possible. Changes in optical properties of mediums are observed in many experiments, such as, the photoinduced second harmonic generation and degenerate parametrical amplification of sub-harmonic of light and ets. The possibility of the optical poling of different isotropic media (glasses and waveguides, polymer consisted and hybrid organic-nonorganic films) has been shown by now. The observed processes of the conversion of a radiation in photo-integrated nonlinear-optical structures attract attention of scientists both from the point of view of fundamental scientific research and due to the possibility of the obtaining new broadband optoelectronic elements.

In this paper we discuss the possibilities of the creation of small periodic micro structures of nonlinear polarizability in materials. The theoretical consideration of the formation of the nonlinear-optical spatially-periodic structures with various view of their profiles and the detailed analysis of properties of the inserted nonlinear polarizability have been presented. The obtained results of the experimental investigations show that, in comparison with the widely known simple method of the creation of nonlinear-optical structures by means of the plane-parallel laser beams, the considered case of the "volumetric" creation, by means of the crossed Gaussian beams in a volume of a sample, gives the important advantage connected with possibility of a wide variation of properties for the induced polarizability in volumetric media, allowing to create small-scale micro structures of the photo-integrated anisotropy with the different dimensions. As a result, the possibility of the creation of the spatially homogeneous photo-integrated volumetric modulation of anisotropy in oxide glass materials has been experimentally demonstrated. The studied photo-integrated

nonlinear-optical spatially-periodic micro structures may be useful in future for the creation of the various photonic devices.

8169-20, Session 5

Dispersion compensator for optical communication using chirped fiber Bragg grating

J. Singh, Sri Satya Sai Institute of Science and Technology, Sehore (India); A. Khare, Univ. Institute of Technology, RGVP (India)

In modern days the Optical Fiber Communication is growing and becoming more modernized. But attenuation due to dispersion, absorption and scattering decreases the transmitted power. More over nonlinearly in spectral profile of the optical amplifiers limits the dense WDM transmission. Thus limiting the progress of high speed transmission over long distance. The dispersion occurs when the light spread out in fiber cable during optical signal transmission. The Dispersion is due to material (chromatic), wave-guide and modal dispersion. The material dispersion occurs due to variation of refractive index with wavelength. The waveguide dispersion depends on shape, design and chemical composition of the fiber core. Only 80% light confined with the core while other lost in cladding which travel faster due to less refractive index of cladding. This 20% of light travel faster velocity. Consequently, signals of differing frequencies and wavelengths are dispersed and the pulse becomes indistinguishable. Other dispersion is due to different modes of transmission through optical fiber. Thus dispersion compensating device can be used to work with Erbium-Doped fibers for effective DWDM transmission and reduced dispersion. High performance WDM system can be designed using Chirped Fiber Bragg Grating.This paper will present an overview of fabrication, designing of Chirped Optical Fiber Bragg Grating with application in dispersion compensation for high speed communication. We will develop numerical analysis for dispersion compensating properties of CFBG. The sensitivity of chirped, chirp parameter, index modulation and grating length will be examined.

Results: We have done numerical analysis of dispersion compensating properties of CFBG extensively and designed reflective Bragg grating dispersion compensators. We have reduced dispersion to negligible value in the range of wavelength 1500nm to 1600 nm using chirped Fiber Grating. The numerical analysis is done using Runge-Kutta method.

The designed model will produces frequency-dependent time delays in the reflected pulse, and will provides dispersion compensation.

8169-07, Poster Session

Metrology challenges in testing a 45-degrees 50/50 beam-splitter coating

A. Chtanov, M. Gross, S. Dligatch, Commonwealth Scientific and Industrial Research Organisation (Australia)

The design of beam splitter coatings for almost any specification is routine. However, measurement of the performance of these coatings is not necessarily straightforward. Here we describe the rationale behind the measurement of the performance of specified 50±0.1% beamsplitter coating for p-polarized light at 1064 nm and 45 degree AOI on a 300mm diameter silica substrate.

The normal method for measuring such a coating is to take a reference measurement in reflection from some ‘known’ surface and compare this with the actual coating reflection. However, in the present case, all references that can be sufficiently well characterized either have very high or very low reflectance. For example, pure silica, with very well known optical constants, has only ~0.7% reflection under the present parameters. A very high reflectance multilayer coating can be used as a reference, since the reflectance can be made arbitrarily high and certainly above 99.99% under the present conditions. However, the possible reference-to-coating ratios will be at least a factor of 2 and possibly much more. At this level, signal amplifier gain switching errors and optical detector linearity errors are typically above +/-0.5%, which is already well outside the coating tolerance.

In order to minimize the difference between the coating reflected signal and that of a reference surface, the present measurement setup is designed to obtain the ratio of separately measured reflected and transmitted signals. The measurements must be made with a required precision of ±0.05% per reading. In order to be only small contribution to the error in the transmitted signal, the antireflection coating on the rear surface of the substrate needs have a reflectance less than 0.01% or to be known to at least this precision. Since the signals are of almost equal magnitude, detector linearity and amplifier gain errors are small. In addition, all other sources of error, such as polarization purity, and angle of incidence error must be quantified and minimized in order to achieve the desired level of accuracy. Examples of measurements of such a coating are given to show the limits of precision and reproducibility achievable.

8169-38, Poster Session

Extremely aspheric surfaces

Z. Challita, E. Hugot, M. Ferrari, D. Le Mignant, S. Vives, J. Cuby, Observatoire Astronomique de Marseille-Provence (France)

Active optics is a correcting technique of optical defects particularly used in catoptric systems of telescopes and instruments for astrophysical observations. This technique is first of all intended to correct geometrical aberrations led by the optical elements themselves (deformation of optical surfaces under their own weight, thermal variations, etc.). For that purpose, active optics techniques use actuators serving to deform the optical surfaces in a controlled way.

Developed since the 80’s, the active optics is today the object of new developments with the aim of improving its performances and adapting itself to the new instrumental needs, for the ground-based large telescopes, like the future E-ELT (European Extremely Large Telescope), or space-based instruments.

In this perspective, we develop innovative instrumental concepts based on optical surfaces presenting large aspherical coefficients, the amplitude of the deformations reaching several millimetres.

For example, we demonstrated that two very aspheric optical surfaces, with 6 mm of asphericity, can replace a spectro-imaging system consisted of about ten successive group of lenses. With the same resolution and higher sensibility, the obtained system also becomes less complex, easier to align, to calibrate and to control. It will allow to decrease the cost and the dimensions of instruments and to increase the scientific output, while assuring a final optical quality at the level of astrophysical needs.

The work presented here aims to develop a new manufacturing process for this kind of extremely aspherical surfaces, also allowing the necessary high optical quality which cannot be obtained today with classical processes.

The proposed process to allow obtaining such surfaces is based mainly on the Elasticity Theory of materials and the phenomenon of plasticizing, which is the capacity of materials to deform itself, in a permanent way following the applied level of constraints. The first step is to select the best candidate materials from the study of their mechanical properties and the non-linear behaviours which can appear according to the general sizing of mirrors. Finite Element Analysis (FEA) allows bringing to light this particular mechanical behaviour and will make converge the study on an opto-mechanical design and, at mid term, an experimental prototype.

This R&D project is part of European OPTICON program on “Smart Instrument Technologies”, in collaboration with the United Kingdom Astronomical Technology Centre (UKATC), Durham University, plus ASTRON and CSEM as industrial partners.

8169-40, Poster Session

Two-dimensional thickness measurement of a dielectric thin layer on a metal by use of surface-plasmon-resonance-based ellipsometry

T. Iwata, Y. Wada, K. Nishigaki, Y. Mizutani, Univ. of Tokushima (Japan)

In order to carry out precise measurements of the thickness of a dielectric layer deposited on a metal surface two-dimensionally, we have introduced an ellipsometric measurement technique (EMT) to the modified Otto configuration (MOC) that is used for observing surface plasmon resonance (SPR). In the conventional MOC, a planoconvex coupling singlet lens that contacts with the planer air-metal interface at a one point is used, by which the SPR reflectance dip is formed as a two-dimensional circular fringe pattern. In the present study, in order to avoid the unnecessary physical contact between the dielectric layer and the lens, we introduced a thin air-gap layer between them. In addition, we used a cylindrical lens instead of the planoconvex one to enlarge the measurement area. By the cylindrical coupling lens, two SPR dips with parallel straight lines are formed. On locations of the two dips, we can carry out precise measurements in comparison on that without the SPR. In the experiment, we first have measured the thickness of the Au layer basing on a four-layer structure model: prism (BK7)-air-Au-substrate (BK7). Then we have measured that of a TiO_2 layer deposited on the Au layer basing on a five-layer structure model: prism (BK7)-air-TiO_2-Au-substrate (BK7). We have proved experimentally that the combination of EMT and MOC is effective for precise two-dimensional measurements of the thickness of the dielectric layer on the metal.

8169-41, Poster Session

Wavefront instabilities in mirrors with a ground backside

S. Bouillet, T. Lanternier, E. Lavastre, C. Chappuis, F. Macias, Commissariat à l'Énergie Atomique (France)

LMJ and LIL are two French high power lasers dedicated to fusion and plasma experiments. These laser beams involve hundreds of rather large optical components, the clear aperture of the beams being 400x400 mm^2. Among these components, an adaptative mirror is used to correct wavefront distortion in the amplification section. A simple design has been chosen with push/pull actuators glued on the backside of a thin glass plate (9 mm). To ensure the bonding mechanical steadiness, we need enough roughness on this backside. That is why it is ground. We noticed figure instabilities on several of these ground backside substrates. Those wavefront distortions can be of several hundreds of nanometers. We designed a specific mount to avoid the possibility of measurement discrepancies due to mechanical holding. We noticed then significant evolutions over a time-scale of a few months. The possibility of slow stress variations in the ground backside has then been considered. It has been known for a long time that a ground surface is in a compressive state and consequently tends to take a convex shape, this effect being named Twyman effect after its discoverer. Anyway, as far as we know, there is still doubt on the physical mechanisms involved and no publication has been made on the fluctuations of this effect. We wish to expose here the results of preliminary tests that led us to believe that instabilities are also linked to the external stress which is seen during transport or storage. Finally, we present the experimental program we put in place on samples to improve our knowledge on this phenomenon and to test potential solutions.

8169-42, Poster Session

Absolute calibration of three reference flats based on an iterative algorithm: study and implementation

C. Morin, S. Bouillet, Commissariat à l'Énergie Atomique (France)

LMJ and LIL are two French high power lasers dedicated to fusion and plasma experiments. These laser beams involve hundreds of rather large optical components, the clear aperture of the beams being 400x400 mm^2. In order to control the flatness requirements of its optics, the CEA has an 800 mm diameter Fizeau interferometer. Determining if optical components respect the very strict wavefront specifications can be difficult because they have defects which can be equivalent to those of the reference flats. That's why we want to calibrate our reference flats in order to subtract their defects from the performed measurements. This absolute calibration is based on an iterative algorithm requiring three reference flats. In addition to the three basic combinations of the three flats, this method uses rotations and translations of one flat with respect to the others. First, we shall present a characterization of this method. The choice of different parameters, as the operations of translations and rotations required for instance, will be discussed. Moreover, experimental errors have been introduced in the simulations and their limit values have been studied with regard to the other parameters. An application of this method on our three reference flats has been implemented over a 600 mm diameter. An absolute calibration requires a very precise implementation of the measurements and then we will see why data processing is necessary to reduce the residual shifts in translation but also in rotation and in zoom between the different measurements. Lastly, first uses of the absolute maps show a factor 5 to 10 improvement on the final accuracy.

8169-43, Poster Session

Functional test of aspheric beam shaping components for LEDs by experimental raytracing

U. Ceyhan, D. Hilbig, F. Fleischmann, T. Henning, Hochschule Bremen Univ. of Applied Sciences (Germany); D. Knipp, Jacobs Univ. Bremen (Germany)

A new approach for quantifying the properties of freeform optical elements and systems is presented including measurement examples of complex beam shaping optics for LEDs.

The application field for LEDs is rapidly growing resulting in a higher demand for appropriate beam shaping components. Security and navigation light systems would benefit from the advantages of LED but are strongly bound to international regulations which demand extremely well-defined luminous intensity distributions for signal lights. Complex beam shaping components are necessary to adapt the intensity profile of an ordinary LED to such requirements. However, the functionality of these components can not be measured directly due to their intricate shape. Instead, the functionality of the complete system is verified at the final development state.

The proposed method is capable of quantifying the properties of such complex beam shaping components already on the component level with a high dynamic range and without the need for additional reference objects. Its basic idea follows the principle of raytracing where physical rays are sequentially cast through the complete optical system to analyse its properties. Each transmitted ray will be detected at different locations along the propagation direction. The slopes of each ray that passed through the optical system will be determined by linear regression and can be evaluated to obtain various properties as wavefront aberrations, focal length, aspheric surface profiles and the output intensity distribution.

As typical examples, commercial beam shaping components for a naval LED navigation light were investigated with regard to their beam shaping capabilities. The complex samples were composed of 6 working surfaces including one surface with a strong aspherical shape. A direct verification of their optical properties, independent of the LED characteristic, would be impossible with existing technologies.

For the measurement with the proposed method, the device under test was rotated around its pivot axis which is the point where the LED would be positioned at system level. This allows to determine the local ray slopes as a function of the rotation angle. Finally, the intensity distribution as a function of the rotation angle can be calculated from this gradient field.

The results were compared with the original design data and numerical simulations. Samples which do not meet the design specifications could be easily detected already at the component level and the fabrication process could be identified as the actual error source. Subsequent direct measurements of the intensity with the samples already integrated into their final systems approved the results of the experimental raytracer.

The results showed that the proposed measurement method is a valuable tool for design verification, quality assurance and failure analysis in the development of complex optics as demanded by today's LED sector. The experimental results from the beam shaping lens for LED applications verify the potential of the introduced scanning approach.

8169-44, Poster Session

Measurement of the angular diameter of the sun by the Moire technique

F. Jafariani, M. T. Tavassoly, Univ. of Tehran (Iran, Islamic Republic of)

The angular diameter of the sun has been measured by different methods. In our work we have used a pin-hole camera and moiré technique for this measurement . A pin-hole camera is installed to catch the sun light perpendicularly . The image of the sun appears as circular disk . We put a Ronchi grating of pitch q0 on the sun image .Then we installed another similar grating at distance L from the first grating with line exactly parallel to lines of the first grating . the projection of the first grating on the second grating behave like a grating with a pitch slightly larger than q0 because of the divergence of the sun light . Thus , moiré fringes of parallel to grating lines but different pitches are formed . By measuring the moiré pitch and using the well known moiré formula qm= q*q0/(q-q0) one can obtain q . This pitch is related the angular diameter of the sun , α , by α=n*(q-q0)/L where n is the number of the first grating lines in the first image of the sun . by this method we have measured the angular diameter of the sun by few arc second .

8169-45, Poster Session

Ellipsometric characterization of CdTe(111) surfaces subjected to laser irradiation

D. V. Gnatyuk, L. V. Poperenko, I. V. Yurgelevych, National Taras Shevchenko Univ. of Kyiv (Ukraine); T. Aoki, Shizuoka Univ. (Japan)

The optical properties of a surface layer of (111) oriented CdTe single crystals modified by nanosecond laser irradiation have been studied by multiple-angle-of-incidence single-wavelength ellipsometry.

In practical use of CdTe, especially as high-energy radiation detectors, it is important to have a chemically clean and structurally perfect crystal surface for further modification of the crystal surface region (doping, creation of homo- or hetero-junctions, formation of dielectric- or metal-semiconductor interfaces etc.). Besides cleavage along the crystal plane, different surface treatments of CdTe are used, e.g. mechanical or chemical processing, irradiation with laser or high-energy particles and others for etching, polishing, oxidation, passivation or another kind of modification of the surface state.

Recently, nanosecond laser irradiation has been successfully used for many technological procedures under surface treatment of CdTe crystals. However, laser processing of the semiconductor can be accompanied by changes in morphology and structure of the surface layer, formation of elastic fields, etc. In addition, parameters of different faces of (111) oriented CdTe crystals can vary differently under the same kinds of treatment. Therefore, the study of laser effect on CdTe(111) samples is interesting in a practical application of nanosecond laser irradiation for etching, cleaning of the crystal surface, doping of a surface layer, formation of contacts, etc.

The CdTe samples were irradiated with a single pulse (7 ns) of the second harmonic (532 nm) of a YAG:Nd laser with energy density below and above the melting threshold of CdTe in air at room temperature. The ellipsometric measurements were performed both on Cd- and Te-terminated surfaces of semi-insulating CdTe(111) single crystals. The ellipsometric parameters Δ and Ψ were obtained at several light incidence angles and the principal angle ϕ and minimum value of the azimuth Ψ of the restored linear polarization were calculated. The data were interpreted based on the semi-infinite medium model and model of a uniform absorbing surface layer located on an absorbing substrate. In the second model, the surface layer was considered as an equivalent uniform film with flat boundaries and effective optical parameters with taking into account the surface roughness. An increase in the refractive index of the CdTe surface layer after laser irradiation was observed and possible causes of the optical parameter changes in the CdTe crystals are discussed.

8169-21, Session 6

Multimodal high-sensitivity ARS set-up

M. Zerrad, M. Lequime, C. Amra, Institut Fresnel (France)

Losses due to the scattered light are known to be the main limitation of optical components performances, so, identifying and quantifying the scattering sources with an accuracy which allows to characterize “quasi perfect” optical components remains a challenge. In this context, a multimodal Angular Resolved Scattering (ARS) apparatus was developed by our group. The set-up allows to record the Bidirectionnal Reflectance Distribution Function (BRDF) under a tunable illumination wavelength with very high sensitivity. The illumination can be chosen monochromatic or with an arbitrary spectral width and any wavelength can be generated on the whole CCD detection range (400-1000 nm). The set up will be described, its performances and limits will be discussed and we will present how measurements performed with this multimodal set up allows to extract complementary information on the intrinsic structure of the component with an inherent multiscale analysis.

8169-22, Session 6

Symmetry and anisotropy ARS analysis of optical components

A. von Finck, T. Herffurth, M. Hauptvogel, A. Duparré, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Most light scatter distributions of optical and non-optical components can be assumed as isotropic over the reflectance and transmission hemispheres, which allow a sufficient characterization by single in-plane angle resolved scatter (ARS) measurements. However, anisotropic roughness components, complex surface geometries or even a non-zero angle of incidence result in anisotropic light scatter behavior. Typical sample related representatives are ultra-precision (UP) diamond turned and float glass surfaces, gratings and gemstones, which pose difficult or even impossible characterization challenges without full hemispherical measurement capability.

The compact table top system ALBATROSS-TT (3D-Arrangement for Laser Based Transmittance, Reflectance and Optical Scatter meaSurement - Table Top) has been developed at the Fraunhofer Institute in Jena to enable high sensitive measurements of ARS, reflectance and transmittance of arbitrary surfaces, materials and components within the entire 3D-sphere. Anisotropy analysis is demonstrated on ARS measurements of UP fabricated surfaces. A symmetry evaluation method of gemstone cuts is proposed.

8169-23, Session 6

Light scattering based roughness sensor

T. Herffurth, M. Hauptvogel, S. Schröder, A. Duparré, A. Tünnermann, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

To comply the need for a roughness measurement method with in line capabilities, the roughness sensor horos (high sensitive optical roughness sensor) was developed at the Fraunhofer IOF. The light scattering based measurement principle provides a fast, non-contact and robust surface characterization method. The area of application covers quality assessment of polished, ultra-precision, and coated surfaces as well as the characterization of scattering properties of arbitrary surfaces, materials and coatings.

The sensor features a laser diode module operated at 650 nm to illuminate the sample. A CMOS matrix is used to simultaneously record the 3D angle resolved scattering (ARS) within a cone of +/- 5° around the specular reflected beam. Hence, a single measurement can be performed in less than one second. The ARS data is analyzed to evaluate the surfaces nano structure as well as isotropy properties. For optically smooth surfaces, light scattering theories are used to calculate the rms-roughness values and power spectral density functions within the spatial frequency range f = 0.02 ... 0.2 /µm. The sensitivity of the sensor allows the characterization of surfaces with

rms-roughness values down to 0.5 nm.

The measurement principle, uncertainty evaluation, as well as examples of application for diamond turned surfaces and metallic coatings are presented.

8169-24, Session 6

Spectrophotometric bench dedicated to the characterization of micro-patterned optical coatings

S. Sorce, L. Abel-Tibérini, M. Lequime, Institut Fresnel (France)

Characterization of the spectral transmission of micro-patterned optical coatings requires accurate and highly localized measurement means. However, the capabilities of commercial equipments are generally limited, and either they do not provide sufficient spatial and spectral resolution, or they modify the spectral transmittance properties of the sample by using a large half angle illuminating light cone.

In this work, we propose a new approach based on the recording, using a high performance photodiode array camera, of monochromatic magnified images of the sample illuminated by a filtered and fiber-coupled super-continuum laser source. In such case, the spatial resolution is directly given by the size of the individual CCD pixels and by the magnification of the imaging objective, while the spectral resolution is defined by the slit width of the filtering monochromator.

This paper will give a detailed description of the main features of this spectrophotometric bench, and will demonstrate its ability to record the spectral transmittance of patterned samples with micrometer spatial resolution and sub-nanometer spectral resolution in the visible and near infrared ranges.

8169-25, Session 7

SCPEM-based polarization modulation ellipsometry in the NIR

F. Bammer, Technische Univ. Wien (Austria); R. Petkovsek, Univ. of Ljubljana (Slovenia)

For quality control in high volume manufacturing of thin layers and for tracking of fast physical and chemical processes, polarization modulation ellipsometry is a common and fast measurement technology. For such kinds of applications we presented in a former publication a novel approach of fast ellipsometric measurements in the VIS. Instead of a conventional setup that uses a standard photo-elastic modulator, we use a 92 kHz Single Crystal Photo-Elastic Modulator (SCPEM), which is a LiTaO3 crystal with a size of 28 × 9 × 4 mm. This small, simple, and cost-effective solution also offers the advantage of direct control of the retardation via the current amplitude, which is important for the repeatability of the measurements. The light source is a low noise laser diode with 4mW at 635nm. Instead of a Lock-In Amplifier, an automated digital processing based on a fast analog to digital converter controlled by a highly flexible Field Programmable Gate Array is used. This and the extremely compact and efficient polarization modulation allow fast ellipsometric testing where the upper limit of measurement rates is only limited by the desired accuracy and repeatability of the measurements. The standard deviation that is related to the repeatability +/-0.002° for dielectric layers can be easily reached.

Now we present an extension of this measurement from 635nm in the VIS to 1064nm in the NIR. For that a low noise Nd:YAG laser is used. As a special difficulty it turned out that most photodiodes, even that specified for very high slew rates are not able to track the modulation in the 100 kHz-range of the reflected light in the NIR, whereas no problem was encountered in the VIS. The problem was reduced with extremely fast photo-diodes, however it seems, that for accurate measurements an additional frequency dependent amplitude decrease and phase shift must be taken into the calculation.

The final goal is to compare results at these two different wavelengths with special focus on materials from photo-voltaic production. Since many of these are optimized in the VIS for high transmission or high absorption, VIS-ellipsometry is not useful in this field.

We expect that a fast and compact NIR-SCPEM-ellipsometer can be a cost-effective and important control device in this industry.

8169-26, Session 7

Roughness characterization of large EUV mirror optics by laser light scattering

M. Trost, S. Schröder, T. Feigl, A. Duparré, A. Tünnermann, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Optical components for EUV-lithography at 13.5 nm face challenging demands for high throughput, optimal imaging properties, and long-term stability. This leads to tremendous requirements on the surface finish. While low- and mid-spatial frequency roughness components degrade the image contrast, high-spatial frequency roughness (HSFR) leads to increased losses. Even small amounts of surface and interface roughness can be critical at this short wavelength. Therefore, characterizing the surface roughness over the entire range of relevant spatial frequencies is of crucial importance.

Unfortunately, classical metrology tools like atomic force microscopy are often limited because of the large dimensions of EUV optics. This limitation can be overcome by light scattering measurements, because of the contactless data acquisition. An instrument has been developed at Fraunhofer IOF that is capable of performing scatter measurements even on large and curved optics. The high sensitivity to roughness (down to 0.1 nm rms) and robustness of this method is exemplified for a 660 mm diameter EUV collector mirror substrate. Through Angle Resolved Scattering measurements at a wavelength of 405 nm the Power Spectral Density of the surface was determined over the entire sample and HSFR roughness maps were determined. Moreover, the EUV reflectance of the entire multilayer mirror can be predicted prior to the coating process.

8169-27, Session 7

3D features measurement using YieldStar: an angle resolved polarized scatterometer

P. J. Leray, A. Charley, K. D'havé, S. Y. Cheng, IMEC (Belgium)

Metrology on 3D features like contact holes (CH) is more challenging than on lines and spaces (L/S) structures especially if one wants to have profile information. Scatterometry has been widely used on L/S structures and has enabled characterization of lithographic features providing with critical dimensions (CD) as well as feature height and side wall angle. In this paper, we will present the application of scatterometry to the measurement of 3D structures using an angle resolved polarized scatterometer: ASML YieldStar S-100. Contact hole measurements will be presented and correlation to standard metrology tools will be shown. Measurement capability will be discussed in terms of reproducibility, calculation time, sensitivity of the parameters of interest and correlation between them leading to a proper model choice. Finally initial results on more complex 3D features (line ends, brick walls,...) will be presented.

