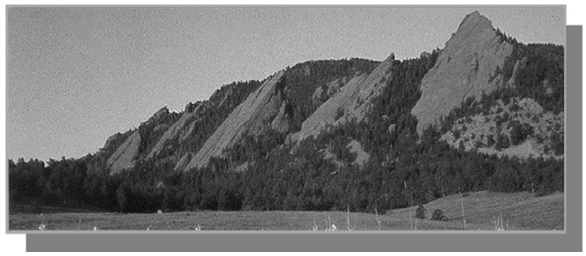
Book of Abstracts



Boulder Damage Symposium XXXVIII

Annual Symposium on

Optical Materials for High Power Lasers

25–27 September 2006

National Institute of Standards and Technology
Lobby, Building 1, 325 Broadway • Boulder, Colorado USA

SPIE The International Society for Optical Engineering

Boulder Damage Symposium XXXVIII

Annual Symposium on

Optical Materials for High Power Lasers

Organizer: SPIE The International Society for Optical Engineering

Co-Sponsors:

Lawrence Livermore National Lab.
Pacific Northwest National Lab.

Cooperating Organizations:

Center for High Technology Materials (CHTM), Univ. of New Mexico

Laser Zentrum Hannover e.V. (Germany)

National Institute of Standards and Technology

Electromagnetic Remote Sensing Defence Technology Ctr. (United Kingdom)

School of Optics: CREOL & FPCE, Univ. of Central Florida

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Boulder Damage Symposium XXXVIII

Annual Symposium on

Optical Materials for High Power Lasers

Special Events

Sunday 24 September

18.00 to 21.00 Registration Material Pick-up and Mixer

Monday 25 September

18.30 to 19.30 Alpine Optics Open House and Reception

Tuesday 26 September

18.00 to 19.30 Wine and Cheese Reception at NCAR

Monday AM • 25 September

07.30 to 08.30 **Registration Material Pick-up,** The Boulder Marriott, Montrachet Room

07.30 to 08.30 **Poster Placement at NIST**
Poster authors for the Monday poster session are to set-up their posters at this time.

08.30 to 09.00 **Opening Remarks**
Chair: **Gregory J. Exarhos,** Pacific Northwest National Lab.

09.00 to 10.00 • SESSION 1

Fundamental Mechanisms I

Chairs: **Gregory J. Exarhos**, Pacific Northwest National Lab.;
Leonid B. Glebov, College of Optics & Photonics/Univ. of Central Florida

09.00: **Femtosecond interaction processes near threshold: damage and ablation** *(Invited Paper)***,** R. Fedosejevs, Univ. of Alberta (Canada) . . . . [6403-01]

09.40: **Limits of performance CW laser damage,** R. S. Shah, J. J. Rey, A. F. Stewart, The Boeing Co. . . . . [6403-02]

10.00 to 10.30 • Monday Poster Overview

All Fundamental Mechanisms and Surfaces, Mirrors, and Contamination poster authors are asked to give 2-minute/2-viewgraph overviews of their posters in the order they appear in the program.

10.30 to 11.30 • Poster Session and Refreshment Break

11.30 to 12.30 • SESSION 1 continued

11.30: **Thermal imaging investigation of modified fused silica at surface damage sites for understanding the underlying mechanisms of damage growth,** S. G. Demos, R. A. Negres, M. W. Burke, P. P. DeMange, S. B. Sutton, M. D. Feit, Lawrence Livermore National Lab. . . . . [6403-03]

11.50: **Damages to optical silica glass: processes and mechanisms,** S. Luo, Los Alamos National Lab.; L. Zheng, Univ. of Missouri/Columbia; Q. An, H. Wu, Univ. of Science and Technology of China (China); K. Xia, Univ. of Toronto (Canada); S. Ni, Univ. of Science and Technology of China (China) . . . . [6403-04]

12.10: **Revisited thermal approach to model the laser-induced damage,** D. D. Anthony, Commissariat à l'Energie Atomique (France) . . . . [6403-15]

12.30 to 14.00 • Lunch Break

Femtosecond interaction processes near threshold: damage and ablation

R. Fedosejevs, Univ. of Alberta (Canada)

PRIMARY AUTHOR BIOGRAPHY:
Dr Robert Fedosejevs has over 25 years experience in the development of laser systems and their use in various areas including fusion energy research, the generation of XUV and soft x-ray radiation for lithography applications, micromachining, thin film coatings and studies in ultrafast phenomena. Current research activities include: the application of lasers in material identification sensor applications using techniques such as laser induced breakdown spectroscopy, Raman spectroscopy and laser induced fluorescence; the application of terahertz radiation in characterization of materials; the study of laser plasma interactions on femtosecond and picosecond time scales, including: absorption of the laser light, multiphoton ionization and the generation of x-rays; and, the study of femtosecond high harmonic generation of soft x-rays and applications to x-ray microsocpy.

ABSTRACT TEXT:
A good understanding of the interaction physics near and just above the ablation threshold is necessary in order to understand damage phenomena and in order to achieve the precise control of laser processing. One of the most demanding processes is the removal of thin nanometer scale size layers of material in a controlled manner, i.e. nanomachining. Demand for such techniques with micron lateral resolution and nanometer depth resolution is increasing in microelectronic, MEMS, integrated optical, microfluidic and biophotonic applications where such techniques are required to fine tune the response of high precision electrical or optical devices. We have been studying the ablation mechanism near the threshold intensities for copper and silicon, determining the femtosecond single shot ablation thresholds and the incubation of multi-shot damage which leads to a significant reduction of ablation threshold for multiple shots interactions. In order to better understand the microscopic processes which accompany such near-threshold ablation, a molecular dynamics modeling code is under development which is currently applied to silicon. The results of these experimental and theoretical studies will be presented and compared.

Limits of performance CW laser damage

R. S. Shah, J. J. Rey, A. F. Stewart, The Boeing Co.

ABSTRACT TEXT:
High performance optical coatings are an enabling technology for many applications-navigation systems, telecom, fusion, advanced measurement systems of many types as well as directed energy weapons. The results of recent testing of superior optical coatings conducted at high flux levels have been presented. Failure of these coatings was rare. However, induced damage was not expected from simple thermal models relating flux loading to induced temperatures. Clearly, other mechanisms must play a role in the occurrence of laser damage. Contamination is an obvious mechanism-both particulate and molecular. Less obvious are structural defects and the role of induced stresses. These mechanisms are examined through simplified models and finite element analysis. The results of the models are compared to experiment, for induced temperatures and observed stress levels. The role of each mechanism is described and limiting performance is determined.

Thermal imaging investigation of modified fused silica at surface damage sites for understanding the underlying mechanisms of damage growth

S. G. Demos, R. A. Negres, M. W. Burke, P. P. DeMange, S. B. Sutton, M. D. Feit,
Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:
Education: Ph. D., Physics, Physics Department, City College of New York 1993. B. S., Physics, University of Ioannina, Greece, 1983.

Employment: Research Staff, Lawrence Livermore National Laboratory, November 1998 - present. Research Associate, Lawrence Livermore National Laboratory, January 1997 - October 1998. Research Associate, New York State Center for Advanced Technology, City College of New York, January 1995 - January 1997

ABSTRACT TEXT:
It has been shown that laser-induced damage leads to the formation of a modified material containing various defect species as a result of exposure to extreme localized temperatures and pressures occurring during a damage event. In the case of fused silica, absorption of the laser light within this modified material has been suspected to play a key role in the damage growth process. A possible mechanism involves linear absorption leading to an increase in the temperature of the material above a characteristic temperature. Alternatively, one may need to consider nonlinear absorption mechanisms.

The objective of this work is to estimate the energy deposited under 351-nm CW excitation of laser modified SiO2 via linear absorption mechanisms. Our approach involves the use of an infrared thermal imaging system to map, with adequate spatial and temporal resolution, the dynamics of the local surface temperature of the sample. The laser beam was focused to ~ 100 microns within a single damage site. Following the onset of UV laser irradiation and diffusion of energy deposited within the modified material, a temperature gradient was observed. The increase in surface temperature of the sample is a result of energy dissipation through non-radiative relaxation pathways by the absorbing defects in the modified material. A fluorescence microscope is also used to image the same sites in order to concurrently monitor the radiative relaxation pathways. Based on a thermal diffusion model and the kinetics of the measured surface temperature gradient, we calculate the fraction of energy deposited at damage sites following CW laser excitation and estimate the linear absorption coefficient of the modified material

The results indicate that the damage growth mechanism is not entirely based on linear absorption. Specifically, the absorption cross-section derived above would prove insufficient to cause a significant increase in the temperature of the modified material under nanosecond, pulsed excitation (via linear absorption at ICF laser fluences). In addition, irreversible changes in the absorption cross-section were absorbed arising from photochemical reactions at the absorbing defects within the modified material under prolonged UV, CW laser excitation.

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under contract W7405-Eng.48.

Damages to optical silica glass: processes and mechanisms

S. Luo, Los Alamos National Lab.; L. Zheng, Univ. of Missouri/Columbia;
Q. An, H. Wu, Univ. of Science and Technology of China (China); K. Xia, Univ. of Toronto (Canada); S. Ni, Univ. of Science and Technology of China (China)

PRIMARY AUTHOR BIOGRAPHY:
Dr. Sheng-Nian Luo is a staff physicist at Los Alamos National Laboratory. His research involves mostly materials physics including equations of state, phase transitions and mechanical properties of condensed matter. The techniques utilized include conventional and laser-induced shock waves, static high-pressure experiments, and molecular dynamics simulations.

ABSTRACT TEXT:
We investigate the damage processes and mechanisms of optical silica glass using molecular dynamics simulations. The damages are induced by a UV-laser, laser-produced hot-spots, vacancies (SiO2, SiO, Si, and O), ion implantations, nano-particle impact, shock waves and non-hydrostatic stresses, and manifested as local structural changes (densification, fracture, voids, spall and fragmentation at sub-nm and nm scales) which are expected to undermine the optical properties of silica glass. The atomic structure changes are characterized by Si-O coordination numbers, neutron scattering structure factors, bond angle and ring size distributions, and vibrational density of states. Our results support that densifications induced by various radiations (photons, electrons, ions and neutrons) share the same structure change paths and the Douilliard-Duraud point-defect mechanism. The morphologies and time evolutions of fracture, nano-voids, fragments, crater and spall are also described.

Revisited thermal approach to model the laser-induced damage

D. D. Anthony, Commissariat à l'Energie Atomique (France)

PRIMARY AUTHOR BIOGRAPHY:
Anthony Dyan is a phD student since 2005 at CEA Le Ripault and works on laser induced damage in KDP (DKDP). He worked, during his PhD, on electronic structure calculations and applications to very large systems.

ABSTRACT TEXT:
This paper deals with the understanding of Laser-Induced Damage (LID) in optical materials and particularly KH2PO4 (KDP) or partially deuterated KDP-DKDP (DxKH1-xPO4).

We mainly focussed here on the end of the mechanism which is known to be thermal in nature four our pulse length duration [1]. In this way, an interesting model has been proposed in [2] which is based on Chan equation [3]. Nevertheless, Chan solution is only an approximation that, strictly, does not apply in KDP, or DKDP cases. We thus solve exactly Chan equation and show that the solution is identical to a previous work done by Hopper and Uhlmann [4].

The main physical conclusions, in connection with damage and conditioning, obtained in [2] remain unchanged but the temperature lies in a more realistic range compared to experimental data. Furthermore, the power density damage dependence with fluence is demonstrated. Different experimental results as concerned laser damage probability curved are discussed using this model.

Monday PM • 25 September

14.00 to 15.00 • SESSION 2

Fundamental Mechanisms II

Chairs: **Hervé Bercegol**, CEA Cesta (France);
Amy L. Rigatti, Univ. of Rochester

14.00: **Figures of merit for high-energy laser windows: comments on past and recent formulations,** C. A. Klein, C.A.K. Analytics, Inc. . . . . [6403-06]

14.20: **A feasible mechanism of molecular contamination-induced laser optic damage,** J. S. Canham, Swales Aerospace . . . . [6403-07]

14.40: **Importance of free surfaces for damage crater formation,** M. D. Feit, S. Rubenchik, Lawrence Livermore National Lab. . . . . [6403-08]

15.00 to 16.00 • Poster Session and Refreshment Break

16.00 to 17.40 • SESSION 3

Surfaces, Mirrors, and Contamination

Chairs: **Keith L. Lewis**, Electromagnetic Remote Sensing Defence Technology (United Kingdom);
Claude Amra, Institut Fresnel (France)

16.00: **Using gold nanoparticles as artificial defects in thin films: what have we learned about laser-induced damage driven by localized absorbers?** *(Invited Paper)***,** S. Papernov, A. W. Schmid, Univ. of Rochester . . . . [6403-09]

16.40: **Investigations of sacrificial and plasma mirrors on the HELEN laser CPA beamline,** J. E. Andrew, A. J. Comley, AWE plc (United Kingdom) . . . . [6403-10]

17.00: **Growth rate of laser damage on the input surface in fused silica at 3ω,** M. A. Norton, Lawrence Livermore National Lab. . . . . [6403-11]

17.20: **Study of the evolution of mechanical defects on silica samples under laser irradiation at 355 nm,** M. A. Josse, B. Pussacq, J. Rullier, CEA Cesta (France) . . . [6403-12]

18.30 to 19.30 • Alpine Optics Open House and Reception

Alpine Research Org.

Figures of merit for high-energy laser windows: comments on past and recent formulations

C. A. Klein, C.A.K. Analytics, Inc.

PRIMARY AUTHOR BIOGRAPHY:
Claude A. Klein is a Fellow of the American Physics Society and a former Raytheon Consulting Scientist now working as an independent consultant.

ABSTRACT TEXT:
As early as 1968, Horrigan derived a Figure of Merit (FoM) for assessing the resistance to thermal stresses of laser windows operating at the CO2-laser wavelength [1]. Figures of merit for assessing the performance with regard to thermal lensing were first proposed by Sparks in 1974 [2]. Subsequently, an improved window FoM was derived on the basis of the Strehl ratio [3], thus providing a proper Ansatz for obtaining material FoMs, that is, FoMs that no longer include the window-thickness parameter [4]. Recent progress in characterizing the flexural strength of IR-transmitting materials [5], however, leads to the conclusion that previous FoM expressions for thermal lensing and thermal stresses must be revised. This will be the main topic of my presentation. In addition, it will be demonstrated that Billman's "Figure of Demerit" [6] can be very misleading.

[1] F. Horrigan et al., Microwaves 8(1), 68 (1969).
[2] M. Sparks and H. Chow, J. Appl. Phys. 45, 1510 (1974).
[3] C. Klein, Appl. Phys. Lett. 35, 52 (1979).
[4] C. Klein, Opt. Eng. 36, 1586 (1997).
[5] C. Klein et al., Opt. Eng. 41, 3151 (2002).
[6] K. Billman et al., Proc. 2004 Boulder Damage Symp., p. 207.

6403-07, Session 2

A feasible mechanism of molecular contamination-induced laser optic damage

J. S. Canham, Swales Aerospace

PRIMARY AUTHOR BIOGRAPHY:

Dr. Canham is a Materials Engineer for Swales Aerospace. Dr. Canham received his Ph.D. in Analytical Chemistry from Miami University in 1989. Dr. Canham has been working in Aerospace materials since 1997, and with laser materials since 1999. His principle areas of interest are micromolecular contamination, surface physical chemistry, contamination related laser optic damage and understanding other materials behavior defying normal description.

ABSTRACT TEXT:

This paper will present a mechanism that describes why damage: occurs, does not occur, is delayed, and its morphology. The mechanism is based strictly upon well documented chemical and physical behaviors. The mechanism also applies to certain damage or degradation in the absence of contamination.

6403-08, Session 2

Importance of free surfaces for damage crater formation

M. D. Feit, S. Rubenchik, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:

Michael D. Feit received the BA in physics in 1964 and earned his PhD in physics in 1969. After a post-doc at the University of Illinois, he has been at Lawrence Livermore National Laboratory since 1972. A group leader specializing in optical propagation and the interaction of intense lasers with materials, Dr. Feit is a fellow of both the American Physical Society and the Optical Society of America.

ABSTRACT TEXT:

The presence of a nearby free surface means the morphology of surface damage sites is inevitably different from that of bulk damage sites. In both, the material is subject to compressive stress waves from the initial release of laser energy. However, reflection at the free surface leads to a tensile stress wave. Because material strength is much lower under tension than under compression, surface sites will be larger than bulk sites, all else being equal. We analyze the extent of damage as a function of the amount and position of energy released and compare to experimental results.

6403-09, Session 3

Using gold nanoparticles as artificial defects in thin films: what have we learned about laser-induced damage driven by localized absorbers?

S. Papernov, A. W. Schmid, Univ. of Rochester

ABSTRACT TEXT:
There is general agreement that localized absorbing defects are a major factor affecting thin film performance, and laser-induced damage in films designed for UV, nanosecond-scale, pulsed-laser applications is driven by nanoscale absorbers. However, low number densities and size (few nm) prevent any characterization of these defects and, consequently, deterministic film improvement. This situation also hampers further development of localized defect-driven damage theory, since initial conditions for modeling remain uncertain. Recently, new approach for studying laser interaction with thin film nanoscale defects was implemented in which well-characterized, isolated artificial absorbing defects (gold nanoparticles) are introduced inside thin film. This work is a review in which we discuss main findings made in experiments with gold nanoparticles, such as delocalization of absorption during laser pulse, importance of the defect boundary conditions (contact with the matrix), competition of pure thermal and stress-driven mechanisms of damage crater formation. These experimental results will be compared with results of theoretical description of damage crater formation in such model thin films using both, phenomenological modeling and detailed calculations of the kinetics of damage process. The perspectives of thin-film damage studies using model systems with artificial defects are also discussed.

This work was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement Np. DE-FC03-92SF19460 and the University of Rochester. The support of DOE does not constitute an endorsement by DOE of the views expressed in this article.

6403-10, Session 3

Investigations of sacrificial and plasma mirrors on the HELEN laser CPA beamline

J. E. Andrew, A. J. Comley, AWE plc (United Kingdom)

PRIMARY AUTHOR BIOGRAPHY:
Jim Andrew is a principal scientist at AWE. He graduated from Reading University with a Physics BSc and from Hull University with an Applied Physics PhD for research on rare gas halide lasers. His current interests are in debris mitigation for focusing optics in large aperture laser systems.

ABSTRACT TEXT:
The performance of sacrificial and plasma mirrors has been investigated on the HELEN laser chirped pulse amplification [CPA] beam line. Sacrificial mirrors are initially highly reflective surfaces that degrade during the course of a pulsed laser experiment. They are being considered for protecting the off axis parabolic surfaces used to focus CPA lasers from plasma physics target generated debris and shrapnel. Plasma mirrors are initially low reflectivity surfaces that transmit low intensity beams but produce a reflecting plasma surface during the course of the laser pulse. They are being investigated to prevent prepulse effects in plasma physics experiments and increase the contrast ratio of the incident laser beam.

