Abstract Book

SPIE Laser Damage

XLII Annual Symposium on

Optical Materials for High Power Lasers

26–29 September 2010
National Institute of Standards and Technology
Boulder, Colorado, USA

Connecting minds for global solutions

The leading forum for high-power/high-energy lasers

Laser-Induced Damage Issues:

- Photonic bandgap materials
- High power fiber lasers
- Fibers for high power laser applications
- High power, ultra fast, lasers
- Multi-layer thin films
- Nonlinear optical and laser host materials

Other Laser-Induced Damage Related Issues

- Measurement protocols
- Materials characterization
- Fundamental mechanisms
- Contamination of optical components
- Surface and bulk defects

MINI-SYMPOSIUM: Fundamentals of Laser Ablation

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SPIE Laser Damage

XLII Annual Symposium on

Optical Materials for High Power Lasers

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Special Events

Sunday 26 September

17.00 to 20.30 **Registration Material Pick-up and Mixer at the Boulder Marriott**

17.30 to 19.00 **Roundtable Discussion at the Boulder Marriott**
Multiphoton Ionization vs. Avalanche (Impact) Ionization in LID of Transparent Optical Materials

This year the Round Table focuses on a specific topic related to fundamentals of LID: relation between multiphoton and avalanche (impact) ionization in initiating LID in transparent optical materials. The standard - and the most frequently employed - approach considers overall generation of conduction-band electrons by laser radiation as a result of combined action of the two ionization mechanisms. Among them, the multiphoton ionization is frequently assumed to be a starter of the impact ionization by providing seed conduction-band electrons for development of the electron avalanche. The avalanche is believed to dominate due to its extremely high rate.

Experimental data have already demonstrated that this approach fails to explain some scaling of LID threshold with laser frequency even for nanosecond pulses. Meanwhile, this approach has been spread to the case of ultra-short (femtosecond) laser pulses. The aim of this discussion is to clarify relation between those ionization mechanisms to the maximum possible degree according to the current level of our understanding of laser-induced ionization.

19.00 to 21.00 **Social Mixer at the Boulder Marriott**
Registration Material Pick-up continues until 20.30

Monday 27 September

18.30 to 20.00 **Saint-Gobain Crystals Open House and Reception**

Tuesday 28 September

18.30 to 20.00 **Wine and Cheese Reception at NCAR**

Wednesday 29 September

13.15 to 14.00 **NIST Facility Tour**

17.30 to 19.00 **Precision Photonics Corp. Open House and Reception**

Monday AM • 27 September

07.30 to 08.30 **Registration Material Pick-up,** NIST Lobby Area

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**
Joseph A. Menapace, Lawrence Livermore National Lab. (United States)

09.00 to 09.40 • SESSION I

Thin Films I

Session Chairs: **Vitaly E. Gruzdev,** Univ. of Missouri-Columbia (United States); **Gregory J. Exarhos,** Pacific Northwest National Lab. (United States)

09.00: **Advances in ion beam sputtered optical interference coatings** *(Invited Paper)*, Carmen S. Menoni, Colorado State Univ. (United States) . . . . [7842-01]

09.40: **Complex study of zirconia-silica and niobia-silica composite coatings produced by ion beam sputtering,** Andrius Melninkaitis, Julius Mirauskas, Maksim Jeskevich, Lina Žitkute, Valdas Sirutkaitis, Vilnius Univ. (Lithuania); Xinghai Fu, Benoit Mangote, Myriam Zerrad, Laurent Gallais, Mireille Commandre, Institut Fresnel (France); Tomas Tolenis, Simonas Kicas, Ramutis Drazdys, Institute of Physics (Lithuania) . . . . [7842-02]

Mon. 10.00 to 10.40 • Monday Poster Overview

Poster authors are asked to give a 2-minute/2-viewgraph overview of their posters in the order they appear in the program.

10.40 to 11.40 • Poster Session and Coffee/Refreshment Break

11.40 to 12.40 • SESSION 2

Thin Films II

Session Chairs: **Vitaly E. Gruzdev,** Univ. of Missouri-Columbia (United States); **Gregory J. Exarhos,** Pacific Northwest National Lab. (United States)

11.40: **Evaluation of inclusion sources in e-beam evaporated hafnia/silica coatings**, Justin E. Wolfe, Siping R. Qiu, Christopher J. Stolz, Lawrence Livermore National Lab. (United States); Amy L. Rigatti, James B. Oliver, Univ. of Rochester (United States) . . [7842-21]

12.00: **Study of laser-induced damage of high reflector at 1064nm**, Hongfei Jiao, Tao Ding, Xinbin Cheng, Bin Ma, Jinlong Zhang, Zhengxiang Shen, Pengfei He, Zhanshan Wang, Tongji Univ. (China) . . . . [7842-22]

12.20: **BDS thin film UV antireflection laser damage competition**, Christopher J. Stolz, Lawrence Livermore National Lab. (United States); Michael D. Thomas, Andrew J. Griffin, Spica Technologies, Inc. (United States) . . . . [7842-23]

12.40 to 13.40 • Lunch Break

7842-01, Session 1

Advances in ion beam sputtered optical interference coatings

C. S. Menoni, Colorado State Univ. (United States)

ABSTRACT TEXT:
No abstract available

Complex study of zirconia-silica and niobia-silica composite coatings produced by ion beam sputtering

Andrius Melninkaitis, Julius Mirauskas, Maksim Jeskevich, Lina Žitkute, Valdas Sirutkaitis, Vilnius Univ. (Lithuania); Xinghai Fu, Benoit Mangote, Myriam Zerrad, Laurent Gallais, Mireille Commandre, Institut Fresnel (France); Tomas Tolenis, Simonas Kicas, Ramutis Drazdys, Institute of Physics (Lithuania)

PRIMARY AUTHOR BIOGRAPHY:
Andrius Melninkaitis was born 23 May, 1980, in Jurbarkas (Lithuania). He received his PhD in Physics from the Vilnius University in 2009. Now he holds position as Associate Professor in the Department of Quantum Electronics and Research Fellow in Laser Research Center (VULRC) at Vilnius University in Lithuania.

ABSTRACT TEXT:
In this study, we report on our recent progress in research of single layer mixed zirconia-silica and niobia-silica composite coatings prepared by Ion Beam Sputtering technique. All coatings of the same optical thickness (namely 6QWOT at 1064 nm wavelength) were characterized in terms of reflection/transmission spectrometry (in UV-IR range), X-ray diffraction, atomic force (AFM) and optical microscopy, optical back-scattering (total integrated TIS as well as angle resolved ARS) and 1-on-1 optical resistance (laser-induced damage threshold - LIDT) in nanosecond (12 ns) and subpicosecond (530 fs) mode. The optical resistance, TIS and LIDT results reveal clear dependence on high refractive index material content in composite coating and its crystalline structure. The results are interpreted and discussed by the means of different models available in literature.