8169-28, Session 7

Impact of surface roughness on the scatter losses and the scattering distribution of surfaces and thin film coatings

S. Schröder, T. Herffurth, A. Duparré, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); J. E. Harvey, CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States)

The estimation of the impact of surface roughness onto the light scattering losses and the scattering distribution is of crucial importance for deriving roughness specifications for optical surfaces. A detailed roughness analysis should always be based on surface Power Spectral Density functions and band-limited roughness relevant for the applica-tion at hand. The scatter losses of a single surface

can easily be estimated using simple formulas. The most com-monly used expression, however, is only valid if the roughness is small and the correlation width is large compared to the wavelength of light. A special expression has been used in the thin film community for surface structures with short correlation lengths. It will be demonstrated that distinguishing between these limiting cases is unnecessary simply by using the concept of band-limited roughness. Predicting the influence of roughness onto the optical prop-erties of thin film coatings is also more complicated because of the large number of parameters involved. Simplified models that enable the scattering of thin film coatings to be predicted depending on the deposition process will be discussed. The modeling results will be compared to results of light scattering measurements performed using in-struments developed at IOF for total and angle resolved scatter measurements at various wavelengths in the visible, infrared, as well as the deep and the extreme ultraviolet spectral ranges.

8169-29, Session 8

Large scans without stitching: the nanometer coordinate

H. Rothe, Helmut-Schmidt Univ. (Germany)

No abstract available

8169-30, Session 8

Measurement & analysis of large ultra-precision parts with the Isara 400 CMM

I. Widdershoven, H. Spaan, IBS Precision Engineering bv (Netherlands)

There is a growing demand for 3D coordinate metrology with nanometer-level measuring uncertainty. Various ultra-precision CMMs with small measurement volumes (axes ranges of 100 mm or less) have been developed, but no measurement machine currently enables the measurement of larger products in full 3D with nanometer-level accuracy. To fulfil this demand, IBS Precision Engineering has developed and realized a new ultra-precision CMM with an unprecedented measurement-volume / measurement accuracy ratio.

The current work describes the full calibration of this machine and several test measurements. The main target specifications are a measuring volume of 400 x 400 x 100 mm and a measuring uncertainty of 45 nm (2 sigma) per axis over the full measurement length.

The measuring principle of the Isara 400 CMM conforms to the Abbe principle in full 3D. This means that the position measurements of all three (x,y,z) machine axes are always performed in line with the functional measurement point. The axis positions are measured using laser interferometers; the laser beams to need be aligned to the common "Abbe point". The tip of the touch probe system also needs to be aligned to this point. A specific chain of alignment steps is applied to achieve this, using some special reference artefacts and alignment tools.

Isara 400 uses a mirror table as a reference for all measurements. The flatness and perpendicularity of the three mirrors of this table are calibrated on the machine itself by measuring a calibration block. Three sides of this block are measured on the machine using a capacitance sensor. As the flatness deviations of the block have been optically calibrated with an absolute uncertainty below 10 nm, it is possible to determine the flatness deviations of the mirror table and to compensate accordingly.

Several test measurements were performed on an optical flat and (a) spherical artefacts, using the newly developed "Triskelion" touch probe system. This 3D probe achieves a measurement error better than 10 nm (2σ) for each axis direction. A new probe with a miniature probe tip with a radius of only 36 µm, is the latest innovation in this series of touch probe systems. This new probe has also been fully realized and is being tested.

The laser alignment, the calibration of the mirrors and the implementation of the Triskelion touch probes make the realization of the "Isara 400" complete. The "Isara 400" is thus ready to for its ultimate application, the measurement of larger products with a measuring uncertainty in the nanometer range.

8169-31, Session 8

Advanced PSD-analysis of optical surfaces by mid- and high-spatial frequency metrology

L. Coriand, A. Duparré, A. Tünnermann, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Roughness structures in the micro- and nano-range are of crucial importance for optical and functional surface properties. On the one hand a systematically minimized surface roughness is required (e.g. polished glass surfaces), on the other hand desired functionalities can be achieved only by well-defined roughness characteristics (e.g. wetting properties like superhydrophobicity or anti-fog). This results in increased requirements for characterization methods and analysis techniques, for which common parameter like rms-roughness do not comply with. In contrast, a description of stochastic micro- and nanostructures by Power Spectral Density (PSD) functions based on optical and non-optical measurement techniques yield an advanced roughness characterization: PSD functions gives quantitative information about vertical, as well as lateral distribution of roughness components. Analysis over a wide spatial frequency range through combination of PSDs from different scan areas and different measurement techniques are possible. Furthermore, PSDs enables a reliable link between the surfaces roughness and other surface properties (wetting, light scattering).

Examples for the roughness characterization using atomic force microscopy and white light interferometry of optical substrates and thin films are demonstrated. We also present a short overview of our analysis methodology for superhydrophobic surfaces.

8169-32, Session 8

Non-contact measurement of aspherical and freeform optics with a new confocal tracking profiler

A. Pinto, Sensofar-Tech, S.L. (Spain); F. Laguarta, R. Artigas, C. Cadevall, Univ. Politècnica de Catalunya (Spain)

We introduce a new non-contact technique for the measurement of aspherical and free-form optics. It can be considered the optical, non-contact equivalent of a conventional, mechanical contact profiler.

INTRODUCTION

Manufacturing technologies for optics have evolved rapidly in the latest years due to a demand for ever-complex optical surfaces to be machined. In parallel, requirements for the metrology for such parts have also tightened. Desirable features for such metrology systems are: non-contact, high accuracy and fast measurement speed. The technology we introduce in this contribution, confocal tracking, fulfils them all.

CONFOCAL TRACKING

Slit confocal technology together with high numerical aperture objectives are used to determine focus to a high degree of accuracy.

Initially the sample is focused at the desired measurement initial position. Then it is moved horizontally at constant speed using an air-bearing stage and a closed-loop system drives the sensorhead in a coordinated move along the vertical axis in such a way that focus is kept all the way at the center of the image until the desired measurement length is reached. The sample profile is reconstructed from the moves executed by the horizontal and vertical stages.

This technique provides an accuracy of less than 100 nm and can achieve measurement speeds of 1 mm/s typically or even larger. Depending on sample geometry a microscope objective that can reach slopes up to 65° can be used.

For this technology to reach sub-100 nm accuracy high-quality components have to be used as any departure from ideal move, say flatness and straightness errors, will be superimposed to measured data.

A unique feature that this technology provides is the fact that the system can determine the center of the lens automatically without the need to carry out a measurement. It takes advantage of the fact that is it an image based technique.

8169-33, Session 8

Phase-shifting fringe projection system using freeform optics

S. Zwick, P. Kühmstedt, G. Notni, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Phase-shifting fringe projection is one of the most effective methods for 3D-shape measurement. Conventional phase-shifting fringe projection systems are based on a digital projector, which is imaging fringes into the object plane. These systems are mainly limited to the spectral range of visible light, as projectors in UV or IR-range suffer from technical problems. However, for certain applications especially these spectral ranges may be of interest.

In this contribution, we introduce a novel fringe projection principle by using free-form mirrors. Here, the fringe pattern in the object plane is generated by a single, especially designed free-form mirror, which has been fabricated in a diamond turning process. Phase-shifting can be done by a slight mechanical displacement or rotation of the free-form in respect to the object. This novel principle is wavelength independent as no additional projection optics is needed and therefore applicable in UV and IR spectral range. As only one single optical element is needed, the system is very compact and cost efficient.

In contrary to conventional systems, the beams shaping is done by a ray-optical redistribution of light comparable to classical beam shaping. Therefore it is highly energy efficient. However, it is not comparable to classical imaging, which leads to different criteria of evaluation. Criteria like depth of focus or resolution cannot be estimated in the classical way.

We present the concept and design of this novel fringe projection system. A first setup to proof the principle and a first characterization concerning the quality of the sinusoidal fringes are demonstrated.

8169-34, Session 9

Data handling and representation of freeform surfaces

R. Steinkopf, A. Gebhardt, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); L. Dick, JENOPTIK Polymer Systems GmbH (Germany); T. Kopf, S. Risse, R. Eberhardt, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

State of the art optical design tools are computing with powerful algorithms to simulate freeform surfaces. Even new mathematical approaches are under development /1, 2/. The new optical designs are pushing the manufacturing consequently and novel types of datasets have to proceed through the process chain. The complexity of these data is the huge challenge for the data handling. Because of the asymmetrically 3-dimensional surface, large data volumes have to be created, trimmed, extended and fitted. All these processes have to be performed without loss of design data. Additionally results different types of geometries in different kinds of mathematical representations of freeform surfaces and furthermore the used CAD/CAM tools are dealing with a set of spatial transport formats. These are all reasons why manufacture-oriented approaches for the freeform data handling are not yet sufficiently developed.

This paper suggests a classification of freeform surfaces based on the manufacturing methods which are offered by diamond machining. The different manufacturing technologies, ranging from servo-turning to milling or shaping, require a differentiated approach for the data handling process. The usage of analytical descriptions in the form of splines and polynomials as well as the application of discrete descriptions like point clouds is shown in relation to the previously made classification. The data handling from the optical design to the assembly process is demonstrated by using a typical example. Thereby advantages and disadvantages of freeform representations are discussed. Aspects of the data preparation between different process steps are pointed out and suitable exchange formats for freeform data are proposed.

The described approach offers the possibility for efficient data handling from optical design to fabrication and characterization of optical freeforms in novel optical systems.

[1] V. Oliker, “Mathematical aspects of design of beam shaping surfaces in geometrical optics,” in Trends in Nonlinear Analysis, M.Kirkilionis, S.Krömker, R.Rannacher, and F.Tomi, eds. (Springer-Verlag, 2002), pp. 191-222.

[2] Michaelis, D. et. Al.; “Cartesian Representation of Freeforms in Illumination Systems”, accepted in Opt. Letter, 2011

8169-35, Session 9

Adaptive two-beam interferometer for testing optical surfaces

J. Novak, P. Novak, A. Miks, Czech Technical Univ. in Prague (Czech Republic)

Our work is focused on measurements of the topography of optical surfaces using two-beam interferometry combined with an adaptive optics system. Classical two-beam interferometric methods use a comparison of test and reference wavefronts by means of interferometry. Flat or spherical wavefront is usually used as the reference wavefront. In case of testing spherical optical surfaces with different curvatures it is necessary to use different types of accurate and expensive spherical reference objective lenses of the interferometer. In case of testing surfaces of an aspheric shape it is necessary to use special null-optics systems or synthetic diffraction elements which generate a tailored reference wavefront. The aim of this work is to design an interferometric system that will adapt the shape of the reference wavefront to the shape of the measured optical surface. The designed adaptive two-beam interferometer uses the deformable mirror MiraoTM52 from ImagineEyes for a generation of the reference sphere and it can be applied for measurements of flat and spherical surfaces and even for measurements of free-form surfaces. We perform a detailed analysis of this technique and several possible measurement setups and principles of measurement and calibration of the designed adaptive interferometer are described. The principle of measurement is shown on an example of the experimental set-up of the adaptive interferometer.

8169-36, Session 9

Adaptive null test system using a ferrofluid deformable mirror

D. B. Landry, D. Brousseau, S. Thibault, E. F. Borra, Univ. Laval (Canada)

With the growing number of complex-shaped lenses, aspheric and freeform surfaces, the demand for an appropriate and cost effective measurement technique to test high quality components is still very high. Active null test system using active optical component like liquid crystal programmable spatial light modulator (SLM) is a versatile testing scheme which has been studied during the last few years. For such application, the ability to measure optics with high level of accuracy, repeatability and robustness is essential for the development of such active null testing system. Ferrofluid deformable mirrors (FDMs) offer a promising alternative. The deformable liquid mirror can produce surfaces having very large deformations with accuracy of tenths of wavelength. However, such accuracy has only been demonstrated in a closed-loop system which is inappropriate for metrology applications because it requires an additional measurement instrument that makes the whole system complicated. Consequently, the task is to find an open-loop driving technique that maintains good precision while being simple, robust and stable.

In this paper, we present a new active null test system based on a FDM for the testing of deep aspheric surfaces. We show a new driving method which provides an accurate open-loop operation mode of the FDM. To predict the surface of the deformable mirror, we usually use the normalized actuators influence functions scaled according to the surface to be generated. The main drawback of this approach for open-loop is that one has to deal with scaling residual errors. For open-loop operation in metrology, we need a more accurate FDM surface prediction model. We use a lookup table that contains the influence functions of that FDM, measured at different driving conditions and/or different coupling conditions. We demonstrate that we have a significant improvement in comparison with the normalized influence function technique. The absolute error is no longer scaled

with actuator input. Several parameters have been explored to obtain the best accuracy. The results are encouraging enough for considering an active null test configuration to measure optics having high departures or complicated continuous surfaces. This new active null test system can also be used to test optical systems.

8169-37, Session 9

Optical method for the surface topographic characterization of Fresnel lenses

J. C. Martinez-Anton, J. Alonso Fernandez, J. A. Gomez Pedrero, J. A. Quiroga, Univ. Complutense de Madrid (Spain)

Fresnel lenses and other faceted or micro-optic devices are increasingly used in multiple applications like solar light concentrators and illumination devices, just to name some representative. However, it seems to be a certain lack of adequate techniques for the assessment of the performance of final fabricated devices. As applications are more exigent this characterization is a must. We present a technique to characterize the surface profile of Fresnel lenses and validate the expectations for the fabricated device. The method is based on a new photometric strategy able to codify the height information in terms of optical signal. A detailed topographic map is simple and fast to acquire. A height resolution of few microns is possible depending on several factors that we analyze. Some experimental cases are presented to validate this approach.

Conference 8170: Illumination Optics II

Wednesday-Thursday 7-8 September 2011

Part of Proceedings of SPIE Vol. 8170 Illumination Optics II

8170-01, Session 1

Boundary conditions for balancing light in tailoring freeform surfaces

H. Ries, OEC AG (Germany)

Freeform surfaces suitable for illumination tasks can be designed by 3d-tailoring. The underlying the Monge-Ampere PDE are well known, whereas the boundary conditions have not yet been extensively investigated. In this contribution we present several alternative boundary conditions which ensure that the total desired power on target matches the available power from the source. This is a necessary and sufficient condition for the existence of a unique solution. We present pros and cons of each alternative, relative to the type of problem and show the resulting solutions for selected examples.

8170-02, Session 1

Field method for dielectric concentrator design

A. Garcia Botella, Univ. Politécnica de Madrid (Spain); A. A. Fernandez-Balbuena, D. Vázquez-Moliní, Univ. Complutense de Madrid (Spain)

Field method, also called geometrical vector flux field method, is a well established technique to design concentrators [1] and in general nonimaging optical systems. The method is based on building reflective concentrators with the geometry of field lines, these concentrators do not disturb the flux field and become ideal [2]. In this paper we study the properties of surfaces orthogonal to the field vector J. For rotational symmetric systems J is orthogonal to its curl, then exist a family of surfaces orthogonal to the lines of J, surfaces of constant pseudopotential [3]. From the definition of J, pseudopotential surfaces can be interpreted as surfaces of maximum flux density and can play an important role in the design of nonimaging systems. We study refractive concentrators with the geometry of pseudopotential surfaces. Dielectric material modifies the field lines and then the geometry of the system, including compactness and reflective parts, it also introduce total internal reflection which must be considered in the design. We apply this concept to study hyperbolic concentrator modified with pseudopotential refractive optics and we shown that it achieves the theoretical limit of concentration.

[1] A. García-Botella, A. A. Fernández-Balbueana, D. Vázquez, E. Bernabeu, A. González-Cano, "Field method for concentrator design", Nonimaging Optics: Maximum Efficient Design for Illumination and Solar Concentration VI (R. Winston, J. M. Gordon) Proc. SPIE, Vol. 7423, 63-73, 2009.

[2] R. Winston, W.T. Welford "Ideal flux concentrators as shapes that do not disturb the geometrical vector flux field: A new derivation of the compound parabolic concentrator", Journal of the Optical Society of America, 69 (4), 536-539, 1979.

[3] J. T. Winthrop "Propagation of structural information in optical wave fields", Journal of the Optical Society of America, 61 (1), 15-30, 1971.

8170-03, Session 1

New iterative flux-based design strategy for freeform surfaces generation in led-lighting systems

J. Arasa Marti, E. Oteo, J. Fernandez-Dorado, Univ. Politècnica de Catalunya (Spain); P. Blanco, SnellOptics (Spain); C. Pizarro, Univ. Politècnica de Catalunya (Spain); J. A. Diaz, Univ. de Granada (Spain)

The new generation of outdoor and indoor lights will be dominated by the LED technology. The LED lights can have low energy consumption and high performance characteristics if an efficient and correct light distribution is reached [1,3]. However, the intensity distribution is not always the optimum to most of applications. This is why new optical designs have to be done to take whole advantage of LED lights [2,4,5,6,7].

We present a new algorithm to calculate an optimized refractive freeform surface for illumination purposes with a LED source. The algorithm considers the energy emission pattern [8] of the LED and adjusts a plastic refractive surface to achieve the fixed target intensity distribution.

The algorithm uses finite elements to adjust the external refractive surface and has been developed to consider either reflection or refraction conditions in all the surfaces of the lens. A collection of rays departing from the source is created and the rays are traced to the surface position. The internal surface (near to the led source) is considered spherical and is divided in elements small enough so their size is below the fabrication resolution. For each ray arriving to the surface, the normal vector of the surface in the corresponding element is optimized with a merit function that considers the flux energy of the ray and the outgoing target intensity distribution as well as the result of the previous elements calculus.

From the resulting elements with its new normal vectors the surface shape is raised and a NURBS is adjusted. The three-dimensional optical element with this freeform is created in a CAD environment and is then ready to be simulated in standard optical simulation software for its performance analysis.

This algorithm has been firstly tested in a refractive lens whose longitudinal and transversal profiles have been obtained by this process and a 3D surface is generated using both 2D profiles and a squared cosine interpolation. The resulting lens has been simulated and successful results have been obtained.

[1] Michael R. Krames, Oleg B. Shchekin, Regina Mueller-Mach, Gerd O. Mueller, Ling Zhou, Gerard Harbers, and M. George Craford, "Status and Future of High-Power Light-Emitting Diodes for Solid-State Lighting," J. Display Technol. 3, 160-175 (2007).

[2] Scientifical and Technical basis in optical design for embedded leds in energy saving streetlights. J.Fernández-Dorado, Esther Oteo , P. Blanco , Carles Pizarro , J. Arasa, J. Caum, Nuria Tomás. European energy conference, 2010.

[3] Conception and design of illumination light pipes. Thèse. Juan Manuel Teijido, Neuchâtel, février 2000.

[4] "Etendue-preserving mixing and projection optics for high-luminance LEDs, applied to automotive headlamps" Aleksandra Cvetkovic, Oliver Dross, Julio Chaves, Pablo Benitez, Juan C. Miñano, and Rubén Mohedano

[5] Zexin Feng, Yi Luo, and Yanjun Han, "Design of LED freeform optical system for road lighting with high luminance/illuminance ratio," Opt. Express 18, 22020-22031 (2010)

[6] Automating design of free-form optics for LED lighting, Bo Yang, 25 February 2008, SPIE Newsroom

[7] Holden Chase, Optical design with rotationally symmetric NURBS, Proc. SPIE 4832, pp. 10-24, 2002

[8] Simulating the irradiance and the efficiency of the LED and fluorescent lights used in indoor lighting design.Tsuei, Chih-Hsuan; Pen, Jui-Wen; Sun, Wen-Shing. Optics Express, Vol. 16 Issue 23, pp.18692-18701 (2008)

8170-05, Session 1

Spiral optical designs for nonimaging applications

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

Many optical designs present several 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 (i.e. illumination applications), these restrictions may limit the optical efficiency of the system or affect the

generation of undesired artifacts on the illumination pattern.

For this important reason we present here a novel design concept, in which optical 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. 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 process renders very easy.

This new manufacturing concept is especially useful when dealing with faceted optical elements such as Fresnel or TIR lenses, widely used for nonimaging applications. In this way optical surfaces are calculated as free-form surfaces describing a spiral trajectory around z axis (each facet converting into the adjacent one after each turn around z axis). For faceted elements, it is possible to use this technique even when designs present a cross section with negative draft angles, in this way 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. Several new spiral designs, whose 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.

8170-32, Session 1

Tolerancing free-form optics for illumination

A. L. Timinger, S. Junginger, J. Unterhinninghofen, OEC AG (Germany)

Free form surfaces allow elegant solutions in illumination optics. A complex function of the system can be achieved by a single optical element.

Free-form elements are usually manufactured by reproduction techniques, such as injection moulding of plastic. Manufacturing tolerances are crucial to maintain the required function while at the same time yielding the lowest possible price at the same time.

We implemented a Monte Carlo tolerancing method for illumination systems. Tolerances include shape deviations of optical elements and assembly tolerances.

In the absence of standards for free-form tolerances and illumination optics tolerancing, communication between optics design, manufacturing and testing is often inefficient.

In order to enable a highly automated evaluation of part measurement data to assess compliance with tolerances, we developed an approach to combine information from optics design, mechanical construction, manufacturing and testing into one continuous data chain.

The research project is granted by the German Ministry of Education and Research.

8170-06, Session 2

A review of beam shaping strategies for LED lighting

F. R. Fournier, Synopsys, Inc. (United States)

Light emitting diodes are routinely used for general and specialized lighting tasks such as automotive headlights, streetlights, luminaires, and medical illuminators. Because of their small size and directionality, LEDs enable unique light collection and shaping techniques. This paper reviews strategies that can be used to shape light according to a desired target distribution given target uniformity and system compactness constraints imposed by each application. We address design techniques for LED secondary optics, including TIR lenses, freeform reflectors, and lens and mirror arrays.

8170-07, Session 2

Automotive headlamp concepts with low-beam and high-beam out of a single LED

P. Brick, T. Schmid, OSRAM Opto Semiconductors GmbH (Germany)

Recent years have seen a surge in LED-based automotive headlamps including a variety of lighting functions like low-beam, high-beam, day-time running light as well as fog-light. Many of those lighting functions have been realized by designs that statically provide specific illumination patterns. In contrast, existing adaptive designs rely on either moving shutters or electronically-complex matrix sources.

In this talk, alternative options will be explored for an automotive headlamp that combines low-beam and high-beam out of a single LED.

The light source comprises two rows of chips arranged on a common carrier resulting in a compact LED. At the same time, electronic complexity is reduced by driving just the two rows independently.

Primary optics collects the emission of the two closely-spaced chip rows and simultaneously provides a way to separate respective contributions. The subsequent secondary optics is based on facetted reflector shapes to realize low-beam and high-beam patterns.

Efficiency, tolerances, system size, and cross talk will be evaluated for different primary optics based on refraction, reflection as well as TIR.

8170-08, Session 2

Novel signal light using a freeform reflector design

L. Chen, G. Keiser, National Taiwan Univ. of Science and Technology (Taiwan)

Traditional signal lights for traffic control are designed from old-fashioned lamp LEDs. The light source output points towards the road, so when any LED, electric circuit, or electric component is broken, one will see obvious dark spots. Moreover, the electric circuits are parallel rows of series-connected LEDs, so if one LED is broken it can disable the whole series circuit, which results in a noticeable dark area. The Novel Signal Light (NSL) design addresses these issues. The NSL design uses indirect light that comes from a surface mount device (SMD) LED and is distributed by a reflector, so human eyes will not see the light source directly. Therefore, if an LED or other component is broken, no dark spot is seen in the distributed light. Many LEDs and electronic components are combined on the same light dish in a traditional signal light design. Therefore, every time there is a failure, it is difficult to determine whether the LED or the circuit is broken. However, in the NSL the LED module is separated from the constant-current power supply module. Thus another advantage of this design is that if anything is broken, the faulty parts can be located easily and then be repaired or replaced. The reflector design was done with geometrical optics. We assume the light source is an ideal source. The reflector needs to deflect the ray parallel to the Z axis. Generally, the design of a collimator reflector uses a parabolic equation, but this approach cannot limit the mechanism size. However, because the specifications for traffic signal lights limit the mechanical size, the design must be made in accordance with the standard rule. For this reason, the reflector design uses the freeform surface approach, which uses a point-by-point calculation to draw and make the reflector surface.

8170-09, Session 2

Design of high-efficient freeform LED lens for road illumination

M. A. Moiseev, L. L. Doskolovich, N. L. Kazanskiy, Image Processing Systems Institute (Russian Federation)

Nowadays for illumination of elongated rectangular areas (such as a road surface) LED optics with single freeform refractive surface is usually used but it cannot provide high light efficiency. As an example, for the case of Lambertian light source, 10 meters source - target plane distance and 50 meters by 8 meters illumination region size the maximal light efficiency that can be reached with use of the single surface optics is less than 60%. The reason is the performance limitations of the refractive surface in terms of ray rotation.