The sacrificial mirrors were operated at 45 degrees angle of incidence and an average input beam diameter of ~14 mm with intensities in the range 8 TW/cm2 to 44 TW/cm2. Dielectric protected silver and gold coatings as well as dielectric multi layers were studied as the mirror surfaces for directing all of the short pulse [500fs] laser beam onto tantalum foil targets of 10 and 100 microns thickness. Proton emissions from the foils monitored by radiochromic film were used to evaluate the beam irradiance achieved from the mirror surfaces. Glass witness plates were used to evaluate debris and shrapnel emissions from the mirror surfaces, the diagnostics and the target foils. The plasma mirrors were operated in a similar configuration but with beam diameters of ~8mm and irradiances of 57 TW/cm2 to 235 TW/cm2. Uncoated and sol gel anti-reflection coated fused silica were used as the high intensity mirror surfaces. The influence of surface coating on laser damage morphology will be described as well as post shot inspection of debris distributions.

6403-11, Session 3

Growth rate of laser damage on the input surface in fused silica at 3ω

M. A. Norton, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:
M. A. Norton received the A.B. degree in Physics from Emmanuel College in Boston, and an M. S. and a Ph. D. in Physics from the University of Arizona. After nine years at M. I. T. Lincoln Laboratory, she joined Lawrence Livermore National Laboratory in 1987 where her current research interests are laser damage and growth in fused silica and KDP.

ABSTRACT TEXT:
Growth of laser initiated damage is an important consideration in determining the lifetime for use of laser optics in high energy laser systems. Though the threat to laser initiated damage is highest on the exit surface some damage sites are found on the input surface. We have investigated the growth of laser initiated damage in fused silica when the damage occurs on the input surface of the optic. We have measured both the threshold for growth as well as the lateral growth rate at 351 nm. The lateral growth of damage on the input surface is best described as having a linear dependence on shot number. The rate of growth has a linear dependence on fluence, with an extrapolated threshold of approximately 6 J/cm2. This behavior will be contrasted to growth of damage located on the exit surface. The behavior will be compared to growth of input surface damage when the wavelength is 1053 nm and 527 nm.

6403-12, Session 3

Study of the evolution of mechanical defects on silica samples under laser irradiation at 355 nm

M. A. Josse, B. Pussacq, J. Rullier, CEA Cesta (France)

PRIMARY AUTHOR BIOGRAPHY:

Michel Josse received his PhD in 1976 when he was working on stellar interferometers at the Observatory of Paris-Meudon, France. Then he joined the Cea in 1978 and worked on high power lasers for fusion.

ABSTRACT TEXT:

During the life of a high-power laser chain, optical components may be damaged due to local high fluence levels in the inhomogeneous beam. The origin of the laser damage can be impurities, surface defects or flaws and cracks resulting from polishing, or it may be produced by self-focusing in the component. The aim of this study is to better understand the correlation between a surface crack on a silica optical component and laser damage. Therefore, calibrated indentations and scratches were performed on silica samples. Then, we observed the evolution in time of cracks, especially when a stress is present around the mechanical defect. The samples were irradiated later with a Nd :Yag laser at 355 nm. Observations were made with an optical microscope and a Nomarski (polarizing) microscope. We present results obtained on different silica samples.

Monday Poster Session • Room 1

Fundamental Mechanisms, and Surfaces, Mirrors, & Contamination

10.30 to 11.30 and 15.00 to 16.00

Excimer laser purification of bulk carbon single-walled nanotubes and damage of carbon allotropes

K. E. H. Gilbert, D. A. Keenan, National Institute of Standards and Technology; A. C. Dillon, National Renewable Energy Lab.; J. H. Lehman, National Institute of Standards and Technology

PRIMARY AUTHOR BIOGRAPHY:

Katherine Gilbert completed her B.S. in Natural Science from the University of Puget Sound in 1996. She received a MS in chemical engineering from the Colorado School of Mines for her work on zeolite memberanes supported by NASA in 2000. She completed her Ph.D. thesis work in 2005 at the National Renewable Energy Laboratory investigating purification and gas adsorption properties of single-walled carbon nanotubes. Katherine is currently a postdoctoral researcher working in the Optoelectronic Division at NIST.

ABSTRACT TEXT:

Laser treatment of bulk carbon single-walled nanotubes (SWNTs) using an excimer laser is demonstrated as a potentially simple and fast purification method. Quantitative evidence for the selective removal of carbon impurities without destruction of nanotubes is shown by the decrease in the full width at half maximum of the Raman D-band for increasing fluence level, without changing the diameter distribution of the nanotube sample. Qualitative changes in the topology and morphology upon exposure are also shown by scanning electron microscopy. A 5 % change in responsivity of a pyroelectric detector coated with SWNTs is presented as a novel assessment of the change in SWNT coating topology.

In the context of damage mechanisms, the resonance of the incident photons and the pi-plasmon in the SWNT material is proposed as a theoretical basis for understanding the solid state properties of the SWNT versus the carbon allotropes. The interaction of both 248 nm and 193 nm incident photons with the SWNT material is considered. Additionally, exposure of the nanotube samples in air and in an inert atmosphere provides insight into the possible mechanism of purification.

Fabrication of refractive index gratings in optical glasses by the filamentary propagation of femtosecond laser pulses

E. Gaižauskas, V. Vaičaitis, V. Kudriašov, M. Peckus, T. Balčiūnas,
V. Sirutkaitis, Vilnius Univ. (Lithuania)

PRIMARY AUTHOR BIOGRAPHY:
Dr. E. Gaižauskas received his Ph.D. in Natural Sciences (Quantum Radiophysic) from the Lebedev Institute of Physics (Moscow, Russia) in 1979. He worked as a junior researcher for Institute of Physics (Vilnius, Lithuania) in 1978-1983. Since 1983 he is senior researcher at Laser Reserach Center of Vilnius University. His principal areas of interest are femtosecond spectroscopy, nonlinear and extreme optics.

ABSTRACT TEXT:
Exploitation of the conical waves in the non-linear regime offers conditions when matter responds only to the high-intensity part of the wave, being transparent to low-intensity radiation, even if it contains most of the beam energy. This phenomenon has been widely used in nonlinear optics and material processing, but the full understanding of the processes behind the local change of refractive index caused by intense conical waves as well as its precise characterization is still lacking.

In the theoretical part of this work the model has been developed describing the process of such laser-matter interaction in which light filament itself represents the central part of the conical wave, continuously regenerated during the propagation from its periphery (reservoir). Numerics based on the model, capable to capture the glass refraction index changes in the areas previously affected by the femtosecond laser pulses, predict possibilities of refractive index grating writing in the bulk of optical glasses. Supplementary diffraction measurements in fabricated samples offers fast-track method for the characterization of induced refractive index changes.

In the experiment, we have used a mode-locked Ti:sapphire laser having the average power of 1 W, pulse width of 130 fs, wavelength of 800 nm, and repetition rate of 1 kHz. The residual periodical refraction index changes in the bulk of glass were obtained by propagating the femtosecond laser pulses with different (Gaussian and Bessel) initial intensity distributions. When the pulse power exceeded the critical power level, the laser beam self-focussed to a narrow highly intense filament. In this high intensity zone the residual refraction index modification with the waveguide formation was observed. A various sets of diffractive transmission gratings have been fabricated in this way with varying laser power, scanning speed, focusing degree and number of pulses exposed to the specimen. For the characterization of produced diffractive gratings a He-Ne laser and CCD camera were used. The He-Ne laser was directed to the specimen at the right angle to its surface. Then the transmitted light and diffracted beams were directed to the entrance of the camera through the short focal length lens. Such registration system allowed us to register the directions of diffracted beams as well as their relative intensities. Since the angle and efficiency of diffraction into a different orders depends on the shape and size of diffracting grooves, we were able to derive the dimensions of periodic refraction index changes as well as the absolute values of the diffraction index in the glass areas affected by the femtosecond laser pulses.

Laser damage on diffractive optics

L. Gallais, G. Demesy, M. Commandré, Institut Fresnel (France);
S. Tisserand, Silios Technologies (France)

PRIMARY AUTHOR BIOGRAPHY:
Laurent Gallais received his PhD degree in Physics in 2002, after his work on laser damage in optical components. Since 2003, he is assistant professor in the field of optics at the Ecole Centrale Marseille and work in the laser damage team at the Institut Fresnel.

ABSTRACT TEXT:
Laser damage studies are made on a phase mirror, used for laser beam shaping in high power laser applications. This component is composed of a glass substrate with defined patterns to encode a phase, on top of which a multilayer mirror is deposited.

We describe in this paper the LIDT obtained (at 1064nm, 6ns) and the specific laser damage test procedure that has been used. A morphologic analysis of the damage sites is made with Nomarski and Atomic Force Microscopy, to obtain information on the damage initiation and its localization on the structured component. The results are completed with model simulations of the electric field within the multilayer, to obtain localization and quantification of the light intensification occurring in the structure.

Numerical and experimental study of focal spot degragation induced by particles on surface optics

B. Martinez, V. Beau, J. Rullier, CEA Cesta (France)

ABSTRACT TEXT:
Correctly defining the lifetime of optical components is a major issue in the operation of high power laser facilites such as the Laser Mégajoule developed by the Commissariat à l'Energie Atomique (CEA). Laser damage which occurs at the surface is a main cause of optical ageing, and may lead to dramatic degradation of the focal spot. To estimate the effect of such defects, we measured and calculated the beam perturbation induced by "model defects". These "model defects" are circular silica dots randomly distributed on a silica substrate. The experiments were conducted in the Antalia facility at the Centre d'Etude Scientifique et Technique d'Aquitaine. We performed the numerical calculations of beam propagation with Mirò software, developed by the CEA. We obtain a remarkable correlation between measurements and simulations in the central part of the focal spot for large defects. However, experimental noise and measurement dynamics become a serious problem when we confine our attention to smaller defects ($<500\mu m$) or to diffuse light around the central part of the focal spot.

We present some modifications of the Antalia experimental setup designed to solve this problem.

6403-19, Poster Session

Size influence of artificial metallic defects on laser surface cleaning process

J. Capoulade, J. Natoli, Institut Fresnel (France); S. Palmier, S. Garcia, J. Rullier, I. Tovena-Pecault, CEA Cesta (France)

ABSTRACT TEXT:
Contamination by metallic particles has been known to initiate laser damage on high power laser optics. To evaluate the effect of metallic contaminants which are present on the LIL optics, silica substrates were artificially polluted by aluminum square dots of two different sizes (5x5 μm2 and 50x50 μm2). The metallic dots are irradiated by a 6 ns pulsed laser at 1064 nm for different fluences. The morphology of irradiated sites is observed by Nomarski microscopy and optical profilometry. Furthermore, local absorption measurements are performed by photothermal microscopy. The sites absorption cartographies taken after irradiations permit to evaluate with accuracy the laser cleaning fluences and give information on the laser damage initiation process.

We have shown last year that, thanks to an adapted laser irradiation of the optics polluted by metallic particles, it is possible to avoid functional laser damage. In this paper, we detail the specific role of the metallic defects size on this laser cleaning surface process. In particular we show that the fluence value of pre-irradiation as well as the pre-irradiation mode (1:1 or S:1), required in the particle removal process, appear clearly dependent on the contaminant size.

Effects of laser-induced damage on optical windows in the presence of adhesives under simulated thermal-vacuum conditions

C. Y. Sheng, Genesis Engineering; P. T. C. Chen, R. J. Hedgeland, NASA Goddard Space Flight Ctr.; J. S. Canham, Swales Aerospace

PRIMARY AUTHOR BIOGRAPHY:

Dr Sheng is currently the scientist at GES working on contamination effects on laser optics. Before coming to GES, he was an NRC post-doctoral fellow at the National Institute of Standards and Technology working on the chemical characterization of a aerosol particles. He has also worked on developing the chemical mechanism that occurs within a solid oxide fuel cells at the Colorado School of Mines. Dr Sheng has a PhD in Chemical Engineering from New Jersey Institute of Technology.

ABSTRACT TEXT:

The current research focused upon ascertaining the extent of induced laser damage that occurs due to the outgassing species from adhesives that will contaminate the optics. The adhesives that are being studied are actual flight materials that are being used in mounting optics in existing 1064nm LIDAR laser systems. Five different adhesives were tested in our vacuum system. Each sample was loaded onto an effusive source and a PID controller controls the set point temperature of the adhesive. Two different types of optics were tested, a commercial grade fused silica window and an anti-reflective coated BK7 window. An oil free vacuum pump system was used to pump the system down to approximately 10-5 Torr. The vacuum pressure of the system was measured by use of a thermocouple gauge and a Bayard Alpert ion gauge. The test windows were irradiated with a 20 Hz Nd:YAG laser at 1064 nm with a nominal fluence of 1 J-cm-2 for at least 1 million shots. All sample windows are analyzed by use of bright field and dark field light microscope. The different types of results observed between materials makes the data set very complex, and thus difficult to derive a direct cause-and-effect relationship.

6403-21, Poster Session

Evaluation of cleaning methods for multilayer diffraction gratings

B. Ashe, K. L. Marshall, C. Giacofei, A. L. Rigatti, T. J. Kessler, A. W. Schmid, J. B. Oliver, J. C. Keck, A. Kozlov, Univ. of Rochester

PRIMARY AUTHOR BIOGRAPHY:

Brian Ashe is a Research Engineer at the University of Rochester, Laboratory for Laser Energetics, where he is responsible for various material research for the OMEGA EP system. Brian recieved his BS in Chemistry from Nazareth College, and his MS in Material Science and Engineering from Rochester Institute of Technology. Prior to working at the Laboratory for Laser Energetics, Brian has held various positions within the semiconductor industry.

ABSTRACT TEXT:

Multilayer dielectric (MLD) diffraction gratings are an essential component for the OMEGA EP short-pulse, high-energy laser system. There has been a great deal of effort in optimizing most of the process parameters required to fabricate these gratings to produce 2.6-kJ output energy per beam. The MLD gratings must have both high optical diffraction efficiency and high laser damage threshold in order to be suitable for use within the OMEGA EP laser system

Using 100mm diameter MLD grating fabricated at LLE, we evaluated different cleaning methods designed to optimize both optical diffraction efficiency and laser damage threshold of these gratings for the OMEGA EP laser system. In this paper, we discuss the different chemical processes investigated for grating cleaning. Diffraction efficiency and damage threshold data were correlated with both scanning electron microscopy (SEM) and Time-of-Flight Mass Spectroscopy (ToF-SIMS) to determine the best cleaning processes and chemistry. Conventional integrated circuit manufacturing cleaning processes were used within this study. We found that using these cleaning processes we were able to exceed the LLE diffraction efficiency and laser damage specifications.

Monday Poster Session • Room 2

Surfaces, Mirrors, & Contamination

10.30 to 11.30 and 15.00 to 16.00

Impact of organic contamination on 1064-nm laser-induced damage threshold of dielectric mirrors, A. A. P. Pereira, S. S. B. Becker, J. Coutard, CEA Grenoble (France); I. Tovena-Pecault, CEA Cesta (France); P. R. Bouchut, CEA Grenoble (France) . . . . [6403-23]

Laser-induced contamination of silica coatings in vacuum, S. S. B. Becker, A. A. P. Pereira, P. R. Bouchut, F. Geffraye, CEA Grenoble (France) . . . . [6403-24]

Surface damage growth mitigation on KDP/DKDP optics using single-crystal diamond micromachining ball end mill contouring, P. Geraghty, Lawrence Livermore National Lab. [6403-25]

The effect of pulse duration and shape on SiO2 surface damage site growth and morphology, C. W. Carr, Lawrence Livermore National Lab. . . . . [6403-26]

Mitigation of growth of laser initiated surface damage in fused silica using a 4.6-μm wavelength laser, G. M. Guss, Lawrence Livermore National Lab. . . . . [6403-27]

Ultra-precision machining of CaF2 single crystals and bulk laser-induced damage threshold, Y. Namba, S. Yoshida, T. Yoshida, Chubu Univ. (Japan); T. Kumada, T. Kamimura, K. Yoshida, Osaka Institute of Technology (Japan) . . . . [6403-28]

MRF applications: manufacture of large-aperture ultraviolet laser resistant continuous phase plates for high-power lasers, J. A. Menapace, P. J. Davis, Lawrence Livermore National Lab. . . . . [6403-29]

Impact of organic contamination on 1064-nm laser-induced damage threshold of dielectric mirrors

A. A. P. Pereira, S. S. B. Becker, J. Coutard, CEA Grenoble (France); I. Tovena-Pecault, CEA Cesta (France); P. R. Bouchut, CEA Grenoble (France)

PRIMARY AUTHOR BIOGRAPHY:

Thesis : “Physico-chemical processes of spacecraft surfaces photo-induced contamination” ; Ingeneer in materials sciences at CEA Grenoble since march 2005.

ABSTRACT TEXT:

The lifetime of optical components submitted to high laser fluences is degraded under organic contaminant environment. The molecular background of the Ligne d_Integration Laser (LIL), prototype of the future Laser Mégajoule, may reduce the laser damage threshold of exposed fused silica surfaces. This paper reports the interaction effects between pure model contaminant deposits and a 1064 nm radiation of a pulsed laser on the coming out of mirror damage. The experimental setup allowed us to condense nanolayers of model contaminants on optics, the deposit impacts were then investigated by Laser Induced Damage Threshold (LIDT) tests using Rasterscan mode. In order to highlight physical processes emphasizing the emergence of optics damage, we characterized the irradiated deposit using interferometric microscopy analysis and spectrophotometric analysis. The challenge was to determine physical and phenomenological processes occurring during the irradiation of a pure contaminant deposit with a 1064 nm pulsed laser and to study the impact of this model contaminant on the LIDT of dielectric SiO_2/HfO_2 mirrors.

Laser-induced contamination of silica coatings in vacuum

S. S. B. Becker, A. A. P. Pereira, P. R. Bouchut, F. Geffraye, CEA Grenoble (France)

PRIMARY AUTHOR BIOGRAPHY:
Research engineer at CEA/LITEN (Grenoble); Study of the laser induced contamination of optical components at 532 nm; Involvement in the Megajoule Project of CEA-CESTA

Expert fields : Thin layers, laser/matter interaction, vacuum technologies, optical characterizations; Participation in the Laser Damage Workgroup of CEA

ABSTRACT TEXT:
Under vacuum conditions, the accumulation of low fluence laser pulses generally leads to an organic contamination of the surface irradiated. This phenomenon reduces the optical component lifetime. Experimental conditions such as laser characteristics, environment composition and structure of the coating influence strongly the contamination mechanisms. Silica being the most employed material for optical treatments, this study aims at describing the influence of the silica coating deposition technique on laser-induced contamination. E-Beam evaporated, Ion Beam Sputtered and Solgel silica have been exposed to several billions 600 mJ/cm2 - 532 nm laser pulses under vacuum. This paper presents the observations made on laser-induced contamination and discusses the physical mechanisms involved.