Keywords: mixture coatings, LIDT, laser damage, IBS

Evaluation of inclusion sources in e-beam evaporated hafnia/silica coatings

J. E. Wolfe, S. R. Qiu, C. J. Stolz, Lawrence Livermore National Lab. (United States);
A. L. Rigatti, J. B. Oliver, Univ. of Rochester (United States)

PRIMARY AUTHOR BIOGRAPHY:
Justin Wolfe has been at Lawrence Livermore National Laboratory (LLNL) since 2004 working on optical metrology, laser damage, and optics production.

ABSTRACT TEXT:
Inclusions buried within laser multilayer coatings have been shown to cause electric field intensification and can be precursors for laser damage events. Reduction of the number of particle defects within coating structures is critical for improving laser damage performance of large (0.2 m^2) dielectric mirrors. Earlier efforts found high numbers of hafnia defects were greatly reduced by replacing the hafnia sources with Hf metal sources. To further reduce particle counts, improved understanding of the source and nature of current inclusions is needed to direct improvement efforts.

In this study, clean, low-defect silicon wafers were processed at the University of Rochester and evaluated at Lawrence Livermore National Laboratory with scanning optical microscopy. Wafers were exposed to the various steps and environments in the coating process then evaluated for particle density and size. Wafers were coated with single layers of hafnia and silica under varying process parameters. Multiple samples with full multilayer mirror coatings have been created to assess the run to run distribution of total particle counts.

Study of laser-induced damage of high reflector at 1064nm

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

PRIMARY AUTHOR BIOGRAPHY:
Hongfei Jiao has graduated from physics department in 2004, and obtained his PhD degree in Optics from Tongji University in 2009. Now he is a post-doctor in School of Aerospace Engineering and Applied Mechanics in Tongji University. He researches on the design and fabrication of optical thin films.

ABSTRACT TEXT:
Optical property and laser damage resistance of TiO_2/SiO_2 and HfO_2/SiO_2 high reflectors were investigated. The optical performance of the high reflectors was measured using Cary 5000 spectrophotometer, both S and P polarization reflectivity is higher than 99.5% for the angle of incidence of 45°at 1064 nm. The surface thermal lens technique was used to detect the thermal absorptance of the coatings at 1064 nm, 3mm*3mm area was scanned for every sample. The average absorption of TiO_2/SiO_2 high reflectors is about 200 ppm, and HfO_2/SiO_2 high reflectors have the rather lower absorption that is less than 20 ppm. The laser induced damage thresholds (LIDT) of these high reflectors were tested using a 10 ns pulsed YAG-laser under different testing mode according to ISO-11254. Scanning electron Microscope (SEM) and Nomarski microscope technique were used to analyze the damage morphologies of TiO_2/SiO_2 and HfO_2/SiO_2 high reflectors. For TiO_2/SiO_2 high reflectors, catastrophe damages were always founded when the laser fluence is about 7 J/cm^2 for the R-on-1 testing mode. The main damage morphologies TiO_2/SiO_2 high reflectors are round melting pits, which reveals that thermal melting mechanism plays an important role in the initiation of damage. The HfO_2/SiO_2 high reflectors have much lower absorption and have higher R-on-1 LIDT more than 40J/cm^2. The dominant damage morphologies are micrometer-sized nodules ejected pits, which are believed to be the result of the thermal stress initiated damage.

Keywords: thin films, laser damage, 1064, high reflector

BDS thin film UV antireflection laser damage competition

C. J. Stolz, Lawrence Livermore National Lab. (United States);
M. D. Thomas, A. J. Griffin, Spica Technologies, Inc. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Christopher Stolz has been in the laser program at Lawrence Livermore National Laboratory (LLNL) since 1989 researching high-power laser coatings. He is currently responsible for the Optics Production group for the National Ignition Facility (NIF). Chris has served as a cochair or program chair for numerous conferences including Laser Induced Damage in Optical Materials (a.k.a. Boulder Damage Symposium) and Optical Interference Coatings. He has coauthored over 70 journal and proceeding articles and 1 book on the subject of optical coatings.

ABSTRACT TEXT:
UV antireflection coatings are a challenging coating for high laser power applications as exemplified by the use of uncoated Brewster's windows in laser cavities. In order to understand the current laser resistance of UV AR coatings in the industrial and university sectors, a double blind laser damage competition will be conducted. The coatings have a maximum reflectance of 0.5% at 351 nm at normal incidence. Damage testing will be performed using the raster scan method with a 5 ns pulse length on a single testing facility to facilitate direct comparisons. In addition to the laser resistance results, details of deposition processes, coating materials and layer count, and spectral results will also be shared.

Monday PM • 27 September

13.40 to 15.00 • SESSION 3

Thin Films III

Session Chairs: **Jonathan W. Arenberg,** Northrop Grumman Aerospace Systems (United States); **Jérôme Néauport,** Commissariat à l'Énergie Atomique (France)

13.40: **Investigations on SiO_2/HfO_2 mixtures for nanosecond and femtosecond pulses**, Lars O. Jensen, Mathias Mende, Holger Blaschke, Detlev Ristau, Laser Zentrum Hannover e.V. (Germany); Duy Nguyen, Luke A. Emmert, Wolfgang Rudolph, The Univ. of New Mexico (United States) . . . . [7842-24]

14.00: **Laser damage by ns and sub-ps pulses on hafnia/silica anti-reflection coatings on fused silica double-sided polished using zirconia or ceria and washed with or without an alumina wash step**, John C. Bellum, Damon Kletecka, Mark Kimmel, Patrick Rambo, Ian Smith, Jens Schwarz, Briggs Atherton, Sandia National Labs. (United States); Zachary Hobbs, Sydor Optics, Inc. (United States) . . . . [7842-25]

14.20: **Mixed metal dielectric pulse compression gratings**, Jérôme Néauport, Stéphanie Palmier, Commissariat à l'Énergie Atomique (France); Nicolas Bonod, Institut Fresnel (France) [7842-75]

14.40: **Submicrometer-resolution mapping of ultraweak 355nm absorption in HfO_2 monolayers using photothermal heterodyne imaging**, Semyon Papernov, Univ. of Rochester (United States); Alex Tait, Princeton Univ. (United States); Wade Bittle, Ansgar W. Schmid, James B. Oliver, Peter T. Kupinski, Univ. of Rochester (United States). . . . . [7842-27]

15.00 to 16.00 • Poster Session and Refreshment Break

16.00 to 18.00 • SESSION 4

Fundamental Mechanisms I

Session Chairs: **Jonathan W. Arenberg,** Northrop Grumman Aerospace Systems (United States); **Jérôme Néauport,** Commissariat à l'Énergie Atomique (France)

16.00: **Imaging the early material response associated with exit surface damage in fused silica** *(Invited Paper)*, Stavros G. Demos, Raluca A. Negres, Rajesh N. Raman, Lawrence Livermore National Lab. (United States) . . . . [7842-28]

16.40: **Temperature activated absorption during laser-induced damage**, Christopher W. Carr, Jeffrey D. Bude, Lawrence Livermore National Lab. (United States). . . . . [7842-29]