We suggest a new LED secondary optics design that provides high light efficiency (up to 92%) and makes possible generation of required irradiance distribution in elongated rectangular region. This design is intended for road illumination systems. It assumes that the LED lens includes two refractive surfaces. The internal, bottom surface is a cylindrical surface and can be computed analytically. It generates a cylindrical wave front inside of the optical element from the light source's spherical wave front. The lateral part of the internal surface works on the total internal reflection principle and allows to redirect all the light flux from the light source to the target area. The external, upper surface is a freeform surface. It redistributes the light flux from the incident cylindrical beam and generates the prescribed irradiance distribution in the target plane. The external surface is computed with the use of special optimization method. We represent the external surface by a bicubic spline function. In this case the optimization parameters are the values of function, its first derivatives and its mixed derivative in the spline nodes. For optimization purposes the Broyden-Fletcher-Goldfarb-Shanno gradient method is used. The merit function is the root-mean-square deviation of the produced irradiance distribution from the required one. Solving the optimization problem requires the solution of the direct problem. The direct problem consists in computation of the irradiance distribution in the target plane produced by the prescribed optical element. We obtained the analytical expression for the irradiance distribution.

Two optical elements, that produce uniform irradiance distribution from the Cree® XLamp® XP-G light-emitting diode, were designed with the use of the proposed approach. The light efficiency of elements is more than 85% while nonuniformity of generated irradiance distribution is less than 5%-10%. The illuminated area sizes correspond to the road surface size (50 meters by 12 meters and 50 meters by 6 meters). The performance of the designed optical elements was compared with the performance of commonly used freeform optics that has only one working freeform refractive surface. The simulation results show that the usage of the proposed LED secondary optics design provides at least 20%-35% increase of the light efficiency in the case of elongated rectangular area (like road surface or hall floor) illumination.

8170-10, Session 2

Optical design of adaptive automotive headlight system with digital micro-mirror device

C. Tsai, Kun Shan Univ. (Taiwan); Y. Fang, National Kaohsiung First Univ. of Science and Technology (Taiwan)

This paper propose an optical design of adaptive automotive headlight system with advanced light-emitting diodes (LEDs) and digital micro-mirror device (DMD). In recent days, safety of on-road drive plays the role at automotive industries so that fast response of adaptive automotive headlight system becomes a critical issue especially in mountain road drive. In order to integrate the function of low and high beam into a single headlight without sacrifice of volumetric size of whole system, a DMD is employed in this optical design. Simulation shows that new optical design not only promotes light efficiency but also reduce volumetric size. Besides, light from adaptive automotive headlight system could make the projected light much suitable for drivers according to individual driver's vision experience. Results show that volumetric size of all system might be reduced up to 30 percent but light efficiency could be promoted up to 20 percent.

8170-11, Session 3

Design of extreme anamorphic laser illumination systems

A. M. Herkommer, Univ. Stuttgart (Germany); H. Münz, Carl Zeiss Laser Optics GmbH (Germany); R. M. Reichle, Univ. Stuttgart (Germany)

Many laser applications, for example material processing or fluorescence imaging, require uniform illumination over a rectangular, slit shaped area with extreme aspect ratio: The short dimension of the illumination field typically requires diffraction limited imaging, respectively focusing, on a micrometer scale. In contrast the extension in the long dimension can be hundreds of millimeter. This class of systems requires a highly anamorphic system design for the homogenization as well as for the projection of the illumination pattern. Aberrations within the projection optical system, as for example induced by cylindrical optical components, need to be analyzed and controlled. In some cases the application additionally requires the substrate to be illuminated under some tilted angle, which requires specific solutions within the optical design. The presentation will illustrate corresponding design examples and solutions for this class of illumination systems.

8170-12, Session 3

Near-infrared laser illuminator for very long-range flash active imaging applications

Y. Lutz, N. Metzger, Institut Franco-Allemand de Recherches de Saint-Louis (France)

For very long-range flash active imaging applications, a powerful and narrow beam divergence pulsed laser illuminator is needed. Conventional high fill factor 1-centimeter diode bars are not well suited to produce a homogeneous and narrow beam divergence in an easy way. In the present paper, a concept based on a QCW nibars laser diode stack, focusing lenses and beam homogenisation is presented. With fifteen 1.5 mm conductively cooled fast axis collimated mini bars, a peak power of 803 Watt at a wavelength of 810 nm is achieved with a maximum duty cycle of 2 percent. After collimation, the laser beam on the scene shows very homogeneous rectangular illumination geometry with a ratio of 4:3 well adapted for active imaging purposes. The beam divergence is reduced to 3.35 2.53 mrd with a two lenses objective of focal length f = 573 mm and f-number f# = 4.8

8170-13, Session 3

A laser speckle reduction system

J. M. Cobb, Corning Tropel Corp. (United States)

Interferometers commonly incorporate speckle reduction systems. These systems often use spinning diffuser discs to mix multiple speckle patterns within the capture frame of the camera system. This paper will discuss a novel method of speckle reduction that reduces the vibration of these systems while increasing the speed so that faster cameras can be used. The experimental apparatus and the results will be presented.

8170-15, Session 3

Mask aligner process enhancement by spatial filtering

U. Vogler, A. Bich, SUSS MicroOptics SA (Switzerland); L. Stürzebecher, U. D. Zeitner, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); R. Voelkel, SUSS MicroOptics SA (Switzerland); M. Hornung, SUSS MicroTec Lithography GmbH (Germany)

Mask Aligners are used in the Semiconductor Industry to transfer structures with moderate resolution requirements onto substrates. With the casting of the shadow a photochemical reactive resist is exposed. As diffraction appears at the mask structures the exposure wavelength and the proximity gap between mask and wafer influence the quality of the image in the resist. As both parameters are very often not changeable for processes there was a big need to find another way to improve the resist image. In this paper a new approach to enhance the exposure result will be presented. Instead of one Kohler Integrator with macroscopic lenses the novel MO Exposure Optics uses a combination of two microlens Kohler Integrators. The combination of both guarantees that the illumination settings are not affected by the adjustment of UV light source anymore and it ensures extremely uniform angular spectrum over the whole mask plane .

The adoption of a large area Kohler Integrator enables spatial filtering. In this paper different practical approaches for the spatial filtering are presented and analysed in regard of the optical characteristic of the light source, e.g. by means of the etendue.

Finally, we demonstrate the improved quality of the aerial image by the spatial filtering and discuss the new application spectrum of mask aligners given by the combination of SMO, simulation and advanced mask aligner lithography tools like Talbot-lithography and diffractive mask elements.

8170-16, Session 4

Optics detailed analysis of an improved collimation system for LED light sources

D. Vázquez-Moliní, M. González Montes, A. A. Fernandez-Balbuena, Univ. Complutense de Madrid (Spain); A. Garcia-Botella, Univ. Politécnica de Madrid (Spain); E. Bernabeu Martinez, Univ. Complutense de Madrid (Spain)

The improved efficiency of light emitting diodes has made it possible that Lighting LED systems have been developed for applying them in many fields in which a few years ago it was unaproachable. Nowadays it is possible to find in the market a lot of different optics devices which use Led as light source. The lighting industry is changing its old catalogues to new ones with a main role for LED systems. Many research centres and companies are developing specific optic systems for this kind of light sources in which they optomize peak intensity, efficiency, output flux, uniformity and so on. The size of these light sources makes it possible to design more compact devices. Collimation optics systems are a kind for which the market demands new solutions. In this work we studied the possibilities and limits of a collimation device developed at Optics Department of Universidad Complutense de Madrid. We show the relations between design parameters, size constraints, materials and tolerances on the final behaviour of the collimation system.

8170-17, Session 4

Metal-less V-groove RXI collimator

D. Grabovickic, Univ. Politécnica de Madrid (Spain); J. C. Miñano Dominguez, P. Benítez, Light Prescriptions Innovators Europe, S. L. (United States)

A metal-less RXI collimator has been designed using the Simultaneous multiple surface method (SMS). The collimator is completely made of plastic (PMMA) and does not include any mirrored surface, unlike to the convectional RXI collimators, whose back surface is metalized to provide a specular reflection. The back surface of the V-groove RXI is designed as a grooved surface providing two TIR reflections for all rays impinging on it.

The LED and the collimator are separated by an air gap. A ray coming from LED refracts first at the entrance surface, then reflects at the front surface by TIR, and reaches the back surface. There, on the back surface, the ray is reflected twice by TIR at each groove side and redirected toward the front surface, where the ray will be refracted again. Considering the ray path from the LED, each ray suffers five deflections: a refraction, three total internal reflections, and again refraction. Thus, this design can be named RI3R collimator.

The main advantage of the presented design is lower manufacturing cost since the entire collimator is made of plastic, and there is no need for the expensive process of metalization. The price is especially low in the case of mass production using injection molding machines.

Also, unlike to the conventional RXI collimators this design performs good colour mixing. This means that RGB LED chips can be used, as well. It is well known that the conventional RXI designs form good image of the source. This feature is bed when colour mixing is needed. When four different colour LED chips are used (for example RGGB or RGBW LED), in the far field appears four separated images of each chip. The V-groove RXI rotates the far field pattern of each chip LED, performing a good colour mixture.

The experimental measurements of the first prototype are presented, as well.

8170-18, Session 4

LED collimation using high-index glass

R. Biertümpfel, S. Reichel, SCHOTT AG (Germany)

LEDs emit light over a broad range of angles. Additionally, a narrow collimation of LED light is difficult because of the broad emission area of the LED. In order to implement an efficient beam shaping with small optics we propose to use a design of lenses made out of glass with a refractive index (nd) greater than 1.7. Our design is characterized by a very small size and a high efficiency. This enables us to design optical arrays with an extremely high packing density of LEDs.

The use of glass has significant advantages like high temperature resistance, climate resistance and stability against solarization.

For many applications the footprint of the light beam should not only be collimated but also formed into a specific shape. Design results for a rectangular or oval beam shaping using SCHOTT's high refractive index glass are presented. The designs collimate the broad emitted LED light and are optimized to incorporate also the manufacturing of the lens.

The proposed lens designs can easily be manufactured by modern pressing techniques, thus, the proposed solutions are suitable for mass production.

8170-23, Poster Session

Methods for color mixing

S. Hadrath, OSRAM GmbH (Germany)

Challenging demands on illumination design engineers have been driven by new sources (e.g., solid state sources) and advances in fabrication technologies. In addition, several optical design software companies have developed, and continue to develop and improve, sophisticated illumination modeling and optimization tools to aid the illumination design engineer. In addition to the design of an optical system with high efficiency the main goal is to reach homogeneity in illumination and color distribution. Due to the use of sources of different color to reach high performance in e. g. color rendering there is a strong need of optical system for color mixing.

In this presentation a review of different color mixing tools is given. The use and functionality of micro lens arrays (also known as fly's eyes), diffuser materials and setups based on multiple reflections / scattering are discussed.

A micro lens array (MLA) consists of a transparent plate of glass or plastic with tiny (mainly spheric) lenses (also called lenslets) on both sides. The lenslets are often but not necessarily regularly arranged e. g. in rectangular or hexagonal order whereas each lenslet on one side has an identical copy on the opposite side. The thickness of the MLA is given by the focal length of each lenslet. By means of MLAs a homogeneous illuminance and color distribution can be reached. Furthermore, the light distribution can be adjusted by changing size and order of the lenslets.

Different diffuser materials and diffuser shapes can also be used for color mixing. This is especially appropriate for mixing of similar colors (such as different bins of LEDs of the same color) without loosing too much efficiency.

Adequate color mixing can also be reached by using the effect of total internal reflection (such as in mixing rods) in combination with scattering at highly reflective diffuse surfaces.

8170-28, Poster Session

An application of low-discrepancy sequences to evaluation of illumination optical systems

S. Yoshida, S. Horiuchi, Z. Ushiyama, K. Yoshidome, M. Yamamoto, Tokyo Univ. of Science (Japan)

In this paper, we propose a numerical evaluation method of illumination optical systems with the quasi-Monte Carlo method using low-discrepancy sequences (LDS). The LDS is a generating method for numerical sequences, and it is used for high dimensionality numerical integral problems. The quasi-Monte Carlo method converges faster than the Monte Carlo method which is using random numbers. Therefore, we applied the quasi-Monte Carlo method with LDS to evaluation of illumination optical systems instead of the Monte Carlo method, and clarified convergence performance. In the performance evaluation, we assumed an optical system including gradient-index (GRIN) lenses as an evaluation system, and evaluated convergence performance by comparing with theoretical illuminance distribution. From evaluation results, we confirmed that quasi-Monte Carlo method is effective method for better convergence, and its convergent rate is several times higher than the Monte Carlo method on average. Moreover, we consolidated image reconstruction method in illumination optical systems using quasi-Monte Carlo method. Comparing this method with conventional Monte Carlo method, image reconstruction method with quasi-Monte Carlo method is an exceptional method in accuracy or convergence performance. These results shows quasi-Monte Carlo method using LDS is effective method for evaluation of illumination optical systems

8170-29, Poster Session

Smooth light extraction in lighting optical fiber

A. A. Fernandez-Balbuena, D. Vazquez-Molini, Univ. Complutense de Madrid (Spain); A. Garcia-Botella, Univ. Politécnica de Madrid (Spain); J. C. Martinez-Anton, E. Bernabeu Martinez, Univ. Complutense de Madrid (Spain)

Recent advances in LED technology have relegated the use of optical fiber for lighting. Nowadays the use of high intensity LED to inject light in optical fiber increases the possibility of conjugate fibre + LED for lighting applications. New optical fibres of plastic materials, high core diameter up to 12.6 mm transmit light with little attenuation in the visible spectrum but there is no way to extract the light during the fiber path so all the light is concentrated at the end of the fiber. Side extracting fibers extracts all the light on 2π angle so is not well suited for controlled lighting. In this paper we present an extraction system for mono-filament optical fiber which provides efficient and controlled light distribution. These lighting parameters can be controlled with an algorithm that set the position, depth and shape of the optical extraction system. The extraction system works by total internal reflection in the core of the fiber with high efficiency and low cost. A 10 m length prototype is made with 45° sectional cuts in the fiber core as extraction system. The system is tested with a 1W white LED illuminator in one side.

8170-30, Poster Session

Lighting quality for aluminum and prismatic light guides

B. Garcia-Fernandez, D. Vazquez-Molini, A. A. Fernandez-Balbuena, Univ. Complutense de Madrid (Spain)

The use of high reflectance aluminum lighting guides is established as a standard for actual natural lighting systems. Reflectance over the entire length of a light guide changes the color of the output light at the end of the guide. In this paper we present a 3D raytracing and theoretical simulation for aluminum and prismatic light guides of different shapes (rectangular and cylindrical) and lengths over the entire visible spectrum. As is recommended in the office lighting normative (CIE, UNE,...) lighting quality is important so changes in color temperature may affect normative approval. Output light color temperature related to several illuminants and CRI are evaluated for the simulated aluminum and prismatic light guides. Prismatic light guides seem more robust in lighting quality maintenance regardless of conditionals like angle acceptance for TIR guiding, aluminum guides are efficient and maintain light quality only for short distances.

8170-33, Poster Session

Ultra-slim collimator with an inverse design

E. Aslanov, N. Petrov, A. Borodulin, G. Tananaev, LG Electronics Inc. (Russian Federation)

Original construction is proposed to collimate light into a narrow beam. The solution is very compact and provides high efficiency. Two elements are used. Freeform reflector and a plate of PMMA with a special pyramid structure on the first surface. LED source is mounted in a plastic plate and emits light into opposite direction. After reflection from freeform reflector light beam suffers TIR in plastic plate and is collimated with a very high efficiency into desired direction. Thickness of proposed design is about 5 mm. Efficiency and divergence depends on the size of emitting area and diode's package size. For diode with a size of emitting area of 2 mm and a package size of 6 mm last ones were 88% and 7 degree.

8170-19, Session 5

Dielectric multilayer angular filters for coupling LEDs to thin light guides

C. Mu, H. J. Cornelissen, Philips Research Nederland B.V. (Netherlands); F. Bociort, Technische Univ. Delft (Netherlands)

A new approach is described to couple light from high-power blue LEDs (1x1mm2) into a thin light guide using a dielectric interference multilayer angular filter. This new method overcomes the drawbacks of structuring holes or recessions in the light guides when using side-emitting LEDs. The light emitted below the critical angle is reflected back to the LED and recycled. Large-angle emitted light transmits through the filter and keeps propagating in the thin light guide due to total internal reflection.

Three different types of dielectric multilayer thin-film filters are designed according to their own filter specifications regarding angle, wavelength, and manufacturing. Initial thin-film design and multi-parameter optimizations are performed in Essential Macleod software or proprietary Matlab programs. A previous design, that was made of two dielectric materials suffered from large transmittance difference between S and P polarized light when the light is above the critical angle. Thus, we design several new filters to improve the polarization transmittance equality and coupling efficiency. Firstly, we can add a third material with a refractive index in between the other two, where different optimization techniques have been applied to design this filter. Secondly, we can also use polymeric materials such as PMMA and PEN to construct stacks of polymeric layers. Finally, a birefringent polymeric material multilayer of 3M company is investigated. All the methods prove to effectively reduce the polarization dependence and improve the coupling efficiency of the filter.

This is demonstrated by using optical ray tracing software LightTools. We design the coupling a multitude of LEDs to a thin light guide sheet, which enables thin large area light sources such as backlighting systems for Liquid Crystal Displays (LCD). The specified designed filters and different prototypes with the filters are modelled, studied and tested. In addition, arrays of micro-optics elements such as white paint dots can be employed with specific design of the positions. With these well defined scattering patterns, light can be extracted from the thin light guides and give out a uniform illumination distribution.

8170-20, Session 5

Optical design of a self-disinfecting operation interface powered by UV(A) LEDs

L. Ye, P. Belloni, K. Möller, Hochschule Furtwangen Univ. (Germany)

We are developing a self-disinfecting operation interface with a glass panel and several integrated UV-LEDs, which will find its application in hospitals, food industry or similar fields where hygiene is strictly required. The concept of self-disinfection is based on the exploitation of the photocatalytical effect induced by a TiO2-coating on the glass surface under UV(A). The main goal of the optical design is to generate

an efficient and preferably homogeneous UV field on the TiO2 under the following constraints: 1) the LEDs should be kept invisible to the user; 2) behind the glass panel there is a none-UV-transparent print circuit; 3)the touch screen should be thin and frameless; 4) the minimum UV intensity reaching the TiO2-coating must be at least 2.5mW/cm² to trigger the release of free ions in the semiconductor.

Our system was modeled and finally constructed as follows 1) two rows of two sideways-coupled UV-LEDs (peak λ=375 nm, optical output=230mW/cm²); 2)a thin reflective film on the bottom; 3)a bulk of "T-form" light guide made of glass (205mm*110mm, refractive index=2.55 by λ=375 nm), with a printed serigraph designed on the bottom aimed to redirect the rays towards the TiO2-layer; 4)a diffuser layer, to recycle the light on the second level; 5) two additional BEFs in cross direction (Vikuiti® brightness enhancement film, BEF II 90/50) to further help tailor the uniformity. The components from 2) to 5) were set up as a sandwich-structure.

The optical simulation was done with the software LightTools® to first predict the UV intensity and distribution on the TiO2 and then optimise the system parameters, such as the trim location of the "T-form", LED position, glass thickness, shape and arrangement of the printed serigraph.

Three patterns for the serigraph, each with different radius and spacing were investigated, compared and evaluated: 3D-sphere texture, 3D-rectangular texture and 2D-serigraph.

The best pattern turned out to be a 2D-circle-serigraph on the bottom of the glass with a 0.3mm radius defined as a lambertian-reflective material. With this particular configuration we reach after optimisation both a minimum radiation intensity of about 2.5mW/cm2 on the upper glas surface and a uniformity distribution as well.

These system parameters fulfill all the requirements while reducing the costs of production of the self-disinfecting operation interface.

8170-21, Session 5

A study of optical design of backlight module with external illuminance

C. Yen, National Formosa Univ. (Taiwan); Y. Fang, C. Huang, National Kaohsiung First Univ. of Science and Technology (Taiwan)

This research proposes the concept of Light Guide Film (LGF) at the back side of Back Light Unit (BLU). This new design may induce the exterior light, and then improve the power-saving of existent BLU. Two design models are reseated: One is design for 14 inch LCD monitor of notebook computer, which might improve 21% compared to traditional one. Another is designed for 3.5 inch LCD for mobile phone display, which might improve 15% compared to traditional one.

8170-22, Session 6

Using the on-axis BSDF at a dielectric surface to model the BSDF at off-axis angles

W. J. Cassarly, Synopsys, Inc. (United States)

The Bidirectional scattering distribution function (BSDF) is used to describe the multidimensional aspect of light scattering properties of a surface. Often, the BSDF is broken into the two parts: the bidirectional reflectance distribution function (BRDF), and the bidirectional transmittance distribution function (BTDF). In this talk, we investigate the on-axis BTDF at a dielectric surface (i.e., a surface where the index of refraction is different on the two sides of the surface) and show how it relates to the off-axis BRDF and BTDF of textured surfaces that are commonly used in illumination modeling and design. Numerous interesting Monte Carlo simulation results are provided.

8170-24, Session 6

What's in a ray set: moving toward a unified ray set format

J. A. Muschaweck, OSRAM GmbH (Germany)

For the purpose of optical simulation, a plethora of formats exist to describe the properties of a light source. Except for the EULUMDAT and IES formats which describe sources in terms of aperture area and far field intensity, all these formats are vendor specific, and no generally accepted standard exists. Most illumination simulation software vendors use their own format for ray sets, which describe sources in terms of many rays. Some of them keep their format definition proprietary. Thus, software packages typically can read or write only their own specific format, although the actual data content is not so different. Typically, they describe origin and direction of each ray in 3D vectors, and use one more single number for magnitude, where magnitude may denote radiant flux, luminous flux (equivalently tristimulus Y), or tristimulus X and Z. Sometimes each ray also carries its wavelength, while other formats allow to specify an overall spectrum for the whole source. In addition, in at least one format, polarization properties are also included for each ray. This situation makes it inefficient and potentially error prone for light source manufacturers to provide ray data sets for their sources in many different formats.

Furthermore, near field goniometer vendors again use their proprietary formats to store the source description in terms of luminance data, and offer their proprietary software to generate ray sets from this data base. Again, the plethora of ray sets make the ray set production inefficient and potentially error prone.

In this paper, we propose to describe ray data sets in terms of phase space, as a step towards a standardized ray set format. It is well known that luminance and radiance can be defined as flux density in phase space: luminance is flux divided by etendue. Therefore, single rays can be thought of as center points of phase space cells, where each cell possesses its volume (i.e. etendue), its flux, and therefore its luminance. In addition, each phase space cell possesses its spectrum, and its polarization properties. We show how this approach leads to a unification of the EULUMDAT/IES, ray set and near field goniometer formats, making possible the generation of arbitrarily many additional rays by luminance interpolation. We also show how the EULUMDAT/IES and individual ray set formats can be derived from the proposed general format, making software using a possible standard format downward compatible.

8170-25, Session 6

Optical model for LED with ceramic converter

A. Linkov, D. Eisert, M. Sabathil, OSRAM Opto Semiconductors GmbH (Germany); K. Bergenek, OSRAM GmbH (Germany); M. Raukas, J. Kelso, G. C. Wei, N. Zink, OSRAM SYLVANIA Inc. (United States)

For high performance LED applications such as projection, head lamps or other high intensity spot lights with high color rendering index, LEDs with ceramic converters offer the advantage of excellent thermal stability in combination with conversion efficiencies close to the physical limit.

To generate understanding of the theoretical limits and to support the development process of LEDs with ceramic converter, a self-consistent optical model was created coupling the InGaN pump chip, the ceramic converter and the package. We chose raytracing as a simulation tool, due to its ability to provide a fast and precise analysis which enables the optimization of the entire illumination system. To highlight the advantages of the ceramic converter we also performed a comparison with the conventional solution using phosphor particles in silicone.

In the conventional solution, with the phosphor particles immersed in silicone, the particles act as the main source of light scattering which might lead to additional optical losses. In this case the difference between refractive indices of the phosphor (1.8-2.0) and silicone (1.4-1.6) leads to the volume scattering. Depending on degree of conversion, volume scattering can decrease or increase the extraction efficiency of the system. Especially for green conversion, where the degree of conversion is relatively high, using of the conventional

phosphor-silicone solution our model predicts large losses in the system.

If we consider the solution with ceramic phosphor, the air pores inside the volume of the sintered body constitute the main sources of scattering. By choosing particular sintering conditions it is possible to tune the size and distribution of the pores within a certain range up to the case of an almost scattering-free ceramic converter. In this case the efficiency of the system is predicted to be independent of the degree of conversion because the net absorption of the pump light is no longer dependent on the scattering within the converter. Another technological advantage of using the ceramic phosphor is a better thermal management in the system which was optimized using coupled optical and thermal models.

The optical models of the chip and the ceramic converter were developed and calibrated by using a comprehensive set of experimental data enabling the modeling of parameters such as efficiency, optical spectrum, color and angular distribution of the emission. The simulation of the coupled system including InGaN chip, phosphor ceramic and package provides not only the optimization of single components, but more important the optimization of the complete LED module.

The simulations results show, that optimal solution for this system should have a minor component of volume or surface scattering for best light extraction efficiency. Additional optimization is expected to yield optimal configurations that make use of surface and/or volume scattering in system.