Surface damage growth mitigation on KDP/DKDP optics using single-crystal diamond micromachining ball end mill contouring

P. Geraghty, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:

Paul Geraghty has worked at Lawrence Livermore National Laboratory since 1984. During this time he has supported many of the large laser projects including NOVA, AVLIS, and now the NIF. Paul has a master's degree from Stanford University in mechanical engineering, is a licensed Professional Engineer (PE) in the state of California, and is certified by the Society of Manufacturing Engineers (SME) as a Tool Engineer (CMfgE). He is currently the Responsible Engineer for the NIF Crystal Production Facility.

ABSTRACT TEXT:

A process to stabilize laser-initiated surface damage on KDP/DKDP optics by micro-machine contouring using a single-crystal diamond ball nose end mill is shown to mitigate damage growth for subsequent laser shots. Our tests show that machined circular contours on output surfaces of uncoated doubler (KDP) and tripler (DKDP) crystals are stable for laser exposures at 526nm, ~8ns pulses at ~12J/cm2 fluences. Other tests also confirmed that the machined contours on the output surface of an uncoated tripler are stable for combined 1053nm and 526nm, ~8ns pulses at ~12J/cm2 total fluences (~6J/cm2 each wavelength) for greater than 100 shots. Laser damage tests have also been conducted on an array machined contours on the output surface of an AR coated tripler at 526nm, ~1ns pulses up to ~8J/cm2 fluences. The machined shapes have been as large as 1.5 mm in diameter and 0.25 mm deep, and as small as 250 microns in diameter and 25 microns deep. Both Gaussian and conical shaped contours have been successfully tested. Computer modeling and measurement of laser beam propagation through the actual contoured shapes have been carried out to confirm downstream intensification is manageable. Details of the micro-machine contouring method are presented, including critical process parameters, contour shape definitions, surface topology, and a plan to implement this method to treat pre-initiated or retrieved-from-service, large-scale optics for use in high-peak-power applications.

The effect of pulse duration and shape on SiO2 surface damage site growth and morphology

C. W. Carr, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:

Dr. C.W. Carr's recent research has included measurements of laser-induced breakdown initiation mechanisms and the dynamics of energy absorption and dissipation during such events. Currently he is the principle investigator at the Optical Science Laser facility at Lawrence Livermore National Laboratory. His most recent experiments have focused on the effect of pulse duration and shape on laser-induced damage growth and initiation.

ABSTRACT TEXT:

Flaws on the surface of SiO2 optics are undesirable because they have a well-known tendency to grow when exposed to high-power laser energy. The rate at which these sites grow is of key concern and has been the subject of substantial study. Experimental data is presented that shows both the morphology and rate at which these site grow is very sensitive to pulse duration in the range of 1-ns to 10-ns, contrary to previously reported results. A simple model is proposed to explain the observed differences.

Mitigation of growth of laser initiated surface damage in fused silica using a 4.6-μm wavelength laser

G. M. Guss, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:

Mr. Gabriel Guss received his bachelor's degree in physics from the University of Oregon in 2001. He is a member of the team at the Lawrence Livermore National Laboratory working on laser induced damage in optical materials. His current work and expertise involves mitigation of surface damage on large aperture, fused silica optics, in support of the National Ignition Facility.

ABSTRACT TEXT:

Damage caused by high fluence 351 nm light to the final optics of the laser being built at the National Ignition Facility (NIF) affects the cost and reliability of its operation. Initiation and growth of surface damage can occur at fluences <14 J/cm2 for 3 ns pulses, the highest fluence expected in normal operation. Surface damage is usually in the form of pits with a rubble-like appearance, and cracks that extend into the bulk below the rubble. These damage sites will grow in both lateral size and depth with repeated exposure to the 351 nm light. Mitigation of this growth has been previously reported using a 10.6 um CO2 laser. Here, we report growth mitigation with the 4.6 um light from a frequency-doubled, 9.2 μm CO2 laser. The motivation for using 4.6 um is the approximately 100 times longer absorption length in fused silica at room temperature compared to that at 10.6 um. Mitigation of subsurface cracks at 10.6 um required evaporation of material to the depth of the cracks. In contrast, it was possible to mitigate the subsurface cracks using 4.6 um light by adjusting the laser spot size and power to maintain the surface temperature just below the ablation threshold. Mitigation of both the rubble pit and the subsurface cracks occurred by melting to depths exceeding 300 um. The depth of the mitigation site was then essentially that of the original rubble pit, much less than it would have been for evaporative mitigation at 10.6 um. Melting of the material around the cracks formed small bubbles, typically somewhat smaller than 50 um in diameter, which did not initiate damage in tests with 7.5 ns pulses of 351 nm light at fluences exceeding 25 J/cm2.

Ultra-precision machining of CaF2 single crystals and bulk laser-induced damage threshold

Y. Namba, S. Yoshida, T. Yoshida, Chubu Univ. (Japan); T. Kumada, T. Kamimura, K. Yoshida, Osaka Institute of Technology (Japan)

PRIMARY AUTHOR BIOGRAPHY:
April 1966 Research Associate in Department of Precision Engineering, Osaka University; October 1971 Lecturer in Department of Precision Engineering, Osaka University; August 1972 Associate Professor in Department of Precision Engineering, Osaka University; August-November 1976 Visiting Associate Professor in Engineering Production, University of Birmingham, UK; November 1981-November 1982 Visiting Associate Professor in Institute of Modern Optics, University of New Mexico, USA April 1987 Professor in Department of Mechanical Engineering, Chubu University

ABSTRACT TEXT:
High purity calcium fluoride (CaF2) single crystals for next-generation optical lithography have been ground on (001), (111) and (110) faces using an ultra-precision surface grinder having a zero-thermal expansion spindle with various resin-bonded diamond wheels. All the crystallographic surfaces were ultra-precision ground without micro-crack under adequate grinding conditions. Surface roughness of 1.06nm rms was obtained using an SD3000-75-B wheel. The roughness of ultra-precision ground samples depends on the crystallographic plane and direction as well as on the grinding conditions. The depth of the mechanically-damaged layer was also measured by etch pit technology.

CaF2 (111) single crystals were float polished to a flatness of 32 nm p-v on 90-mm-diameter samples that had a surface roughness of 0.077 nm rms, as measured with a Scanning Probe Microscope (SPM). The SPM observation showed the float-polished surface had a perfect (111) lattice with small atomic steps, and no subsurface damage. The polished surface roughness depends on the mismatch between the sample surface and the (111) plane.

Various CaF2 (111) single crystals were tested by the n-on-1 laser irradiation of 266nm wavelength, and the laser-induced damage threshold (LIDT) were obtained in the bulk. The LIDT values depend upon the etch pit density of CaF2 single crystals.

MRF applications: manufacture of large-aperture ultraviolet laser resistant continuous phase plates for high-power lasers

J. A. Menapace, P. J. Davis, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:
Ph.D., Physical Chemistry, Colorado State University, 1987; B.S., Chemistry, U.S. Air Force Academy, 1982; LLNL: Manager and Group Leader for Advanced Finishing, Laser Materials & Optics Technology, C&MS, 1997–present. Manager and technical interface for NIF large-aperture optic finishing operations at the Zygo Corporation and the International Telephone and Telegraph Space Systems Division. Application of advanced finishing techniques such as magnetorheological finishing, hydrofluoric acid wet etching, and ultraviolet laser conditioning during fused silica optic fabrication for improved ultraviolet laser damage resistance. Development of magnetorheological finishing techniques for diffractive optic applications that require the imprinting of complex topographical information onto optical surfaces for laser beam manipulation, wavefront shaping, and correction.

ABSTRACT TEXT:
Over the past two years we have developed MRF instruments and procedures to manufacture large-aperture (430 X 430 mm) continuous phase plates (CPPs) that are capable of operating in the infrared portion (1053-nm) of high-power laser systems. This is accomplished by polishing prescribed patterns of continuously varying topographical features onto finished plano optics using MRF imprinting techniques. We have been successful in making and testing large-aperture CPPs whose topography possesses spatial periods as low as 4 mm and surface peak-to-valleys as high as 5 microns. Combining this application of MRF technology with advanced MRF finishing techniques that focus on ultraviolet laser damage resistance makes it potentially feasible to manufacture large-aperture CPPs that can operate in the ultraviolet (351 nm) without sustaining laser-induced damage. During this presentation, we will discuss the CPP manufacturing process and the results of 351-nm/3-nsec laser performance experiments conducted on large-aperture CPPs manufactured using advanced MRF protocols.

Tuesday AM • 26 September

07.30 to 08.30 **Poster Placement at NIST**
Poster authors for the Monday poster session are to set-up their posters at this time.

08.40 to 10.00 • SESSION 4

MINI SYMPOSIUM: Optics in a Hostile Environment

Chairs: **Alan F. Stewart**, The Boeing Co.;
Jerry B. Franck, U.S. Army Night Vision & Electronic Sensors Directorate

08.40: **Optical coatings and surfaces in space: MISSE,** A. F. Stewart, The Boeing Co.; M. M. Finckenor, NASA Marshall Space Flight Ctr. . . . . [6403-31]

09.00: **Surface contamination of the LIL optical components and their evolution under laser irradiation,** S. Palmier, S. Garcia, L. Lamaignère, J. Rullier, I. Tovena-Pecault, CEA Cesta (France); L. Servant, Univ. Bordeaux I (France) . . . . [6403-32]

09.20: **Contamination in chemical lasers and damage-resistant coatings for laser mirrors,** S. C. Dass, Boeing LTS, Inc.; D. W. Reicher, S. Systems, Inc.; V. A. Valdez, Boeing LTS, Inc. . . . . [6403-33]

09.40: **Ophthalmic optical coatings: the real world can be more aggressive than you think,** M. E. Mildebrath, Essilor of America, Inc. . . . . [6403-34]

10.00 to 10.30 • Tuesday Poster Overview

All Fundamental Mechanisms and Surfaces, Mirrors, and Contamination poster authors are asked to give 2-minute/2-viewgraph overviews of their posters in the order they appear in the program.

10.30 to 11.30 • Poster Session and Refreshment Break

11.30 to 12.30 • SESSION 4 continued

11.30: **A mechanism for erosion of optics exposed to a laser-generated EUV plasma,** J. W. Arenberg, Northrop Grumman Space Technology . . . . [6403-35]

11.50: **Xtreme optics: the behavior of cavity optics for the Jefferson Lab Free-Electron Laser,** M. D. Shinn, Thomas Jefferson National Accelerator Facility; C. Behre, Jr., Naval Surface Warfare Ctr.; S. Benson, D. Douglas, H. F. Dylla, C. Gould, J. Gubeli III, D. Hardy, K. Jordan, S. Zhang, Thomas Jefferson National Accelerator Facility . . . [6403-36]

12.10: **Laser-induced optical damage in neutron-irradiated fused silica,** J. F. Latkowski, R. P. Abbott, V. K. Kanz, B. K. Bell, Lawrence Livermore National Lab. . . . . [6403-37]

12.30 to 14.00 • Lunch Break

6403-31, Session 4

Optical coatings and surfaces in space: MISSE

A. F. Stewart, The Boeing Co.; M. M. Finckenor, NASA Marshall Space Flight Ctr.

PRIMARY AUTHOR BIOGRAPHY:

ALAN F. STEWART is an Associate Technical Fellow for the Boeing Company. His work in government service, commercial industry and now government programs at Boeing has given him the opportunity to develop expertise in characterization, fabrication, and test of thin films. He has published work in laser damage, ion beam sputtering of coatings, applications of Raman spectroscopy, and surface analytical techniques. Recent efforts involve refinement of methods for laser calorimetry and application of the cavity ringdown lossmeter for evaluation of high quality and rather large optics.

ABSTRACT TEXT:

The space environment presents some unique problems for optics. Components must be designed to survive variations in temperature, exposure to ultraviolet, particle radiation, atomic oxygen and contamination from the immediate environment. To determine the importance of these phenomena, a series of passive exposure experiments have been conducted which included, among others, the Long Duration Exposure Facility (LDEF, 1985- 1990), the Passive Optical Sample Assembly (POSA, 1996-1997) and most recently, the Materials on the International Space Station Experiment (MISSE, 2001-2005). The MISSE program benefited greatly from past experience so that at the conclusion of this 4 year mission, samples which remained intact were in remarkable condition. This study will review data from different aspects of this experiment with emphasis on optical properties and performance.

6403-32, Session 4

Surface contamination of the LIL optical components and their evolution under laser irradiation

S. Palmier, S. Garcia, L. Lamaignère, J. Rullier, I. Tovena-Pecault, CEA Cesta (France); L. Servant, Univ. Bordeaux I (France)

PRIMARY AUTHOR BIOGRAPHY:
PhD student working on the influence of particulate contamination on laser induced damage of optics

ABSTRACT TEXT:
In the context of the Laser Mégajoule project, we have studied the consequences of particle contamination on an optical component's surface for its ageing under laser irradiation. The experimental procedure includes four steps; cleaning silica samples, placing them as collectors in the Ligne d'Intégration Laser (LIL), quantifying and characterizing the particle contamination collected and finally observing the behaviour of both particles and substrates under 1064 nm or 355 nm laser irradiation. By comparison with the results obtained both before and after irradiation of the silica samples, the "cleaning effect" is quantified. In parallel, the chemical composition of particles is determined by Scanning Electronic Microscopy and Energy Dispersion Spectroscopy.

Although different areas of the LIL facility have been concerned in this study, the main result is that a "cleaning effect" is demonstrated. The proportion of removed contaminant depends strongly on the laser fluence and the particle size. Concerning optical damaging, a few effects have been observed which did not grow under subsequent irradiation.

Contamination in chemical lasers and damage-resistant coatings for laser mirrors

S. C. Dass, Boeing LTS, Inc.; D. W. Reicher, S. Systems, Inc.;
V. A. Valdez, Boeing LTS, Inc.

PRIMARY AUTHOR BIOGRAPHY:

Dr. Dass received his Ph.D. degree from University of New Brunswick in 1971. He has been working in Lasers and Laser Systems for the past 27 years. He has been working as a Senior Scientist at Boeing LTS for last 8 years. Before that, he was working Vice President Technology at Lasertechnics, Inc. He has published some 16 papaers in scientific journals.

ABSTRACT TEXT:

Chemical lasers present a very hostile environment, especially, for cavity optics used as reflectors. Chemicals flowing through the laser cavity may cause surface contamination that could easily damage mirrors in the presence of a high intensity laser beam. An investigation was conducted to minimize the optical damage. It was found that the caustic solution used in chemical lasers partially dissolves a typical dielectric coating thin film layer on mirrors. When exposed to a high energy laser beam, the coating and substrate were catastrophically damaged. The coating layer design was reformulated to achieve protection of the outer layer on the mirror surface. This new outer coating material is not soluble in caustic solutions such as Basic Hydrogen Peroxide. The coatings were deposited by reactive DC magnetron sputtering. A combination of the bulk density and low absorption achieved using this deposition technique with the revised coating design, protected the mirrors from chemical attack and excessive heating.

6403-34, Session 4

Ophthalmic optical coatings: the real world can be more aggressive than you think

M. E. Mildebrath, Essilor of America, Inc.

PRIMARY AUTHOR BIOGRAPHY:

I am currently the manager of a local team of people responsible for the industrialization of new products and processes to be used in ophthalmic processing labs throught the world. My whole career has been spent in optical coatings covering a wide range of applications. Eleven of those year have been spent in the ophthalmic coatings field. But I have also spent a number of years doing traditional laser coatings as well as band pass filter coatings for telecommunications.

ABSTRACT TEXT:

Ophthalmic antireflection coatings are not normally considered to be in the same category as other traditional optical coatings with respect to environmental damage. However, as a group, eyeglass lens wearers tend to subject their optical-coated eyewear to a broader and more aggressive range of environmental aggressions than at first imagined. This paper presents in some detail the environmental aggressions and the resultant coating defects observed in coated ophthalmic optics. Further, development of test methods for defect replication, to enable product improvements will be discussed. Real-life environments combine thermal, chemical, and mechanical “aggressions” which spectacle lenses are subjected to. These aggressions generate optical coating defects and failure modes involving abrasion, corrosion, and loss of adhesion. In addition, market forces driven by retail customer perceptions lead to product liabilities not normally considered to be of any consequence in traditional optical coating applications.

6403-35, Session 4

A mechanism for erosion of optics exposed to a laser-generated EUV plasma

J. W. Arenberg, Northrop Grumman Space Technology

ABSTRACT TEXT:
This paper introduces an explanation for material erosion in proximity to a laser drive EUV source. The mechanism advanced is a x-ray induced ablation. A semi-empirical model is introduced and shown to agree well with experiemental results. It is futher shown that these results are consistent with critical energy densities typical of laser induced damage thresholds. These results are then used to develop a strategy for mitigation of erosion effects in EUV sources.

6403-36, Session 4

Xtreme optics: the behavior of cavity optics for the Jefferson Lab Free-Electron Laser

M. D. Shinn, Thomas Jefferson National Accelerator Facility; C. Behre, Jr., Naval Surface Warfare Ctr.; S. Benson, D. Douglas, H. F. Dylla, C. Gould, J. Gubeli III, D. Hardy, K. Jordan, S. Zhang, Thomas Jefferson National Accelerator Facility

PRIMARY AUTHOR BIOGRAPHY:

Dr. Michelle Shinn, Chief Optical Scientist of the FEL Division, has been at Jefferson Lab since 1995. From 1996-1999, she led the design, procurement, and installation activities for the IR Demo free electron laser (FEL) optical cavity, transport and diagnostics, and since 1999 performs the same duties on the Upgrade FEL projects. She actively collaborates with a number of teams that use the FEL, and in particular, as been pursuing her own research on ablation of materials, and laser-induced damage of optical components. Before coming to Jefferson Lab, she was a physicist in the Laser Division at Lawrence Livermore National Lab (1984-1990), and Associate Professor of Physics at Bryn Mawr College (1990-1995).

ABSTRACT TEXT:

The cavity optics within high power free-electron lasers based on energy-recovering accelerators are subjected to extreme conditions associated with illumination from a broad spectrum of radiation, often at high irradiances. This is especially true for the output coupler, where absorption of radiation by both the mirror substrate and coating places significant design restrictions to properly manage heat load and prevent mirror distortion. Besides the fundamental lasing wavelength, the mirrors are irradiated with light at harmonics of the fundamental, THz radiation generated by the bending magnets downstream of the wiggler, and x-rays produced when the electron beam strikes accelerator diagnostic components (e.g., wire scanners and view screens) or from inadvertent beamloss. The optics must reside within high vacuum at ~ 10-8 Torr and this requirement introduces its own set of complications. This talk discusses the performance of numerous high reflector and output coupler optics assemblies and provides a detailed list of lessons learned gleaned from years of experience operating the Upgrade IR FEL, a 10 kW-class, sub-ps laser with output wavelength from 1 to 6 microns.