17.00: **Morphological changes induced by CO_2 laser-based damage mitigation of SiO_2 surfaces**, Michael D. Feit, Ibo J. Matthews, Thomas F. Soules, James S. Stolken, Ryan M. Vignes, Steven T. Yang, Diane J. Cooke, Lawrence Livermore National Lab. (United States) . . . . [7842-30]

17.20: **Molecular dynamics study of silica glass during laser heating/cooling**, Thomas F. Soules, George H. Gilmer, Manyalibo J. Matthews, James S. Stolken, Lawrence Livermore National Lab. (United States) . . . . [7842-31]

17.40: **Tridimensionnal multiphysical model for the study of photo-induced thermal effects in laser damage phenomena,** Mireille Commandré, Guillaume Demesy, Laurent Gallais, Institut Fresnel (France) . . . . [7842-32]

18.30 to 20.00 • Saint-Gobain Crystals Open House and Reception

SAINT-GOBAIN CRYSTALS

7842-24, Session 3

Investigations on SiO_2/HfO_2 mixtures for nanosecond and femtosecond pulses

L. O. Jensen, M. Mende, H. Blaschke, D. Ristau,
Laser Zentrum Hannover e.V. (Germany); D. Nguyen, L. A. Emmert, W. Rudolph,
The Univ. of New Mexico (United States)

ABSTRACT TEXT:
On the quest for ideal processes, designs and materials for high power laser coatings, oxide mixtures can be considered as a promising approach. With respect to the high refractive index material, the extension of spectral transmission to shorter wavelengths and increased damage thresholds are principal benefits from this concept. For Rugate Filters and particularly in the ultra short pulse regime, these features have provided the basis for strong improvements.

This work presents results for ternary oxide material phases produced by mixing of Silica and Hafnia in an ion beam sputtering process. The intention is to establish an increased understanding of the damage process and to improve optics in the nanosecond and femtosecond time domain, based on such materials. An extensive set of single layers was produced and analyzed to gain insights into the damage processes of the two sputtered materials and their mixed states. Also, high reflectors with different designs involving mixed coatings were studied. Rather large differences in the damage performance of the different coatings were observed. As a major result, the experimental findings deduced from single layers could be efficiently employed to enhance the power handling capability of high reflectors.

Keywords: oxide mixtures, LIDT, SiO_2/HfO_2, damage mechanisms

Laser damage by ns and sub-ps pulses on hafnia/silica anti-reflection coatings on fused silica double-sided polished using zirconia or ceria and washed with or without an alumina wash step

J. C. Bellum, D. Kletecka, M. Kimmel, P. Rambo, I. Smith, J. Schwarz, B. Atherton, Sandia National Labs. (United States); Z. Hobbs, Sydor Optics, Inc. (United States)

PRIMARY AUTHOR BIOGRAPHY:
John Bellum is an optical scientist and project lead for Sandia's Large Optics Coating Operation. He holds a PhD in physics from the University of Florida and has over 30 years of experience as an academic researcher and teacher, and a scientist and engineer in optical, laser and optical coating technology.

ABSTRACT TEXT:
Single transverse and longitudinal mode, ns pulse, laser induced damage threshold (LIDT) tests of hafnia/silica anti-reflection (AR) coatings on polished fused silica show lower LIDTs for ceria than for alumina-silica polishing [1]. Our tests [2, 3] are with multi transverse and longitudinal mode pulses representative of Sandia's ZBacklighter terawatt and petawatt lasers and have been for coatings on substrates pitch polished using ceria with an alumina wash step to remove residual polishing compound and minimize its role in laser damage. These LIDTs for ns pulses (NIF-MEL) at 1064nm and 532nm and for sub-ps pulses (Sandia measurements) at 1054nm are all reasonably high, affording adequate laser damage resistance for large ZBacklighter laser optics. Another such AR coating confirms this with LIDTs of 33.0J/cm^2 for 3.5ns pulses and 1.8J/cm^2 for 350fs pulses. We investigate ceria and zirconia in double-sided polishing (common for large flat ZBacklighter laser optics) as they affect LIDTs of AR coatings on fused silica washed with and without the alumina wash step. This will confirm, for double-sided polishing of surfaces, whether ceria or zirconia polishing makes AR coated surfaces less susceptible to multi longitudinal and transverse mode laser damage and also how well alumina wash steps minimize effects of polishing compound on laser damage.

References

[1] Smith, A. V., et al., Proc. of SPIE Vol. 7132, 71321T (2008).
[2] Bellum, J. C., et al., Proc. of SPIE Vol. 7504, 75040C (2009).
[3] Kimmel, M., et al., Proc. of SPIE Vol. 7504, 75041G (2009).

Keywords: laser induced damage threshold, large optics coatings, anti-reflection optical coatings, high intensity pulsed lasers, optical surface polishing

Mixed metal dielectric pulse compression gratings

J. Néauport, S. Palmier, Commissariat à l'Énergie Atomique (France);
N. Bonod, Institut Fresnel (France)

ABSTRACT TEXT:
A Petawatt facility called PETAL (PETawatt Aquitaine Laser) is under development near the LIL (Ligne d'Integration Laser) at CEA Cesta, France. PETAL facility uses chirped pulse amplification (CPA) technique [1]. This system needs large pulse compression grating exhibiting damage threshold of more than 4 J/cm² beam normal at 1.053µm and for 500fs pulses. In this paper, we study an alternative design to the classic multilayer dielectric (MLD) grating [2] called "mixed metal-multilayer dielectric grating" (MMLD). This design consists in a gold reflective layer coated with a few pairs of HfO_2/SiO_2 [3]. The top low index SiO_2 layer of the stack is then engraved to receive the grating. We evidenced in a previous work that leads to high efficient pulse compression gratings [3]. We have shown in last Boulder Damage Symposium that mixed mirror is equivalent to a "classic" MLD mirror [4]. We herein detail the damage performances obtained on the MMLD gratings and compare them with these of MLD gratings.

This work is being performed under the auspices of the Conseil Régional d'Aquitaine, of the French Ministry of Research and of the European Union and with the technical supports of the Institut Lasers et Plasmas.

1.N. Blanchot, et al "Overview of PETAL, the multi-Petawatt project on the LIL facility", Plasma Phys. Control. Fusion 50 (2008) 124045
2.M. D. Perry, R. D. Boyd, J. A. Britten, B. W. Shore, C. Shannon and L. Li, "High efficiency multilayer dielectric diffraction gratings", Opt. Lett. 20, 940-942 (1995)
3.N. Bonod, J. Neauport, "Optical performances and laser induced damage threshold improvement of diffraction gratings used as compressors in ultra high intensity lasers", Optics Communication, Vol 260, Issue 2, pp 649-655, 2006
4.S. Palmier, J. Neauport, N. Baclet, E. Lavastre, G. Dupuy, "High reflexion mirror for mixte metal dielectric gratings" Optics Express, Vol. 17, Iss. 22, pp. 20430-20439 (2009)

Keywords: gratings, laser damage, short pulse, multidielectric grating, gold, metal

7842-27, Session 3

Submicrometer-resolution mapping of ultraweak 355nm absorption in HfO_2 monolayers using photothermal heterodyne imaging

S. Papernov, Univ. of Rochester (United States); A. Tait, Princeton Univ. (United States); W. Bittle, A. W. Schmid, J. B. Oliver, P. T. Kupinski, Univ. of Rochester (United States)

PRIMARY AUTHOR BIOGRAPHY:

In 1979 received Ph.D. degree in Physics from Latvian University. In 1988 joined Laboratory for Laser Energetics (LLE), University of Rochester. Currently work at LLE as a scientist. Areas of scientific interests include optical materials for high-power lasers, laser-induced damage, thin solid films, Atomic force microscopy.