The model results confirm that the use of ceramic converters provides a highly efficient LED light source especially for full conversion applications. This is also supported by the recent development of green converted LEDs yielding a 100% performance increase compared to conventional InGaN green LEDs.

8170-26, Session 6

Illumination design for an LED based projection display for flight instrument simulation

M. Thorpe, K. Dalzell, C. Reimer, S. Atalick, Raytheon ELCAN Optical Technologies (Canada)

This paper discusses design and performance of an LED illumination system for a compact NVIS compatible DLP based rear projection display designed and used successfully as a cockpit display simulator. Recent progress in LED technology has allowed simplification of the design of both optics and mechanics while giving improved display performance.

LED development over just a few years has made use in some cockpit projection displays feasible. Musazzi et. al reported in 2007 on an LED based NVIS compatible 4” diagonal projection display designed for avionics which achieved a luminance of ~300cd /m2 , this was considered too dim for the application. Our projector, using commercially available high brightness LEDs and working at the same 4” diagonal screen size in NVIS mode would achieve a luminance of ~850cd /m2 . In its design screen configuration (10” diagonal) it achieves a luminance of 136cd /m2 in NVIS mode which is sufficiently bright for the application.

The source illumination assembly(defined as sources plus color combining optics) which feeds light to the illumination relay has evolved from use of 3 separate LED packages with a complex combining assembly to a single multi-die LED package with a much simpler combining package. Initially the source illumination used the Phlatlight® PT85 R,G,B chip family. These devices have very high peak lumen output, 1100,2200,425 lumens respectively in pulsed mode. In order to meet screen luminance specifications of 340cd /m2 it was required to couple the light into the projector at an efficiency approaching 4% while minimizing chromaticity differences. There are various standard methods of color combining. Our approach was to use a lightpipe structure consisting of a tapered lightpipe at each source followed by a dichroic fold mirror and a straight mixing section which feeds into the illumination relay. Color uniformity is limited by the length of the mixing section. The efficiency of the built system using this illumination assembly matched the model well as measured by screen luminance. However chromaticity variation was approximately twice the predicted value giving variations in screen chromaticity coordinates of ~ x<.005, y <.015 with perceptible shading patterns.

The current generation of source illumination assembly uses the Phlatlight® CBM290 chip. This chip has R,G,B LEDs on a single substrate each emitting similar power to the PT85 chips. Use of a single emitting device trades off maximum screen luminance but has allowed a simpler approach to color combining. After modeling different approaches we designed a composite lightpipe assembly for color combining. Despite the etendue increase, a target screen luminance of is 136cd /m2 is achieved in NVIS mode. Color mixing is improved with virtual elimination of color shading. Simplification of the optomechanical design comes at the expense of added complexity in thermal design as in order to achieve stable output performance with an LED package dissipating up to 60W the heat sink design becomes more critical. Overall projector cost is reduced and performance is improved.

8170-27, Session 6

Laser dark-field illumination system modeling for semiconductor inspection applications

W. Zhou, D. Hart, R. Roy, Rudolph Technologies, Inc. (United States)

Dark-field defect inspection is an essential quality control method for the semiconductor fabrication industry, and it is broadly applied for micro particles detection in almost every fabrication process. Diode laser based dark-field illumination systems (LDFs) play a critical role in such illumination schemes due to its unique optical/mechanical properties. This paper discusses a complete LDF system model, includes the mathematical and optical descriptions of LDF system fundamentals. A series of trade-off curves are developed in this model, which describe system performance under different constraints. This model can either efficiently facilitate system design work for generic/unique applications, or can be used to evaluate existing LDF system performance.

8170-31, Session 6

Optics designs for an innovative LED lamp family system

H. Weiss, OSRAM GmbH (Germany)

On the general lighting market of LED lamps for professional applications there are still mainly products for single purpose solutions existing. There is a lack of standardized lamp families like they are common for conventional lighting technologies. However, a comprehensive range of LED lamp types which can substitute standardized professional lighting solutions is an essential requirement for a quick adoption of LED lamps. The key to such a system is the availability of powerful secondary optics which also fit to the thermal, electrical and mechanical requirements of LED lamps. Within a publicly funded project promoted by the German Federal Ministry for Education and Research (promotion reference No. 13N9399) an LED lamp family was studied using high power LED which provides for all specifications needed for a universal toolbox for the lighting designer. This comprises the realization of sets of lamp types with compact and linear shapes as well as with light distribution characteristics ranging from diffuse to extreme collimation at exceptionally high candle power. A variety of innovative secondary optics has been studied which allow both, the design of lamps with non-bulky shape and to obtain sufficient colour mixing when using multicolour LED. As a universal LED basis the OSLON SSL LED range from OSRAM Opto Semiconductors was used throughout the whole lamp family. Primary optics of FWHM = 80° or 150° have been chosen according to the best combination of primary and secondary optics. Multicolour LED combinations have been used in order to achieve high luminous efficacy and most ambitious colour rendering properties. Optics colour mixing performance of those systems is crucial for future applications which make use of white light with tunable colour temperature and which can thus utilize the chronobiological effect of light on human beings. Compact lamps with such a feature cannot be realized with conventional lighting technology.

As a result of the study a comprehensive LED lamp family system for general lighting suitable for standardization could be demonstrated for the first time.

Conference 8171: Physical Optics

Monday-Tuesday 5-6 September 2011

Part of Proceedings of SPIE Vol. 8171 Physical Optics

SPIE Optical Systems Design

8171-01, Session 1

Temporal and spectral degrees of polarization of light

P. Réfrégier, Institut Fresnel (France); T. Setälä, Aalto Univ. School of Science and Technology (Finland); A. T. Friberg, Kista Photonics Research Ctr. (Sweden)

The degree of polarization is a central quantity in the characterization of random electromagnetic beams and it has been introduced both in the time and the frequency domains. Physically, the spectral degree of polarization corresponds to that of a field obtained by filtering a generally broad-band light by a narrow-band filter. It is known that the two degrees of polarization can generally assume different values and no simple relationship exists between them. For example, a stationary field can have an arbitrary degree of polarization in the frequency domain although the field is fully unpolarized in the time domain. On the other hand, the field can be fully polarized at every frequency, but in the time domain the field may be anything between unpolarized and polarized. In this work, we study the connections between the time and frequency domain degrees of polarization. We introduce a mean spectral degree of polarization and show that it provides an upper limit for the value of the time-domain degree of polarization that can be obtained if arbitrary unitary transformations are performed in the frequency domain. It follows, for example, that a field which is fully polarized in the frequency domain can be made fully polarized also in the time domain by unitary transformations in the frequency domain, i.e., without absorption of energy. We also show that the mean spectral degree of polarization cannot be increased by unitary transformations in the frequency domain. The results are important for the processing of light and clarify the character of light's polarization.

8171-02, Session 1

Random media confer high-polarization degree to natural light

M. Zerrad, J. Sorrentini, G. Soriano, C. Amra, Institut Fresnel (France)

The state of polarization is one of the main observable parameters of an optical field. Many practical situations exist that make the light polarization properties depend on the spatial location. Indeed the state polarization of a light beam will change by focusing, by propagation in free-space, by propagation in turbulent atmosphere, after scattering by a rough surface or an inhomogeneous medium

Many works are devoted to the loss of polarization that can take place on the incident light, considering a full polarization but different spatial and temporal coherence properties for the incident beam. Different formalisms were proposed including Mueller-Stokes, cross spectral density matrices and electromagnetic theories. Such loss of polarization (or depolarization process) most often originates from a temporal average of uncorelated polarization modes of the optical field, though spatial average may also be responsible for depolarization of a fully polarized incident beam when the state of polarization rapidly varies within the detection area.

Scattering by arbitrary inhomogeneous media is known to modify the polarization or depolarization properties of the illumination beam. Usually the incident polarization of a light beam is lost after scattering by a highly inhomogeneous medium, which reduces the interest of polarimetric techniques to probe random media. However one can have the benefits of a reversible effect in the sense that the same media may allow to significantly increase the polarization degree of a fully depolarized incident light. This is the scope of this paper where it is shown that natural light can be "ordered" by a random scattering process.

A phenomenological approach is first used to calculate the spatial repartition of the local Degree of Polarization (DOP) of natural light after transmission by a random medium and propagation in air. The average value and the probability density function (pdf) of the DOP are investigated and an excellent agreement is obtained between numerical and experimental results. The high average polarization degree of light (≈ 75%) compared with the incident one (0%) allows considering that light has been ordered when passing through the disordered medium.

8171-03, Session 1

Evolution of vortex density in a nondiffracting speckle field with its continuous-phase removed

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

A coherent superposition of multiple plane waves scattered from a rough surface gives rise to a speckle field with random distributed phase in the far field. An interesting and unconventional speckle field, so-called a non-diffracting speckle field, can be obtained if the rough region is illuminated through a ring slit aperture. Optical vortices always exist at the points of zero intensity and around which the phase increase or decrease by 2π.

A non-diffracting speckle field in its equilibrium state has a homogeneous vortex distribution. Similar with a Bessel beam, propagation of such a speckle field over some distances will not change the field due to its diffraction invariant property. During its propagation, the rate of vortex dipole annihilation is statistically equal to the rate of vortex dipole creation so that the average vortex density remains constant. At the mean time, it always has a homogeneous vortex distribution.

We won't study the properties of such a static non-diffraction speckle field. However, we break down the equilibrium state and the diffraction invariant property of a non-diffracting speckle field by removing the continuous part of phase while leaving all vortices behind. During the propagation of such a non-diffracting speckle field after its least-square phase have been removed, the vortex density drops down to a minimum value and then comes back to an equilibrium value which is even higher than the initial one.

Actually, we do not wait until the field returns back to equilibrium again. Another least-square phase removal will be done at the position with a minimum vortex density to further remove vortices from the field. Such a process of removing least-square phase and propagating the phase corrected field over a distance can be repeated to eliminate most of optical vortices. We found that most of optical vortices can be removed from a non-diffracting speckle field. From the scintillation index curve, one can also find that the final value is very small which means very small fluctuations left in the amplitude. The vortex density also drops down to zero which means no vortices left in the final field. Finally, a semi-plane wave without optical vortices can be obtained from the initial non-diffracting speckle field with multiple steps of least-square phase correction.

8171-04, Session 1

Electromagnetic Hanbury Brown-Twiss phenomenon

T. Hassinen, J. Tervo, Univ. of Eastern Finland (Finland); T. Setälä, Aalto Univ. School of Science and Technology (Finland); A. T. Friberg, Kista Photonics Research Ctr. (Sweden)

The classic Hanbury Brown-Twiss experiment has played a major role in the development of astronomy and quantum optics. In the experiment, the correlations between photons in two light beams are measured by detecting the correlations of the fluctuations of photoelectron currents from detectors placed in the beams. Usually, analyses have been made with scalar-wave treatment, i.e. considering only one polarization mode, but as electromagnetic theories for coherence and polarization have developed, there has been increasing interest towards the vector treatment of the Hanbury Brown-Twiss experiment.

In 2003, the Hanbury Brown-Twiss effect was briefly analyzed in the space-time domain with electromagnetic waves obeying Gaussian statistics. It was shown that in such case the normalized intensity correlation function in two points is given by the square of the

electromagnetic degree of coherence. This is in full analogy with the classical scalar-wave result according to which the correlation function equals the degree of coherence in similar (scalar) situation. However, in some recently published papers the normalized intensity correlation function for Gaussian electromagnetic fields has been expressed using the degree of cross-polarization and the usual intensity fringe visibility. In this work we discuss how this kind of approach can be problematic in some situations. Moreover, we extend the previously mentioned electromagnetic analysis of Hanbury Brown-Twiss phenomenon from space-time domain to space-frequency domain and demonstrate that the effect with thermal vector fields is fully specified by the spectral electromagnetic degree of coherence.

8171-05, Session 1

Farther discussion of Huygens-Fresnel principle

Z. Liu, K. Uchikawa, Nikon Corp. (Japan)

Huygens-Fresnel principle is well used in analyzing the wavefront propagation in vacuum. However, we should clear if this principle is available in the space including absorptive object, such as a grating. To analyze it, we used a special interferometer [1]. The interferometer has an extended spatial incoherent light source modulated by a binary grating. The light source is imaged onto a sinusoidal transmissivity grating. The pitch of the binary grating is half of the period of the sinusoidal grating. Let us analyze the change of total intensity after the sinusoidal grating when the sinusoidal grating is shifted. Two kinds of method are considered. The first method is using Huygens-Fresnel principle: the concave wavefront is resolved to a series of planar waves. Each planar wave is diffracted by the sinusoidal grating. One color interferogram interfered by -1 and +1 order beams should be observed because the sinusoidal grating is set on the focus point and the pitch of the binary grating is half of the period of sinusoidal grating, as mentioned by Braat. By shifting the sinusoidal grating the interferogram phase should be modulated, therefore, the intensity after the grating will CHANGE. On the other hand, another analysis method gives a different result. The second analysis method is to estimate the intensity after the sinusoidal grating point by point. Intensity after the sinusoidal grating from an arbitrary point of the light source is described as I=[1+sin(2pi*x/period)]PSF, where x is the coordinates on the grating, "period" is the period of the sinusoidal grating and PSF is the point spread function of the imaging system. We noticed that the pitch of the binary grating is half of the period of the sinusoidal grating; so that the light coming from two neighbored slits of the binary grating contributes to the total intensity in one period of the sinusoidal grating. Light coming from neighbored slits of the binary grating is modulated by the sinusoidal grating with pi phase difference. Therefore the total intensity after the sinusoidal grating DOES NOT CHANGE even if the sinusoidal grating is shifted. To clear the reason of the different results, I review the developing of Huygens-Fresnel principle from Maxwell equations. To get Huygens-Fresnel principle, condition of non absorptive elements is required. Because the grating is an absorptive element, Huygens-Fresnel principle should not be used in the space including a grating.

To demonstrate it, a simple experiment with interferometer described before is performed. A checker board grating is used instead of the sinusoidal grating. Intensity change was not observed in our experiment when the checker board grating is shifted.

[1] J. Braat and A.J.E.M.Janssen, "Improved Ronchi test with extended source",Opt.Soc. Am.A Vol.16, No.1/January 1999, 131-140.

8171-06, Session 1

Physical property of structural color in butterflies

M. Lo, C. Lee, National Central Univ. (Taiwan)

Butterfly's wing has paid great attention due to its unique properties, such as attractive iridescence, superhydrophobic characteristics, and quick heat dissipation ability. These characteristics are closely related to its surface structure. The multilayer thin-film structures that make up a butterfly's wing produce a bright iridescence from reflected daylight. In this study, we will introduce the characteristics of structural color effect. Moreover, the optical properties in the reflection and transmission spectra of the wings will be shown. Since both the reflection and the transmission patterns are extended in angle, we have to use a spectrophotometer equipped with an integrating sphere. According to the result, the color of butterfly's wing depends on the viewing-angle. In addition, the directional and strongly angle-dependent reflection of the ventral wings suggests the question whether or not the wing reflections may play a role in visual signaling by the butterflies during flight. Compare the spectrum of reflection among different color part in butterfly's wing, we found that all spectrum of reflection has high infrared response. According to the high IR response, it can associate with quick heat dissipation ability of butterfly's wing. For the study of butterfly's surface structure, scanning electron microscopic (SEM) of top view and cross section through different color's reflective cover scale shows the individual structure. The individual structure will decide the attractive iridescence of the wing. More surface structure of butterfly's wing will be shown in detail in the following content.

8171-07, Session 2

The nature of light coherence: photons

P. O. Demyanenko, K. Demianenko, F. Demianenko, Y. Zinkovskiy, National Technical Univ. of Ukraine (Ukraine)

The nature of electromagnetic (EM) phenomena, including light, is not fully clear. Postulated rejection of EM ether as a hypothetical habitat and distribution of EM waves, holds in the uncertainty and the problem of understanding the existence of most of these waves, because the notion of "wave" inseparable from the concept of "environment". EM ether, as a hypothetical environment of origin and propagation of EM waves, was declined by postulate. This keeps the uncertainty in the problem of understanding the existence of these waves actually, since the definition of "wave" is an part of the definition of "environment". The input in physics of the concept of wave "coherence", which was necessary to explain the phenomenon of interference of light, also requires a transparent physical interpretation.

Today use of the idea of the several-meters- length wave zugs, which are emitted by individual atoms, is at least unconvincing, thus there is technical ability to generate powerful light pulses of n*10-15 s.

A quantum model of the structure of the optical packet stream, which provides a transparent physical interpretation of all parameters of coherent light, is offered. In this model parameters of coherence are organically linked with the geometry parameters of the quantum packets. Developments of classical wave optics will not be discarded.

To coordinate with the quantum-packet model and modern views about the nature of light, we either give them a new interpretation or adjust, or develop these developments. In particular, a new interpretation of the experimental fact increase the radius of coherence of light coming from distant sources (stars) is offered.

Modern conception of light corpuscles-photons is formulated. The estimations of the size of the spatial localization of the photon is received. "Diffraction of photons" is considered.

8171-08, Session 2

Analysis of intrinsic perturbation by thermal stress birefringence

C. M. Jadhao, G.S. College of Khamgaon (India); D. S. Dhote, Brijlal Biyani Science College of Amravati (India)

Birefringence and polarization dispersion in elliptical core fiber are seen to depend on thermal stress rather than geometrical anisotropy for relatively small relative index differences. Numerical examples are presented for germanosilicate, borosilicate, and phosphosilicate glass fibers. The differential thermal expansion coefficient (Δ) and temperature difference (ΔT) play an important role in estimating birefringence and polarization dispersion. The experimental results are obtained for germanosilicate, borosilicate, and phosphosilicate dopant materials and results are obtained for different ellipticity. The result obtained shows that birefringence induced by intrinsic perturbation by thermal stress for different material is affected by the ellipticity and shows that the delta beta and DGD goes on increasing for increase in ellipticity. Birefringence and polarization dispersion caused by thermal stress in single-mode fibers were formulated in terms of fiber structure and thermo elastic parameters by using a modified coupled-mode theory. Numerical comparison was made for germanosilicate, borosilicate, and phosphosilicate fibers. This also shows that Germania-Silicate fiber is high birefringent. Thermal stress rather than geometrical anisotropy plays an essential role in estimating the birefringence characteristics values of the elliptical core fiber for a relatively small relative index difference. Thus the polarization is effective when intrinsic stress is applied.

8171-09, Session 2

Polarization modeling in square ring resonators with the consideration of output mirror's stress effect

J. Yuan, X. Long, P. Zhang, Y. Wang, M. Chen, H. Yang, Z. Kang, National Univ. of Defense Technology (China)

Abstract: A polarization model for calculating the ellipticities of the clockwise and counterclockwise output beams in square ring resonators is established in this article. The model takes into account the following parameters such as Ar, g, ξ and simultaneously, where Ar is the distortion angle, g is the phase shift of all four mirrors, ξ is the angle between the S-polarization and the substrate "fast" axis of the output mirror, is the birefringence angle of the output mirror. All optical elements inside the square ring resonator have been written as two dimensional Jones matrixes. The clockwise and counterclockwise overall cavity Jones matrix represents the laser cavity as a single element beginning at the output mirror in the cavity, and it have been obtained by taking the product of Jones matrices representing the individual cavity elements in the order in which the field in the laser cavity encounters them during a single pass around the cavity. By utilizing the matrix formulation, the eigenvector and eigenvalue can be obtained. The ellipticities of the clockwise and counterclockwise output beams in square ring resonators have also been obtained by considering the stress effect of the output mirror. The stress effect of output mirror has been found to have different influences on the ellipticities of clockwise and counterclockwise light beams. Based on the numerical analysis, the parameters such as g, ξ and have been found to have unsymmetrical influences on the ellipticities of clockwise and counterclockwise output beams. The distortion angle is unequal to zero when the ellipticities of clockwise and counterclockwise output beams are equivalent. Based on those novel results, the alignment method to decrease the magnetic bias by reducing the distortion angle to 0 when the ellipticities of clockwise and counterclockwise output beams are equivalent, which is proposed in R. H. Moore's patent, has been found ineffective and it has been proved by our experiment. A novel method to reduce the distortion angle during the alignment process with the eliminatation of the output mirror's stress effect simultaneously has been proposed in this article and this method can decrease the magnetic bias of square ring resonators effectively. This method is important to reduce the magnetic effect in ring laser gyroscope. These interesting findings are important to the research of high precision and super high precision ring laser gyros.

8171-10, Session 3

The minimum spanning tree method applied to the study of optical speckle fields: spatial characterization of a Gaussian transition and its phase singularities

O. Vasseur, D. Upadhyay, I. Bergoënd, X. Orlik, ONERA (France)

The optical speckle field generated by the scattering of a laser beam on a rough surface contains useful information about the surface properties especially in the case of the incident beam illuminates only a few correlation cells of the surface roughness. The study of the transition from the non Gaussian to the Gaussian regime of the speckle field can increase the amount of accessible information concerning the surface roughness. The probability density function of intensity is helpful to characterize an optical speckle field, but we do not obtain information about the qualification of spatial distribution of the field. To qualify this spatial intensity distribution, we propose to use the Minimum Spanning Tree methodology. From the tree constructed from the set of points of the local maxima of the intensity distributions in an observation plane, we determine the mean and the standard deviation of the edges length of the tree and we qualify the distributions of this points (ordered, cluster, random...). The distribution of intensity maxima corresponds to a cluster distribution in the strongly non gaussian regime. When the number of illuminated cells increases, this distribution evolves to a gradient distribution around the Gaussian transition and then approach the random distribution in the Gaussian regime. The Minimum Spanning Tree method exhibits a maximum of the standard deviation of the edges length around the Gaussian transition when about 4 correlation cells of the surface roughness are illuminated.

We will present the first results concerning the study of a Gaussian transition of a speckle field by the Minimum Spanning Tree method and some preliminary results about the study of the spatial distribution of phase singularities in this transition.

At the end, we will highlight that this new approach appears to be a very robust way to characterize the correlation length of a surface roughness and its illumination conditions, and offers a new criterion to study the optical speckle field.

8171-11, Session 3

Multiscale spatial depolarization: electromagnetism versus statistical optics

M. Zerrad, J. Sorrentini, G. Soriano, C. Amra, Institut Fresnel (France)

Electromagnetic theory is used to calculate the gradual loss of polarization in light scattering from surface roughness. In a first step, the study of speckle phenomena by electromagnetism calculation is shown to be fully complementary of statistical optics analysis. Then a spatial averaging process analysis allows to take into account the receiver aperture and to consider temporal depolarisation as a spatial effect. At last the evolution of polarization degree is connected with the structural parameters of surfaces.

8171-12, Session 3

The observation of multiplication effect on space diffraction grating in laser-produced plasma

V. A. Skvortsov, Moscow Institute for Physics and Technology (Russian Federation); N. I. Vogel, Technische Univ. Chemnitz (Germany)

In experiments with laser-produced plasma the picture of multiplication had been observed. The characteristic diameter of target was about of 5 mm, the distance to image plate and length of focus were L = F = 50 cm. The TV -filming was in infrared ray (the wavelength of laser radiation l=1.06 micron, pulse duration on half width was about t=100 ps). The effect of multiplication (and self-reproduction) can be obtained without any lenses, if one have plate (or volumetric) diffraction grating. In present case the diffraction (quadratic) grating forms (under pulse illumination) in spherical plasma object during short interval of time (t= 100 ps). The image as in Talbot's effect will be produced at the distance L=(2d**2/l)n, where n- integer number [1]. The plane wave with spatial frequency Um =2pi*m/d (d - period of grating, m-integer number, pi=3.14...) corresponds to each image of target. Line coordinates in Fourier plate of central points of images Xm= UmF/k =2pi*mF/(d*k). The step of spatial quantization is X=2pi*F/(d*k). We can estimate X=10 mm by using our snapshot. Hence it is easy to find the distance d=2piF/(X*k)= l*F/X = 50 micro meters. Thus the multiple number is about of n= Ll/2d**2=100. The typical Debye length in such plasma is not higher then 1 micro meter. So we can't to explain the observed diffraction picture by lattice of Langmuir's cavitons. It may be connected with plasma crystal or by specific spatial effect [2] in laser-produced plasma [3, 4].

1.Kozel S.M., Listvin V.I., Lokshin G. R. Introduction in coherent optics and holography. Moscow. MIPT, 2000. - 42 pages.

2.Vjal'tsev A.N. The discrete space-time. Moscow, KomKniga. 2006.-400 pages.

3.Skvortsov V.A., Vogel N.I. Miniature black-holes generation by laser-induced electromagnetic collapse in plasma. Proc. 31st EPS Conference on Plasma Phys. London, 2004 ECA Vol.28G, P-4.029

4. Skvortsov V.A.,Vogel N.I. The generation of exotic quasiparticles. Proc. 11th Lomonosov Conference on Elementary Particle Physics.. Moscow, 25-29 Aug.2003. In book: "Particle Physics in Laboratory. Space and Universe. Ed. by A.I. Studenikin. World Scientific. Singapore. 2005, pp. 373-382.

8171-13, Session 4

Tests for assessing beam propagation algorithms

B. D. Stone, Synopsys, Inc. (United States)

Given a beam propagation algorithm - whether it is a commercial implementation or some other in-house or research algorithm, it is not trivial to determine whether the algorithm is suitable either for a wide range of applications or even for a specific application. In this presentation, we describe a range of tests with "known" results; these can be used to exercise beam propagation algorithms and assess their robustness and accuracy.