6403-37, Session 4

Laser-induced optical damage in neutron-irradiated fused silica

J. F. Latkowski, R. P. Abbott, V. K. Kanz, B. K. Bell, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:

Nuclear Engineer, New Technologies Engineering Division, Lawrence Livermore National Laboratory (LLNL). PhD, Nuclear Engineering, University of California at Berkeley, 1996; BS, Nuclear Engineering, University of Illinois at Urbana-Champaign, 1990. Recipient of the first LLNL Director's Performance Award for environmental, safety and health evaluations of the National Ignition Facility. Currently Deputy Associate Program Leader for Fusion Technology within LLNL's Fusion Energy Program. Responsibilities include x-ray damage experiments and modeling, neutron and ion damage testing of final optics, IFE chamber design, and methods for optics protection in IFE.

ABSTRACT TEXT:

The final optic in an inertial fusion energy (IFE) power plant would be exposed large doses of high-energy neutrons and gamma-rays. Exposure to radiation leads to the production of color centers, which can reduce the laser transmission. Despite this, previous work has shown that a thin, transmissive final optic (Corning 7980 fused silica) may be an attractive option for operation at a wavelength of 351nm. In addition to a reduction in transmission, absorption may lead to the onset of optical damage at lower-than-expected laser fluences. Here, we report upon laser damage tests that have been conducted with Corning 7980 that has been neutron-irradiated to a total dose of 10^9 Gy, which is equivalent to several months of exposure in the IFE application.

Tuesday PM • 26 September

14.00 to 15.20 • SESSION 5

Thin Films I

Chairs: **M. J. Soileau**, College of Optics & Photonics/Univ. of Central Florida;
Kunio Yoshida, Osaka Institute of Technology (Japan)

14.00: **Recent advances in magnetron sputtered superlattice and quantum well structures** *(Invited Paper)***,** P. M. Martin, W. D. Bennett, L. C. Olsen, C. H. Henager, Pacific Northwest National Lab. . . . . [6403-38]

14.40: **Laser-induced damage in gradual index layers and rugate filters,** M. Jupe, L. S. Jensen, M. Lappschies, K. Starke, D. Ristau, Laser Zentrum Hannover e.V. (Germany) . . . . [6403-39]

15.00: **Glancing angle deposited thin films and their applications in laser systems,** J. Shao, S. Wang, Z. Shen, X. Fu, H. He, Z. Fan, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [6403-40]

15.20 to 16.20 • Poster Session and Refreshment Break

16.20 to 17.40 • SESSION 6

Thin Films II

Chairs: **M. J. Soileau**, College of Optics & Photonics/Univ. of Central Florida;
Kunio Yoshida, Osaka Institute of Technology (Japan)

16.20: **A year of automated LDT testing on ion-beam sputtered thin film optics and laser conditioning of IBS films,** D. C. Ness, T. E. Bittancourt, A. D. Streater, Research Electro-Optics, Inc. . . . . [6403-41]

16.40: **Study of laser-induced damage at 2 μm on coated and uncoated ZnSe substrates,** H. T. Krol, Institut Fresnel (France); C. Grèzes-Besset, Cilas Marseille (France); L. Gallais, J. Natoli, M. Commandré, Institut Fresnel (France) . . . . [6403-42]

17.00: **Direct measurements of residual absorption in fluoridic thin films and optical materials for DUV laser applications,** C. Mühlig, W. Triebel, S. Kufert, C. Noppeney, Institut für Physikalische Hochtechnologie e.V. (Germany); H. Bernitzki, JENOPTIK Laser, Optik, Systeme GmbH (Germany); S. Schröder, Fraunhofer Institut für Angewandte Optik und Feinmechanik (Germany) . . . . [6403-43]

17.20: **Multilayer dielectric gratings for femtosecond optical pulse compressor,** Y. Dai, S. Liu, J. Shao, K. Yi, Z. Fan, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [6403-44]

18.00 to 19.30 • Wine and Cheese Reception at NCAR

6403-38, Session 5

Recent advances in magnetron sputtered superlattice and quantum well structures

P. M. Martin, W. D. Bennett, L. C. Olsen, C. H. Henager, Pacific Northwest National Lab.

PRIMARY AUTHOR BIOGRAPHY:

Dr Martin has worked at Battelle, PNL (BNW) for the past 28 years and currently holds the position of Lab. Fellow, specializing in developing thin film coatings for energy, biomed, space & defense applications. He pioneered the use of reactive magnetron sputtering technology to fabricate novel coatings, superlattice & quantum well materials and engineered coatings with improved durability, adhesion, & performance, & also specializes in large-area coating development. Currently, Pres. of the Society of Vacuum Coaters, Sec. for the AVS Advanced Surface Engineering Div. Executive Committee, & Technical Advisory Committee member for the Society of Vacuum Coaters. He was elected a Fellow of SVC in 2003. He has written over 200 technical publications, given over 200 technical presentations, won three R&D 100 Awards for his work in microfabrication and barrier coatings for flat panel displays, two FLC awards, distinguished inventor, and PNNL 2005 Inventor of the Year. He has 24 patents.

ABSTRACT TEXT:

cIn the past fifteen years, hard coating, optical and electrical device technologies have advanced beyond the use of single layer coatings with the development of nanoscale compositionally modulated coatings, or superlattices and quantum well structures. Thin film superlattice and quantum well materials can exhibit physical, optical and mechanical properties very different and often superior to those of single layer counterparts. A typical superlattice or quantum well structure consists of hundreds to thousands of nm-scale layers with alternating compositions and/or crystalline phases. It is possible to engineer the electrical and mechanical properties by choice of layer thicknesses and compositions. Typical layer thicknesses are between 2 and 100 nm. We report of four types of superlattice coatings: (1) AlN/Si3N4 optical superlattice for abrasion protection of ZnS IR windows, (2) Al/Cu structural superlattices for space applications, (3) Si/Si0.8Ge0.2 quantum well structures and (4) novel thermoelectric quantum well structures. All superlattice and quantum well coatings were deposited by DC and RF reactive magnetron sputtering. The AlN/Si3N4 superlattice had layer thicknesses of 2 nm and exhibited a nanohardness of 35 GPa. The Al/Cu superlattice had layer thicknesses of 1.5 nm and a hardness near 6.5 GPa and is being developed for lightweight optics for space applications. The both Si/Si0.8Ge0.2 and AgxSbTeyGez/GeTe superlattice/quantum wells are being developed for thermoelectric power generation from waste heat sources, and AgxSbTeyGez/GeTe has demonstrated a thermoelectric figure of merit (ZT) ~ 1.5.

6403-39, Session 5

Laser-induced damage in gradual index layers and rugate filters

M. Jupe, L. S. Jensen, M. Lappschies, K. Starke, D. Ristau,
Laser Zentrum Hannover e.V. (Germany)

ABSTRACT TEXT:
The development of advanced and reliable techniques for the production of optical coating systems with a continuous variation of the refractive index opens the way towards a new generation of optical components in laser technology and modern optics.

The present paper is dedicated to an Ion Beam Sputtering (IBS-)concept for the production of coatings with gradual index layers and rugate filters. On the basis of a spectrophotometric online-control system, rugate filter coating systems were produced with high precision and reliability. Besides the optical performance, especially the laser damage properties of the coating systems were investigated in respect to defined mixtures of two coating materials and the influence of gradual index layer designs. A clear increase of the laser induced damage thresholds was observed for the produced rugate coatings. The experimental results are discussed considering the special properties of gradual coating systems.

6403-40, Session 5

Glancing angle deposited thin films and their applications in laser systems

J. Shao, S. Wang, Z. Shen, X. Fu, H. He, Z. Fan,
Shanghai Institute of Optics and Fine Mechanics (China)

PRIMARY AUTHOR BIOGRAPHY:
Jianda Shao received his BS degree at Zhejiang University in 1986 and MS and PhD degree in optical instrument from the Shanghai Institute of Optics and Fine Mechanics, CAS in 1993 and 1998 respectively. He is a professor and director of R&D Center for Optical Thin Film Coatings. His current research interests include thin film techniques, x-ray coatings, laser-thin film interaction.

ABSTRACT TEXT:
Glancing angle deposition (GLAD) is a novel way to produce nanostructural thin films with engineered porosity. It is based on physical vapor deposition (PVD), and employs oblique incident angle and adjustable substrate motion to engineer thin film microstructures in three dimensions. The film structures obtained by GLAD are different from those by conventional methods, and it is possible to make new optical components combining both isotropic and anisotropic films.

In this paper, ZrO2 and TiO2 dielectric thin films were grown by electron beam evaporation with GLAD technique. By controlling the incident flux angle and substrate rotational speed, some unique cross-sectional structures, such as slanted column, helix and pillar structure were achieved. For different GLAD films deposited at 0°-80°, optical properties, such as transmittance and refractive index were characterized. With the increasing of incident flux angle, transmittance increases and refractive index decreases gradually, this can be ascribed to the increasing porosity caused by self-shadowing effect.

As examples for applications of the GLAD thin films, several optical components were then designed and fabricated, such as graded-index rugate filter, broadband antireflection coating and quarter-wave plate for visible and near infrared laser systems. Finally, optical properties and laser-induced damage threshold were measured and discussed for the special samples. To some extent, GLAD provides a new solution for making optical components used in laser systems.

A year of automated LDT testing on ion-beam sputtered thin film optics and laser conditioning of IBS films

D. C. Ness, T. E. Bittancourt, A. D. Streater, Research Electro-Optics, Inc.

ABSTRACT TEXT:
The automated laser damage testing system at REO has been in operation for over a year, providing quantitative and detailed information on laser damage of ion beam sputtered (IBS) thin films in a production setting. Results have accumulated in a database, which can be queried in complex ways. We present statistical analysis on event curves (number vs. fluence) for various defect size groups. We examine the differences in event curves for high-threshold and lower-threshold IBS optics. We also present results of experiments on laser conditioning of IBS thin films.

6403-42, Session 6

Study of laser-induced damage at 2 μm on coated and uncoated ZnSe substrates

H. T. Krol, Institut Fresnel (France); C. Grèzes-Besset, Cilas Marseille (France); L. Gallais, J. Natoli, M. Commandré, Institut Fresnel (France)

PRIMARY AUTHOR BIOGRAPHY:

Hélene Krol is graduated from Ecole Supérieure d'Optique (Orsay, France) in 2002. She is currently a PhD student at the Institut Fresnel in Marseille, supported by CILAS Marseille (Compagnie Industrielle des Lasers). Her research interests deal with the study of laser-induced damage phenomena in optical multilayer components.

ABSTRACT TEXT:

Laser damage characteristics of infrared substrates and coatings at 2-μm wavelength have been rarely studied until yet, even if the need of optical components with high laser-induced damage threshold in the mid-infrared is important. Use of an infrared nanosecond laser, tunable in the range 2 to 5 microns, allowed us to develop an automatic test facility for the determination of accurate LIDT curves for different test procedures. We choose to particularly study polycrystalline zinc selenide (ZnSe) material used as substrates for infrared dielectric coatings. This material is known to have a very low hardness and should be able to release the strong thermo-mechanical constraints when irradiated by high power lasers. This property is in agreement with the results observed with multiple laser irradiations on ZnSe substrates (LIDT measurements, analysis of damage morphologies...). Furthermore, irradiation of ZnSe substrates with parallel laser beam shows that surfaces always break clearly before bulk material, this shows that surfaces must be carefully prepared. We particularly exhibit the influence of polishing processes on substrates LIDT. Then the influence of different cleaning methods before coatings deposition is studied. Practical implications for the fabrication of highly laser resistant multilayer coatings at 2-μm are finally discussed.

6403-43, Session 6

Direct measurements of residual absorption in fluoridic thin films and optical materials for DUV laser applications

C. Mühlig, W. Triebel, S. Kufert, C. Noppeney, Institut für Physikalische Hochtechnologie e.V. (Germany); H. Bernitzki, JENOPTIK Laser, Optik, Systeme GmbH (Germany); S. Schröder, Fraunhofer Institut für Angewandte Optik und Feinmechanik (Germany)

PRIMARY AUTHOR BIOGRAPHY:

Since 1998 Christian M¸hlig has been a member of the Laser Diagnostic Department of IPHT in Jena. In 2005 he received his PhD in physics from the University of Jena. Main field of interests are laser spectroscopy and UV laser interaction with optical materials and systems.

ABSTRACT TEXT:

The performance of optical coatings for high power DUV/VUV laser applications depends amongst others on residual absorption in the thin film layers due to impurities or defects. Especially in nowadays ArF laser lithography thin film absorption can cause unwanted temperature distributions in optical elements yielding a reduction of the polarization contrast.

By means of the laser induced deflection (LID) technique weak thin film absorption between 4E-4 and 9E-3 are measured in high reflecting as well as high transmitting systems on CaF2 substrates. A particular focus is given to the experimental procedure of measuring absorption in highly transmitting thin films, especially in the presence of high scattering within the thin films. For complete optical characterization combined transmission, absorption and scattering measurements are performed to examine the energy balance.

Since the established LID setup requires particular substrate dimensions (cuboids) optical elements like laser mirrors or windows could not be measured so far, e.g. prior to or within their use in laser systems. Modifying the LID setup by a special sample adapter allows the direct measurement of optical elements of different geometries. The principle of the new sample adapter is introduced and first measurements are presented.

6403-44, Session 6

Multilayer dielectric gratings for femtosecond optical pulse compressor

Y. Dai, S. Liu, J. Shao, K. Yi, Z. Fan,
Shanghai Institute of Optics and Fine Mechanics (China)

PRIMARY AUTHOR BIOGRAPHY:

Yaping Dai obtained doctor degree of optical engineering from shanghai institute of optics and fine mechanics in 2000. In 2003, be engaged as professor on grating tiling.

ABSTRACT TEXT:

In high-energy laser systems based on chirped pulse amplification, multilayer dielectric (MLD) gratings with good output waveform, high diffraction efficiency and high damage threshold play an important role. In the past decade, many efforts were devoted to improvement of design and fabrication of high performance MLD gratings for picosecond pulses. Recently, MLD gratings have been obtained to have very good specifications, such as \>96% (1053 nm) diffraction efficiency over an aperture of ~1m2 and 4.5J/cm2 laser-induced damage threshold (LIDT) for 10-ps pulses. However, until now there are few reports on design and fabrication of MLD gratings for femtosecond pulse compressor, and the reflection bandwidth of MLD gratings shall be considered for broad spectral pulses.

In this paper, we first introduce a method for optical characteristic analysis of MLD gratings under irradiation of ultrashort optical pulses, which is based on the integration of Fourier spectrum decomposition and rigorous modal method. The dependence of reflected pulses on the reflection bandwidth of MLD gratings is analyzed for incident pulses with different duration times. The effects of construction parameters, including grating depth, duty cycle, refractive index and structure of high reflection film, on the reflection bandwidth of MLD gratings are discussed in detail. Optimization of the near-field distribution is also performed in order to improve the damage resistant capabilities of the MLD gratings to ultrashort pulses. Finally, optimized MLD gratings for 100-fs pulse compressor are fabricated by using e-beam evaporation, holography and reactive ion etching. Experiment results are given for both diffraction efficiency and LIDT.

Tuesday Poster Session • Room 1

Thin Films

10.30 to 11.30 and 15.20 to 16.20

Ion-beam deposition of (NbTa)2O5/SiO2 multilayers for high-efficiency 800-nm dielectric gratings for high-average power laser systems, C. S. Menoni, D. Patel, F. Brizuela, Y. Wang, M. A. Larotonda, K. J. Hsiao, J. J. G. Rocca, Colorado State Univ.; H. T. Nguyen, T. C. Carlson, C. R. Hoaglan, J. D. Nissen, M. D. Aasen, J. E. Peterson, J. A. Britten, Lawrence Livermore National Lab. . . . . [6403-45]

Assessing the impact of atomic oxygen in the damage threshold and stress of hafnia films grown by ion-beam assisted deposition, D. Patel, F. Brizuela, Y. Wang, M. A. Larotonda, J. J. G. Rocca, C. S. Menoni, Colorado State Univ.; F. G. Tomasel, Advanced Energy Industries, Inc.; S. Kholi, P. R. McCurdy, Colorado State Univ. . . . . [6403-46]

Improvement in laser light resistance of fs- dielectric optics using silica mixtures, M. Jupé, L. S. Jensen, M. Lappschies, K. Starke, D. Ristau, Laser Zentrum Hannover e.V. (Germany) . . . . [6403-47]

Morphology investigations of laser-induced damage, B. Wu, L. S. Jensen, M. Jupé, K. Starke, D. Ristau, Laser Zentrum Hannover e.V. (Germany) . . . . [6403-48]

Laser resistivity of selected multilayer designs for DUV/VUV applications, S. Günster, H. Blaschke, D. Ristau, Laser Zentrum Hannover e.V. (Germany) . . . . [6403-49]

The microstructure and LIDT of Nb2O5, ZrO2, and Ta2O5 optical coatings, R. Buzelis, G. Abromavicius, R. Drazdys, Fizikos Institutas (Lithuania); A. Melninkaitis, V. Sirutkaitis, Vilnius Univ. (Lithuania); A. Skrebutenas, Optida Co. (Lithuania); R. Juskenas, A. Selskis, Institute of Chemistry (Lithuania) . . . . [6403-50]

Optical characterization of antireflective sol-gel coatings fabricated using dip coating method, A. Melninkaitis, K. Juskevicius, M. Maciulevicius, V. Sirutkaitis, A. Beganskiene, I. Kazadojev, A. Kareiva, Vilnius Univ. (Lithuania); D. Perednis, Institute of Physics (Lithuania) [6403-51]

Ion-beam deposition of (NbTa)2O5/SiO2 multilayers for high-efficiency 800-nm dielectric gratings for high-average power laser systems

C. S. Menoni, D. Patel, F. Brizuela, Y. Wang, M. A. Larotonda, K. J. Hsiao, J. J. G. Rocca, Colorado State Univ.; H. T. Nguyen, T. C. Carlson, C. R. Hoaglan, J. D. Nissen, M. D. Aasen, J. E. Peterson, J. A. Britten, Lawrence Livermore National Lab.

ABSTRACT TEXT:
The ion beam deposition of (NbTa)2O5 has been investigated for realizing high reflectance multilayer stacks of high damage threshold for applications in the engineering of 800 nm dielectric gratings. Deposition conditions were optimized to yield fully oxidized films as determined from x-ray photoelectron spectroscopy (XPS). The film properties were also investigated using spectroscopic ellipsometry, and spectrophotometry from which the films refractive index and thickness were obtained respectively. Damage threshold testing was performed on single films using an amplified Ti:Sapphire laser producing a train of 170 ps pulses at a wavelength of 800 nm with an average energy of 100 mJ. The laser output was focused at the surface of the samples with a 0.5 m focal length lens to generate fluences ranging from 0 to 9 J/cm2.