ABSTRACT TEXT:

Nanosecond-pulse UV-laser-damage initiation in multilayer coatings comprised from metal oxide as a high-index component, and silica oxide as a low-index material, is strongly linked to metal oxide. The nature of the absorbing species and their physical properties remain unknown because of extremely small sizes. Previous experimental evidence provided by high-resolution mapping of damage morphology points to a few-nanometer scale of these absorbers. This work demonstrates submicrometer mapping of 355-nm absorption in HfO2 monolayers using a recently developed photothermal heterodyne imaging technique. Comparison of absorption maps with spatial distribution of UV pulsed-laser-induced damage morphology allows for a better estimation of size and densities of nanoscale absorbing defects in hafnia thin films. Possible defect-formation mechanisms are discussed.

Keywords: Laser damage, heterodyne imaging, absorbing defects

7842-28, Session 4

Imaging the early material response associated with exit surface damage in fused silica

S. G. Demos, R. A. Negres, R. N. Raman,
Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Stavros G. Demos is an experimental physicist and has been involved in the field of Laser Damage since he joined Lawrence Livermore national Laboratory in 1997 as a post doctoral fellow. He has over 86 journal publications and 20 patents in the fields of laser-matter interactions, laser damage, laser and optical materials, optical diagnostics, and biomedical photonics.

ABSTRACT TEXT:

The processes involved at the onset of damage initiation on the surface of fused silica have been a topic of extensive discussion and thought for more than four decades. Limited experimental results have helped develop models covering specific aspects of the process. In this work we present the result of an experimental study aimed at imaging the material response from the onset of the observation of material modification during exposure to the laser pulse through the point that material ejection begins. The system involves damage initiation using a 355 nm pulse, 7.8 ns FWHM in duration and imaging of the affected material volume with spatial resolution on the order of 1 μm using as strobe light a 150 ps laser pulse that is appropriately timed with respect to the pump pulse. The observations suggest that the onset of material modification is associated with increased absorption which suggests formation of an electronic excitation that leads to reduction of the transmission to only a few percent within a time interval of about 1 ns. This area subsequently rapidly expands at a speed of about 1.2 μm/ns and is accompanied by the propagation of radial cracks that seem to initiate about 2 ns after the onset of the expansion of the modified region. The damage sites continue to grow for about 25 ns but the mechanism of expansion after the termination of the laser pulse is via formation and propagation of lateral cracks. During this time, the affected area of the surface appears to expand forming a bulge of about 40 μm in height. The first clear observation of material cluster ejection is noted at about 50 ns delay.

Temperature activated absorption during laser-induced damage

C. W. Carr, J. D. Bude, Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Dr. C.W. Carr currently leads the National Ignition Facility's optics lifetime projections group at Lawrence Livermore National Laboratory. His group's recent work has demonstrated the strong effect of laser pulse shape and wavelength mixture on both growth and initiation of damage on SiO_2 and crystalline optics. Other research interests include the mechanisms and dynamics of energy deposition during laser induced damage

ABSTRACT TEXT:
Previously at this conference we have shown that the size of laser induced damage sites in both KDP and SiO_2 are approximately proportional to the duration of the laser pulse which creates them. This suggested the presence of a laser-driven absorption front which grew in proportion to the pulse duration. However, this interpretation is complicated in two ways: it did not account for the fraction of pulse required to initiate the absorption front, nor were measurements of final damage site size alone capable of uniquely identifying the full extent of the absorption front.

In this work, we use a two-part pulse in which the initial part of the pulse initiates small damage sites with a narrow size distribution, followed by a longer, lower intensity portion to drive the absorption front in a controlled way. The molten region of the site is differentiated from the mechanically damaged portion using SEM which allows clear identification of the region were the laser energy was deposited. This work confirms that laser damage generates a solid-state laserdriven absorption front. Moreover, we have developed a model for this absorption front which predicts the effect of various pulse shapes and intensities on the damage site size. We surmise that the evolution of absorption front results from the temperature-activated deep sub band-gap optical absorptivity, free electron transport and thermal diffusion in defect-free silica. In addition to the practical application of selecting an optimal laser for pre-initiation of large aperture optics, this work serves as a platform for understanding general lasermatter interactions in dielectrics under a variety of conditions.

Morphological changes induced by CO_2 laser-based damage mitigation of SiO_2 surfaces

M. D. Feit, I. J. Matthews, T. F. Soules, J. S. Stolken, R. M. Vignes, S. T. Yang, D. J. Cooke, Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Michael D. Feit has been at Lawrence Livermore National Laboratory since 1972 and in the Laboratory's laser program since 1994. Specializing in optical propagation, nonlinear optics, materials science and the interaction of intense lasers with materials, he has authored or co-authored over 200 journal, review and proceedings articles, and is a fellow of both the American Physical Society and the Optical Society of America.

ABSTRACT TEXT:

Knowing the ultimate surface morphology resulting from CO_2 laser mitigation of induced laser damage is important both for determining adequate treatment protocols, and for preventing deleterious intensification upon subsequent illumination of downstream optics. Physical effects such as evaporation, viscous flow and densification can strongly affect the final morphology of the treated site. Evaporation is a strong function of temperature and will play a leading role in determining pit shapes when the evaporation rate is large, both because of material loss and redeposition. Viscous motion of the hot molten material during heating and cooling can redistribute material due to surface tension gradients (Marangoni effect) and vapor recoil pressure effects. Less well known, perhaps, is that silica can densify as a result of structural relaxation, to a degree depending on the local thermal history. The specific volume shrinkage due to structural relaxation can be mistaken for material loss due to evaporation. Unlike evaporation, however, local density change can be reversed by post annealing. All of these effects must be taken into account to adequately describe the final morphology and optical properties of single and multiple-pass mitigation protocols. We have investigated, experimentally and theoretically, the significance of such densification on residual stress and under what circumstances it can compete with evaporation in determining the ultimate post treatment surface shape. In general, understanding final surface configurations requires taking all these factors including local structural relaxation densification, and therefore the thermal history, into account.

7842-31, Session 4

Molecular dynamics study of silica glass during laser heating/cooling

T. F. Soules, G. H. Gilmer, M. J. Matthews, J. S. Stolken,
Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Thomas F. Soules has been at Lawrence Livermore National Laboratory since 2002 working on materials problems related to the SSHCL and DPAL lasers including the development of transparent ceramic materials for lasers. Prior to LLNL, he worked 34 years for the General Electric Company in the Lamp Division working on the development of new phosphor lamp coatings, glass science and technology, lamp modeling and design and electrode and discharge phenomena. He has 47 patents, over 50 journal publications and several management awards. Soules received his Ph.D. in Physical Chemistry from Purdue University.