There are a number of different classes of such tests that can be run. One class includes tests of self-consistency. Such tests often rely on symmetry to make guarantees about some aspect of the resulting field but don't provide "known" results everywhere. While passing such tests does not guarantees that the algorithm produces correct results in detail, they can nonetheless point towards problems with an algorithm when they fail and build confidence when they pass.

Another class of tests that will be discussed compares the entire complex field to values that have been experimentally measured. While the experimental data is not always known in detail, and the experimental setup might not always be accessible, these tests can provide reasonable quantitative comparisons that can also point towards problems with the algorithm.

The final class of tests presented is those for which the propagated complex field can be computed independently. The test systems for this class of tests tend to be relatively simple, such as diffraction through apertures or propagation through ideal imaging systems. Despite their relative simplicity, there are a number of advantages to these tests. For example, they can provide quantitative measures of accuracy. These test systems also allow one to develop an understanding of how the execution time (or similarly, memory usage) scales as the region-of-interest over which one desires the field is changed (e.g., say an algorithm is run and the results accurately model the first 10 Airy rings in an ideal system, what increase in execution time would be expected to accurately model the first 20 Airy rings). Tests to investigate such properties of beam propagation algorithms are also discussed.

8171-14, Session 4

Efficient use of grating theories with partially coherent illumination

J. Tervo, Univ. of Eastern Finland (Finland)

It is well known that the S-matrix-based propagation algorithm offers a stable and efficient tool for solving the light-grating interaction problem in several different implementations of the rigorous grating theory. Even though it is usually used in combination with a single illuminating plane wave, its extension to more general input fields is rather straightforward: One just has to divide the input field into discrete Rayleigh bases, each of which is propagated through the grating analogously to the single plane wave. The separate output fields are then re-combined after the solution is found for all fields.

In this work, we discuss how the method can be generalized to partially coherent and in general also partially polarized fields such that the method remains computationally as effective as possible. The method is based on the combination of the division of the general field into a set of completely coherent, but mutually uncorrelated modes that may or may not be orthogonal. This set is then employed in the S-matrix propagation algorithm such that the partial coherence itself does not increase the computational burden significantly. The logic can be easily extended to other areas of optics in which the input-output logic of the S-matrix approach can be used. The efficiency of the method is illustrated with enlightening numerical examples.

8171-15, Session 4

Vectorial geometrical optics propagation using multi-scale boundary operators

M. Kuhn, LightTrans GmbH (Germany); F. Wyrowski, Friedrich-Schiller-Univ. Jena (Germany)

The generalization of classical ray tracing techniques leads to the concept of field tracing which considers harmonic fields instead of ray bundles. In order to apply geometrical optics propagation in this new framework a fully vectorial formulation of the operator using components of the electric field is required. Besides a better level of physical approximation this approach also allows to combine the geometrical optics propagation with other, even rigorous, propagation methods within one simulation task, which we call unified optical modeling.

In this talk we introduce a new vectorial geometrical optics propagation operator using multi-scale boundary operators. It is applicable to systems with refractive and diffractive surfaces and it generalizes the well known concepts of the local plane interface approximation (LPIA). The new operator decomposes the overall propagation task into laterally shifted tubes. Each tube can be considered independent of others due to the geometrical optics approximation. The propagation through a system of optical interfaces results in a sequence of alternating free-space steps and interface transitions. The optical function of the interfaces is formulated by boundary operators. We consider multi-scale boundary operators in order to separate the different physical quantities and in order to use individual interpolation methods for them according to their smoothness. In this way it is possible to consider refraction and diffraction effects at the same time.

The algorithm starts with a smooth phase approximation of the field in the input plane yielding a direction function. This function is used to define guiding rays for triangularly shaped tubes. The intersection points of the guiding rays with the subsequent optical interface define the prismatic tube. The size of the tube is adjusted in order to allow linear or quadratic interpolation for smooth quantities as directions, optical path length and field scaling due to Fresnel losses and cross talk. A second set of quantities per tube is associated with scattering effects. The boundary operator realizes the interface transition for all the quantities. For example, directions, positions, scaling and phase shifts are modified according to local interface rules. The x- and y-component of the electric field can always be reconstructed at any lateral point from the quantities using the interpolation rules. At the target plane, this ensures that the geometrical optics operator can be integrated in the framework of unified optical modeling.

Some examples and simulation results obtained with the software VirtualLab (www.lighttrans.com) are presented.

8171-16, Session 4

Gaussian beam mode analysis of optical pulses

R. J. Mahon, A. Murphy, National Univ. of Ireland, Maynooth (Ireland)

The application of the Laguerre-Gaussian and Hermite-Gaussian truncated series expansions in the simulation of paraxial optical pulses is discussed and presented through examples of pulse modulation by diffractive Fresnel lenses and axicons. The Gaussian beam mode method allows for efficient computation of Fresnel diffraction effects, with the field at each point in space calculated as a finite series with a relatively low number of terms with negligible deviation from the conventional diffraction integral results.

The discussion of the numerical advantages of the Gaussian beam mode expansion is supplemented by a description of the physical properties of paraxial ultrashort Laguerre-Gaussian beams which exhibit interesting effects in the near field of their propagation, namely

superluminal group velocities and dispersion-like behaviour. With a numerical description of these properties, the structure of pulse fields diffracted at apertures can be calculated as a summation of these ultrashort pulse modes with suitable weightings. Features generated by pulse diffraction at a circular aperture, i.e. boundary waves, can be compared with the propagation of higher order Gaussian modes which exhibit similar characteristics.

We also describe the use of these modal techniques outside the paraxial regime using recently derived expressions for the non-paraxial propagation of Hermite-Gaussian modes, which allow for an efficient modal synthesis of Rayleigh-Sommerfeld diffraction effects in the far-field.

8171-17, Session 4

Non-sequential field tracing methods

M. Kuhn, LightTrans GmbH (Germany); F. Wyrowski, Friedrich-Schiller-Univ. Jena (Germany)

Field tracing generalizes the concepts of ray tracing. In particular harmonic fields are traced through the system instead of ray bundles. Hence field tracing utilizes and provides more information about the light in optical systems. The error due to the physical approximation can be minimized and consequently many effects as e.g. diffraction and interference are modeled much more accurate than by ray tracing. In order to apply field tracing, the system that is to be modeled is decomposed into subdomains. In the final stage, the subdomains are regions of quasi-homogeneous media (constant refractive index or smooth variation of the refractive index). These regions are separated by optical interfaces where jumps of the refractive index typically occur. In this talk, we introduce a new approach for the analysis of multiple reflections that appear between the optical interfaces of a lens or other optical system. We establish the non-sequential field tracing formulation of the multiple reflection problem by combining individual propagation steps between two optical interfaces at a time. The non-sequential modeling approach yields an algorithm that applies the propagation through single interfaces and the adjacent media multiple times. The analysis of the convergence of the tracing algorithm is based on Neumann series. The resulting simulation algorithm is modular and requires two types of propagation operators: one for quasi-homogeneous media and one for the transition through optical interfaces. Because of this modularity and following the ideas of unified optical modeling, different propagation methods can be used for the individual propagation steps. We may mention the combination of different free space propagation methods (e.g. spectrum of plane waves, Fresnel or far field integral) and geometrical optics propagation methods as an important case. All these methods are being coupled based on a fully electromagnetic representation of light. The methods can be adjusted locally according to the structural properties of the subdomains and optical interfaces. They are selected in order to keep the physical errors as small as required and in order to minimize the numerical effort (memory consumption and CPU time) at the same time. This is a non-trivial task since rigorous simulation methods, i.e. those methods with no physical error, typically result in large and even infeasible numerical requirements. Some examples and convergence results obtained with the software VirtualLab (www.lighttrans.com) are presented.

8171-18, Session 4

Low-splice loss design of DS and DF single-mode fibers

C. M. Jadhao, G.S. College of Khamgaon (India); D. S. Dhote, Brijlal Biyani Science College of Amravati (India)

The Wavelength of zero first order chromatic dispersion can be shifted to the lowest loss wavelength for silicon fibers at 1.55 m to provide both low dispersion and low loss fiber. Dispersion-Shifted Single Mode Fiber achieves this. However, the design flexibility required to obtain particular dispersion, attenuation, and MFD, bend and Splice Loss characteristics has resulted in specific profile. An alternative modification of the dispersion characteristics of Single Mode Fiber involves the achievement of low dispersion window over the low loss wavelength region and allow flexible WDM i.e. Dispersion-Flattened Single Mode Fiber. The comparison of Splice Loss sensitivities of Dispersion-Shifted and Dispersion-Flattened Single Mode Fiber is analyzed. Since Splices are highly tolerant for longitudinal separation, transverse offset and angular tilt are considered. The comparative analysis shows that these losses are steady in Dispersion-Flattened Single Mode Fibers

8171-19, Session 5

Numerical optimization of illumination and mask layout for the enlargement of process windows and for the control of photoresist profiles in proximity printing

K. Motzek, A. Erdmann, Fraunhofer-Institut für Integrierte System und Bauelementetechnologie (Germany)

“Proximity printing” is the lithographic technique of transferring the picture of a photomask onto a wafer by placing the wafer a certain (small) distance behind the illuminated mask. The technological equipment used to accurately place mask and wafer and to illuminate the mask is called “mask aligner”. Despite its importance for the back-end processes in the manufacturing of semiconductor devices, the modeling and simulation of proximity printing has not attracted much interest in the past. With the improved accuracy and flexibility of the last generation of mask aligners this is gradually starting to change.

The newly introduced ability to control the angular spectrum of the illuminating light provides a new degree of freedom that can be used to counter-balance diffraction effects from the most critical features on a mask. A larger angular spectrum suppresses diffraction effects more effectively. However, it also leads to a smearing of the entire image and thus to a loss of contrast. We will present results that demonstrate how simulations can be used to find the illumination that generates the largest process window. Process windows can be enlarged further by adding assist features to the mask that are optimized in size, shape and position, i.e. by performing ‘Optical Proximity Correction’ (OPC). We will show that in proximity printing OPC-structures will, in general, look quite different from the ones used in projection printing. Presenting different examples, we will demonstrate how numerical simulations can be used as a tool to introduce OPC into the world of proximity printing. We will also show examples of a co-optimization of illumination and mask layout, i.e. of “Source-Mask-Optimization” (SMO).

One of the main difficulties in the simulation of proximity printing is the nonlinear interaction between light and photoresist and the accurate modeling of photoresist development. Both of these have a major impact on the profile of the developed photoresist, e.g. on the side wall angles. We will show how our algorithms for the optimization of illumination and mask layout can be combined with photoresist models, e.g. for the popular Novolak-DNQ-resists, to control the 3D profile of the developed photoresist. We will pay special attention to the influence of the properties of the photoresist onto the resulting profile.

8171-20, Session 5

Illumination pupilgram prediction and control method in advanced optical lithography

T. Matsuyama, N. Kita, Nikon Corp. (Japan); D. G. Smith, Nikon Research Corp. of America (United States)

Source Mask Optimization (SMO) is one of the most important techniques available for extending ArF immersion lithography. The combination of freeform source shape and complex mask pattern, determined by SMO, can extend the practical resolution of a lithography system. However, imaging with a small k1 factor (~0.3 or smaller) is very sensitive to many imaging parameters, such as illumination source shape error, lens aberration, process property, etc. As a result, care must be taken to insure that the source solution from SMO can be produced by the real illuminator, which is subject to its own imaging constraints. One approach is to include an illuminator simulator in the SMO loop so that only realizable illumination pupils are considered during optimization. Furthermore, the real source shape must be re-adjusted to realize expected imaging performance as may be seen, for example, in an Optical Proximity Effect (OPE) curve.

In this paper we present and describe both the illuminator simulator, which can predict the real pupilgram on the exposure tool quickly, and an illumination pupilgram re-adjustment method that can effectively control the various illumination parameters to get optimum imaging performance, which is required for the lithography process design.

The adjusting method uses pupilgram modulation functions, which are similar to Zernike polynomials used in wavefront aberration analysis for lithographic projection lens, to describe the optimal pupilgram adjustment, and the resulting modulation can then be realized by the illuminator system.

We demonstrate the effect of the pupilgram simulator and the adjustment method. Using this combination of techniques, SMO solutions will be more realistic and practical for extending ArF immersion lithography.

8171-21, Session 5

Predictive modeling of EUV-lithography: the role of mask, optics, and photoresist effects

A. Erdmann, P. Evanschitzky, F. Shao, T. Fühner, Fraunhofer-Institut für Integrierte System und Bauelementetechnologie (Germany); E. Hendrickx, G. Lorusso, A. Goethals, R. Jonckheere, IMEC (Belgium); T. Bret, T. Hofmann, Carl Zeiss SMS GmbH (Germany)

Extreme ultraviolet (EUV) - lithography at a wavelength of 13.5 nm is considered as the most promising successor of optical projection lithography. First pre-production tools have already been delivered to leading semiconductor fabrication companies. The application of these tools in manufacturing requires a comprehensive optimization of all components of the lithographic process.

Predictive simulation of EUV-lithography provides valuable input for the further optimization of this technology. The paper starts with an overview of simulation models for EUV lithography. This includes a rigorous modeling of light diffraction from reflective multilayer-based masks, the image computation using a mirror system, and the modeling of physical and chemical effects during the processing of the photoresist. Some of the model parameters, specifically the photoresist parameters, have to be calibrated with experimental data. The role of the different mask, optical, and photoresist parameters in the calibration procedure with experimental data from the EUV alpha demo tool (ADT) at IMEC is investigated. For example, the mask stack has to be carefully analyzed to provide appropriate reflectivities of the multilayer and absorber over a certain range of incidence angles. Results of a model calibration for 12 different combinations of absorber widths, pitches, and illumination directions and resulting linewidth data over multiple focus and dose settings are presented together with all relevant model parameters. The calibrated model is verified for additional mask features.

Finally, the obtained model is used to simulate the printing of multilayer defects for different focus and dose settings. These multilayer defects belong to the most critical issues for future applications of EUV lithography. Predictive simulations can be applied to investigate the defect printing characteristics.

8171-22, Session 5

Analytical model for EUV mask diffraction field calculation

Y. Cao, X. Wang, Shanghai Institute of Optics and Fine Mechanics (China) and Graduate School of the Chinese Academy of Sciences (China); A. Erdmann, Fraunhofer-Institut für Integrierte System und Bauelementetechnologie (Germany); P. Bu, Y. Bu, Shanghai Institute of Optics and Fine Mechanics (China) and Graduate School of the Chinese Academy of Sciences (China)

In extreme ultraviolet (EUV) lithography, the combination of off-axis illumination and mask topography impacts the wafer image, resulting in an orientation dependent pattern shift and bias. As feature size shrinks and imaging performance requirements increase, accurate analysis of mask topography effects is required. The rigorous mask simulation is usually limited by the runtime or memory requirement of the simulator. For a better understanding and analysis of the mask diffraction effects, approximate but fast methods have to be developed.

In this paper, an analytical model is proposed to describe the mask diffraction in EUV lithography. An EUV mask consists of a reflective multilayer (ML) and a thick absorber pattern deposited on the top of the ML. In this model, the multilayer and absorber are simulated separately. A ray tracing model is used to combine the separate simulations. From a physical point of view, the incoming plane wave is first diffracted by the absorber layer, and then reflected by the ML and propagated upwards through the absorber again. The ML reflection is calculated by a mirror approximation. The mirror location is determined by the equivalent phase shift of the ML. The absorber transmission is calculated by a modified Kirchhoff model, where it is considered to be thin and located in a certain plane. Considering the edge diffraction effects, a pulse function is used to modify the complex transmission function of the thin absorber layer. The parameters of the pulse function are calibrated by a single rigorous simulation using the spectrum matching method. Moreover, an analytical expression of the diffraction spectra of masks with arbitrary pattern orientation is deduced.

To validate the accuracy of this model, aerial images of dense and isolated line patters were simulated by this model. Comparison with a rigorous simulation using the development and research simulator Dr.LiTHO are used to validate the accuracy of the developed simplified model. It predicts mask diffraction of 16 nm wide line features. For 0.35 NA EUV systems with an incident angle of 6° the simulated CD error was below 1 nm within the defocus range of ±100 nm. This model is analytical, fast and accurate. It can be used to analyze mask topography effects in EUV lithography imaging simulations.

8171-23, Session 5

Influence of geometry variations and defects on the near field optical properties of pulsed compression gratings

J. Wang, A. Erdmann, S. Liu, J. Shao, Y. Jin, H. He, K. Yi, Shanghai Institute of Optics and Fine Mechanics (China)

The internal electric field enhancement is critical for the laser induced damage properties of pulse compression gratings (PCG) in high-energy laser systems. Due to complex fabrication processes of PCG such as coating, interference lithography and etching, different kinds of defects, like nodular defects in the multilayers and non-uniformities of the grating profiles in the PCG, can't be practically avoided. Even though some of these defects have little effect on the spectral response of optical elements, they may produce huge changes of internal electric fields and thus decrease the damage threshold value of PCG. To obtain a better understanding of the dependence of the internal electric field enhancement on these defects and their dimensions, it is necessary to investigate the near field distributions of defective PCGs using rigorous electric magnetic field (EMF) solvers.

In this paper, the influence of fabrication processes inducing PCG geometry and material parameters variations and defects on the electric field in the grating will be analyzed. Different models will be established for nodular defects, missing grating lines, insufficient uniformity of grating depth and periods observed in the experimental PCG samples. Various modeling approaches will be employed to calculate the near field electric field distributions in the defective PCGs in order to investigate the sensitivity of the internal electric field enhancement to different process variations and defects. Some typical EMF solvers such as the Waveguide method, the Fourier modal method, and effective medium theory are used with respect to different types of defects in the PCGs. One example of calculation results for the defect of missing grating lines (illustrated in Fig. 1) in PCG is shown in Fig. 2. Finally, these analysis results will be used to analyze the experimental results of damage spots occurred in the PCG and the damage development under high-energy laser irradiation.

8171-24, Session 5

A ridge waveguide quantum well ALGAAS/GAAS laser beam design

M. Nazari, Islamic Azad Univ. (Iran, Islamic Republic of)

An advanced structure of AlGaAs laser diodes has been designed using the simulation software.

Simulation results suggest that the thicknesses of SCH layers, inner cladding and outer cladding layers should be changed in order to give low loss, narrow far-field divergence angle and high confinement factor. The Thickness of the etch stop layer is optimized to give the required effective lateral refractive index. At the end the channel width and ridge width are also optimized to obtain single lateral mode.

The aim of our study was three folds: (1) to provide the comprehensive analysis and calculations to design a ridge waveguide laser. In the simulations, the thicknesses of SCH layers, inner cladding layers and outer cladding layers are varied in order to observe variations of far-field divergence and the total confinement factor as functions of layer thicknesses. Comparison among loss, narrow far-field divergence and high confinement factor are made to optimize layer thicknesses, (2) The thickness of an etch stop layer is optimized to achieve the required lateral effective refractive index difference, and also the far-field divergence of the ridge waveguide laser, (3) the channel width and ridge width are designed to maintain single lateral mode and low loss by using the three layer dielectric slab waveguide calculations. The details of simulation using WAVEGUIDE software are provided in the following figures. Also there is a summary of the designed laser:

Confinement factor (Γ): 0.01297672 , far field Divergence angle (θ) : 26 0

Conclusion: It is believed that our study might provide an accurate analytical approach to design ridge waveguide lasers. The width of the ridge region is obtained by calculation for single-lateral-mode operation and we have 3.47 micrometers for it which only TE0 mode can propagate which satisfies neff In ridge region: 3.372425 , neff in wing regions: 3.37020 the minimum requirement for a perfect laser. The present results are also useful for the design of other equivalent lasers.

8171-26, Poster Session

Higher-order ghost imaging with partially polarized classical light

H. Kellock, T. Setälä, Aalto Univ. School of Science and Technology (Finland); T. Shirai, National Institute of Advanced Industrial Science and Technology (Japan); A. T. Friberg, Aalto Univ. School of Science and Technology (Finland)

It is known that the visibility in quantum and classical ghost imaging with scalar light improves as the order of imaging increases. Recently also electromagnetic ghost imaging has started to attract attention and it is important to assess the role of partial polarization in these situations. In this work we analyze the effects of both the order of imaging and the degree of polarization of an incident, classical, random electromagnetic beam on the visibility (or contrast) of the ghost image.

The beam is split into N parts which are directed either into the object or reference arms and Nth-order intensity correlations are calculated. In each order the obtainable visibility depends also on the number of object and reference arms, since the reference beams contain no information on the object but contribute to the background. We make use of two different definitions for the visibility in Nth-order ghost imaging and derive, under the assumption of Gaussian statistics, closed-form expressions for the maximum attainable visibility. Both expressions lead to the conclusion that the visibility increases with the order of imaging and the degree of polarization. For instance, in the 2nd-order the visibility increases (according to one of the definitions) from 1/5 for unpolarized light to 1/3 for a polarized beam, whereas in 3rd-order ghost imaging with two object arms the visibility ranges from 1/2 to 5/7. With higher-order ghost imaging the visibility approaches unity. We emphasize that the numerical values depend on the definition of the visibility and on the number of object arms used.

We also discuss briefly some recently published results on (second-order) electromagnetic ghost imaging and optical coherence theory.

8171-27, Poster Session

Corrected coupled-wave theory for non-slanted reflection gratings

L. A. Estepa, C. Neipp López, J. Francés Monllor, A. Márquez, S. Bleda, M. Pérez-Molina, M. Ortuño, S. Gallego, Univ. de Alicante (Spain)

In this work we present an analysis of non-slanted reflection gratings by using a corrected Coupled Wave Theory which takes into account boundary conditions. It is well known that Kogelnik's Coupled Wave Theory predicts with great accuracy the response of the efficiency of the ze¬ros and first order for volume phase gratings, for both reflection and transmission gratings. Nonetheless, since this theory disregards the second derivatives in the coupled wave equations derived from Maxwell equations, it doesn't account for boundary conditions. Moreover only two orders are supposed, so when either the thickness is low or when high refractive index high are recorded in the element Kogelnik's Theory deviates from the expected results. In Addition, for non-slanted reflection gratings, the natural reflected wave superimpose the reflection order predicted by Coupled Wave theories, so the reflectance cannot be obtained by the classical expression of Kogelnik's Theory for reflection gratings. In this work we correct Kogelnik's Coupled Wave Theory to take into account these issues, the results are compared to those obtained by other methods, such as Rigorous Coupled Wave Theory and a Matrix Method, showing good agreement between the three theories.

8171-28, Poster Session

Self-disappearance of the frequency doubling of light in germanium-silicate patterns

V. A. Smirnov, L. I. Vostrikova, V. Lashkaryov Institute of Semiconductor Physics (Russian Federation)

The phenomenon of photo-induced frequency doubling of light, which appears during the illumination of media by inter-coherent bi-chromatic powerful laser radiation, is intensively investigated in different volumetric samples: glass materials, polymer films and also in optical fibers and planar waveguides. One of the basic tasks is to obtain the maximal of the generation efficiency which is necessary for the possible practical applications of this phenomenon for the creation of the new modern elements for coherent powerful laser optics and optoelectronics. So, the questions what causes the restriction of a process of the forming of photo-induced periodical electric field grating in different class of studied samples? or what blocks the value of the nonlinear frequency doubling of light? have the principal character. In given report we present the results of the observation of the process of photo-induced frequency doubling of light in germanium-silicate patterns. During the investigation a big anomalous growth of light absorption has been detected in the region of high induced electric field. The absorption blocks the process of the writing of the grating of nonlinear second-order susceptibility and leads to the self-disappearance of the frequency doubling. Some properties of the observed phenomenon have been studied and the possible mechanisms of the dynamics of process are discussed.

Conference 8172: Optical Complex Systems: OCS11

Monday-Thursday 5-8 September 2011

Part of Proceedings of SPIE Vol. 8172 Optical Complex Systems: OCS11

SPIE Optical Systems Design

8172-01, Session 1

Illuminating biomedical discovery with advanced optical and opto-acoustic imaging

V. Ntziachristos, Helmholtz Zentrum München GmbH (Germany)

No abstract available

8172-02, Session 1

Micrometer scale resolution images of human corneal graft using full-field optical coherence tomography (FF-OCT): link with the scattered intensity

O. Casadessus, G. Georges, L. Siozade Lamoine, C. Deumié, Institut Fresnel (France); L. Hoffart, J. Conrath, Hôpital de la Timone (France)

A preliminary graft sorting is necessary to ensure good chances of success for a corneal transplant. One of the key parameters considered during the sorting procedure is the transparency of the graft. Opaque corneas are rejected from the tissue banks, but this criterion remains subjective as based on the operator visual appreciation. The loss of transparency of the cornea is due to an increase of its scattering properties, and we aim here to analyse them in order to get information about the quality of the tissue. This study proposes to explore the possibility to quantitatively characterize the transparency of corneal grafts through the study of their scattering properties.

The corneal oedema is mainly due to a high hydration of the corneal bulk (stroma). To control this corneal hydration, we use osmotic solutions in this study. The thicknesses of the considered samples evolve approximately from 450 µm to 1000 µm.