At the optimum deposition conditions for highest optical quality and damage threshold, high reflector stacks of (NbTa)2O5/SiO2 were fabricated. These stacks were employed to fabricate dielectric gratings with 1740 l/mm for use with 800 nm light. At an input angle of 8 from Littrow and a wavelength from 770 to 830 nm, \>90% diffraction efficiency is achieved, with peak diffraction efficiency of \>97%. The demonstration of dielectric gratings at 800 nm is opening the pathway to significantly increase the power handling capabilities of grating compressors for picosecond and femtosecond chirped pulse amplifications systems.

Portions of this work were performed under the auspices of the United States Department of Energy by the Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48. The support of the Engineering Research Centers Program of the National Science Foundation under NSF Award Number EEC-0310717 is also acknowledged

6403-46, Poster Session

Assessing the impact of atomic oxygen in the damage threshold and stress of hafnia films grown by ion-beam assisted deposition

D. Patel, F. Brizuela, Y. Wang, M. A. Larotonda, J. J. G. Rocca, C. S. Menoni, Colorado State Univ.; F. G. Tomasel, Advanced Energy Industries, Inc.; S. Kholi, P. R. McCurdy, Colorado State Univ.

ABSTRACT TEXT:
Hafnium oxide is undoubtedly one of the high-index oxide coatings of choice for high power laser applications. One of the key goals to achieve oxide films with high laser induced damage threshold (LIDT) is to reduce the number of film imperfections, in particular stoichiometry defects. For hafnia films deposited by ion beam reactive sputtering of a hafnium metal target, stoichiometry is controlled by injection of molecular oxygen, either close to the substrate or mixed with the sputtering gas. Good stoichiometry is important to reduce the density of unoxidized particles buried into the coatings which affect the LIDT. However, good stoichiometry is usually not reached unless a significant amount of oxygen is supplied. This work evaluates the potential advantages of using pre-activation of oxygen in the ion beam deposition of HfO2, with special emphasis on its impact on LIDT and film stress. For the experiments, oxygen was activated by an independent plasma source and then introduced into a commercial ion beam deposition chamber. The optical quality of the films was characterized using spectro-photometry and ellipsometry. Their structural quality and composition was determined from x-ray diffraction and x-ray photoelectron emission spectroscopy, and the stress was obtained from interferometric measurements. For optimized conditions, a LIDT of ~ 2 J/cm2 was measured on single films at λ=800 nm, 120 ps, 25 mJ pulses from a chirped amplification Ti:Sapphire laser. The impact of the atomic oxygen incorporation on the film performance will be discussed.

Improvement in laser light resistance of fs- dielectric optics using silica mixtures

M. Jupé, L. S. Jensen, M. Lappschies, K. Starke, D. Ristau,
Laser Zentrum Hannover e.V. (Germany)

ABSTRACT TEXT:
Investigations of fs- laser damage mechanisms of the recent years indicate that damage mechanisms in the fs-range are based on electronic interaction schemes in the material. Often, a direct correlation of the power handling capability to the band gap structure of the material and the field strength distribution in the optical system is observed.

The present work is focused on the optimization of high refractive index coating materials by mixing with silica. The different compositions of mixed materials are manufactured in an IBS coating process using a zone target. This technique allows a continuous variation of the material composition.

In addition, new coating designs were developed to adapt the contents of silica within the layers to the high field strength. By combining these techniques an increase of the laser damage threshold could be achieved.

Morphology investigations of laser-induced damage

B. Wu, L. S. Jensen, M. Jupé, K. Starke, D. Ristau,
Laser Zentrum Hannover e.V. (Germany)

ABSTRACT TEXT:
During the last decades, the rapid development of laser technology opened a variety of innovative application fields. As a consequence of the ever increasing output power of the applied laser systems and the development of laser concepts with improved beam parameters, modern optical components have to meet demanding specifications in respect to their stability and optical quality. In many advanced laser based manufacturing facilities, the economy and reliability of the process is limited by the power the handling capability and stability of the employed optical components.

Therefore, the development of high power optics and a fundamental understanding of laser damage processes are of essential importance for further progresses in laser technology.

In many cases, the morphology of the damage sites has been investigated for a detailed analysis of the damage mechanisms. In the present paper extended methods (Laser Scanning Microscopy, Scanning Electron Microscopy and Nomarski Microscopy) were used to inspect the damage sites of samples for ns and fs applications. In the fs-regime, the morphology of TiO_2/SiO_2 stacks with modified field strength distribution was investigated, whereby a characteristic morphology was caused by the special designed vertical field strength profile, depending on the local power density. In the ns-regime, the morphology of the damage sites has shown significant differences between the quarter wave stacks and the systems without abrupt interfaces in the functional layer. Typically, Rugate high reflectors did not show catastrophic damage. Rather the damage becomes apparent by the creation of colour centres.

Laser resistivity of selected multilayer designs for DUV/VUV applications

S. Günster, H. Blaschke, D. Ristau, Laser Zentrum Hannover e.V. (Germany)

PRIMARY AUTHOR BIOGRAPHY:

Dr. Stefan Günster is research scientist at the Thin Film Laboratory at LZH since 1994. He received his Diploma in Physics from the RWTH in Aachen (Germany). The PHD thesis of Dr. Guenster covers the production and characterisation of thin film solar cells made from organic materials. At the Thin Film laboratory at LZH, Stefan G¸nster is responsible for the service in optical coatings.

ABSTRACT TEXT:

The optical properties of coatings in the DUV spectral range are determined by the selection of the material, the selection of the deposition process, and finally by the choice of the multilayer design. Results on the comparison of the optical parameters of high reflecting systems deposited for the central wavelength 193 nm are reported in this contribution. High reflecting mirror systems were produced with conventional (thermal evaporation) and sputtering (IBS) deposition method. Fluoride materials (MgF2, LaF3) as well as oxide materials (SiO2, Al2O3) are employed for the production of standard HR- stacks and bi-stacks altering the optical thicknesses for the high and low index material. Moreover, combined systems merging evaporated fluoride stacks with dense IBS SiO2 protection layers were manufactured and characterised. The characterisation of the different multilayer structures has been performed with respect to their spectral behaviour in the DUV range, their absorption at 193 nm, and laser resistivity.

The microstructure and LIDT of Nb2O5, ZrO2, and Ta2O5 optical coatings

R. Buzelis, G. Abromavicius, R. Drazdys, Fizikos Institutas (Lithuania); A. Melninkaitis, V. Sirutkaitis, Vilnius Univ. (Lithuania); A. Skrebutenas, Optida Co. (Lithuania); R. Juskenas, A. Selskis, Institute of Chemistry (Lithuania)

PRIMARY AUTHOR BIOGRAPHY:
Born in Lithuania.

Education: Vilnius University, Department of Physics (Lithuania) 1976 – 1981. Degrees or diplomas obtained: Ph.D. thesis theme “Effective cascade pulse compression of pulses of pulse-periodic lasers by transient stimulated scattering” at 2992.

Present position: Senior Research Fellow, Head of Optical Coatings Group of Applied Research Laboratory.

ABSTRACT TEXT:
High power laser systems are one of the most rapidly growing areas in the development of laser technology. This also leads towards higher requirements for environmental stability of optical components and their resistance to laser radiation. There are some reports showing that porous dielectric coatings are more resistant to intense laser radiation, however they have smaller environmental stability than denser coatings, which are more sensitive to laser radiation.

The influence of important technological parameters (deposition rate, substrate temperature, energy of ions) on optical and microstructural properties of high reflection dielectric coatings based on Nb2O5/SiO2, ZrO2/SiO2 and Ta2O5/SiO2 in VIS spectral region is presented.

Furthermore the LIDT measurements using repetitive nanosecond laser pulses of ZrO2/SiO2, Nb2O5/SiO2 and Ta2O5/SiO2 high reflecting optical coatings based on ISO 11254-2 standard are presented.

Optical characterization of antireflective sol-gel coatings fabricated using dip coating method

A. Melninkaitis, K. Juskevicius, M. Maciulevicius, V. Sirutkaitis,
A. Beganskiene, I. Kazadojev, A. Kareiva, Vilnius Univ. (Lithuania);
D. Perednis, Institute of Physics (Lithuania)

PRIMARY AUTHOR BIOGRAPHY:
A. Melninkaitis was born in Jurbarkas, Lithuania, in 1980. He graduated Vilnius University with a B.S. and M.S. in physics in 2002 and 2004 respectively. Now he is a PhD student. His current research interests are the mechanisms of laser induced damage and characterization of optical components.

ABSTRACT TEXT:
In recent years, there has been a growing interest in development of sol-gel method which can produce ceramics and glasses using chemical precursors at relative low-temperatures. The applications for sol-gel derived products are numerous. Department of General and Inorganic Chemistry with Laser Research Center of Vilnius University and Institute of Physics continues an ongoing research effort on the synthesis, deposition and characterization of porous sol-gel. Our target is highly optically resistant anti-reflective (AR) coatings for general optics and nonlinear crystals. The growth reaction of silica nanoparticles was initiated by mixing equal volumes of tetra-ethyl-ortho-silicate-solvent (TEOS) solution and water-ammonia-solvent solution. All reactions occurred at room temperature: TEOS concentration remained fixed, while the ammonia, water and solvent concentrations were varied to control the growth speed and size of the particles. In order to produce AR coatings a silica (SiO_2) sol-gel has been dip coated on the set of fused silica substrates. All samples were characterized performing ellipsometric, total scattering and laser-induced damage threshold measurements. Herewith we present our recent results on synthesis of sol-gel solvents, coating fabrication and characterization of their optical properties.

Tuesday Poster Session • Room 2

Mini Symposium: Optics in a Hostile Environment, and Materials & Measurements

10.30 to 11.30 and 15.20 to 16.20

Laser qualification testing of space optics, W. Riede, P. Allenspacher, German Aerospace Ctr. (Germany) . . . . [6403-53]

Damage threshold investigations of high-power laser optics under atmospheric and vacuum conditions, L. S. Jensen, M. Jupé, M. Lappschies, H. Ehlers, K. Starke, D. Ristau, Laser Zentrum Hannover e.V. (Germany); W. Riede, P. Allenspacher, H. Schröder, German Aerospace Ctr. (Germany); K. R. Mann, U. Leinhos, Laser-Lab. Göttingen e.V. (Germany) . . . [6403-54]

Characterization tools for KDP/DKDP crystals investigation: toward the identification of laser-damage precursor defects, part 2: optical characterizations, M. Pommiès, D. Damiani, B. Bertussi, X. Leborgne, H. Piombini, A. S. Surmin, J. Birolleau, F. Pilon, F. P. Guillet, S. Lambert, CEA Le Ripault (France) . . . . [6403-55]

Characterization tools for KDP/DKDP crystals investigation: toward the identification of laser-damage precursors, part 1, A. S. Surmin, F. P. Guillet, S. Lambert, F. Pilon, J. Birolleau, M. Pommiès, D. Damiani, B. Bertussi, H. Piombini, X. Leborgne, CEA Le Ripault (France) . . . . [6403-56]

Influence of the laser beam size on laser-induced damage threshold measurement in KDP components, J. Capoulade, J. Natoli, Institut Fresnel (France); B. Bertussi, M. Pommiès, A. Dyan, D. Damiani, H. Piombini, CEA Le Ripault (France) . . . . [6403-57]

A new expedited approach to evaluate the importance of different crystal growth parameters on the laser damage performance in KDP and DKDP, R. A. Negres, N. P. Zaitseva, P. P. DeMange, S. G. Demos, Lawrence Livermore National Lab. . . . . [6403-58]

Understanding the basic properties of damage precursors for optimizing conditioning in KDP and DKDP, P. P. DeMange, R. A. Negres, H. B. Radousky, S. G. Demos, Lawrence Livermore National Lab. . . . . [6403-59]

The effect of pulse duration on laser-induced bulk damage by 1053-nm light in potassium di-hydrogen phosphate crystals, C. W. Carr, Lawrence Livermore National Lab. . . . . [6403-60]

Characterization of KDP crystals used in large aperture doublers and triplers, M. Barkauskas, A. Melninkaitis, D. Miksys, L. Meslinaite, R. Grigonis, V. Sirutkaitis, Vilnius Univ. (Lithuania); H. Bercegol, L. Lamaignère, CEA Cesta (France) . . . . [6403-61]

Laser qualification testing of space optics

W. Riede, P. Allenspacher, German Aerospace Ctr. (Germany)

PRIMARY AUTHOR BIOGRAPHY:
Wolfgang Riede studied Physics and Quantum Optics at the University of Stuttgart, Germany and at the Swiss Federal Institute, Zurich, Switzerland.

He joined German Aerospace Center (DLR) in the early nineties, working as a scientist. Currently, he is head of a group involved with laser damage at the Institute of Technical Physics in Stuttgart. His main interests and working areas are short and ultrashort pulse laser damage, imaging and tracking systems, and adaptive optics.

ABSTRACT TEXT:
Laser optics being used in space laser systems are usually exposed to high vacuum conditions under the absence of air or oxygen. In the past, several space-based laser missions have suffered from anomalous performance loss or even failure after short operation times. To mitigate the risks involved in these long-term operational conditions, a laser damage test bench has been developed and is operated at the German Aerospace Establishment to test laser optics in the IR, VIS, and in the UV spectral range.

The testing is performed under application oriented conditions, i.e. under high-vacuum using dry pump systems. The main goal of the test campaign is to identify the critical components in terms of their laser damage threshold for very high pulse numbers applied per site. Characteristic damage curves according to ISO 11 254 are evaluated for each component under investigation for up to 10 000 shots per site. The characteristic damage curves are used for the estimation of the performance at very high pulse numbers. The typical behavior found was a sharp drop in LIDT for small pulse numbers followed by a smooth decrease for larger pulse numbers (laser fatigue effect).

The work is supported by the European Space Agency (ESA/ESTEC) and ASTRIUM-F.

Damage threshold investigations of high-power laser optics under atmospheric and vacuum conditions

L. S. Jensen, M. Jupé, M. Lappschies, H. Ehlers, K. Starke, D. Ristau, Laser Zentrum Hannover e.V. (Germany); W. Riede, P. Allenspacher, H. Schröder, German Aerospace Ctr. (Germany); K. R. Mann, U. Leinhos, Laser-Lab. Göttingen e.V. (Germany)

ABSTRACT TEXT:
In many cases, optical coatings are the limiting factor for the operational reliability of measurement systems and other technical devices based on laser irradiation. Especially in space applications, the reliability of an optical system is of essential importance. In this context, the behavior of the laser induced damage threshold (LIDT) both, in vacuum and under atmospheric pressure is of major interest. On one hand the LIDT at the fundamental wavelength of the well established Nd:YAG (1.064 μm) pulse laser was determined, and on the other hand damage threshold investigations at the third harmonic of 355nm were performed on equivalent coatings. Initial experiments have shown a loss of performance of coatings that were exposed to vacuum conditions. In addition, S-on-1 LIDT measurements were conducted at the wavelength of 351nm (XeF excimer laser), indicating slightly lower damage resistance under vacuum conditions. The results are compared to calorimetric absorptance data obtained at the same wavelength.

Compared to normal atmospheric conditions, significantly different spectral characteristics were observed for dielectric coatings, which were produced by various coating processes (electron beam evaporation, ion assisted deposition (IAD) and ion beam sputtering (IBS)), under vacuum. In the present paper the damage mechanisms in the ns range are investigated against the background of the experimental results attained for the different environments.

Characterization tools for KDP/DKDP crystals investigation: toward the identification of laser-damage precursor defects, part 2: optical characterizations

M. Pommiès, D. Damiani, B. Bertussi, X. Leborgne, H. Piombini, A. S. Surmin, J. Birolleau, F. Pilon, F. P. Guillet, S. Lambert, CEA Le Ripault (France)

PRIMARY AUTHOR BIOGRAPHY:
The main author made its PhD at Alcatel Optronics, Marcoussis, France in the field of reliability and degradation mechanisms of semiconductor components from 1999 till 2002. In 2003-2004 he joined the University of Valladolid, Spain to characterize semiconductor lasers by optical spectroscopy. He is currently working at CEA-Le Ripault in France where he is in charge of optical materials characterization and laser conditioning of KDP materials.

ABSTRACT TEXT:
In large aperture lasers for fusion research (LMJ or NIF) a critical issue remains the relatively low Laser-Induced Damage (LID) resistance of silica and KDP/DKDP materials. The maximal fluence of the LMJ laser lines is mainly limited by KDP-based optical components used to convert the 1.06 μm high-power pulses to pulses at 351 nm. Moreover the exceptional size (40*40 cm2) of these components required the development of rapid growth methods. In spite of recent progress, the robustness of such materials is not sufficient and consequently, investigations are still necessary to improve the rapid growth processes and to define more efficient conditioning procedures.

Within this framework, we focus among others on the localization and characterization of low/high LIDT regions in KDP/DKDP samples which is a key point for an easier identification of the most critical defects involved in laser-induced damage [Pommiès et al, Boulder 2005]. Different techniques have been implemented to characterize the KDP-based samples among which light scattering, photothermal deflexion, Raman spectroscopy, luminescence and strain-induced birefringence. In this work KDP and DKDP crystals are characterized by these techniques and the relevance of new diagnostics (i.e. the detection of luminescent centers by laser pumping and residual strain by polariscopy) is estimated. These whole results are discussed taking into account the structural characteristics [Surmin et al., this conference].

6403-56, Poster Session

Characterization tools for KDP/DKDP crystals investigation: toward the identification of laser-damage precursors, part 1

A. S. Surmin, F. P. Guillet, S. Lambert, F. Pilon, J. Birolleau, M. Pommiès,
D. Damiani, B. Bertussi, H. Piombini, X. Leborgne, CEA Le Ripault (France)

PRIMARY AUTHOR BIOGRAPHY:
Principal author started PhD work in november 2004, he subject of which is "determination of structural and micro-structural elements responsible for laser damage in KDP crystals". This work is supervised by F. Guillet, second author, who is in charge of X-ray caracterisation of compounds and materials at CEA/Le Ripault since 1997.