ABSTRACT TEXT:

In the CO_2 laser mitigation of laser damage, silica is locally heated and cooled at high rates over a large temperature range to remove or smooth the damaged area and prevent damage site growth. Heating rates from 1*103 to 3*108 degrees K/s and final temperatures of 2000K to greater than 5000K respectively can be achieved by adjusting the power, spot size and duration of the mitigating CO_2 laser. These temperatures and heating/cooling rates are in regions where silica properties and relaxation phenomena have not been reported previously and are difficult or impossible to obtain experimentally. Nevertheless they are important to enabling understanding and modeling of the topology and stress distribution that actually occurs during laser mitigation. For example, at the slower laser heating rates structural relaxation occurs and the silica densifies. The densification and resulting stress pattern is then frozen in at the fictive temperature during cooling. At the highest heating/cooling rates, stress and structural relaxation do not have a chance to occur until temperatures over 4000K are reached and silica evaporates essentially from the solid state.

Heating/cooling rates comparable to the fast experimental laser heating/cooling rates during mitigation can be achieved in molecular dynamic (MD) simulations with LLNL computers. The MD simulations behave similarly to real silica glass during very fast laser heating/cooling with relaxation occurring at temperatures > 4000K. There is a history dependent fictive temperature and hysteresis during cooling and reheating. The heat capacity increases as the silica goes through the glass transition at these high heating/cooling rates. Simulations are also performed at as slow a cooling/heating rate as practical with current MD and state of the art computers. Results including the change in the heat capacity - fragile to strong glass behavior - and liquid densification/expansion behavior are investigated. Liquid properties including thermal expansion and heat capacity and relaxation properties that cannot be measured experimentally are obtained for use in our finite-element model.

Tridimensionnal multiphysical model for the study of photo-induced thermal effects in laser damage phenomena

M. Commandré, G. Demesy, L. Gallais, Institut Fresnel (France)

Primary Author Biography:
Mireille Commandré is a professor at the Ecole Centrale Marseille. At the Fresnel Institute (UMR CNRS 6133) she is currently head of research team "High power photonics and random media". Her research interests include laser damage, thermal properties, optical characterization and optical thin film deposition techniques.

ABSTRACT TEXT:
Nano-sized absorbing defects take a part in the initiation of laser damage phenomena especially in the nanosecond range of pulse duration. A special interest has been devoted to the modelling of photo-induced thermal effects in order to get a better understanding of the laser damage mechanisms and many 1D models have been presented. In this paper we present a 3D model based on the FEM method (Finite Elements) which allows the calculation of 3D temperature distribution in nanostructures with complex geometries irradiated by a laser. We present examples of application of the method in the field of laser damage, such as the case of two spheres of hafnium embedded in hafnium dioxide. The purpose of these examples is to show the relevance of taking into account as precisely as possible the full opto-thermal and geometric characteristics of a system.

Keywords: laser damage mechanisms, photoinduced thermal effects, Finite element method, multiphysical model, nano defects

Fundamental Mechanisms

10.40 to 11.40 and 15.00 to 16.00

Femtosecond laser damage and ablation of dielectrics: determinism, selectivity and nanometric resolution, Nicolas Sanner, Olivier P. Uteza, Benoit Chimier, Arnaud Brocas, Nadezda Varkentina, Marc L. Sentis, Lasers, Plasmas et Procédés Photoniques (France); Philippe Lassonde, François Légaré, Jean-Claude Kieffer, Institut National de la Recherche Scientifique (Canada). [7842-03]

Temperature dependence of nonlinear optical phenomena in silica glasses, Katsuhiro Mikami, Shinji Motokoshi, Masayuki Fujita, Takahisa Jitsuno, Masakatsu Murakami, Osaka Univ. (Japan). . . . . [7842-04]

3D morphology of laser-induced bulk damage in KDP crystal with different orientations, Guohang Hu, Hongji Qi, Hongbo He, Dawei Li, Yuanan Zhao, Jianda Shao, Zhengxiu Fan, Shanghai Institute of Optics and Fine Mechanics (China). . . . . [7842-05]

Calculation and measurement of fs-LIDT of $Ti_xSi_{1-x}O_2$ mixtures, Marco Jupé, Lars O. Jensen, Mathias Mende, Detlev Ristau, Laser Zentrum Hannover e.V. (Germany); Luke A. Emmert, Wolfgang Rudolph, Duy Nguyen, The Univ. of New Mexico (United States); Andrius Melninkaitis, Valdas Sirutkaitis, Vilnius Univ. (Lithuania) . . . . [7842-06]

KDP crystal orientation influence on the nanosecond laser-induced damage at 1064 nm, Stéphane Reyné, Guillaume Duchateau, Commissariat à l'Énergie Atomique (France); Jean-Yves Natoli, Institut Fresnel (France); Laurent Lamaignère, Commissariat à l'Énergie Atomique (France). . . . . [7842-07]

Femtosecond pulse S on 1 LIDT in dielectric materials: comparison of experiment and theory, Luke A. Emmert, Mark Mero, Duy N. Nguyen, Wolfgang Rudolph, The Univ. of New Mexico (United States); Dinesh Patel, Erik M. Krous, Carmen S. Menoni, Colorado State Univ. (United States) . [7842-08]

Detonation regimes of optical discharge propagation in silica-based optical fibers, Vladimir E. Fortov, Vladimir P. Efremov, Institute for High Energy Densities (Russian Federation); Eugeny M. Dianov, Igor A. Bufetov, Artem A. Frolov, A.M. Prokhorov General Physics Institute (Russian Federation)[7842-09]

Extreme nonlinear optics and laser damage, Evaldas K. Maldutis, The General Jonas Zemaitis Military Academy of Lithuania (Lithuania) . . . . [7842-87]

Thin Films

10.40 to 11.40 and 15.00 to 16.00

Laser-induced damage threshold of 266 AR coatings with different coating designs, Byungil Cho, Edward J. Danielewicz, J. Earl Rudisill, Newport Corp. (United States) . . . . [7842-10]

Laser damage resistance of dichroic mirrors at 532nm and 1064nm, Xinbin Cheng, Tao Ding, Zhengxiang Shen, Hongfei Jiao, Jinlong Zhang, Bin Ma, Zhanshan Wang, Tongji Univ. (China) . . . . [7842-11]

Effects of electric field distribution and pulse durations on the ultra-short pulse laser damage resistance of laser coatings, Shunli Chen, Meiping Zhu, Dawei Li, Hongbo He, Yuanan Zhao, Jianda Shao, Zhengxiu Fan, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [7842-12]