On one hand, a Full Field Optical Coherence Tomography (FF-OCT) setup has been developed to image the microstructure of the cornea. The experimental apparatus is based on a Linnik interferometer, and provides micrometer scale three-dimensional images. OCT enables the detection and localization of refractive index inhomogeneities inside the tissue, and we highlight here structures which size and distribution evolve with the oedematous state of the cornea.

On the other hand, structural information are completed with angle resolved scattered intensity measurement providing information about the scattering properties and the transparency of the graft. The sample is illuminated in its center with a He-Ne laser and the scattered intensity is measured in all directions of space with a rotating optical fiber linked to a photomultiplier tube. We find a close link between the scattered intensity level and the thickness of the cornea as a function of its hydration rate. Moreover, angle resolved measurement enables the determination of the scattering origin (i.e. surface or bulk contribution).

To go further, theoretical modelling is developed in order to predict the angular scattered properties as a function of the structure of the bulk. Both exact electromagnetic calculations (based on differential method) and first order approximation theory are used to determine the scattering properties of the modelled corneal graft structure. The influence of the size and distribution of scatterers is then studied on the resulting scattered intensity. This approach is developed to figure out the scale of the structures responsible for the scattering behaviour of the cornea when oedema develops, and the first results show an increase of the scattered level as a function of the size and the spatial repartition of the scatterers.

Transparency loss and more generally scattered intensity increase in corneal graft is strongly linked to its thickness (and then to its hydration degree), but the phenomenon itself remains complicated to describe in relation with the corneal structure. However, considering micrometric scale inhomogeneities and their evolution in oedematous tissues offers scattering behaviours explaining partially the experimental results.

8172-03, Session 1

Optical system for monitoring the internal image of foods and human body

N. Aisha, L. Fugang, T. Genta, K. Yamaguchi, M. Fukuda, Toyohashi Univ. of Technology (Japan)

Various systems, such as magnetic resonance imaging and x-ray computed tomography, have been researched and developed for safety in our daily lives and practically used in broad area of our lives. Monitoring techniques for alien substances in foods and blood vessels in human body is now strongly required in the food and the medical-care industry. For this purpose, a compact and simple equipment using near infrared ray is developed in this study, and its applicability to food is analyzed in detail.

The equipment developed in this study has an optical source and a CMOS sensor with very wide dynamic range. The wavelength of the optical sources was set at around 850-nm band since optical absorption is lower than that at the other wavelength band in foods. Various optical sources, such as a laser diode, a super luminescent diode (SLD), and a panel composed of their diodes, were examined to observe the inner image formed by the light penetrated through foods. Alien substances intentionally added in foods were clearly monitored on the image. Based on these images, their clearness was discussed in correlation with the properties of food.

Various kinds of foods, such as bread, biscuit, chocolate, ham, sausage, etc., were examined with the equipment developed in this study, and the clearness of the image tended to be high as water content decreases. This was due to water absorption of light, and the influence of water was clearly confirmed by monitoring the intensity of penetrated light while the water content in the bread was changed. In addition, alien substances such as human hairs and insects were monitored in the images more clear in homogeneous material such as biscuits and sausages than in inhomogeneous one such as bread. Many air bubbles were included in bread and this lowered the clearness of image. The spatial resolution of inner images was confirmed to be about 100 µm, and a human hair mixed in 8-mm-thick sausage was detected in the image penetrated through it.

From these result, the simple optical imaging system developed in this study has been confirmed to be applicable to the detection of alien substances in food (and the medical field) with high spatial resolution. In the conference, we will present the detail of the optical system composed of recent advanced optical and optoelectronic parts. Various kinds of monitoring images will be also presented.

8172-04, Session 1

Depth selectivity in biological tissues by polarization analysis of backscattered light

C. Deumié-Raviol, A. da Silva, Institut Fresnel (France)

Optical Imaging in human tissues for medical applications is a purpose linked with light scattering in random media expertise. The aim is to deal with scattering tissues presenting multiple light scattering sources with different scattering regimes, which have to be separated in all space directions. The inverse problem appears to be a complex problem, and has to be connected with imaging objectives.

The use of polarized light allows the partial discrimination of scattering sources, and the probing of tissues. First investigations by using of coherent illumination revealed potentialities of interferences on the polarized states. Techniques with tunable polarization components have been explored to reveal pertinent signatures in the case of mineral materials, but revealed a specific problematic linked with spatial and temporal coherence dependence of the polarization state, with limits in the case of human tissues and living analysis.

In another point of view, the case of an incoherent illumination configuration is different, and the use of polarized light allows the probing of tissues on a specific depth depending on the polarization type and the tissues properties. This is called polarization gating and

has been widely used to probe biological tissues. Depth selectivity for accurate depth volume examination is crucial for medical applications such as skin (burned tissues, melanoma) diagnosis and superficial morphology probing or brain monitoring, for which in vivo examination is required. Accurate depth examination of tissue however requires a high selectivity of the probed depth. It was shown that linearly and circularly polarized illuminations allow polarization gating up to a specific depth depending on the illumination polarization and optical properties of the medium. Monte Carlo simulations prove that circularly polarized light maintains a higher degree of polarization (DOP) in depth compared to the DOP of linearly polarized light for media with Mie scattering regime. It has been showed experimentally that circularly polarized light maintains its DOP up to a depth of about 10 mean free paths (MFP) while for linearly polarized light the DOP is negligible after only 2 MFP.

In this presentation we propose and simulate the use of different elliptically polarized illuminations for continuous depth examination in between linearly and circularly polarized illumination. Monte Carlo simulations and the calculation of the general DOP confirm that circularly polarized illumination penetrates deeper than linearly polarized illumination in a semi-infinite scattering medium containing Mie scatterers. Furthermore, we validated with Monte Carlo simulations that elliptically polarized light can be tuned in its penetration depth continuously between the penetration depth of linearly polarized light and circularly polarized light.

8172-05, Session 1

Snapshot Mueller polarimetry for biomedical diagnostic related to human liver fibrosis: evaluation of the method for biomedical assessments

P. Babilotte, M. Dubreuil, S. Rivet, Y. Lijour, D. Sevrain, L. Martin, G. Le Brun, Y. Le Grand, B. Le Jeune, Univ. de Bretagne Occidentale (France)

In this report, we evaluate a new Snapshot Mueller polarimeter developed in our lab as a diagnosis tool of human liver fibrosis. 16 µm-thick paraffin histological sections of human surgical liver biopsies fixed with formaldehyde and stained with picro-sirius red were studied. Picro-sirius red dye is well known to enhance birefringence of collagen fibres, which is mainly due to co-aligned molecules of Type-I collagen. Moreover, Type-I collagen over-production and accumulation in within the extracellular matrix (ECM) is the main feature of liver fibrosis progression, leading to cirrhosis and cancer with high morbidity and mortality rates in chronic hepatitis B or C virus infections and alcohol intake. Then quantification of Type-I collagen deposits is at the basis of a number of histological methods. However most of these methods lack of precision and suffer to intra and inter operator variability.

Optical polarimetry and especially Mueller polarimetry have been qualified as a relevant and robust approach in the biomedical field (for skin and ocular diseases for instance), as well as in food-processing and material science (anisotropic materials such liquid crystals).

Our snapshot Mueller polarimeter used a superluminescent diode (SDL, P < 100 mW at 829 nm ±15 nm FWHM) as the broadband light source. It was composed of a polarization state generator made of a linear polariser followed by two calcite plates of thickness e=2.08mm, a pair of microscope objectives (10x, 0.25 NA) used as focusing and collection lenses, and a polarization state analyser made of two calcite plates of thickness 5e=10.4mm followed by a linear polariser. The transmitted light was send to a spectrometer equipped with a CCD camera. The Fourier transform of the spectrum at each point of the sample settled near the beam waist provides a local Mueller matrix. Using a Lu and Chipman decomposition, polarimetric images (birefringence, dichroism, depolarization) of regions of interest (ROI) were reconstructed by scanning the sample across the beam.

From comparison with intensity images (absorption is mainly due to picro-sirius red at visible wavelengths), we showed that birefringence is the most relevant polarimetric contrast with regards to Type-I collagen in liver fibrosis, as expected from picro-sirius red staining of collagen fibres. Moreover snapshot Mueller polarimetry also provide the image of the birefringence axes, which could allow to reconstruct the orientation field of Type-I collagen so as to exploit morphological features of fibrosis disease. Polarimetric imaging will also be compared to SHG measurements.

The polarimetric characteristics of the media are then correlated to the degeneracy level of tissue.

Different results linked to the clinical analysis will be presented and compared with previous performed works. A statistical analysis of the distribution of polarimetric parameters will be proposed, and linked to the METAVIR level (characterising fibrosis state of the tissues) between F0 (low level of fibrosis) and F4 (strong level of fibrosis).

This research work is financially supported by Conseil Général du Finistère.

8172-06, Session 1

Biomedical implications of dental-ceramic defects investigated by numerical simulation, radiographic, microcomputer tomography, and time-domain optical coherence tomography

C. G. H. Sinescu, M. L. Negrutiu, Univ. de Medicina si Farmacie Victor Babes, Timisoara (Romania); C. Ionita, Univ. at Buffalo (United States); L. Marsavina, Politehnica Univ. Timisoara (Romania); A. G. Podoleanu, Univ. of Kent (United Kingdom)

Imagistic investigation of the metal-ceramic crowns and fixed partial prostheses represent a very important issue in nowadays dentistry. At this time, in dental office, it is difficult or even impossible to evaluate a metal ceramic crown or bridge before setting it in the oral cavity. The possibilities of ceramic fractures are due to small fracture lines or material defects inside the esthetic layers.

Material and methods: In this study 25 metal ceramic crowns and fixed partial prostheses were investigated by radiographic method (Rx), micro computer tomography (MicroCT) and optical coherence tomography (OCT) working in Time Domain, at 1300 nm. The OCT system contains two interferometers and one scanner. For each incident analysis a stuck made of 100 slices was obtain. These slices were used in order to obtain a 3D model of the ceramic interface. After detecting the presence and the positions of the ceramic defects the numerical simulation method was used to estimate the biomechanical effect of the masticatory forces on fractures propagations in ceramic materials.

Results: For all the dental ceramic defects numerical simulation analysis was performed. The simulation of crack propagation shows that the crack could initiate from the upper, lower or both parts of the defect and propagates through the ceramic material where tensile stress field is present. RX and MicroCT are very powerful instruments that provide a good characterization of the dental construct. It is important to observe the reflections due to the metal infrastructure that could affect the evaluation of the metal ceramic crowns and bridges. The OCT investigations could complete the imagistic evaluation of the dental construct by offering important information when it is need it.

8172-07, Session 1

Ceramic and polymeric dental onlays evaluated by photo-elasticity, optical coherence tomography, and micro-computed tomography

C. G. H. Sinescu, Univ. de Medicina si Farmacie Victor Babes, Timisoara (Romania); A. G. Podoleanu, Univ. of Kent (United Kingdom)

Dental onlays are restorations used to repair rear teeth that have a mild to moderate amount of decay. They can also be used to restore teeth that are cracked or fractured if the damage is not severe enough to require a dental crown. The use of onlays requires less tooth reduction than does the use of metal fillings. This allows dentists to conserve more of a patient's natural tooth structure in the treatment process.

The aims of this study are to evaluate the biomechanical comportment of the dental onlays, by using the 3D photo elasticity method and to investigate the integrity of the structures and their fitting to the dental support. For this optical coherence tomography and micro-computed tomography were employed. Both methods were used to investigate 37 dental onlays, 17 integral polymeric and 20 integral ceramic.

The results permit to observe materials defects inside the ceramic or polymeric onlays situate in the biomechanically tensioned areas that could lead to fracture of the prosthetic structure. Marginal fitting problems of the onlays related to the teeth preparations were presented in order to observe the possibility of secondary cavities. The resulted images from the optical coherence tomography were verified by the micro-computed tomography.

In conclusion, the optical coherence tomography can be used as a clinical method in order to evaluate the integrity of the dental ceramic and polymeric onlays and to investigate the quality of the marginal fitting to the teeth preparations.

8172-08, Session 2

The scattering of light from two-dimensional randomly rough surfaces

A. A. Maradudin, Univ. of California, Irvine (United States)

No abstract available

8172-09, Session 2

Nonlinear modeling of active or passive optical Lamellar nanostructures

A. V. Kildishev, X. Ni, Purdue Univ. (United States); L. J. Prokopeva, Institute of Computational Technologies (United States)

Most recently, promising optical effects made possible through the use of hyperbolic metamaterials (HMMs) has come into focus. It was reported that HMMs have special properties of converting evanescent wave into propagating wave and therefore have the capability of forming an imaging device with subwavelength resolution, and they also have a unique broadband singularity in the photonic density of states (PDOS). There is considerable interest in accurate, computationally inexpensive, and hence presumably one-dimensional tools for modeling the dynamics of plane waves in a most general HMM structure. Therefore, a universal approach to modeling the refraction of a monochromatic plane wave incident on an optical metamaterial arranged of arbitrary (passive, active, anisotropic, or plasmonic) layers of linear or feebly non-linear elemental materials is examined. The approach is built on an alternative formulation of the method of single expression [1,2], which works well upon different combinations, including non-linear lossy dielectric, graded-index Kerr medium, gain medium with metal, and anisotropic medium, upon either p-polarized or s-polarized light. We start with the monochromatic scalar wave equation, a possible non-linearity of permittivity was introduced through additional dependence field component, which allows for lossy or gain elemental materials with sharp or continuous changes in linear permittivity and non-linear susceptibility. We show that the case for the s-polarized incident light (electric field is perpendicular to the incident plane) can be formulated relatively straightforwardly. However, the case for p-polarized incident light (magnetic field is perpendicular to the incident plane) is more complicated, since an implicit material equation is involved, which can be converted into an explicit form within a selected numerical scheme. For both s-/p-polarization cases, the scalar wave equation was eventually reformatted into a classical Riccati equation. The initial condition can be obtained from the transmission side by assigning a transmitted field. At the illumination side, the Sommerfeld radiation condition can be used for splitting incident and reflected light. The proposed method was implemented using the explicit Runge-Kutta scheme. A metal-dielectric multilayer structure arranged of alternating layers of silver and Vanadium Pentoxide has been used to validate the approach with numerical simulations of a multilayer stack of silver-dielectric layers with nanoscale thicknesses. Full-wave electromagnetic simulations have been completed using commercial finite-element software and our spatial harmonic analysis (SHA) technique [3]. The obtained transmittance and reflectance spectra, angular dependent spectra, and input field strength dependent transmittance and reflectance are in good agreement with those obtained from the proposed method.

[1] H. V. Baghdasaryan and T. M. Knyazyan, “Problem of Plane EM Wave Self-action in Multilayer Structure: an Exact Solution,” Optical and Quantum Electronics, 31, 9/10, 1059-1072 (1999).

[2] H. V. Baghdasaryan and T. M. Knyazyan, “Modelling of strongly nonlinear sinusoidal Bragg gratings by the Method of Single Expression, “ Optical and Quantum Electronics, 32, 6/8, 869-883 (2000).

[3] X. Ni, Z. Liu, A. Boltasseva, A. V. Kildishev, “The validation of the parallel three-dimensional solver for analysis of optical plasmonic bi-periodic multilayer nanostructures”, Applied Physics A 100, 365-374 (2010).

8172-10, Session 2

Numerical modeling of an active plasmonic metamaterial

L. J. Prokopeva, Institute of Computational Technologies (Russian Federation); J. Trieschmann, Ruhr-Univ. Bochum (Germany); T. A. Klar, Johannes Kepler Univ. Linz (Austria); A. V. Kildishev, Purdue Univ. (United States)

In this work we present a numerical study of an active plasmonic metamaterial, using finite-difference time-domain (FDTD) method. The metamaterial consists of Rh800-epoxy composite sandwiched inside an Ag-nanostrip-thin film structure [1]. The gain medium is modeled with an auxiliary differential equation (ADE) approach employing experimentally fitted parameters from our pump-probe tests. The plasmonic elements are modeled utilizing a recently proposed generalized dispersive media (GDM) model [2]. As the computational complexity of the time-domain solvers increases sufficiently when coupled with the auxiliary differential material equations for active and dispersive media, we show the complete details of efficient implementation of composite media to time-domain solvers, such as FDTD, FVTD, and FETD.

Having accurate models of the interaction of light with optical gain materials is imperative for achieving the complete compensation of losses in plasmonic elements of optical metamaterials. In the visible, a loss-free and active negative-index material has been recently experimentally demonstrated [1], supported by numerical simulations based on the finite element method (FEM) in frequency domain. In contrast to FD, time domain (TD) analysis provides a time-resolved description of the system kinetics. A kinetic description of gain media is described using a system of balance equations of the 4-level atomic system [3], which is coupled to FDTD Maxwell’s solver with ADE method. The parameters of the atomic system are matched in order to retrieve the specific gain system parameters of Rh800 dye in a dielectric host. First, the reference data are obtained from a pump-probe experiment with a uniform slab of Rh800 dye embedded in epoxy and deposited on ITO-coated glass substrate. Then, the parameters of the ADE model are tuned to match these experimental data.

On the other hand in order to numerically study optical plasmonic metamaterials in time-domain, an accurate analytical description of the dispersive behavior of both metals and dielectrics is required, particularly one which can be efficiently implemented in a numerical time domain solver. Our dispersion modeling technique that employs universal Padé approximants is (i) a generalized way to describe the optical responses of several classes of elemental optically dispersive materials, including Debye, Drude, Sellmeier, Lorentz, and critical points models (ii) a systematic method of switching between a number of known algorithms, based on ADE and recursive convolution (RC) methods, and (iii) an effective modeling approach in terms of flops and memory requirements. The proposed technique was already tested and presented for the FDTD method [2].

The example numerical model adequately and effectively (in terms of computational costs) represents the core dynamics of the given active metamaterials system, providing a well-defined physical background for modeling nanostructured active metamaterials.

References

[1] U.K. Chettiar, A.V. Kildishev, T.A. Klar, and V.M. Shalaev, Negative index metamaterial combining magnetic resonators with metal films, Opt. Express, Vol.14, No.17, 7872-77 (2006).

[2] L. J. Prokopeva, J. Borneman, and A. V. Kildishev, Optical dispersion models for time-domain modeling of metal-dielectric nanostructures, IEEE T. Magn. (in press).

[3] A. E. Siegman, Lasers (University Science Books, 1986).

8172-11, Session 2

Light scattering from photofabricated random rough surfaces

G. Soriano, Lab. d'Optique des Surfaces Couches Minces (France); G. Maire, Institut Matériaux Microélectronique Nanosciences de Provence (France); H. Giovannini, Institut Fresnel (France); V. Brissonneau, Thales Optronique S.A. (France); F. Flory, Ecole Centrale Marseille (France); L. Escoubas, Institut Matériaux Microélectronique Nanosciences de Provence (France); G. Berginc, Thales Optronique S.A. (France)

The roughness of an interface can be seen as a default, its associated scattering being considered as a noise, but roughness is also a way to modify and thus to tune the interface optical or wave properties. In order to reduce reflecting, or to shape the scattering pattern, one has to design fabrication processes to get target surface statistics. This requires a control of the wave-surface interaction and thus modelization of the electromagnetic wave scattering from a random rough surface. Such a stochastic process is usually characterized under stationary assumption by its height distribution and two-points correlation function. Since experimental and theoretical studies on rough surfaces are difficult research topics, they are often driven at different places and times. In this talk, we compare rigorous and approximate modelizations of the light scattering from photofabricated rough surfaces to experimental measures. Surfaces are generated by exposing a photosensitive layer to a UV speckle pattern, following an original extension of the Gray method, and then metallized. The roughness is thus two-dimensional, and with a single exposure, height should meet an exponential distribution. With multiple independent exposures, a gamma law is promissed, with a normal distribtuion at the limit. Under simplifying assumptions, it can be proved that the correlation function is relied to the shape of the beam used to get the UV speckle. We will thus show how, starting from Gaussian, the correlation can be modified by use of a spatial light modulator. The photofabricated samples are optically characterized by interferometric microscopy in order to retrieve the complex polarized scattered field for three different wavelengths, and by spectrogoniophotometer measures of BRDF on the whole visible domain. First order models, namely the small perturbation method, the small slope approximation and the Kirchhoff-tangent plane approximation are compared to data. For the two last theories, statistical formulations are usually based on a normally distributed height assumption, but exponential law can also be handled, as it will appear. Finally, some photofabricated samples show roughnesses in the resonant domain. Here, a method of moments is used, coupled with an impedance approximation for curved surfaces. Statistical results are obtained through Monte Carlo average ; once again, the two normal and exponential distributions are addressed.

8172-12, Session 2

Optical properties and modeling of thin film including quantum dots: examples of CdSe/ZnS and ZnO in PMMA layers

H. Lin, Y. Chen, National Central Univ. (Taiwan); J. Le Rouzo, Institut Matériaux Microélectronique Nanosciences de Provence (France); S. Chen, National Central Univ. (Taiwan); F. Flory, Institut Matériaux Microélectronique Nanosciences de Provence (France) and Ecole Centrale Marseille (France); C. Lee, National Central Univ. (Taiwan)

The optical properties of nanocrystals of a few nanometers depend on quantum confinement of electrons. In particular the energy bandgap of semiconductor nanocrystals is modified and change with their size. Lots of applications for optical systems are concerned like lasers, light emitting diodes, tags for biology and solar cells.

A model, similar to the one used for multilayer waveguides, based on the effective mass approximation, allows to calculate the energy levels of electrons and holes in periodic and non-periodic multiple quantum wells. We will present how the energy bandgap varies with the nanocrystal size for different quantum dot materials. Morever, quantum dot core/shell structure as CdSe/ZnS are taken into account in our calculation.

The discretization of energy levels of electrons and holes induce photoluminescence and modification of the absorption spectrum. Comparison between calculation and measured absorption and photoluminescence spectra of PMMA layers including ZnO and CdSe/ZnS quantum dots are given. The refractive indices of the layers are deduced.

8172-13, Session 3

Active plasmonic metamaterials: numerical modeling and optical characterization

A. V. Kildishev, V. P. Drachev, S. Xiao, X. Ni, V. M. Shalaev, Purdue Univ. (United States)

The analysis of propagation of light in nanostructured dispersive metal-dielectric composites is a subject of fundamental as well as practical importance. In recent years attention has focused in particular on artificial metal-dielectric composites (plasmonic metamaterials, PMMs) in which for example either a negative magnetic permeability (metamagnetics) or a negative refractive index (negative index materials) can be obtained in the visible range.

PMMs offer the opportunity for compressing optical signals and optical energy in space, dramatically reducing the device footprint and enhancing light-matter interactions. Thus, the interaction of light with optical gain materials is of great importance especially in metal-dielectric nanostructures, where the compensation of losses is essential for practical engineering - so that lasers, amplifiers, detectors, absorption modulators and wavelength converters could be miniaturized, and the cost of integrated optical circuits and devices could be reduced. In order to design active nanoplasmonic devices, accurate models of this light-matter interaction are required. A loss-free and active PMM in the visible has been recently experimentally demonstrated at our Birk Nanotechnology Center at Purdue; this experiment was supported by finite-element simulations in frequency domain and the appropriate retrieval of the effective bianisotropic properties. Our recent progress in this field will be reviewed followed by a brief discussion of the challenges of the time-domain and frequency-domain modeling and characterization of thin PMM samples with gain inclusions.

8172-14, Session 3

Tunneling of ultrashort EM wave pulses in gradient metamaterials: paradoxes and perspectives

A. B. Shvartsburg, Joint Institute for High Temperatures (Russian Federation)

Giant artificial dispersion, both normal and abnormal, of nanogradient photonic barriers, formed by transparent dielectric films with continuous spatial distributions of refractive index across the film, is considered. Controlled non - Fresnel reflectance and transmittance spectra, stipulated by the profound influence of gradient and curvature of refractive index distribution, are examined. Formation of cut-off frequency of transparent barrier, governed by the technologically managed spatial profile of refractive index, is shown to provide the resonant tunneling of EM wave through barrier. Unlike the traditional tunneling through media with negative dielectric susceptibility , the new trends in energy and information transfer, arising due to reflectionless tunneling through the barrier with >0, but grad <0, are shown. Ultrafast reshaping of tunneling femtosecond pulse, accompanied by formation of superluminal precursors on the pulse front edge, while the center of gravity of reshaped pulse stays subluminal, is visualized. Applications of these tunneling effects to design of new generation of miniaturized

filters, large angle polarizers, frequency-selective interfaces, highly dispersive photonic crystals, broadband subwavelength coatings and reflectors are considered. Scaling of these effects, based on new exact analytical solutions of Maxwell equations, to microwave range is illustrated.