ABSTRACT TEXT:
LMJ and NIF high power lasers use KDP or DKDP single crystals for frequency conversion purposes. The ability of these crystals to sustain high laser power is an important subject as laser damage impacts not only the performance of these devices but also the maintenance cost. Laser conditioning has been known since decades to enhance the resistance of KDP/DKDP frequency converters. However, a few is known about the defects that lead to laser damage. Whereas several studies pointed out that crystalline defects can be a cause for laser damage (see for example [1]), the role of each defect one can expect in such crystals is still unknown. This may be partly due to the fact that this topic is a broad field of research only loosely connected to laser designers direct concerns. However, a detailed analysis of past and present results on laser damage properties of different crystals give insights that allow to identify the pertinent structural investigations to carry out. Firstly, recent studies [2] have shown that these defects have a density that can be estimated of about several defects per mm3. Secondly, the laser damage mechanism recently proposed by Feit [3] (see also [4]) suggests the existence of absorbing initiators which can exist in the crystal prior to laser irradiation or be a result from the first steps of the laser damage mechanism. It can be supposed that these absorbers are particles or 3D crystalline defects that exist in the KDP/DKDP crystal prior to irradiation. The typical size for such initiators have been estimated to 100nm, leading to an estimated concentration of 10-3ppb. Such a low concentration requires appropriate tools in order to be able to evidence and characterize such defects. On a bigger scale, concentration of punctual defects caused by ionic impurities can be considered equal to impurities concentration in the crystal, which corresponds to several ppm. This consideration shows that the link between ionic impurities and laser damage threshold is not trivial.

A previous study reported the interested of high energy X-Ray topography applied to characterization of KDP single crystals [5]. Recent development of this method and results are reported. Moreover, the need for stating on the existence nanometric centers with a very low concentration calls for use of synchrotron radiation which gives access to high resolution as well as a 3D localization of diffracting volume. Measurements near the ferroelectric transition temperature are expected to highlight defects existing in the studied samples. First results using this technique at the ESRF will be presented. Concerning the chemistry of KDP/DKDP crystals, correlation between growth defects characterized in previous studies [2, 5] and ionic impurities have been carried out using several chemical analysis methods. The obtained results give access to the physical and chemical nature of crystals grown using the LMJ growth process. The implications of these results on pertinent optical characterization are discussed in another communication [6].

[1] C.W. Carr, H.B. Radousky and S.G. Demos, « Wavelength Dependance of Laser Induced Damage: Determining the Damage Initiation Mechanism », Phys. Rev. Letter, 91, 127402-1 (2003).
[2] M. Pommies, D. Damiani, H. Piombini, B. Bertussi, J. Capoulade, J.-Y. Natoli and H. Mathis, « Detection of Lower LIDT Regions in KDP Material », proc. SPIE, 5991 59911T (2006)
[3] M.D. Feit and M. Rubenchik, « Implicaitons of Nanoabsorber Initiators for Damage Probability Curves, Pulselength Scaling and Laser Conditioning », Proc. SPIE 5273, 74 (2004)
[4] A. Dian, this conference
[5] A. Surmin, F. Guillet, S. Lambert, D. Damiani and M. Pommiès, « Structural Study of Large Scale KDP Crystals using High Energy X-Ray Diffraction », Proc. SPIE 5991 5991W (2006)
[6] M. Pommies et al, this conference.

Influence of the laser beam size on laser-induced damage threshold measurement in KDP components

J. Capoulade, J. Natoli, Institut Fresnel (France); B. Bertussi, M. Pommiès, A. Dyan, D. Damiani, H. Piombini, CEA Le Ripault (France)

ABSTRACT TEXT:
For large aperture solid state lasers (like the LMJ project), the breakdown of the optical components remain an important limitation for the performances and the maintenance costs. Since decades, laser induced damage has been intensively studied in order to understand and control the origin of the phenomenon. LIDT measurements are usually performed with table top lasers whose characteristics change from one to another. The use of an adapted metrology permits to compare the majority of data but in some cases, simple scaling laws are not sufficient to explain the differences.

In this context, a previous study (Pommies et al. Boulder 2005) has shown that in KDP crystals, the size of the irradiated volume can influence strongly the determination of the damage probability. This disparity of values was imputed to the existence of two kinds of defects with different LIDT and density. According to this result, we present in this paper a systematic study realized on z-cut KDP crystal to quantify the influence of the beam size on the LIDT measurement at 355 nm. Experimentally, the use of a unique Gaussian beam ranges from micronic to sub-millimetric size permits to study these different precursor centers involved in the damage initiation.

A new expedited approach to evaluate the importance of different crystal growth parameters on the laser damage performance in KDP and DKDP

R. A. Negres, N. P. Zaitseva, P. P. DeMange, S. G. Demos,
Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:

Raluca A. Negres graduated from University of Bucharest in 1993 and received her Ph.D. degree in Optical Physics from School of Optics/CREOL, University of Central Florida, Orlando, in 2001. She is currently a Postdoctoral Researcher with Lawrence Livermore National Laboratory, studying laser-induced damage in wide bandgap materials.

ABSTRACT TEXT:

Our knowledge on how to improve damage resistance in KDP and DKDP crystals still remains very limited. Extensive past work has focused on measuring the damage threshold (DT) in crystals that were grown under different conditions including impurity content, speed of growth, growth temperature, etc. However, the variation in DTs observed even from crystals grown under presumed “identical” conditions along with the probabilistic nature of the DT measurement resulted in a difficulty to obtain reproducible experimental results which in turn led to extensive and labor intensive efforts. Arguably, a fundamental improvement in the damage characteristics of these materials may require the development of techniques that can offer reliable and expedited information regarding the role of the different growth conditions on the ultimate damage performance of the material.

In this work, we investigate the laser-induced damage resistance at 355 nm in DKDP crystals grown with varying growth parameters, including temperature, speed of growth and impurity concentration. In order to perform this work, a DKDP crystal was grown over 34 days by the rapid-growth technique with varied growth conditions. By using the same crystal, we are able to isolate growth related parameters affecting the laser-induced damage from raw material or other variations that are encountered when testing in different crystals. The objective is to find correlations of damage performance to growth conditions and reveal the key parameters for achieving DKDP material in which the number of damage initiating defects is reduced. This approach can lead to reliable and expedite information regarding the importance of different crystal growth parameters on the laser damage characteristics of these crystals.

Two of the DKDP samples used in this investigation were cut as 1-cm cross-sectional plates containing both prismatic and pyramidal sectors grown at various speeds, including a “dead zone” dividing the early and late growth material. The damage characteristics of various growth regions were assessed by measuring the density of pinpoint damage sites as a function of laser fluence and evaluated against the corresponding growth parameters and measured absorption spectra.

The results obtained in this proof-of-principle experimental work provide strong evidence that this approach is valid. Specifically, within this single experiment, we were able to reproduce and confirm earlier conclusions as well as reveal new relationships previously not addressed.

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under contract W7405-Eng.48.

Understanding the basic properties of damage precursors for optimizing conditioning in KDP and DKDP

P. P. DeMange, R. A. Negres, H. B. Radousky, S. G. Demos,
Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:
Paul DeMange is a graduate student in the physics department at the University of California at Davis. He is working on his PhD research at Lawrence Livermore National Laboratory studying the fundamental mechanisms of laser-induced damage.

ABSTRACT TEXT:
KDP and DKDP are optical crystals used for frequency conversion and Pockels cells in large-aperture laser systems. As such, these crystals are expected to perform for varying exposure parameters. These parameters include a) multiple pulses over time, b) wide ranges of fluences, and c) different frequencies. However, the formation of laser-induced damage sites sets constraints on the acceptable range of exposure parameters. One important property of KDP and DKDP is that sub-damage pre-exposure results in an increase to the damage resistance, referred to as laser conditioning. Laser conditioning is currently being explored as a method to improve the damage performance of large-aperture laser systems such as the National Ignition Facility and the Laser Megajoule.

In order to understand the origin and characteristic behaviors of conditioning, we have performed experiments to investigate the conditioning effectiveness in KDP and DKDP from exposure to variable number of laser pulses, fluences, and frequencies from a nanosecond-pulsed Nd:YAG laser (fundamental at 1064 nm). The results showed that there are two precursor populations: a first giving rise to damage at 532-nm and 355-nm and a second giving rise to damage at 1064-nm. For the 532-nm and 355-nm precursors, there are two conditioning pathways, one providing conditioning for 532-nm only and one providing conditioning for both 532-nm and 355-nm . For the pathway providing conditioning for 532-nm only, exposure to higher number of pulses demonstrates a continuous increase to the damage performance. Moreover, there is a very low threshold fluence for this conditioning pathway. For the pathway providing conditioning for both 532-nm and 355-nm , exposure to a few pulses provides nearly optimal conditioning. The threshold fluence required for this conditioning pathway is much higher by comparison, close to the damage threshold fluence of the material. These experiments also demonstrate that conditioning does not result in an annihilation of the damage precursors but rather a shift of their damage performance toward higher fluence.

This work reveals the underlying processes involved in laser conditioning for operation at different frequencies. With this basic knowledge, we can better understand the observed conditioning behaviors and help design conditioning protocols that offer optimized performance at the desired operational conditions (laser fluences and wavelengths) while minimizing the damage risk and pre-processing time from conditioning. For example, optimizing conditioning for operation at 532-nm and 355-nm may involve two distinctly different approaches, taking advantage of the different conditioning pathways of the damage precursors. The first approach suggests that optimal improvement to the damage resistance at 355-nm can be achieved with exposure to few pulses just below the damage threshold. The other approach shows that a continuous increase to the damage performance at 532-nm may be achieved with exposure to increasing number of pulses at fluences posing no risk of damage.

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under contract W7405-Eng.48.

The effect of pulse duration on laser-induced bulk damage by 1053-nm light in potassium di-hydrogen phosphate crystals

C. W. Carr, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:

Dr. C.W. Carr's recent research has included measurements of laser-induced breakdown initiation mechanisms and the dynamics of energy absorption and dissipation during such events. Currently he is the principle investigator at the Optical Science Laser facility at Lawrence Livermore National Laboratory. His most recent experiments have focused on the effect of pulse duration and shape on laser-induced damage growth and initiation.

ABSTRACT TEXT:

Laser induced damage in potassium di-hydogen phosphate (KDP) has previously been shown to depend significantly on pulse duration for 351-nm Gaussian pulses. In this work we studied the properties of damage initiated by 1053-nm temporally Gaussian pulses with 10ns and 3.5ns FWHM durations. Our results indicate that the number of damage sites induced by 1053-nm light scales with pulse duration (τ) as (τ1/τ2) 0.16 in contrast to the previously reported results for 351-nm light, (τ1/τ2) 0.35. It was also determined that the size of damage sites produced by 1053-nm light scales linearly with fluence, similar to damage sites induced by 351-nm light. Because scattered light can limit laser performance, these size and density measurements can be used to estimate the amount of light scattered from damage.

Characterization of KDP crystals used in large aperture doublers and triplers

M. Barkauskas, A. Melninkaitis, D. Miksys, L. Meslinaite, R. Grigonis, V. Sirutkaitis, Vilnius Univ. (Lithuania); H. Bercegol, L. Lamaignère, CEA Cesta (France)

ABSTRACT TEXT:
We report on laser-induced damage threshold (LIDT) and UV-laser excited defect formation measurements in large aperture KDP crystals developed as doublers and triplers for mega-Joule laser at CEA/Cesta. Measurements of LIDT were performed according to the ISO 11254-2 standard for repetitive pulses with duration ~ 4 ns and repetition rate of 10 Hz. The results for different laser wavelengths (1064, 532 and 355 nm) and polarizations are presented. The largest LIDT was observed for 532 nm pulses and the 1064 nm wavelength had a strong dependence on laser polarization. The LIDT values at 532 nm and 355 nm also depended on the crystal cutting angle, which is different for doublers and triplers. A comparison of LIDT with crystal absorptance at different wavelengths for investigated crystals is also performed.

The UV-laser induced defect formation was investigated by the means of pump-probe technique. The excitation was performed with a single pulse of ns Nd:YAG laser (355 or 266 nm wavelength) and probing with another Nd:YVO4 laser system (532 nm) operating at 1KHz. This gave us a temporal resolution of 1ms. The transient absorption of defect states relaxed non-exponentially and fully disappeared in ~10 s. A comparison is made between crystal grown by distinct growth methods and between different laser polarizations. An influence of laser conditioning on UV induced defect state formation is also revealed.

Wednesday AM • 27 September

07.30 to 08.30 **Poster Placement at NIST**
Poater authors for the Wednesday poster session are to set-up their posters at this time.

08.20 to 10.00 • SESSION 7

Materials and Measurements I

Chairs: **Christopher J. Stolz**, Lawrence Livermore National Lab.;
Masataka Murahara, Tokai Univ. (Japan)

08.20: **Optical characterization in laser damage studies (***Invited Paper)***,** M. Commandré, J. Natoli, L. Gallais, F. R. Wagner, C. Amra, Institut Fresnel (France) . . . . [6403-62]

09.00: **IR thermoluminescence: the missing link to laser-induced damage in fused silica,** P. R. Bouchut, F. Milési, C. Da Maren, J. Coutard, CEA Grenoble (France) . . . . [6403-63]

09.20: **In-situ observation of UV laser-induced deposit formation by fluorescence measurement,** H. B. Schroeder, German Aerospace Ctr. (Germany) and ESA/ESTEC (Netherlands) and CSMA Ltd. (United Kingdom); W. Riede, German Aerospace Ctr. (Germany); E. M. Reinhold, D. Wernham, Y. Lien, ESA/ESTEC (Netherlands); H. Kheyrandish, CSMA Ltd. (United Kingdom) . . . . [6403-64]

09.40: **Measuring part per million thin film absorption during deposition,** G. Dubé, MetaStable Instruments, Inc.; A. J. Braundmeier, Jr., Southern Illinois Univ.; S. Chelli, Deposition Research Lab., Inc.; R. E. Juhala, A. N. Webb, MetaStable Instruments, Inc. . . . . [6403-65]

10.00 to 10.30 • Wednesday Poster Overview

All Materials and Measurements poster authors are asked to give 2-minute/2-viewgraph overviews of their posters in the order they appear in the program.

10.30 to 11.30 • Poster Session and Refreshment Break

11.30 to 12.30 • SESSION 7 continued

11.30: **Results of sub-nanosecond laser-conditioning of DKDP crystals,** J. J. Adams, Lawrence Livermore National Lab. . . . . [6403-66]

11.50: **Laser conditioning of KDP crystals using excimer and Nd:YAG lasers,** B. Bertussi, D. Damiani, M. Pommiès, A. Dyan, H. Piombini, X. Leborgne, CEA Le Ripault (France); A. During, L. Lamaignère, G. Gaborit, M. Loiseau, S. Mardelle, T. Donval, CEA Cesta (France) . . . . [6403-67]

12.10: **Dynamics of bulk damage formation in KDP,** C. W. Carr, Lawrence Livermore National Lab. . . . . [6403-68]

12.30 to 14.00 • Lunch Break

6403-62, Session 7

Optical characterization in laser damage studies

M. Commandré, J. Natoli, L. Gallais, F. R. Wagner, C. Amra, Institut Fresnel (France)

PRIMARY AUTHOR BIOGRAPHY:

Mireille Commandré graduated from ENSIEG (Grenoble) in 1979 and received a PhD in materials for microelectronics in 1981. She is currently a professor at the Ecole Généraliste d'Ingénieurs de Marseille. At Fresnel Institute she is head of research team “High power photonics and random media”. Her research interests include laser damage, optical thin films, photothermal microscopy, optical absorption, thermal properties.

ABSTRACT TEXT:

The development of high power lasers and optical micro-components requires optical characterization techniques for studying behavior of optical materials under illumination, laser damage phenomena and ageing. More usual optical characterization tools are based on measurements of absorption, scattering and luminescence; they are non destructive evaluation techniques. It is important to combine several tools which allow getting different information. Optical tools can be used in damage initiation studies or to characterize properties of damaged areas. Because defects involved in laser damage initiation are sub-micrometer sized, both high spatial resolution and high sensitivity are required to detect defects as small as possible. Furthermore optical tools have to be implemented in damage set-up for a detailed analysis of damage mechanisms. We present an overview of recent developments in the field of optical characterization in connection with laser damage. Especially, photothermal deflection has been widely employed to characterize optical absorption, thermal properties of optical materials and for mapping defects with high resolution.

6403-63, Session 7

IR thermoluminescence: the missing link to laser-induced damage in fused silica

P. R. Bouchut, F. Milési, C. Da Maren, J. Coutard, CEA Grenoble (France)

ABSTRACT TEXT:
We have developed a non destructive, high spatial resolution, mapping characterization technique of fused silica surface. CO2 laser induced IR thermoluminescence, which was previously unknown, enables us to reveal surface and sub surfaces defects, made by polishing techniques. We show that there is a strong correlation between a low laser induced damage threshold at 3ω and a high IR thermoluminescence signal. We also show that laser conditioning is a thermal effect. We discuss how the silica matrix contributes to laser damage.

6403-64, Session 7

In-situ observation of UV laser-induced deposit formation by fluorescence measurement

H. B. Schröder, German Aerospace Ctr. (Germany) and ESA/ESTEC (Netherlands) and CSMA Ltd. (United Kingdom); W. Riede, German Aerospace Ctr. (Germany); E. M. Reinhold, D. Wernham, Y. Lien, ESA/ESTEC (Netherlands); H. Kheyrandish, CSMA Ltd. (United Kingdom)

PRIMARY AUTHOR BIOGRAPHY:

Helmut Schröder was born in Bremen, Germany. He studied physics in Gˆttingen, graduated in 1981 and obtained his PhD degree in 1985. In 1986 he joined the German Aerospace center (DLR) in Stuttgart. He worked first in the field of space and aircraft tribology and later in epitaxy of group IV nitrides by Pulsed Laser Deposition. Since 2005 he is engaged in laser induced damage and contamination investigations of optics.

ABSTRACT TEXT:

As part of the ongoing effort to mitigate against laser-induced deposition on the optics for the European Space Agency_ ADM-Aeolus satellite, a new measurement method has been introduced to observe the formation of deposits on optics under simulated space conditions. The presence of outgassing materials in satellite borne laser systems involves significant risks, especially in case of high laser fluences and short wavelengths. In vacuum, the outgassing of non-metallic, particularly organic materials is unavoidable. By the interaction with laser radiation these contaminants can lead to formation of deposits on the optics. In this paper, we report on systematic investigations of UV laser-induced deposit formation, conducted in the frame of the ADM-Aeolus mission. The laser source was a frequency tripled Nd:-YAG with 355 nm wavelength, 3 ns pulse duration, and 100 Hz repetition rate. Uncoated fused silica optics were exposed to fluence values between 0.01 and 1 J/cm2. Space conditions were simulated in a vacuum chamber with a base pressure better than 10-6 mbar. As contamination samples, epoxy, silicone, and polyurethane based materials, typically utilized in space components and structures, were tested at T = 30° C and T =100° C. The deposit formation was monitored online and in-situ by measuring the fluorescence distribution and intensity with a CCD camera, where the UV laser beam itself served as the excitation source. The fluorescence of layers of nanometer scale is bright enough to allow observation of the onset and the temporal evolution of deposit formation. It is shown that the deposits build up already within several minutes after starting the laser irradiation. 3D-surface structure profilometry of the deposits was investigated by white light interferometry. Analysis of the chemical composition of the deposits was conducted using time of flight secondary ion mass spectroscopy. Initial trials investigating the potential inhibition of the laser-induced deposition using partial pressures of air and water are also reported.