LIDT of HfO_2/SiO_2 HR films by different test modes at 1064nm and 532nm, Bin Ma, Tao Ding, Hongfei Jiao, Gang Zhou, Zhengxiang Shen, Xinbin Cheng, Jinlong Zhang, Tongji Univ. (China); Huasong Liu, Yiqin Ji, Tianjin Jinhang Institute of Technical Physics (China); Pengfei He, Zhanshan Wang, Tongji Univ. (China) . . . . [7842-13]

Database on laser-induced damage thresholds for AR and HR coatings in Japan, Shinji Motokoshi, Katsuhiro Mikami, Takahisa Jitsuno, Kota Kato, Osaka Univ. (Japan) . . . . [7842-14]

Influence of cleanliness on weak absorption and laser-induced damage of HR coatings at 1064 nm, Zhengxiang Shen, Tao Ding, Xiaodong Wang, Xiaowen Ye, Bin Ma, Xinbin Cheng, Tongji Univ. (China); Huasong Liu, Yiqin Ji, Tianjin Jinhang Institute of Technical Physics (China); Zhanshan Wang, Tongji Univ. (China) . . . . [7842-15]

Optical properties and LIDT of AR coatings on LBO crystals, Rytis Buzelis, Institute of Physics (Lithuania); Giedrius Abromavicius, Institute of Physics (Lithuania) and Optida Co., Ltd. (Lithuania); Ramutis Drazdys, Kestutis Juskevicius, Simonas Kicas, Institute of Physics (Lithuania); Kai Starke, Wjatscheslaw Sakiew, Lars O. Jensen, Marco Jupé, Detlev Ristau, Laser Zentrum Hannover e.V. (Germany) . . . . [7842-16]

Exposure of high-reflecting fluoride coatings under high fluence conditions at 193nm, Holger Blaschke, Laser Zentrum Hannover e.V. (Germany); Werner Riggers, Laseroptik GmbH (Germany); Detlev Ristau, Laser Zentrum Hannover e.V. (Germany) . . . . [7842-17]

N on 1 testing of AR and HR designs at 1064 and 355 nm, Wolfgang Riede, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Jon H. Herringer, Arrow Thin Films, Inc. (United States); Paul Allenspacher, Alessandra Ciapponi, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Jon W. Arenberg, Northrop Grumman Aerospace Systems (United States). . . . . [7842-18]

Investigation of laser damage in single layer coatings with pulse durations from 45fs to 24ps, Benoit Mangote, Laurent Gallais, Institut Fresnel (France); Andrius Melninkaitis, Julius Mirauskas, Vilnius Univ. (Lithuania); Myriam Zerrad, Institut Fresnel (France); Maksim Jeskevic, Valdas Sirutkaitis, Vilnius Univ. (Lithuania); Mireille Commandré, Institut Fresnel (France) . . . . [7842-19]

Stress compensation in HfO_2/SiO_2 multilayer by ion assisted electron beam evaporation, Tao Ding, Hongfei Jiao, Bin Ma, Jinlong Zhang, Zhengxiang Shen, Xinbin Cheng, Zhanshan Wang, Tongji Univ. (China) . . . . [7842-20]

7842-03, Poster Session

Femtosecond laser damage and ablation of dielectrics: determinism, selectivity and nanometric resolution

N. Sanner, O. P. Uteza, B. Chimier, A. Brocas, N. Varkentina, M. L. Sentis, Lasers, Plasmas et Procédés Photoniques (France); P. Lassonde, F. Légaré, J. Kieffer, Institut National de la Recherche Scientifique (Canada)

PRIMARY AUTHOR BIOGRAPHY:

Nicolas Sanner received a MS in Physics, an Engineer diploma in Optics (2002) and a PhD on adaptive laser beam shaping for laser-matter interaction (2005).He is now Assistant-Professor at the University of Méditerranée (France), where he carries researches in the field of femtosecond-laser - matter interaction and its applications.

ABSTRACT TEXT:

Industrial implementation of laser-based micromachining applications requires the characterization of the material response to different levels of laser exposure, ranging from laser damaging evaluation for laser technology purposes to determination of laser ablation characteristics for micromachining processes. With this twofold objective, we present here a systematic study of laser damage and ablation of a dielectric material in the femtosecond range, under a wide excursion of pulse duration (< 10 fs to 450 fs) and applied fluence (Fth < F < 10 Fth). To provide valuable information on the effective ionization mechanisms and to progress towards accuracy and predictability of the material behaviour exposed to femtosecond laser irradiation, the precise experimental knowledge and comprehensive analysis of both damage and ablation thresholds are essential. We therefore introduce dedicated procedures and methodologies [1] to accurately distinguish and determine the laser-induced damage (irreversible alteration of the surface) and ablation (removal of matter) fluence thresholds of fused silica.

Experimental measurement of the determinism strength of material damage is provided by the study of evolution of the two damage thresholds (high-threshold and low-threshold) with pulse duration. In particular, we demonstrate that laser damage occurrence tends to be dramatically deterministic for few-cycle pulses (7 fs), which is attributed to the increasing importance of tunneling ionization as the major channel for the generation of free-carriers in the conduction band [2]. Our approach also provides important information for micro- and nano- machining applications by assessing pertinent “processing fluence ranges”.

Strong determinism is also associated to an abrupt decrease of both damage and ablation thresholds, making possible the ablation of materials with unprecedented precision. Our investigations provide knowledge over important laser ablation parameters on micrometer scale in dielectrics like removed volume, thickness, processed diameter and resultant shape and expected efficiency as a function of applied laser intensity using single shot femtosecond pulse (7 - 450 fs). In particular, we show that it is possible to access different ranges of axial selectivity or resolution (crater depths) with a precision of ~10 nm by selecting different pulse durations while the transverse selectivity or resolution (crater diameter) only depends on the applied fluence. Calibrated controlled removal of small amounts of material is more easily accessed with ultrashort pulses (30 fs) but at the expense of the magnitude of the removal versatility. Moreover, selective crater morphology, e.g. Gaussian-like to top-hat micrometer crater, can be obtained without recourse to any additional spatial shaping system (as a consequence, without any supplementary cost and complexity) only by varying the applied intensity on the material. These results can serve as a dimensioning basis for the choice of laser parameters in the frame of industrial development of micromachining processes.

Keywords: Laser-induced damage, Ablation, ultrashort pulses

Temperature dependence of nonlinear optical phenomena in silica glasses

K. Mikami, S. Motokoshi, M. Fujita, T. Jitsuno, M. Murakami, Osaka Univ. (Japan)

PRIMARY AUTHOR BIOGRAPHY:
Katsuhiro Mikami was born in 1986. He is student of master course in Osaka University.

ABSTRACT TEXT:
Previously, the results were reported that The laser-induced damage thresholds in silica glasses at different temperature conditions (123 K - 473 K) by Nd:YAG laser fundamental and third harmonic 4 ns pulses were measured. As the results, the damage thresholds increased at low temperature. At 1064 nm, the temperature dependence became strong by the concentration of impurities. However, at 355 nm, the temperature dependence of almost sample was constant. In the discussion, there were many questions about the reason for temperature dependence of LIDTs and effects of temperature to the non-linear optical phenomena, especially self focusing. In fact, various nonlinear phenomena are known in silica glasses besides the damage in high intensity. It is necessary to clear the temperature dependences of nonlinear optical phenomena.