8172-15, Session 3

Surface plasmon effect on metallic nanoparticles integrated in organic solar cells

S. Vedraine, Institut Matériaux Microélectronique Nanosciences de Provence (France); V. Gernigon, Institut d'Electronique du Solide et des Systèmes (France); P. Torchio, Institut Matériaux Microélectronique Nanosciences de Provence (France); F. Flory, Ecole Centrale Marseille (France); T. Heiser, P. Lévêque, Institut d'Electronique du Solide et des Systèmes (France); L. Escoubas, Institut Matériaux Microélectronique Nanosciences de Provence (France)

Photovoltaic is receiving increasing interest as a serious solution to sustainable energy production. However, the price of traditional crystalline silicon solar cells is high. New thin film Organic Solar Cells (OSCs) have a strong potential to reduce the cost of photovoltaic. But the efficiency of this technology is rather low, due to the high gap of organic materials and to the short exciton diffusion length, limiting the thickness of the active layer. Several photonic concepts are currently developed per many researchers such as plasmonic structures in order to excite localized surface plasmons on metal nanoparticles (MNPs). Indeed, plasmon is an interaction between an incident electromagnetic wave and conduction electrons of these MNPs. This can lead to an increase of light absorption in the active layer via an exaltation of the electromagnetic field in the embedded layer around the MNPs. But the incorporation of such MNPs can generate some losses such as absorption by the MNPs (dissipated by heat), charges recombination, shunt currents, etc... A numerical study is first performed on a P3HT:PCBM bulk heterojunction incorporating plasmonic structures in order to investigate the optical effect of some geometrical parameters (MNPs diameters, periods, positions). Moreover, MNPs are deposited via joule effect evaporation and included in OSCs. The impact of such MNPs on OSCs properties is investigated.

8172-16, Session 3

Random rough-surface photofabrication

V. Brissonneau, Thales Optronique S.A. (France); F. Flory, Ecole Centrale Marseille (France) and Institut Matériaux Microélectronique Nanosciences de Provence (France); L. Escoubas, Institut Matériaux Microélectronique Nanosciences de Provence (France); G. Berginc, Thales Optronique S.A. (France); G. Soriano, G. Maire, Institut Matériaux Microélectronique Nanosciences de Provence (France); H. Giovannini, Institut Fresnel (France)

Random rough surfaces are of primary interest for their optical properties: reducing reflection at the interface or obtaining specific scattering diagram for example. Thus controlling surface statistics during the fabrication process paves the way to original and specific behaviors of optical waves when reflected on such surfaces..

We detail an experimental method allowing the fabrication of random rough surfaces showing tuned statistical properties. A two-step photoresist exposure process was developed. In order to initiate photoresist polymerization, an energy threshold needs to be reached by light exposure. This energy is brought by a uniform exposure equipment comprising UV-LEDs. This pre-exposure is studied by varying parameters such as optical power and exposure time. The second step consists in an exposure based on Gray method. The speckle pattern of an enlarged scattered laser beam is used to insolate the photoresist. A specific photofabrication bench using an argon ion laser was implemented. Parameters such as exposure time and distances between optical components are discussed. Then, we describe how we modify the speckle-based exposure bench to include a spatial light modulator (SLM). The SLM used is a micromirror matrix known as Digital Micromirror Device (DMD) that allows spatial modulation by displaying binary images.

Thus, the spatial beam shape can be tuned and so modify the speckle pattern on the photoresist. As the photoresist photofabricated surface is correlated to the speckle pattern used to insolate, the roughness parameters can be adjusted.

Finally the surface correlation is linked to the scattered beam spatial repartition by measuring the BRDF of the fabricated rough surfaces using a spectrogoniophotometer.

8172-17, Session 3

Wavelength and temperature dispersion of refractive index of thin films

T. M. Wood, J. Le Rouzo, Institut Matériaux Microélectronique Nanosciences de Provence (France); F. Flory, Ecole Centrale Marseille (France); L. Escoubas, Institut Matériaux Microélectronique Nanosciences de Provence (France)

Nowadays, optical thin films are incorporated into a wide range of products, with applications in the fields of solar cells, gas sensors, lasers and other optoelectronic devices. For such applications, knowledge of the film refractive index over a range of operating wavelengths is essential, and in demanding environments the variation of the refractive index with the temperature of the film is an equally important factor.

The temperature dispersion of the refractive index of a thin film can be very small, of the order 10^-5/K, and as such a highly sensitive measurement method is needed. We propose the m-lines method, based on inducing guided modes in thin films deposited in a waveguide structure. Using this technique, the refractive index of the guiding film can be determined to a precision of 10^-3, whilst the sensibility to variations of the index is around 10^-6. The film thickness may also be determined to a precision of 1nm.

The experimental setup is highly versatile, relatively compact and can be adapted in order to measure the dependence of the refractive index on external or intrinsic factors, such as film temperature. A variable hot air flow and a thermocouple on the film surface have been used in conjunction with a multi-wavelength laser and in house software in order to investigate the temperature and chromatic dispersion of silica-polymer blend low-loss films.

Results obtained by m-lines can be verified using an ellipsometre equipped with a remote-controlled heating stage, and reflexion coefficient measurements from an integrating sphere treated with purpose built programmes.

8172-18, Session 3

Opto-electronic properties of photovoltaic solar cells including silicon nanowires

M. Zhu, J. Le Rouzo, Institut Matériaux Microélectronique Nanosciences de Provence (France); F. Flory, Ecole Centrale Marseille (France); V. Brissonneau, J. Simon, L. Escoubas, Institut Matériaux Microélectronique Nanosciences de Provence (France)

Nowadays, the use of silicon nanowires in several optoelectronic devices such as bio-sensors or high mobility transistors is very usual. This integration is made possible thanks to the many interesting properties of these nanostructures such as chemical, electronic or optical. Despite this fact, silicon nanowires are not well used in the field of photovoltaic solar cells due to technological barriers like diameter and density control, doping or again electrical contacts.

In this work, we will show the great interest of integrated silicon nanowires in solar cells. In this context, two lines of research can be followed for these nanostructures. First, a layer of silicon nanowires can play the role of a good antireflective effect, on the top of the cell. Secondly, a silicon solar cell can be made with the integration of nanowires solar cells either in a single junction solar cell or in a tandem

solar cell (two junctions). In these two cases, optical and electrical measurements are necessary to confirm the importance of these structures.

After describing the chemical process we use to obtain nanowires, the reflection and diffusion measurements on this layer will be presented. Some previous measurements show promising results in reflection under 2%. We will also show the electrical results (lifetime or current-voltage measurements) that we obtain. Finally, optoelectronics results on a complete cell including silicon nanowire solar will be presented.

8172-51, Session 3

Polarized light in nanogradient metamaterials

A. I. Kuzmichev, National Technical Univ. of Ukraine (Ukraine); A. B. Shvartsburg, Joint Institute for High Temperature (Russian Federation); O. D. Volpian, Y. A. Obod, P. P. Yakovlev, M.F. Stelmakh Polyus Research and Development Institute (Russian Federation)

Propagation and tunneling of polarized light through gradient nanophotonic barriers, formed by continuous distributions of dielectric susceptibility across the films, fabricated from dielectrics without free carriers, are considered. The decisive influence of giant artificial heterogeneity - induced non -local dispersion, both normal and abnormal, stipulated by the gradient and curvature of distribution , is shown to provide the polarization - dependent tunneling of radiation in any spectral range in need. New trends in technology of sputtering of gradient silicon films of controlled distribution of on the substrate are developed, and the parameters of films, fabricated by means of these technologies, are measured. Special methods for polarimetric testing of gradient dielectric nanofilms, based on new exact analytical solutions of Maxwell equations for inclined incidence of polarized waves, are presented. New types of dispersive elements for photonic crystals, based on polarization effects in gradient dielectric nanofilms, including, e.g., mode selectors, miniaturized phase shifters and large angle polarizers, are discussed.

8172-19, Session 4

Required Devices for Future Quantum Communications

N. Sangouard, Univ. of Geneva, Group of Applied Physics, Optiq (Switzerland)

Physicists are sometimes divided into two categories: theorists or experimentalists. In a long held preconception, the former sometimes produce clever concepts and the latter show that they are unrealistic. In this talk, we will try to be more pragmatic and examine some recent proposals allowing one to further develop and advance the field of quantum communications. We will start by recalling the principles of the quantum key distribution and looking at some of the available protocols. We will then look at several novel ideas that assist in the problems of simplifying the security of practical implementations and those for the distribution of keys over very long distances. We will finish by giving the specifications on the photon sources, the detectors and the quantum memories that are required to implement these proposals. The future will tell whether these theoretical ideas are good, but, hopefully, they could provide the motivation to realize more efficient devices.

8172-20, Session 4

Enabling quantum communication using integrated nonlinear optics

V. D'Auria, F. Kaiser, A. Martin, L. Labonté, M. P. De Micheli, D. B. Ostrowsky, O. Alibart, S. Tanzilli, Univ. de Nice Sophia Antipolis, Lab. de Physique de la Matière Condensée (France)

Periodically poled lithium niobate waveguides (PPLN/W) are considered to be one of the most useful toolboxes for enabling quantum communication experiments. Thanks to the high optical confinement over longer lengths than in bulk configurations (a few cm in our case), such structures provide highly efficient non-linear interactions, i.e., in parametric down-conversion, or sum and difference frequency generation regimes. Within the framework of long-distance quantum communication at telecom wavelengths, PPLN/Ws have therefore been proved to be a key ingredient for building ultra-bright sources of time-bin, as well as polarization entangled photons, and for photonic quantum interfaces providing coherent wavelength conversions from telecom to visible wavelength range, and conversely. During the presentation, we will discuss some recent experimental advances regarding polarization entanglement sources and quantum interfaces.

8172-21, Session 4

Integrated quantum photonics for quantum information processing

M. G. Thompson, Univ. of Bristol, Ctr. for Quantum Photonics (United Kingdom)

Quantum information technologies offer a completely new and powerful approach to processing and transmitting information by combining two of the greatest scientific and technological revolutions of the 20th century: quantum mechanics and information theory. Quantum information processing promises huge computation power, whilst quantum communications offer the ultimate in information security - guaranteed by the laws of physics.

By harness the quantum mechanical properties of light, practical quantum technologies can be realised. Until recently, optical implementations of quantum architectures have been implemented using large-scale (bulk) optical elements, bolted onto optical tables. This approach has lead to severe limitations in the miniaturization, scalability and stability of such systems. Recent progress has removed this bottleneck through the implementation of integrated quantum circuits, allowing quantum optical schemes to be realized with greatly increased capacity for circuit complexity. Such recent demonstrations include on-chip quantum logic, quantum metrology experiments with two and four-photon entangled states, multi-particle quantum walks and a simple factoring algorithm. These key steps are crucial for the progress of experimental quantum information science and the development of practical quantum photonic technologies.

8172-22, Session 4

Quantum memory for light in rare earth ion doped crystals

M. Bonarota, V. Damon, R. C. Tongning, M. F. Pascual-Winter, A. Louchet-Chauvet, T. Chanelière, Lab. Aimé Cotton (France); J. Le Gouet, Univ. Paris-Sud 11 (France)

Interaction of quantum light with an ensemble of atoms has sparked off intense research efforts during the past decade. The emblematic quantum memory challenge includes the mapping of a quantum state of light onto an ensemble state of matter and the recovery of the original state of light. Electromagnetically induced transparency (EIT) led to convincing experimental demonstrations in atomic vapors. However EIT-based protocols offer a small bandwidth, practically limited to the spectral components over the inhomogeneous width of the absorption line, according to the well-known photon echo scheme. In this context, solid-state materials such as rare-earth ion doped crystals offer a prime alternative to atomic vapors since they combine the absence of motion with long coherence lifetime and large inhomogeneous width.

8172-23, Session 4

Development of superconducting single photon detectors for integrated quantum photonics applications

R. Leoni, A. Gaggero, Istituto di Fotonica e Nanotecnologie (Italy); J. P. Sprengers, Technische Univ. Eindhoven (Netherlands); F. Mattioli, Istituto di Fotonica e Nanotecnologie (Italy); D. Sahin, S. J. Nejad, Technische Univ. Eindhoven (Netherlands); J. Beetz, M. Lermer, M. Kamp, S. Hoefling, Julius-Maximilians-Univ. Würzburg (Germany); A. Fiore, Technische Univ. Eindhoven (Netherlands)

Single photon detectors exist so far exclusively as discrete devices, while their implementation in waveguide photonic quantum circuits will open the possibility of quantum optical circuits and experiments that would otherwise be impossible to implement using bulk optics. Nanowires superconducting single-photon detectors (SSPDs) are good candidates for integration due to their relative ease of fabrication: the detection principle is based on the photon-induced hot-spot creation in ultranarrow superconducting wires [1], that can provide ultrahigh sensitivity at telecommunication wavelengths, high counting rates, broad spectral response and high temporal resolution due to low jitter values. The superconducting material of choice for the fabrication of SSPDs is NbN that has been recently integrated with GaAs, using a low-temperature process specifically developed for these substrates [2]. In this way the first waveguide single-photon detectors (WSPDs), based on superconducting nanowires integrated with GaAs/AlGaAs ridge waveguides, has been demonstrated. Here, together with the working principles and the electrical characterization, we present the SSPD's fabrication process based on electron-beam lithography and reactive-ion etching with particular attention to their integration with GaAs/AlGaAs ridge waveguides. The device structure and process is compatible with the fabrication of on-chip different optical elements such as single-photon sources based on InAs quantum dots, ridge waveguides, splitters and multimode interferometers.

[1] G. N. Gol'tsman et al., Appl. Phys. Lett. 79 (6), 705 (2001).

[2] A. Gaggero et al., Appl. Phys. Lett. 97, 151108, (2010).

8172-24, Session 5

Adaptive optics for large astronomical telescopes: a typical example of optical complex systems

T. Fusco, ONERA (France)

In the past decades, ground based astronomy has taken a new direction with the availability of 8m-class telescopes (so called Very Large Telescopes [VLT]), which have been equipped progressively with high angular resolution instruments. We recall that angular resolution at the diffraction limit is made possible by the use of adaptive optics [AO] that corrects, in real time, for the limitations induced by atmospheric turbulence. Since the first astronomical AO system (COME-ON at European Southern Observatory), classical AO, based on a single mirror and a single sensor, has gained maturity and has been deployed on most VLTs. Nevertheless, astronomy is in constant pressure for higher sensitivity (for fainter objects), better dynamics (fainter companions) or wider field of view (larger objects or simultaneous observation of small objects). They have triggered the development of new AO concepts on the verge to be available on 8-m class telescopes and also motivated the development of the so-called ELT (42m diameter European ELT [E-ELT], TMT, GMT...) that should have their first light in a decade or so.

These new instrumental developments also impose a complete rethink of the AO concept: towards eXtreme AO [XAO] to improve dynamics, or towards wide field AO [WFAO] to either have a wide science field of view or a wide technical field of view in which to find Guide Stars for sensing. Moreover wide field AO generally uses several artificial laser guide stars in order to improve sky coverage and avoid relying on the presence of bright natural guide stars.

These cutting-edge adaptive optics systems require an unprecedented level of inter-disciplinary competences, spanning adaptive optics theory and associated technological developments, control and post-processing theory, computer sciences, and finally, astrophysical exploitation.

Future Extremely Large Telescopes, equipped with revolutionary adaptive optics concepts (which are the quintessence of optical complex systems), will initiate a new era in astronomy and allow fundamental astronomical questions to be answered.

8172-25, Session 6

Comparison between analytical and “end-to-end” numerical modeling of astronomical adaptive optics systems

M. Carbillet, Univ. de Nice Sophia Antipolis (France); L. Jolissaint, aquilAOptics (Switzerland)

We compare in this contribution the analytical approach together with the so-called “end-to-end” approach in the framework of astronomical adaptive optics (AO) modeling. The two tools used for this purpose are well-known and already widely used within the astronomical AO community: PAOLA (Jolissaint et al. 2006, Jolissaint 2010) on the one hand, and the Software Package CAOS (Carbillet et al. 2005) on the other hand. In addition to inter-validate the two codes, trade-offs are clearly searched in order to find optimal compromises permitting to face both exploratory simulations and large instrumental projects while combining effectiveness and certainty.

8172-26, Session 6

Experimental comparison of Wide Field AO control schemes for future AO-assisted systems on Extremely Large Telescopes

T. Fusco, A. Parisot, C. Petit, ONERA (France)

Wide Field Adaptive Optics (WFAO) concepts, such as Laser Tomography AO (LTAO) or Multi-Conjugate AO (MCAO) have been developed in order to overcome the anisoplanatism limit of classical AO. Most of the future AO-assisted instruments of ELTs rely on such concepts which have raised critical challenges such as tomographic estimation and from laser and natural guide star combined with efficient DM(s) control.

In that context, the experimental validation of the various clever control solutions proposed by several teams in the past years is now essential to reach a level of maturity compatible with their implementation in future WFAO developments for ELT.

The ONERA wide field AO facility (HOMER bench) has been developed for this very problematic. Gathering a 3D turbulence generator, laser and natural guide stars, two deformable mirrors with variable altitude positions and a PC-based flexible and user-friendly RTC , HOMER allows the implementation and comparison of control schemes from the simplest least-square to the optimal Linear Quadratic Gaussian solutions including Virtual DM and Pseudo-closed loop approaches.

After a description of the bench internal calibrations and ultimate performance, all the control schemes are compared experimentally. Their evolutions as a function of wavefront sensors SNR as well as their robustness to calibration / model errors are particularly emphasised. The specific problem of NGS / LGS measurements and data fusion is also addressed.

Finally, we derive from the previous works some specific calibrations and identifications procedures ensuring both robustness and efficiency of WFAO systems and we extrapolate their applications to the future ELT AO systems.

8172-27, Session 6

SAXO, the VLT-SPHERE extreme AO system, design, performance and experimental validation

C. Petit, T. Fusco, J. Sauvage, ONERA (France); A. Sevin, Observatoire de Paris (France); M. Suarez, European Southern Observatory (Germany)

Direct detection and spectral characterization of extra-solar planets is one of the most exciting but also one of the most challenging areas in modern astronomy due to the very large contrast between the host star and the planet at very small angular separations. SPHERE (Spectro-Polarimetric High-contrast Exoplanet Research in Europe) is a second-generation instrument for the ESO VLT dedicated to this scientific objective. It combines an extreme adaptive optics system, various coronagraphic devices and a suite of focal instruments providing imaging, integral field spectroscopy and polarimetry capabilities in the visible and near-infrared spectral ranges.

The extreme AO system, SAXO, is the heart of the SPHERE system, providing to the scientific instruments a flat wavefront corrected from all the atmospheric turbulence and internal defects. We will present a status of SAXO assembly integration and performance. The main requirements and system characteristics will be recalled, then each sub system will be individually presented and fully characterized and finally the full AO loop performance will be quantified. It will be demonstrated that SAXO will meet its challenging requirements (more than 90% of SR in H band with a residual jitter lower than 3 milli-arcseconds for average observation conditions on the VLT). Thanks to a coronagraphic analysis of the AO residuals, a detailed comparison between actual and simulated residual intensity profiles will be provided and will help to adjust the expected performance of the SPHERE system on sky, knowing that its first light is foreseen for mid 2012.

8172-28, Session 7

MAIA: a multispectral instrument for asteroseismology observations of hot subdwarf stars

J. Vandersteen, G. Raskin, S. Bloemen, J. Morren, R. Oestensen, W. Pessemier, S. Prins, J. Swevers, H. Van Winckel, C. Aerts, Katholieke Univ. Leuven (Belgium)

The Mercator Advanced Imager for Asteroseismology (MAIA) is being designed particularly for asteroseismology of hot subdwarf stars. In order to achieve the required precision on the pulsation amplitude ratios, the photometric variations must be measured simultaneously in several bands with respect to constant reference stars in the field. MAIA is an optical imager to observe simultaneously in three color bands, corresponding approximately with an SDSS u, g, r+i+z photometric system. MAIA covers a wide field of view (FoV) of 9.4' x 14.1' with a sampling of 0.27"/pix on the 1.2m Mercator Telescope. The fully dioptric design uses a common collimator, two dichroic beam splitters (cut-offs at 390nm and 550nm) and three cameras. Each camera holds a fast frame-transfer charge coupled device (CCD) cooled down to -90 oC with a compact Stirling cryocooler. All lenses are axially and radially constrained by a calibrated spring load, with radial adjustment mechanisms to calibrate the centering of each lens. The differential thermal expansion of the optical system is compensated by the thermal expansion of the different materials in the mechanical mountings, resulting in a design that is insensitive to thermal variations. Specific care has been taken to reduce the effect of manufacturing tolerances on the performance of the instrument. The tilt angle of two of the beam splitters is adjustable in two dimensions to compensate for remaining misalignment in the optical system. Finite element models have been constructed to verify that the structural flexure and structural dynamics are within the requirements. A tool has been developed to estimate the performance of the instrument based on the different design parameters. Various commercial software tools have been used to optimize the workflow in this complex system design.

8172-29, Session 7

DSI (Doppler Spectro-Imager): a new instrumental concept of imaging tachometer for the space mission EJSM

L. Soulat, Lab. Fizeau (France); F. Schmider, Univ. de Nice Sophia Antipolis (France); T. Appourchaux, Institut d'Astrophysique Spatiale (France); Y. Bresson, J. Gay, Observatoire de la Côte d'Azur (France); J. Daban, C. Gouvret, S. Robbe-Dubois, Univ. de Nice Sophia Antipolis (France); P. Gaulme, Institut d'Astrophysique Spatiale (France)

Fourier transform spectrometry allows the detection of small Doppler shifts of spectral lines through the measurement of phase shifts in interference patterns. In this paper, we describe the project of a space borne instrument, Doppler Spectro Imager (DSI), applying this technique to Jovian seismology. DSI is proposed by IAS and OCA as part of the Europa Jupiter System Mission, which competes in Cosmic Vision and New Frontiers programs of ESA and NASA.

The instrument principle, inherited from a ground based experiment (Schmider et al, 2007, Gaulme et al, 2008), is a visible Mach-Zehnder interferometer sensitive to Doppler shift of solar spectral lines reflected on the rotating planet. It aims to measure periodic movements of small amplitude generated by internal acoustic modes at the surface of Jupiter with a spatial resolution of 200 kms. This instrument would bring a better knowledge of the internal structure of Jupiter, especially of the central region, and will provide unique constraints on scenarios of giant-planet' formation.

Theoretical studies, based on simulations and analytic models, led to an optical design optimized for this goal. The expected noise level should be below 1 $cm^2s^{-2}\mu Hz^{-1}$ in the frequency range [0.5 -10] mHz. The sensitivity to the thermal environment of the mission has been carefully taken into account, and the final Mach-Zehnder interferometer should have a thermal sensitivity lower than 10 m/s/K.

After the description of the instrument resulting from the optical design study, we present the prototype implemented in OCA to measure real performances in laboratory, necessary to reach the requested Technology Readiness Level 5 for the instrument and its components. We describe its environment and expected results, in terms of wavefront quality, transmission, polarisation, assembly tolerances, and control of the thermal stability of the optical path difference.

8172-30, Session 7

Imaging optimization and deconvolution techniques with a hypertelescope or a dense aperture masking (DAM)

F. Patru, European Southern Observatory (Chile); A. Schutz, M. Carbillet, Lab. Fizeau (France); J. Antichi, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); J. Girard, European Southern Observatory (Chile)

The Dense Aperture Masking (DAM) optimizes the use of the photons collected by a single-dish telescope to provide high contrast images at the limit of diffraction on a small field of view (Patru et al. 2011 in prep). As shown in the case of the hypertelescope concept (Labeyrie 1996), the direct imaging in interferometry is an alternative together with the classical aperture synthesis imaging. Whereas the first image has been reconstructed by aperture synthesis with a 3-telescopes-array by Baldwin in 1996, it had already been achieved with a mask placed on a monolithic telescope ten years ago (Baldwin 1986) with scientific returns. It is now implemented on the Keck (NIRC2, Hinkley et al. 2011) and on the VLT-NACO with the Sparse Aperture Masking (SAM, Tuthill et al. 2006). In such a way, direct imaging can initially be achieved on a monolithic telescope (Pedretti 1999). The project NACO-DAM has been submitted to ESO to install a dense aperture mask between the adaptive optic NAOS and the camera CONICA (Antichi 2011, this proc.). More generally, the DAM is complementary with the current high-contrast imaging techniques view (Patru et al. 2011 in prep). The DAM appears to by perfectly suitable with the coming instrument SPHERE at the VLT or with segmented telescopes, such as the E-ELT. Thanks to its unique spatial frequency sampling and filtering, the DAM can provide a high-quality and stable Point Spread Function (PSF) to cope with the turbulence effects by combining adaptive optics, Angular Differential Imaging (ADI, Marois 2006) and deconvolution techniques closed to the usual post-processing tools used on the current telescopes. We focus here on the optimization of the imaging properties as a function of the pupil configuration, and we describe a set of deconvolution techniques tailored to DAM.