Measuring part per million thin film absorption during deposition

G. Dubé, MetaStable Instruments, Inc.; A. J. Braundmeier, Jr., Southern Illinois Univ.;
S. Chelli, Deposition Research Lab., Inc.; R. E. Juhala,
A. N. Webb, MetaStable Instruments, Inc.

PRIMARY AUTHOR BIOGRAPHY:

Dr. Dubé received BS, MS and PhD degrees from the Institute of Optics at the University of Rochester. He has eight laser related patents and more than twenty publications. Since 1994 he has been a cofounder and President of MetaStable Instruments, Inc.

ABSTRACT TEXT:

Achieving high laser damage thresholds in thin film coatings requires minimizing their absorption of laser light. Expediting the development of minimally absorbing films requires minimizing the turn around time between deposition of the film and measurement of its absorption. Two attenuated total internal reflection ellipsometers were developed for measuring the very low absorption in certain high quality thin films. A fixed angle version was used inside a vacuum chamber to give a real time absorption/loss measurement as the film was being deposited. A variable angle version was developed for laboratory use. The instruments use an evanescently coupled waveguide mode to reduce the total internal reflection from the thin film. The absorption for one linear polarization can be enhanced up to several thousand times compared to single pass absorption at normal incidence, making sensitivity of better than one part per million feasible. These instruments will be described and experimental results will be compared with calculations and measurements using other techniques.

Results of sub-nanosecond laser-conditioning of DKDP crystals

J. J. Adams, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:
John Adams is a physicist at the Lawrence Livermore National Laboratory working in NIF Systems Engineering. He earned his Ph.D. in Engineering-Applied Science from the University of California, Davis. John's research interests include laser damage, laser materials, and nonlinear optical materials.

ABSTRACT TEXT:
We have shown previously that the optimal pulse length for 3 laser conditioning of DKDP crystals lies between 200 ps and 900 ps. A 3, ~500 ps table-top laser system has been built at the Lawrence Livermore National Laboratory for use as a conditioning tool for DKDP crystals. The conditioning effectiveness of this laser in a raster-scan mode is demonstrated by conditioning tripler-cut DKDP crystals to a peak intensity of approximately 10 GW/cm2. Optimization of the conditioning protocols is explored in terms of number of conditioning fluence steps and fluence step-size. We report on the results of 3, 3ns damage testing of the various conditioning protocols.

6403-67, Session 7

Laser conditioning of KDP crystals using excimer and Nd:YAG lasers

B. Bertussi, D. Damiani, M. Pommiès, A. Dyan, H. Piombini, X. Leborgne, CEA Le Ripault (France); A. During, L. Lamaignère, G. Gaborit, M. Loiseau, S. Mardelle, T. Donval, CEA Cesta (France)

PRIMARY AUTHOR BIOGRAPHY:
The main author made its PhD at Institut Fresnel, Marseille, France in the field of laser-induced damage in optical components. He is currently working at CEA-Le Ripault in France where he is in charge of the laser induced damage tests.

ABSTRACT TEXT:
In large aperture solid state lasers for fusion research as the Laser MegaJoule (LMJ) the maximal fluence remains limited by KDP and DKDP components used for harmonic generation. Indeed at very high fluence fluences, scattering centers may be induced in these components located at the end of each laser line at 351 nm. For the LMJ facility, the unusual size of these crystals (40*40*1 cm3) required the development of rapid growth processes enabling to obtain such a crystal in only 2 or 3 months. The maintenance costs can be reduced by implementing post-growth treatments such as laser conditioning that increase components robustness.

In this paper, we present different procedures of laser conditioning realized on KDP doubler crystals. First, components are treated either with an excimer laser (SOCRATE facility, 351 nm, 12 ns) or with a Nd:YAG laser (MISTRAL facility, 355 nm, 6ns). Then damage tests are performed at 532 nm (5ns) and 355 nm (3ns) in order to estimate the conditioning gain.

For the best procedures, results show that it is possible to attain increases in 532 nm damage probability fluences in agreement with the nominal specifications of the LMJ. Moreover, tests realized at 355 nm highlight also improvement encouraging for the laser conditioning of tripler crystals.

Dynamics of bulk damage formation in KDP

C. W. Carr, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:

Dr. C.W. Carr's recent research has included measurements of laser-induced breakdown initiation mechanisms and the dynamics of energy absorption and dissipation during such events. Currently he is the principle investigator at the Optical Science Laser facility at Lawrence Livermore National Laboratory. His most recent experiments have focused on the effect of pulse duration and shape on laser-induced damage growth and initiation.

ABSTRACT TEXT:

It has long been known that damage in potassium di-hydrogen phosphate crystals is manifested as discrete localized sites, often referred to as pinpoints. In recent years the pressures and temperatures associated with pinpoint formation have been measured. Initial energy deposition mechanisms have been shown to be 'not quite linear' with wavelength. We present here a variety of data, including plasma transmission measurements, pump probe, and forensics data which suggest that pinpoints are formed by a variety of energy absorption mechanisms. The transmission measurements suggest a finite growth rate of the pinpoints during the pulse. Pump-probe measurements show that a second pulse following a few ns behind an initial pulse can cause the pinpoints to become several times larger, but only if the second pulse occurs within a few ns. We argue that this evidence points to energy being absorbed on an expanding shock front propagating outward from the site of the initial energy deposition.

Wednesday PM • 27 September

14.00 to 17.20 • SESSION 8

Materials and Measurements II

Chairs: **Detlev Ristau**, Laser Zentrum Hannover e.V. (Germany);
James E. Andrew, AWE plc (United Kingdom)

14.00: **Temporal characterization of high-power ultrashort laser pulses based on the third-order cross-correlation function,** S. E. Egorov, C. C. Barnes, A. J. Carson, N. V. Didenko, A. V. Konyashchenko, Del Mar Photonics, Inc. . . . . [6403-69]

14.20: **The mechanism of ionization radiation-induced compaction in fused silica,** F. Piao, KLA-Tencor Corp. . . . . [6403-70]

14.40: **Nanosecond laser-induced breakdown in pure and Ytterbium-doped fused silica,** A. V. Smith, B. T. Do, Sandia National Labs.; M. J. Söderlund, Liekki Oy (Finland) . . . . [6403-71]

15.00: **Photochemical adhesion of fused silica optical elements with no adhesive strain,** M. Murahara, Tokyo Institute of Technology (Japan) and Tokai Univ. (Japan); T. Funatsu, Tokyo Institute of Technology (Japan); Y. Okamoto, Okamoto Optics Works, Inc. (Japan) . . . . [6403-72]

15.20 to 16.20 • Poster Session and Refreshment Break

16.20 to 17.20 • SESSION 8 continued

16.20: **Characterization of thin films and bulk materials for DUV optical components,** S. Schröder, M. Kamprath, A. Duparré, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany) . . . . [6403-73]

16.40: **Damage of thermal detector platforms based on metal-carbon nanotube composites,** L. A. Lewis, C. L. Cromer, National Institute of Standards and Technology; R. L. Mahajan, Virginia Polytechnic Institute and State Univ.; K. Ramadurai, Univ. of Colorado/Boulder; J. H. Lehman, National Institute of Standards and Technology . . . . [6403-74]

17.00: **Refractive microlens structures with high-damage thresholds enable flexible beam shaping of high-power lasers,** O. Homburg, L. Aschke, V. Lissotschenko, LIMO-Lissotschenko Mikrooptik GmbH (Germany) . . . . [6403-75]

Closing Remarks

Chair: **Arthur H. Guenther**, The Univ. of New Mexico

6403-69, Session 8

Temporal characterization of high-power ultrashort laser pulses based on the third-order cross-correlation function

S. E. Egorov, C. C. Barnes, A. J. Carson, N. V. Didenko, A. V. Konyashchenko,
Del Mar Photonics, Inc.

ABSTRACT TEXT:
High contrast temporal characterization of the output pulse profile of high-power ultrafast laser amplifiers is important in a variety of applications. For example, in high intensity laser-target interactions high contrast in excess of 1010 is often required. Temporal pulse characterization is also important in research on optical materials for high-power lasers A new design of pulse contrast measuring correlator based on the third order cross-correlation function presented. We discuss optical layout that uses two nonlinear crystals to generate second harmonic (SH) and third harmonic (TH) light. The third order cross-correlation function obtained by measuring the TH signal as a function of the optical delay between the fundamental and SH pulses. The device demonstrates the ability to measure a wide array of output parameters including contrast ratio, pulse pedestal, pre- and post-pulses, and amplified spontaneous emission. It also provides information about the third-order cross-correlation function of pulse intensity on a femtosecond temporal scale and can be used for alignment of high power femtosecond lasers. We discuss the results of using third-order cross-correlation technique to characterize the temporal pulse shape of ultrashort laser pulses from Ti:Sapphire regenerative and multipass amplifiers as well as for Cr:Forsterite regenerative amplifier.

The mechanism of ionization radiation-induced compaction in fused silica

F. Piao, KLA-Tencor Corp.

PRIMARY AUTHOR BIOGRAPHY:

Dr. Fan Piao is currently a Senior Staff System Engineer at KLA-Tencor. He has many year experience in MEMS and IC processing. He got his Ph.D. in materials science from UC-berkeley.

ABSTRACT TEXT:

A number of fused silica samples were evaluated for their resistance to densification by deep UV radiation at 193 nm wavelength. Density changes for all the samples equal the product of a material dependent constant and the absorbed two-photon dose to a sublinear power of about 2/3. This dose dependence is consistent with earlier compaction studies using UV, electron, and gamma radiation.

In this talk, we propose a “fictive temperature” model to describe fused silica structure; and the observed stretched power dependence of compaction on deposited energy for ionization damage can be explained by a simple network relaxation process.

Experimental observations of isothermal-annealing behavior of UV-induced compaction in fused silica agree very well with our theoretical predictions (e.g. a strong correlation between thermal recovery of compaction and the compaction rates for different fused silica samples; preheat-treatment can manipulate the compaction damage rates etc.)

Reference:

(1) Ultraviolet-induced densification of fused silica Fan Piao, William G. Oldham, and Eugene E. Haller J. Appl. Phys. 87, 3287 (2000)

(2) The mechanism of radiation-induced compaction in vitreous silica Journal of Non-Crystalline Solids, Volume 276, Issues 1-3, October 2000, Pages 61-71 Fan Piao, William G. Oldham and Eugene E. Haller

Nanosecond laser-induced breakdown in pure and Ytterbium-doped fused silica

A. V. Smith, B. T. Do, Sandia National Labs.; M. J. Söderlund, Liekki Oy (Finland)

PRIMARY AUTHOR BIOGRAPHY:

Arlee V. Smith is a principal member of the technical staff of of the Laser, Optics and Remote Sensing of Sandia National Laboratories.

ABSTRACT TEXT:

The objective of this work is to understand catastrophic optical damage in nanosecond pulsed fiber amplifiers. We used a pulsed, single longitudinal mode, TEM00 laser at 1.064 μm, with 8-nsec pulse duration, and focused it to an 8-μm-radius spot in bulk fused silica.We measured single shot optical breakdown threshold irradiances of 4.9×10^{11} and 6.4×10^{11} Watts/cm^2 for pure fused silica and 1% Ytterbium doped fused silica preform of Liekki

Yb1200 fibers, respectively. These irradiances were corrected for self focusing which reduced the area of the focal spot by 13% relative to its low field value. The pulse to pulse variation in the damage irradiance in pure silica was less than 1%. The damage was nearly instantaneous with an induction time much less than 1 nsec.

We found the damage morphology to be reproducible from pulse to pulse. To facilitate our study of morphology we developed a technique for locating the laser focus based on the third harmonic signal generated at the air-fused silica interface. This gives a very small uncertainty in focal position (~ 10 μm) which is important in interpreting the damage structure. The surface third harmonic method was also used to determine the laser focus spot size.

We also measured surface damage threshold irradiances to be in the range of 1.2×10^{11} to 1.9×10^{11} Watts/cm^2 for the front surface, and 0.63×10^{11} to 1.3×10^{11} Watts/cm^2 for the back surface. These values are factors of approximately 4 and 8 lower than the bulk damage irradiances. We found distinct differences between the damage morphologies for the front and back surfaces.

Earlier reports have claimed that the damage irradiance depended strongly on the size of the focal spot. We are varying the focal volume to look for evidence of this effect, but to date we have not found evidence of this effect.

We have also studied the temporal structure of the broadband light emitted by the optical breakdown. We find the broadband light consists of two pulses, a short one of 16 ns duration and a long one of several hundred ns. The strengths and spectra and time profiles provide clues to the nature of the material modification.

6403-72, Session 8

Photochemical adhesion of fused silica optical elements with no adhesive strain

M. Murahara, Tokyo Institute of Technology (Japan) and Tokai Univ. (Japan); T. Funatsu, Tokyo Institute of Technology (Japan); Y. Okamoto, Okamoto Optics Works, Inc. (Japan)

PRIMARY AUTHOR BIOGRAPHY:

Masataka MURAHARA: Professor, Entropia Laser Initiative, Tokyo Institute of Technology and Professor Emeritus, Tokai University. Masataka Murahara's specialties are laser engineering and photochemical surface modification; he has been conducting researches for more than thirty years. He graduated from Waseda University, School of Science and Technology, in 1969 and received a Doctor of Engineering from the University in March 1979.

ABSTRACT TEXT:

An adhesive method that creates no adhesive strain but heatproof, waterproof, and transparent to ultraviolet ray of 200nm and under in the wavelength has been developed by putting one silica glass to another with the silicone oil which is photo-oxidized by Xe2 excimer lamp.

In general, silicone oil is water-repellent and is known as a mold lubricant for adhesion. Fortunately, dimethyl siloxane silicone oil is composed of siloxane bonds of the main chain like quartz and methyl groups of the side chain. Therefore, the silicone oil was photo-oxidized by irradiating a Xe2 excimer lamp in oxygen atmosphere to change into amorphous glass. The dimethyl siloxane silicone oil (KF-96-10000) was poured into the thin gap between two pieces of silica glass in oxygen atmosphere and was irradiated with the Xe2 excimer lamp (172 nm) at room temperature under the bonding pressure. Consequently, the transmittance, which is most important as an optical material, rose with an exposure time. The transmittance that was 53% when un-irradiated increased to 80% after irradiating for 40 minutes. In addition, the measurement with the ZYGO interferometer showed that there was neither adhesive strain nor bubbles, and the bonding strength of 18MPa was achieved. To compare the heat resistance of the photo-oxidized silicone oil and general-purpose adhesives such as silicone rubber, epoxy, and silicone oil, the shearing tensile strength test was conducted after exposing at high temperatures from 25 to 500°C. As a result, the silicone rubber adhesive exfoliated at 120°C, and the epoxy adhesive, at 150°;C; however, the photo-oxidized silicone oil had 6.5MPa in bonding strength after heating at 500°C.

6403-73, Session 8

Characterization of thin films and bulk materials for DUV optical components

S. Schröder, M. Kamprath, A. Duparré,
Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

PRIMARY AUTHOR BIOGRAPHY:
Sven Schröder received his diploma in physics at the Friedrich-Schiller-University Jena in 2004. Since 2001 he is with the Film and Surface Characterization group at the Fraunhofer Institute for Applied Optics and Precision Engineering (IOF) in Jena where he carried out the work for his diploma thesis in 2003. Now he is PhD student at the IOF, working in the field of light scattering measurements for the characterization of surfaces, thin films, optical components, and systems.

ABSTRACT TEXT:
Increasing demands on optical components for deep ultraviolet (DUV) applications at the excimer laser wavelengths require at-wavelength characterization tools. For a thorough investigation of optical losses, all mechanisms contributing to the total loss have to be taken into account, comprising scattering at surfaces, thin film interfaces, and in bulk materials. Because of the strong wavelength-dependence of the scattering, this in particular holds for DUV optical components designed for high-end applications at 193 nm. Therefore, a system for the measurement of angle resolved and total scattering at 193 nm and 157 nm has been developed at the IOF in Jena. The system enables at-wavelength scattering measurement and analysis of DUV optical components. Results are presented for thin film coatings and bulk materials.

6403-74, Session 8

Damage of thermal detector platforms based on metal-carbon nanotube composites

L. A. Lewis, C. L. Cromer, National Institute of Standards and Technology; R. L. Mahajan, Virginia Polytechnic Institute and State Univ.; K. Ramadurai, Univ. of Colorado/Boulder; J. H. Lehman, National Institute of Standards and Technology

PRIMARY AUTHOR BIOGRAPHY:

Laurence A. Lewis is currently a Summer Undergraduate Research Fellow (SURF) at NIST Boulder. He is a rising junior at James Madison University in Harrisonburg, VA and majoring in physics. He recently was awarded the Serway/Saunders Physics Scholarship and is the Society of Physics Students president. He has presented at several technical conferences, each resulting in an award.

ABSTRACT TEXT:

Today's standards for laser power and energy measurements are inadequate for tomorrow_s high-power high-efficiency diode and fiber lasers. To meet this need, a new generation of thermal detector platforms based on carbon nanotubes (CNTs) and metal is being developed. Commercially available CNTs were selected based on the promise of high thermal conductivity and optical absorptivity reported in the literature. We discuss several techniques for the fabrication of thermal detector platforms including CNTs airbrushed on metal, aligned CNTs grown on copper, and a recently developed electroplating process. In the latter method CNTs were deposited with nickel on copper and then chemically etched to remove surface layers of nickel, thereby exposing the CNTs. We report qualitative evaluation of coating damage at laser irradiance at 10.6 μm up to 10 kW/cm2 by scanning electron microscopy. In addition we present quantitative evaluation of optical properties and thermal conductivity.

Refractive microlens structures with high-damage thresholds enable flexible beam shaping of high-power lasers

O. Homburg, L. Aschke, V. Lissotschenko,
LIMO-Lissotschenko Mikrooptik GmbH (Germany)

PRIMARY AUTHOR BIOGRAPHY:

1969-08-15 born in Bad Oeynhausen, Germany, 1996 diploma degree in physics (characterization of CO lasers), 1999 doctor thesis on blue semiconductor lasers, 2000/2001 product technology of infrared LEDs, since 2002 project and product manage-ment for optical systems.

ABSTRACT TEXT:

High power and high energy laser sources are used in a large variety of industrial and scientific applications for material processing. The most common are welding, soldering, cutting, drilling, laser thermal annealing, micro-machining, ablation and micro-lithography. For optimised processes the most important laser sources today are: CO2-lasers, Nd-YAG lasers, high-power diode lasers, excimer lasers or fiber lasers. Beside the right choice of the suitable laser source the right choice of high performance optics for generating the appropriate beam profile is of high importance for the applications. This takes into account that in many cases simple gaussian shaped laser foci are not the ideal solution.