Temperature dependences of the stimulated Brillouin scattering (SBS) in silica glasses at temperature 173 K to 473 K with single-mode Q-switched Nd:YAG laser fundamental wave were measured. The silica glass sample supported by a copper holder was set in the vacuum chamber (~50 mTorr) to prevent water condensation. Then, the temperature was adjusted by liquid nitrogen and a heater. And, in the SBS measurement, the incidental laser was focused by the lens (f=100) and the SBS signal from the silica glass sample was detected by biplaner phototube.

The temperature dependence of SBS thresholds were increased with decreasing temperature. We also plan to observe the temperature dependence of the self focusing. The relationships between temperature dependence of LIDTs and nonlinear optical phenomena will be discussed at the meeting.

Keywords: Laser-induced damage, Silica glass, Temperature dependence, Self focusing, Stimulated Brillouin scattering

7842-05, Poster Session

3D morphology of laser-induced bulk damage in KDP crystal with different orientations

G. Hu, H. Qi, H. He, D. Li, Y. Zhao, J. Shao, Z. Fan,
Shanghai Institute of Optics and Fine Mechanics (China)

PRIMARY AUTHOR BIOGRAPHY:
Guohang Hu is a PhD candidate at Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences. His current research interests include laser-induced damage to KDP crystals.

ABSTRACT TEXT:
In this study, wet etch process was applied to expose the bulk damage site to surface, which gave us the direct access to the modified material for scanning electron microscopy (SEM), Raman spectroscopy and X-ray diffraction (XRD). And then the 3D morphology of laser induced bulk damage in KDP crystals with different orientations, such as Z-cut, X-cut, double-cut, and triple-cut, was investigated. It is found that the morphology consisted of three distinct regions: a core, some oriented cracks, and a region of modified material. The core was empty, or filled with broken material. And the crack angles to the crystal axis were almost the same in the crystal with the same orientation. Micro-Raman spectroscopy and XRD were applied to analyze the material composition of the damage sites. All of these results help us understand the fundamental mechanism of laser interaction with KDP crystal, which is an anisotropic material.

Keywords: laser induced damage, KDP crystal, damage morphology

Calculation and measurement of fs-LIDT of $Ti_xSi_{1-x}O_2$ mixtures

M. Jupé, L. O. Jensen, M. Mende, D. Ristau, Laser Zentrum Hannover e.V. (Germany);
L. A. Emmert, W. Rudolph, D. Nguyen, The Univ. of New Mexico (United States);
A. Melninkaitis, V. Sirutkaitis, Vilnius Univ. (Lithuania)

ABSTRACT TEXT:
In the ultra short laser pulse regime, the damage process is driven by the interaction of the laser pulse with the electronic structure of the material. The way of excitations in dielectric materials is dominated by multi photon and avalanche ionization processes. Often, the complete theoretical description is limited by the lack of knowledge of the precise material properties. Usually, LIDT measurement data are only available for pure materials (e.g. TiO_2, Ta_2O_5 or SiO_2). The development of composite materials opens the way to vary material properties, continuously. Additionally, all material changes are based on the same chemical elements in different compositions.

The paper compares measurement results of the University of New Mexico and Vilnius University performed on the same set of $Ti_xSi_{1-x}O_2$-mixtures to calculations based on Keldysh theory. When applying simple approximations for the physical properties of the mixture, the theoretical description agrees well with the measurement results.

Keywords: Fs-LIDT, Mixture materials, Keldysh theory, MRE Model

KDP crystal orientation influence on the nanosecond laser-induced damage at 1064 nm

S. Reyné, G. Duchateau, Commissariat à l'Énergie Atomique (France); J. Natoli, Institut Fresnel (France); L. Lamaignère, Commissariat à l'Énergie Atomique (France)

ABSTRACT TEXT:
We investigate the influence of THG-cut KDP crystal orientation on laser damage at 1064 nm under nanosecond pulses. This study makes a connection between precursor defects and the influence of their orientation on the laser damage. Previous investigations have already been carried out in various crystals and particularly for KDP, indicating propagation direction and polarization dependences. We performed experiments for two orthogonal positions of the crystal and results clearly indicate that KDP crystal laser damage depends on its orientation. We carried out further investigations on the effect of the polarization orientation, by rotating the crystal around the propagation axis. We then obtained the evolution of the damage probability as a function of the rotation angle. To account for these experimental results, we propose a model based on heat transfer, the Mie theory and a Drude model. The geometry of the precursor defects is assumed to be ellipsoid-shaped and we numerically introduce absorption efficiency calculations for this geometry. Modeling simulations are in good agreement with experimental results.

Keywords: KDP crystal, precursor defects, nanosecond laser-induced damage

Femtosecond pulse S on 1 LIDT in dielectric materials: comparison of experiment and theory

L. A. Emmert, M. Mero, D. N. Nguyen, W. Rudolph, The Univ. of New Mexico (United States); D. Patel, E. M. Krous, C. S. Menoni, Colorado State Univ. (United States)

ABSTRACT TEXT:
The femtosecond S-on-1 LIDT of dielectric materials (coatings) depends on the number of pulses (S) incident upon the same sample spot. The threshold fluence F decreases monotonically until it reaches a saturation level. It has been well established that the single-pulse damage threshold results from an interplay of multiphoton and impact ionization of the valence band. The multiple-pulse damage threshold is explained by the accumulation of electrons in midgap states by the pulses preceding damage, which are then subsequently ionized and contribute to the ensuing avalanche process.

We developed a comprehensive kinetic model that takes into account relaxation of electrons to the valence band through midgap states. The model groups the midgap states into shallow and deep levels. Shallow states are those near the conduction band and require just one photon for ionization. Deep states require two or more photons for ionization. In addition, deep traps can be pre-existing states, resulting from the coating process, or created by the laser excitation. The creation of these laser-induced states is modeled on the formation of color centers in dielectric materials. A small fraction of the electrons that are excited to the conduction band with each pulse create permanent deep states.

This model is used to explain the multiple (S) pulse damage behavior of hafnia films for different deposition and excitation conditions. The shape of F(S) at short pulse duration (<100 fs) is explained by the slow accumulation of laser-induced deep states. At long pulse duration (1 ps), the F(S) curve is dominated by the rapid saturation of shallow traps after the first laser pulse. Relaxation time constants for the model can be extracted from damage tests with two blocks of pulses with a variable time delay. The model suggests that nitrogen doping reduces the change from F(1) to F(∞), which is in agreement with experiments.