8172-31, Session 7

The Hypertelescope at work with a BIGRE-oriented integral field unit

J. Antichi, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); F. Patru, European Southern Observatory (Chile); P. Rabou, Lab. d'Astrophysique de l'Observatoire de Grenoble (France); E. Giro, INAF - Osservatorio Astronomico di Padova (Italy); J. Girard, European Southern Observatory (Chile); D. Mourard, Observatoire de la Côte d'Azur (France)

DAM (Dense Aperture Masking) is a high-contrast imaging technique which enhances the capabilities of the current direct imaging instrumentation, mainly to detect low bright companions at small separation from their parent star (Patru et al. 2011 in prep.). Thanks to its image quality and stability and thanks to its spectral-coronagraphic capabilities, the direct imaging in interferometry can provide high contrast imaging together with high spatial, spectral and temporal resolutions, either for a monolithic telescope (DAM, this paper) or for an interferometer, initially proposed in the framework of the hypertelescope concept (Labeyrie 1996). If both are based on the same pupil remapping technique, the DAM is a simple and efficient sub-system suitable with large telescopes. The DAM design benefits from the experience achieved with the integral field unit installed on SPHERE spectrograph at the VLT (BIGRE, Antichi et al. 2009) with a very similar optical design. In fact, DAM is obtained by exploiting the BIGRE integral field unit - composed of two consecutive micro-lens arrays - to subdivide the telescope pupil in many sub-pupils. It preserves the relative position of the beams, so as to restore the high-spatial frequency information. DAM can also be seen as a segmented telescope where each segment is spatially filtered and then re-imaged downstream. We present here results of a system study we pursued for a proficient implementation of DAM. We focus on the case of a 8m class telescope coupled with the instrument NACO at the VLT. We detail on how the optical design and the related mechanical implementation of a DAM unit is successfully achieved within NACO, thanks to a wise optimization of the BIGRE micro-lenses array, adopted here as sub-pupils re-imager instead of integral field unit.

8172-39, Poster Session

OCT and Rx validation of metal-ceramic crowns repaired with ceramic materials

E. L. Petrescu, Univ. de Medicina si Farmacie Victor Babes, Timisoara (Romania)

Objective: Study's objectives are focused on non-invasive OCT and RX investigations, of interfaces obtained after repairing a metal-ceramic crown with ceramic materials.

Material and Method: In this study 40 metal-ceramic crowns were involved. Each crown is restoring the first central incisor 1.1. Metallic infrastructure was performed from nickel-chrome WIRON 99 BEGO alloy, and Kiss Ceramic. The defects of 3x3mm were created into ceramic material in the buccal-incisal area with a grinding instrument. The samples were divided into two groups and the defects were reconstructed with two different types of ceramic materials: Kiss and Vita Omega.

The interfaces between crown and ceramic material used for reparation were Rx and OCT investigated which are both non-invasive, imagistic investigation techniques. For better investigation three-dimensional reconstructions were performed.

Results: The interfaces showed defects for both systems used. Major defects such as gaps could be identified at the ceramic-ceramic interface. Also material defects could be observed at the areas of congruence between the two ceramic materials and smaller defects along the interfaces. The defects were present into the deep and superficial layers of interface. The OCT system used a length wave of 1300nm and worked in B-scan mode along the interfaces to be studied while the C-scan mode was only used at the defect areas. Rx investigation detected the macro defects.

Conclusions: Time Domain OCT and RX systems were identifying the faulty areas after repairing artificially created defects, of metal-ceramic crowns with ceramic material, hereby enabling us to establish recommendations for the clinical use.

8172-40, Poster Session

The assessment of orthodontic bonding defects: optical coherence tomography followed by three-dimensional reconstruction

R. O. Rominu, Univ. de Medicina si Farmacie Victor Babes, Timisoara (Romania)

Orthodontic bonding is a simple yet important procedure that can influence the outcome of treatment in case it is performed incorrectly. An orthodontic treatment shadowed by repeated bnding failure cab become unduly long and will decrease patient trust and compliance.

Optical coherence tomography has been widely used in ophtalmology but is relatively new to dentistry.Using OCT one can detect aerial inclusions within the orthodontic adhesive or even identify incongruence between the bracket base and the tooth surface.

The aim of our study was to identify bonding defects and reconstruct them three-dimensionally in order to be able to characterize them more accurately.

We bonded 30 sound human permanent teeth with ceramic orthodontic brackets using a no-mix self-curing orthodontic adhesive. Prior to bonding all teeth were stored in tap water at 4ºC and then professionally cleaned with rotary brushes and pumice. The samples were processed by the same person and the rotary brushes were changed after every fifth tooth. All interfaces were investigated by means of OCT and 4 defects were found. Subsequently, the defects were reconstructed three-dimensionally using an open-source program.

By identifying and reconstructing bonding defects we could assess the quality of the bonding procedure. Since bonding tends to be more accurate in vitro where the environmental conditions are close to ideal, it is probable that defects found in vivo be even greater in number, which leads to the conclusion that this type of investigation is potentially valuable.

8172-41, Poster Session

A new approach of en-face time-domain optical coherence tomography (C Scan OCT): dynamic aspects regarding ethyl acetate effects on cross-linked acrylic teeth

A. E. Stoia, Univ. de Medicina si Farmacie Victor Babes, Timisoara (Romania); A. G. Podoleanu, Univ. of Kent (United Kingdom)

PURPOSE: The aim of this study imply the use of time domain en face optical coherence tomography as a dynamic noninvasive investigation method in order to prove the assumed changes induced by ethyl acetate to acrylic teeth.

Ability of en face optical coherence tomography (C Scan OCT) to capture dinamic optical features of the above mentioned organic solvent-induced changes in the depth of surface layer of cross-linked acrylic teeth is based on classical principles of interferometry according to which subsurface light reflections are resolved to give tomographic visualization using the principle of superposition to combine same frequency separate waves together so that the the phase difference between the two waves generates the resulting patern.

METHOD: 20 first upper acrylic molars pertaining to full denture Spofa Dental teeth kit were milled to samples. A 3 mm diameter acrylate bur was used at 15 sec speed so that the ridge lap area of the 20 acrylic first molars was milled to flat. The flattened surfaces treatment was different: 1) the 10 samples of the control group were left without chemical treatment; 2). the 10 samples of the second group were treated with ethyl acetate for 200 seconds. Dynamic investigation of above mentioned 20 samples surfaces was realized with en face OCT and analyzed within a software.

RESULTS: The type and the action time of organic solvent lead to different changes to the superficial layer specimens.

CONCLUSIONS: En face OCT can be used to investigate the dynamic

changes induced by above mentioned organic solvent to cross-linked acrylic teeth.

8172-42, Poster Session

Optical investigations of various polymeric materials used in dental technology

M. L. Negrutiu, C. G. H. Sinescu, F. I. Topala, Univ. de Medicina si Farmacie Victor Babes, Timisoara (Romania); C. Ionita, Univ. at Buffalo (United States); L. Goguta, C. Marcauteanu, M. Rominu, Univ. de Medicina si Farmacie Victor Babes, Timisoara (Romania); A. G. Podoleanu, Univ. of Kent (United Kingdom)

Dental prosthetic restorations have to satisfy high stress as well as esthetic requirements. Dental prostheses are very complex systems, heterogenous in structure, made up from various materials, with different physical properties. There is a question mark on the physical, chemical and mechanical compatibility between these materials. As a result, this is the point from where the pits and cracks can develop. Their propagation through the material finally leads to damage of the prostheses, which is a frequent clinical finding.

In order to avoid deficiencies of dental prostheses, several alternative systems and procedures were imagined, directly related to the material used and also to the manufacturing technology. Increasing the biomechanical comportment of polymeric materials implies fiber reinforcing. The different fibers reinforcing products made very difficult the evaluation of their performances and biomechanical properties analysis.

There are several known methods which are used to assess the quality of dental prostheses, but most are invasive. These lead to the destruction of the samples and often no conclusion could be drawn in the investigated areas of interest.

Optical tomographic techniques are of particular importance in the medical field, because these techniques can provide non-invasive diagnostic images. OCT is an emerging technology, representing a paradigm shift over conventional light microscopy. It is a tomographic imaging technology capable of producing high-resolution cross-sectional images of the internal architecture of materials in a non-invasive manner. Several studies have demonstrated the potential of optical coherence tomography (OCT) to image, both hard and soft oral tissues and various dental restorations at high resolution. OCT images provide microstructural details that cannot be obtained with any other imaging modalities.

En-face OCT is preferred for microscopy as it can provide real time images with similar orientation as that of microscopy images. A system equipped with a pigtailed superluminescent diode (SLD) emitting at 1300 nm with a spectral bandwidth of 65 nm was used, which determined an OCT longitudinal resolution of around 17.3 µm in tissue.

Using an time domain en-face OCT system, we have recently demonstrated real time thorough evaluation of quality of various dental treatments.

The aim of thees study was to assess the quality of various polymeric materials used in dental technology and to validate the en face OCT imagistic evaluation of polymeric dental prostheses by using scanning electron microscopy (SEM) and microcomputer tomography (µCT).

SEM investigations evidenced the nonlinear aspect of the interface between the polymeric material and the fiber reinforcement and materials defects in some samples.

The results obtained by µCT revealed also some defects inside the polymeric materials and at the interfaces with the fiber reinforcement.

The advantages of the OCT method consist in non-invasiveness and high resolution. In addition, en face OCT investigations permit visualization of the more complex stratified structure at the interface between the polymeric material and the fiber reinforcement.

8172-43, Poster Session

A new basis of polynomials for off-axis highly aspheric surfaces modelisation

M. Gray, M. Ferrari, S. Vives, Observatoire Astronomique de Marseille-Provence (France)

Off-axis highly aspheric surfaces need a new mathematical formalism for modeling in order to implement it into ray-tracing optimization codes. This new description must take into account low order deformation (to de-correlate X and Y axis), medium order deformation (to correct several fields independently) and high order deformation (for local aberrations). This paper presents a new basis based on Bernstein polynomials for a new analytical definition of such surfaces. A general definition of Bernstein polynomials and the mathematical properties are first reviewed. Then, the advantages of using such a basis for modeling aspheric surface is clearly explained and a comparison with other basis (Zernike, Forbes) is described in a mathematical and optical point of view. Finally, a discussion about the optimization in this use for the optical design codes is engaged with different approaches and perspectives.

8172-44, Poster Session

Fast catadioptric telescopes for CCD observation of transient events and space surveillance

A. N. Yudin, A. V. Sankovitch, Santel Ltd. (Russian Federation)

Work covers design and optimization of optical systems for observation of transient events and moving targets in space, such as gamma-ray bursts, asteroids, comets, meteors, satellites, space debris etc. Several all-spherical full-aperture catadioptric designs with focal ratios within f/2.5-f/0.8 range optimized for large format CCD detectors with 400-900 nm spectral range are presented in following families:

1. Small aperture (200..250 mm), extreme focal ratios (f/0.8..f/1.6), medium-size single CCD.
2. Moderate aperture (400..500 mm), extreme focal ratios (f/1..f/1.7), medium-size single CCD.
3. Large aperture (500..800 mm), moderate focal ratios (f/1.6..f/2.5), large single CCD or CCD mosaic.

Analyzed systems may be grouped in following families:

a) Prime-focus/folded Newtonian systems:

1. Hamilton.
2. Sonnefeld.
3. Richter-Slevogt.
4. Shenker (a)

b) Cassegrain systems:

1. Richter-Slevogt-Cassegrain.
2. Hamilton-Cassegrain.
3. Shenker (b).

Principal results of the work are:

1. Development of several optical designs suitable for realization.
2. Tolerances, weight, cost and dimensions comparison of systems of different design families with comparable performance.
3. Analysis of stray light baffles needed in full-aperture catadioptric Cassegrain and folded Newtonian designs of fast focal ratio.
4. Atmospheric dispersion correction in large-aperture systems is analysed, with proposal of compensation by motion of principal optical elements, with no extra components needed and without significant aberrations, such as chromatic distortion variance, typical for sub-aperture ADCs.
5. Historical survey and comparison of all-spherical full-aperture catadioptric telescopes and their overall comparison with “classic” wide-field telescopes, such as Schmidt camera with its complex concentric ascensors, coupled with field-flatteners.

Work present results of development and construction of fast catadioptrics at Santel Ltd, Moscow. Based on previous sucsessful manufacuring and putting into service a number of survey catadioptric instruents new perspective designs for realization in nearest future are presented. Designs are compared with number of current work by competitive companies and study of technical solytions and performance drivers is provided.

8172-45, Poster Session

Design of the optics for an imaging classic mount multi-etalon spectro-polarimeter for the next generation of ground-based solar telescopes

V. Greco, Istituto Nazionale di Ottica (Italy); F. Cavallini, INAF - Osservatorio Astrofisico di Arcetri (Italy)

In the design of the optics for an imaging classic mount multi-etalon spectro-polarimeter as a post-focus instrument for the next generation of ground-based solar telescopes (Advanced Technology Solar Telescope, European Solar Telescope) many constraints are to be considered. The large entrance pupil diameter of the telescope (4 m), the demanded large field of view (≥ 90 arcsec) and high spectral resolving power (≥ 200 000), and the limited field-dependent blue-shift of the instrumental profile in classic mount (≤ 3 FWHM) require Fabry-Pérot interferometers of large diameter (≥ 200 mm) lighted by highly collimated beams. This implies large optical elements and long optical paths. Moreover, to use interference filters with a relatively small diameter (≤ 70 mm) between the interferometers, necessary to reduce the ghosts due to the inter-reflections, a pupil adapter is to be included, with a further increase of the optical paths length. Although a multi-etalon spectro-polarimeter works in quasi-monochromatic condition, the spectral lines of interest cover a wide range of wavelengths (850 nm - 1650 nm) and this demands a good chromatic aberration control. Finally, a low instrumental polarization (≤ 0.5 %) is required to allow a high polarimetric precision. In this paper a diffraction limited optical solution is described, fulfilling all the above requirements in a relative small volume.

8172-46, Poster Session

Active optics: variable curvature mirrors for ELT laser guide star refocusing systems

Z. Challita, E. Hugot, F. Madec, M. Ferrari, D. Le Mignant, J. Cuby, Observatoire Astronomique de Marseille-Provence (France)

The future generation of Extremely Large Telescopes will require a complex combination of technologies for adaptive optics (AO) systems assisted by laser guide stars (LGS). In this context, the distance from the LGS spot to the telescope pupil ranges from about 80 to 200km, depending on the Sodium layer altitude and the elevation of the telescope. This variation leads to a defocusing effect on the LGS wave-front sensor which needs to be compensated. We propose an active mirror able to compensate for this variation, based on an original optical design including this active optics component. This LGS Variable Curvature Mirror (LGS-VCM) is a 120mm spherical active mirror able to achieve 820µm deflection sag with an optical quality better than 150nm RMS, allowing the radius of curvature variation from F/12 to F/2. Based on elasticity theory, the deformation of the metallic mirror is provided by an air pressure applied on a thin meniscus with a variable thickness distribution. In this article, we detail the analytical development leading to the specific geometry of the active component, the results of finite element analysis and the expected performances in terms of surface error versus the range of refocalisation. Two prototypes have been manufactured to compare the real behavior of the mirror and the simulations data. Results obtained on the prototypes are detailed, showing that the deformation of the VCM is very close to the simulation, and leads to a realistic active concept.

8172-47, Poster Session

Compact imaging spectrometer with visible-infrared variable filters for Earth and planet observation

A. M. Piegari, A. Sytchkova, ENEA (Italy); J. Bulir, Institute of Physics of the ASCR, v.v.i. (Czech Republic); M. Dami, G. Aroldi, SELEX Galileo S.p.A. (Italy); B. Harnisch, European Space Research and Technology Ctr. (Netherlands)

Many efforts have been dedicated for some years to the reduction of both mass and dimensions of instrumentation for Space. Accordingly, the European Space Agency has supported a number of projects for the development of compact spectrometers for Earth and planet observation.

The authors participated to some of these projects and in particular to the construction of the breadboard instrument for image spectrometry, based on the concept of linearly variable transmission filters. The project “Ultra-compact medium-resolution spectrometer for Land application”, as follow-up of previous studies on variable filters, demonstrated on one hand the possibility of extending to the SWIR spectrum (up to 2500 nm) the operating wavelength range of variable transmission filters to be combined with dedicated detectors and, on the other hand, to validate the working principle of a spectrometer based on variable filters, providing clues for critical aspects and possible improvements.

These variable filters have a narrow transmission band (<20 nm) which transmission peak is displaced over the filter surface, along one direction, and they should be coupled to array detectors either by gluing them or by coating directly the detector sensitive surface. In this work the first solution was chosen, because in the latter case the graded coating has to be applied during the detector manufacturing process, moreover the coating was deposited by radio-frequency sputtering and this process causes an increase of the detector dark noise if applied directly on the sensitive surface of a CCD. A visible-infrared (VNIR-SWIR) variable filter was deposited on a cover glass having two adjacent areas that correspond to two adjacent detectors with operating wavelength range of 430-930 nm and 930-2500 nm and lateral dimension of 2.1 mm and 6.3 mm, respectively. This approach gives a sort of miniaturized optical sensor which represents the core element of the compact instrument with no moving parts, allowing the elimination of traditional optical components as prisms and gratings.

The instrument operating principle was demonstrated by a breadboard spectrometer consisting of a backside illuminated CCD combined with a short-range variable filter and integrated on a camera system provided with a standard objective and an azimuthal rotation device, in order to allow a relative motion between the spectrometer and the target scene. Dedicated synchronization mechanism and post-processing algorithms were implemented to build hyper-spectral cubes, consisting of spectral-image arrays, and to analyse in real time the spectral and spatial features of the target. The breadboard spectrometer features compactness, fast acquisition and elaboration time, and it is suitable for finite or infinite target distances.

Both the wide-range filter characteristics and the result of the breadboard operation will be reported.

8172-48, Poster Session

Disturbance rejection analysis of LQG control for an adaptive optics system

J. Folcher, Univ. de Nice Sophia Antipolis (France)

In this paper we analyse the performance of an LQG based controller for an adaptive optics (AO) system. The optimal control consists of a partial state-feedback of the disturbance predictions. Such predictions (Kalman filter estimates) are based on a disturbance model of the atmospheric distortion wavefront. In many AO applications wind velocities and the strength of the distortion of the wavefront can change rapidly, rendering the disturbance prediction far from optimal and degrading the disturbance rejection property of the AO loop. Special attention is given to the choice of the disturbance model to ensure satisfactory disturbance rejection performance despite turbulence variations (wind velocities, strength of distortion wavefront). The proposed approach also serves the trade-off between the accuracy of the prediction and the model complexity to limit the computational cost of the LQG control. The achieved performances are evaluated through numerical experiments using the Software Package CAOS.

8172-49, Poster Session

Optical system to extract reflection coefficients and optical admittances of a thin film stack and its application in coating monitoring

C. Lee, K. Wu, Y. Chen, C. Kuo, National Central Univ. (Taiwan)

No abstract available

8172-50, Poster Session

Snapshot Mueller polarimetry for biomedical diagnostic related to human liver fibrosis: evaluation of the method for biomedical assessments

P. Babilotte, IUT de Blois (France)

No abstract available

8172-32, Session 8

Reflection coefficients and optical admittances loci monitoring for thin film coatings and its applications to optical systems

C. Lee, National Central Univ. (Taiwan)

The reflection coefficients and optical admittance under normal incidence of light can be calculated analytically in real time through an optical dynamic interferometer. The reflection coefficients or optical admittances loci monitoring provides an easier and clearer rule to judge the termination points with good error compensation than broadband monitor. Unlike conventional single wavelength monitoring having the lowest thickness control sensitivity on turning point, the reflection coefficient monitoring shows uniform sensitivity everywhere. Besides, if the optical admittance monitoring is applied, the monitoring with phase shift technique will have the highest sensitivity near the intersection of locus and real axis, which corresponds to the turning point. Several optical filters for optical systems fabricated based on this technique will be demonstrated.

8172-33, Session 9

Advanced algorithms for identifying targets from a three-dimensional reconstruction of sparse 3D ladar data

I. Berechet, SISPIA (France); G. Berginc, Thales Optronique S.A. (France)

There is a considerable interest in the development of new optical imaging systems that are able to give three-dimensional images. Potential applications range across medical imaging, surveillance and robotic vision. Identifying targets or objects concealed by foliage or camouflage is a critical requirement for operations in public safety, law enforcement and defense. The most promising techniques for these tasks are 3D laser imaging techniques. The optical non-conventional active imaging explores the advantages of active laser imaging to form a three-dimensional image of the scene. Its principle is to use movable light sources and detectors to collect information on laser scattering, and to reconstruct the 3D object. 3D reconstruction algorithm is a major component in these optical systems for identification of camouflaged objects.

Synthetic images of three-dimensional objects are based on extraction of laser backscattered signals. But 3D reconstruction must take into account sparse collected data i.e. concealed objects and reconstruction algorithms must solve a complex multi-parameter inverse problem. Therefore the inverse problem of recovering the surface three-dimensional shape function from intensity data is more challenging. The robustness of identification of three-dimensional reconstructed images is directly related to the inversion algorithms used in the process of identification. Artefacts from the reconstruction algorithms degrade the quality of identification and the object recognition. A notable limitation of numerous methods is that inversion algorithms produce blurred and noisy images. The strategy of inversion must be optimized.

Common identification algorithms use reference databases but identification of unknown objects which are not included in the knowledge database of objects is difficult. Moreover, all these algorithms rely on incomplete data resulting from the reconstruction of 3D point clouds regardless of the technology used (profilometry, tomography,).

The objective of our paper is to present a new algorithmic approach for the generation of 3D surface data from 3D points clouds corresponding to reconstruction algorithm. This algorithmic approach is based on research of automatic minimization of an energy function associated with a sparse structure of 3D points. The role of this type of algorithmic data-driving process is to complete the lacunar 3D image at satisfactory levels for reliable identification of concealed objects.

8172-34, Session 9

Wide field-of-view all-reflective objectives designed for multispectral image acquisition in photogrammetric applications

K. Seidl, Technische Univ. Dresden (Germany) and Fraunhofer-Institut für Photonische Mikrosysteme (Germany); J. Knobbe, Fraunhofer-Institut für Photonische Mikrosysteme (Germany); K. Apelt, H. Maas, Technische Univ. Dresden (Germany)

In many aerial and close-range photogrammetry applications, the ultraviolet (UV) or near infrared (NIR) spectral range is required in addition to the visible spectral range. So fare, most systems use particular optimized camera systems for each spectral band. Using separate cameras or lenses introduces parallaxes and possibly time-delays between the acquired images, complicating the data fusion process, and it adds weight to the entire system. With the image acquisition through one objective, the complexity of the data fusion and the weight can be reduced. However, in order to use only one objective for different spectral bands, the optical system has to be free of chromatic aberrations. Additionally, for photogrammetric applications a wide field of view and a high resolution is often required.

Therefore, we will present a design and an adapted photogrammetric calibration method of an all-reflective unobscured optical system optimized for full-frame imaging sensors.

All-reflective unobscured optical systems may also be a very efficient imaging tool in combination with unmanned aerial vehicles (UAVs). Due to the limited payload capacity, many UAVs can today only be used with one spectrally limited camera system at the same time. With miniaturized all-reflective camera systems, the image data can be acquired in the visible and e.g. the NIR spectral range simultaneously. Furthermore, it will be shown that the focal length of an all-reflective unobscured objective could be varied without mechanical moving parts, if two mirrors are replaced by variable curvature mirrors.

8172-35, Session 10

A study of blue-ray pickup head optical system with liquid-crystal optics module

C. Yen, National Formosa Univ. (Taiwan); Y. Fang, C. Tsai, National Kaohsiung First Univ. of Science and Technology (Taiwan)

A new optical design inclusive of Blue-Ray Pickup head system and liquid crystal optics is proposed in this paper. With electrode pattern and the differential biased circuit, the gradient of the electric field distribution inside the liquid crystal sample cell are able to vary through the adjustment of driving voltage. Optical power of liquid crystal lens can be determined by changing the polarity of gradient

within the sample cell which posses the homogeneous alignment, then deliver convergence or divergence of specific light beams. These designs are capable of correcting aberrations fast with liquid crystal optics scheme when any misalignment errors occur. According to specification from Blue-ray Disc White paper, there are several kinds of pick up head system with LC liquid optics are designed and discussed in this paper. Different tolerance such as de-focus, tilt, de-center and their related compensation are further analyzed in this research. The simulation results show that optical design using liquid crystal optics with aperture stop setup as a compensation device can eliminate up to 46% compared to traditional ones.

8172-36, Session 10

Application of visible spectroscopy in waste sorting

P. Spiga, A. Bourely, PELLENC Selective Technologies (France)

Today, waste recycling, (bottles, papers...), is a mechanical operation: the waste are crushed, fused and agglomerated in order to obtain new manufactured products (e.g. new bottles, clothes ...). With this mechanical process, the dye contained in the waste is not eliminated so the new product can be colored. The plastics recycling is the main application in color sorting process. The colorless plastics recovered are more valuable than the colored plastics. Few applications are interested by some specific color (e.g. light blue bottles, green bottles ...). Other emergent applications are in the paper sorting. The main goal is to sort dyed paper from the other papers.

Today, Pellenc Selective Technologie manufactures color sorting machines based on RGB cameras. Three dimensions (red, green and blue) are not sufficient to detect low quantity of dye in the considered waste. In order to increase the efficiency of the color detection, a new sorting machine, based on visible spectroscopy, has been developed.

The main constraint has been to design a solution based on a small number of wavelengths to be able to sort in real time: our frequency acquisition process is 100 000 spectra/second. The chosen wavelengths have been identified based on spectral response of a representative color plastic and dyed paper database. Based on our study, we developed our OEM spectrometer and integrated it in our existing industrial machine structure. The machine has been used to sort real raw waste material and the obtained results demonstrate that the visible spectroscopy is more sensitive than classical RGB camera. We have proven that we are able to detect and sort low dye quantity from a wide amount of real waste products.