Refractive micro-lenses and micro-lens arrays based on damage resistant materials are an efficient, compact and flexible solution to achieve adequate intensity distributions on the work piece.

Based on LIMO's unique production technology with computer-aided design free-form micro-lens surfaces can be structured into various kinds of materials. Especially, aspheres with radii between 50μm-200 mm, lens apertures or pitch of 50 μm to 20 mm with surface accuracies in the nanometer range can be produced on substrates with standard sizes of larger than 200 x 200 mm2. Since no chemical etching processes are involved, any kind of material for high-power lasers, e.g. fused silica, BK7, CaF2 for DUV-applications, Si, Ge and ZnSe for CO2-lasers can be processed. The damage resistance of the material is maintained by the structuring process.

With the adequate high-power reflection, anti-reflection, polarizing or filter coating laser beam shapes can be transformed in various ways. Extremely uniform top hat beam profiles with square, rectangular or line shapes and a non-uniformity below 1% peak-to-peak can be generated. This is a necessary prerequisite for many laser-based material processing applications which need to be performed on an industrial scale with small process windows. Examples of selected beam shaping tasks and their applications are demonstrated.

Wednesday Poster Session • Room 1

Materials and Measurements

10.30 to 11.30 and 15.20 to 16.20

Laser damage investigation of RbTiOPO4 crystals coupled with optical characterization, A. Hildenbrand, F. R. Wagner, Institut Fresnel (France); H. Albrecht, F. Theodore, Cristal Laser SA (France); J. Natoli, M. Commandre, Institut Fresnel (France) . . . . [6403-77]

Characterization of two-photon absorption related to the bulk quality in CaF2 crystal, T. Kamimura, T. Kumada, Y. Ikeda, K. Yoshida, Osaka Institute of Technology (Japan); T. Okamoto, Okamoto Optics Work, Inc. (Japan); R. Nakamura, Osaka Univ. (Japan) . . . . . . [6403-78]

Characterization of absorption losses in deep-UV optical materials, K. R. Mann, U. Leinhos, B. Schäfer, Laser-Lab. Göttingen e.V. (Germany) . . . . [6403-79]

Laser-induced bulk damages in Yb:S-FAP crystals, Z. M. Liao, J. J. Adams, A. J. Bayramian, A. Erlandson, J. A. Jarboe, K. I. Schaffers, C. J. Stolz, J. A. Caird, C. Bibeau, Lawrence Livermore National Lab. . . . . [6403-80]

Characterization of the mid-infrared nonlinear crystals LiInSe2 and LiInS2 in the IR range, O. Balachninaite, L. Petraviciute, M. Maciulevicius, V. Sirutkaitis, Vilnius Univ. (Lithuania); L. I. Isaenko, S. Lobanov, A. P. Yelisseyev, Russian Academy of Sciences (Russia); J. Zondy, Observatoire de Paris (France) . . . . [6403-81]

Qualification of materials for application on optic systems in high-fluence lasers, J. A. Pryatel, W. H. Gourdin, D. Behne, Lawrence Livermore National Lab. . . . . [6403-82]

6403-77, Poster Session

Laser damage investigation of RbTiOPO4 crystals coupled with optical characterization

A. Hildenbrand, F. R. Wagner, Institut Fresnel (France); H. Albrecht, F. Theodore, Cristal Laser SA (France); J. Natoli, M. Commandre, Institut Fresnel (France)

ABSTRACT TEXT:
The laser damage characteristics of a material depend on many parameters in particular the amount of absorption and mechanical properties. During the crystal growth process, different zones build up in the crystal. These zones are caused by the different growth speeds along the facets orientations of the seed crystal. Using photothermal measurements at 1.06 µm, different levels of absorption were observed in the different growth zones of one single flux grown RTP (RbTiOPO4) crystal. Performing laser damage measurements in the different zones of a large RTP sample enables us to compare absorption and laser damage characteristics at the same wavelength in the same crystal. Damage testing is done using a Nd:YAG laser with 6 ns pulse duration at the same wavelength as the photothermal measurements. Correlations and practical implications for the fabrication of highly laser resistant RTP crystals are discussed.

Characterization of two-photon absorption related to the bulk quality in CaF2 crystal

T. Kamimura, T. Kumada, Y. Ikeda, K. Yoshida, Osaka Institute of Technology (Japan);
T. Okamoto, Okamoto Optics Work, Inc. (Japan); R. Nakamura, Osaka Univ. (Japan)

PRIMARY AUTHOR BIOGRAPHY:
Tomosumi Kamimura is a lecturer at the department of Electronics, Information and Communication Engineering of Osaka Institute of Technology. He received his PhD degree in Engineering from the Osaka University in 2000. He worked on the studying the bulk and surface laser damage of high-power laser materials.

ABSTRACT TEXT:
With the advent of deep UV optical lithography, calcium fluoride (CaF2) has become important material of choice for F2 and ArF excimer laser components and for chromatic aberration correction of stepper lens system. The developments of ultra-high purity CaF2 single-crystal which resist the damage by excimer laser are strongly required. According to the general mechanism of laser-induced damage, some kinds of defects and contaminations inside the optical materials are very important factors for UV laser-induced damage. In this study, two-photon absorption of CaF2 crystal related to the bulk quality was investigated by using transmittance measurements. Pulsed laser beams at wavelengths of 266 nm and 213 nm were irradiated to CaF2 crystals having several bulk quality while the pulsed laser energy is varied from enough low to be negligible nonlinear absorption up to just below the laser-induced damage threshold. At a wavelength of 266 nm, the nonlinear absorption was not occurred even at the laser fluence just below the damage threshold. In contrast, two-photon absorption depending on the bulk quality was clearly observed at a wavelength of 213 nm. A high-quality CaF2 having a decreased defect density shows the lower two-photon absorption coefficient than that of a low-quality CaF2. A part of this study was supported by Industrial Technology Research Grant Program in 2005 from New Energy and Industrial Technology Development Organization (NEDO) of Japan.

Characterization of absorption losses in deep-UV optical materials

K. R. Mann, U. Leinhos, B. Schäfer, Laser-Lab. Göttingen e.V. (Germany)

PRIMARY AUTHOR BIOGRAPHY:
Klaus R. Mann received his M.S. degree in physics in 1981 and the PhD in 1984 from Univ. of Gˆttingen. After a post-doctoral appointment at IBM Yorktown Heights (USA) and work in industry (Alcan Deutschland GmbH) he joined Laser-Laboratorium Gˆttingen in 1988, where he currently leads the ¥Optics / short wavelength¥ division with activities in UV optics characterization, laser beam propagation and EUV / soft X-ray generation and metrology. He is author of about 70 scientific publications.

ABSTRACT TEXT:
In order to improve the efficiency of optical components for semiconductor microlithography, metrology tools for comprehensive characterization of absorptance in calcium fluoride and fused silica at the wavelength of 193nm were developed at Laser-Laboratorium Göttingen. Absolute absorption data are determined by high-resolution laser calorimetry, providing strongly enhanced accuracy as compared to transmissive measurements. The technique allows evaluation of both single- and two-photon absorption coefficients by monitoring the fluence dependence of the losses. It also accomplishes fast monitoring of degradation phenomena, e.g. laser-induced color center formation. Moreover, a separation of surface and bulk absorptance can be achieved by using samples of different thickness. A strong influence of the polishing grade on the surface absorptance was observed. In case of thin samples (d < 6mm) the surface contribution clearly dominates the overall absorption losses, even at optimum surface finish. The results are discussed in terms of a simple model for the absorption mechanisms in wide band-gap materials based on their electronic band structure.

For an assessment of the optical quality of DUV optics, a specially designed wavefront analyzer based on the Hartmann-Shack principle is employed. By monitoring the wavefront of a collimated test beam transmitted through the laser-irradiated site of a sample, this device can be used as an alternative to interferometric measurements for ´at wavelength´ testing of optics, e.g. for on-line registration of compaction or thermal lensing effects in fused silica.

Laser-induced bulk damages in Yb:S-FAP crystals

Z. M. Liao, J. J. Adams, A. J. Bayramian, A. Erlandson, J. A. Jarboe, K. I. Schaffers, C. J. Stolz, J. A. Caird, C. Bibeau, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:
The author attended University of Rochester, Rochester, NY and received his Ph.D. (2001) in Optics. His thesis work centered on the design of high-capacity soliton transmission systems. He joined the Photon Science and Applications division of LLNL in 2001 as a physicist working on high power solid-state lasers focusing on areas of fiber optics, nonlinear optics, adaptive optics, and laser induced damages.

ABSTRACT TEXT:
Diode-pumped solid-state lasers are one of the potential driver technologies for inertial fusion energy production. The Mercury laser at Lawrence Livermore National Laboratory is a diode-pumped solid-state laser that will deliver 100 J of energy at 1047 nm with a repetition rate up to 10 Hz and is a scalable prototype for a fusion energy laser driver. The Mercury laser uses ytterbium doped strontium fluorapatite (Yb:S-FAP) crystals as the gain medium with a nominal clear aperture of 4 cm x 6 cm. The Yb:S-FAP crystals are grown using the Czochralski method and are finished using conventional pitch lap on one side and magnetorheological finishing (MRF) on the other side. Recent damage test data have shown existence of bulk precursors in Yb:S-FAP that damage at approximately 10 J/cm2 at 9 ns under 1064 nm irradiation. We report on damage probability density function on Yb:S-FAP and our plans to mitigate damages on Mercury laser operations. (UCRL-ABS-221888)

Characterization of the mid-infrared nonlinear crystals LiInSe2 and LiInS2 in the IR range

O. Balachninaite, L. Petraviciute, M. Maciulevicius, V. Sirutkaitis, Vilnius Univ. (Lithuania); L. I. Isaenko, S. Lobanov, A. P. Yelisseyev, Russian Academy of Sciences (Russia); J. Zondy, Observatoire de Paris (France)

ABSTRACT TEXT:
Lithium Indium Sulfide (LiInS2; LIS) and Lithium Selenoindate (LiInSe2 or LISe) are promising nonlinear materials because of their wide transparency range and attractive nonlinear optical properties. Recently, renewed interest has been paid to LIS because of its high damage threshold, large thermal conductivity, large energy gap, and relatively high nonlinear susceptibility. The spectral transparency range and the high birefringence of the biaxial LISe nonlinear optical crystals allow one to realize the second harmonic generation of all widely used mid-IR lasers.

The optical characterization of these crystals is of high importance especially in wide spectral range. We report the absorption and scattering losses measurements of the nonlinear crystals LIS and LISe in the near infrared range by the radiation of the diode-pumped Q-switched nanosecond Nd:YVO4 laser and by the high average power tunable radiation of optical parametric oscillator based on a periodically poled lithium niobate. Measurements of the linear absorption losses were performed according to the ISO11551 standard by the calorimetric method at 1064 nm and at some wavelengths in 1.5-2 μm range. The measurements of scattering losses were performed by total integrated scattering method according international standard ISO19696. Those measurements allow estimation of the quality of the nonlinear crystals in spectral range where they are used and allow the prediction of the performance of the nonlinear optical devices based on such crystals.

Qualification of materials for application on optic systems in high-fluence lasers

J. A. Pryatel, W. H. Gourdin, D. Behne, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:
After receiving a B.S. degree in Mechanical Engineering from Carnegie Mellon University in 1970, James Pryatel had an extensive career in the nuclear power industry, including lead positions in mechanical analysis and project engineering. In 1997 Pryatel joined the NIF project at Livermore National Laboratory and for the past five years has been developing procedures for cleaning and maintaining the cleanliness of the laser system optics and associated mechanical parts.

ABSTRACT TEXT:
High power laser systems require essentially contamination free optics to maintain desired transport efficiency and to preclude optic damage. The required cleanliness is generally achieved through practices that preclude or remove foreign particle contamination. However, there are subtle mechanisms related to the materials utilized in the laser system assemblies and during their construction that can produce particle and residue contamination. As a result, test and analysis methods are needed for screening candidate materials for application in high fluence laser systems.

Laser optic systems may be contaminated by vapor-borne contaminants from material outgassing, by particles ablated from surfaces exposed to amplifier or laser light, or by contact with items used in the production and cleaning of optics and components. To preclude such contamination on the optics of the National Ignition Facility (NIF), a rigorous screening test program was introduced. Basically, this test program replicates conditions in the beam path as well as conditions during production and cleaning. The former is represented by sol-gel exposure tests and by subjecting materials to amplifier flashlamp light and 1w laser light. The latter is represented by organic solvent extraction tests and surface contact tests for items that could contact optic surfaces. This paper will discuss the methodology for, and administration of, these tests and present results for selected materials.

Wednesday Poster Session • Room 2

Materials and Measurements

10.30 to 11.30 and 15.20 to 16.20

6403-83, Poster Session

Mitigation of laser damage on fused silica surfaces with a variable profile CO_2 laser beam

A. During, CEA Cesta (France); P. R. Bouchut, J. Coutard, CEA Grenoble (France);
C. Leymarie, H. Bercegol, CEA Cesta (France)

ABSTRACT TEXT:
Laser damage at 3ω, 351 nm, of fused silica optical components is a major concern for LMJ maintenance. Indeed, even a low density of damage sites is unacceptable due to the exponential growth of surface damage with a series of laser shots. A technique is now used to prevent the growth of initiated damage sites : this mitigation technique consists in a local melting and evaporation of silica by CO_2 laser irradiation on the damage site. Even if the growth is stopped in most cases, we showed previously that some of the mitigated sites re-initiate on their peripheral area, where most of re-deposited debris are located. To further increase the efficiency of mitigation technique, the treatment was improved by varying the spatial profile of the CO_2 laser beam. We present here the new set-up and the results obtained in terms of laser damage resistance: about 98% of the mitigated sites sustained 200 shots of a 10 J/cm2 3ω YAG laser without damage.

Laser-induced damage thresholds of starched PMMA waveplates

A. Melninkaitis, D. Mikšys, V. Sirutkaitis, Vilnius Univ. (Lithuania); G. Slekys, Altechna Co. Ltd. (Lithuania); A. V. Samoylov, Institute of Semiconductor Physics (Ukraine)

ABSTRACT TEXT:
Polymethyl methacrylate (PMMA) is a versatile polymeric material that is well suited for fabrication of many commercial optical components: lenses, fibers, windows, phase waveplates and others. Our focus is achromatic zero-order waveplates made of anisotropic PMMA which can be used to modify the state of polarization of electromagnetic radiation. Such waveplates have a broad range of application in devices where polarized laser radiation is used. For example, when tunable lasers are used or when spectropolarimetric measurements are performed, one needs an achromatic waveplate providing a specific retardation in a wide wavelength range. Herewith anisotropic properties of PMMA subjected to one-axis stretching are analyzed and the technology for manufacturing such achromatic and super-achromatic, one-axis-stretched PMMA waveplates is described. This technology excludes any mechanical processing of waveplate component surfaces. Technical characteristics of achromatic and super-achromatic waveplates manufactured of PMMA including results of laser-induced damage threshold measurements will be discussed in our presentation.

Measurement of low-absorption optics by thermal imaging

A. F. Stewart, The Boeing Co.; W. Hughes, Lockheed Martin Missiles & Space

PRIMARY AUTHOR BIOGRAPHY:
ALAN F. STEWART is an Associate Technical Fellow for the Boeing Company. His work in government service, commercial industry and now government programs at Boeing has given him the opportunity to develop expertise in characterization, fabrication, and test of thin films. He has published work in laser damage, ion beam sputtering of coatings, applications of Raman spectroscopy, and surface analytical techniques. Recent efforts involve refinement of methods for laser calorimetry and application of the cavity ringdown lossmeter for evaluation of high quality and rather large optics.

ABSTRACT TEXT:
An infrared camera system has been used to measure absorption in optical coatings and substrates. Laser light is directed at the test sample and milliwatts of power are absorbed. The camera images the surface of the sample and provides a direct measurement of the 8-12 micron radiation emitted. By considering the effective emittance of the sample and the ambient temperature, the surface temperature of the sample is obtained. Through the use of an equivalent “reference” sample which is not heated by the laser, background variations may be effectively eliminated. The application of standard calorimetric methods to infrared imaging as well as the availability of improved sensors such as the microbolometer array has led to our ability to resolve temperature excursions as low as 0.07 °C with a S/N of roughly 3.

Calibration of the infrared imaging technique is required to produce a direct but noncontact measurement of the actual surface temperature. The calibration process has been performed using direct thermocouple calorimetry and electrical substitution heating. When performed using identical samples in the usual test configuration, this method provides excellent agreement between known heat input and measured temperatures, both from calorimetry and IR imaging methods. The effective emittance for the sample and the ambient temperature are the only variables which may then be set for each sample and used for IR imaging to produce images with absolute temperatures.

The IR imaging method has been used to evaluate many optical coatings and window materials for the ABL program. Because the method is noncontact, it has been used to directly measure absorption on much larger optical surfaces. In some instances, defects have been observed and mapped using this method. Variations in absorption which might be predicted from the coating design have been measured directly. The IR imaging technique thus offers great flexibility and sensitivity comparable to precision calorimetry.

National round robin test: a re-anaysis

J. W. Arenberg, Northrop Grumman Space Technology

PRIMARY AUTHOR BIOGRAPHY:
Jonathan Arenberg is currently Deputy Observatory systems engineer for the James Webb Space Telescope Project. He has been at Northrop Grumman for over 18 years. He holds degrees in physics and engineering, all from UCLA.

ABSTRACT TEXT:
This paper presents a relook at the 1997 German national round robin damage experiment. In this reanalysis a new technique using physically motived fitting functions for the determination of threshold are used. The improved technique is shown to provide improved correlation among measurements.

Automated laser-damage test system with real-time damage event imaging and detection

J. E. Wolfe, S. Schrauth, Lawrence Livermore National Lab.

PRIMARY AUTHOR BIOGRAPHY:
Justin Wolfe manages National Ignition Facility Small Optics Metrology and Quality Assurance group. He joined Lawrence Livermore National Laboratory in 2004 after receiving a Masters degree in Optical Engineering from the University of Arizona. He has developed numerous automated optical metrology instruments for spectral, polarization, and laser damage measurements.

ABSTRACT TEXT:
An automated laser damage test system has been developed by the National Ignition Facility small optics metrology group. The Small Optics Laser Damage (SOLD) system measures the fluence at which laser damage occurs in optical coatings and substrates following the requirements of MEL01-013-OD. Irradiation of the sample is by a 1064nm, 8ns pulse with a 1mm 1/e2 diameter. The test protocol requires raster scanning of a 1cm2 area at increasing fluence levels. Real-time high-resolution imaging of the surface during raster scanning enables automated detection and sizing of defects to 10 microns. Improved imaging resolves actual size of damage events while the automated damage detection removes the subjectivity of the human operator in thresholding damage events In addition, a map is created enabling additional functions such as excluding damage sites on future scans and to returning to the damage site for growth testing.

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.