Keywords: LIDT, subpicosecond laser, modeling, laser-induced defects, dielectric materials

Detonation regimes of optical discharge propagation in silica-based optical fibers

V. E. Fortov, V. P. Efremov, Institute for High Energy Densities (Russian Federation);
E. M. Dianov, I. A. Bufetov, A. A. Frolov,
A.M. Prokhorov General Physics Institute (Russian Federation)

ABSTRACT TEXT:
Laser-induced optical fibers core damage remains a limiting factor both of energy transport and of materials of optical fiber laser amplifiers. Damage propagation as a function of carried energy density has two distinguished mode (burning and detonation). The fast and most catastrophic mode is the laser driven detonation. Destruction wave propagation with high velocities (~3 km/s) through the core of silica-based fiber under intensive laser radiation has been investigated. Such regimes were detected at all investigated core diameters of silica-based fibers (Dc ~1.5-10μ). Plasma and destruction waves in optical fibers were recorded at laser beam intensity up to ~40 W/μ2 with camera exposition time 2ns for the first time. Dense plasma propagation takes place together with movement of cracks zone at investigated energy densities in core. Measurements of temperatures for both “start-stop” points and process of propagation were carried out.

Extreme nonlinear optics and laser damage

E. K. Maldutis, The General Jonas Zemaitis Military Academy of Lithuania (Lithuania)

ABSTRACT TEXT:
The peculiarities of the nonlinear processes in transparent materials upon impact of intensive laser pulses are analyzed where it is shown that nonlinear optical phenomena in extreme conditions of interaction (i.e. when laser radiation intensity is close but less than the threshold of laser damage of material from the first pulse) are different from the traditional nonlinear optical processes. The presented experimental results show that nonlinear optical processes depend not only on intensity of electromagnetic field of laser radiation, but on the pulse number in series of laser pulses as well. The study of these process dynamics provides new information about the properties of the materials.

Role of extreme non-linear optical phenomena in interaction of femtosecond laser pulses with transparent optical material is discussed.

Laser-induced damage threshold of 266 AR coatings with different coating designs

B. Cho, E. J. Danielewicz, J. E. Rudisill, Newport Corp. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Byungil Cho: Senior Thin Film Scientist, Newport Corporation, Irvine, California. He has experience in thin film materials science and engineering, microstructure-property relationships and coating processes. He received the BS and MS degrees from Yonsei University, Seoul, Korea and received a PhD from the Univ. of Texas at Austin in 1994.

ABSTRACT TEXT:

The laser induced damage thresholds (LIDT), N-on-1 test at 266 nm, were measured for the 2-layer and the 4-layer antireflection (AR) coating designs on fused silica. LIDT values for the 2-layer AR coating exhibited a constant level with increased number of laser pulses over a wide range of number of pulses. LIDT values for the 4-layer AR coating decreased relatively rapidly in comparison. The projected lifetime of the 2-layer coating design was thus determined to be longer than that of the 4-layer design. The following measurements: examination of laser damaged surface morphologies, analysis of X-ray diffraction patterns, review of physical and mechanical constants of coating materials, evaluation of optical performance with variances in coating designs were carried out to explain the observed LIDT performance differences.

Keywords: 266 nm, antireflection coating, N-on-1 test, LIDT, lifetime, surface morphologies, coating materials, coating design

7842-11, Poster Session

Laser damage resistance of dichroic mirrors at 532nm and 1064nm

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

PRIMARY AUTHOR BIOGRAPHY:

Dr. Xinbin Cheng got the PHD degree in optics at Tongji University. He has done research on the X-ray multilayers and gradient-index optical films during the doctoral period. His current research focuses on the design, fabrication and characterization of laser coatings.

ABSTRACT TEXT:

HfO_2/SiO_2 dichroic mirrors were prepared using reactive electron beam evaporation process. The mirrors have high reflectance at 532 nm (S polarization) and high transmittance at 1064 nm (P polarization) for angle of incidence of 45º. The absorption at 1064 nm in HfO_2/SiO_2 dichroic mirrors was measured using a photothermal common path interferometry. The average absorption of HfO_2/SiO_2 dichroic mirrors is less than 20 ppm. The laser induced damage thresholds (LIDT) of the dichroic mirrors were tested using a nanosecond pulsed YAG-laser and the damage morphologies were analyzed using Nomarski microscope and scanning electron microscope. Here we reported the laser damage resistance of the dichroic mirrors that were irradiated by 532 nm and 1064 nm laser pulse separately. The effects of two wavelength radiation on the laser damage resistance of the dichroic mirrors are still under investigations. For the deposited dichroic mirrors, micrometer-sized nodular defects are the primary LIDT limiting factors for both 532 nm and 1064 nm pulse laser radiation. The nodules are more sensitive to the 532 nm laser illumination and are ejected easily at lower fluence. Plasma scald frequently happens when the 1064 nm laser fluence is higher than $40J/cm^2$, but there is almost no visible plasma scald before the dichroic mirrors are damaged catastrophically by 532 laser pulse. The measurement results showed that the laser induced damage threshold at 532 nm is less than one third of the one at 1064 nm and is the actual performance limiting factor for the application of the dichroic mirrors.

Keywords: Thin films, Dichroic mirrors, Laser damage, 1064 nm, 532 nm

7842-12, Poster Session

Effects of electric field distribution and pulse durations on the ultra-short pulse laser damage resistance of laser coatings

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Shanghai Institute of Optics and Fine Mechanics (China)

PRIMARY AUTHOR BIOGRAPHY:
Shunli Chen is a PhD candidate at Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences. His current research interests include laser-induced damage under ultra-short pulse.

ABSTRACT TEXT:
In this paper, two kinds of multilayer HfO_2/SiO_2 high reflectors, one with standard 1/4 wavelength design and the other with modified electric field design, were prepared by electron beam evaporation. A femtosecond laser system, central wavelength at 800nm and pulse durations varying from 50fs to 500fs, was employed to investigate the laser-induced damage behaviors of these two kinds of coatings. Optical and AFM microscopes were also applied to investigate morphology and structural information of the damaged sites. Comparison of the Laser induced damage thresholds (LIDTs) of these two kinds of coatings, the appearance indicates that reducing electric field at layer interface can improve the LIDT of multilayer, which shows certain dependency on pulse width. Significantly, the efficiency of enhancing LIDTs by modification of electric field distribution seems to vary with pulse durations. So, diverse roles of several conceivable ionization mechanisms played in the damage process were discussed in order to explain this phenomenon.

Keywords: ultra-short laser, laser induced damage, laser coating

LIDT of HfO_2/SiO_2 HR films by different test modes at 1064nm and 532nm

B. Ma, T. Ding, H. Jiao, G. Zhou, Z. Shen, X. Cheng, J. Zhang, Tongji Univ. (China);
H. Liu, Y. Ji, Tianjin Jinhang Institute of Technical Physics (China);
P. He, Z. Wang, Tongji Univ. (China)

PRIMARY AUTHOR BIOGRAPHY:
Bin Ma has graduated from physics department in 2004, and obtained his PhD in Optics in 2009. Now he is a post-doctor in School of Aerospace Engineering and Applied Mechanics in Tongji University. He researches on the detecting of subsurface quality and laser induced damage threshold (LIDT) test of optical elements.

ABSTRACT TEXT:
Laser induced damage threshold (LIDT) of optical elements limits its application in high power laser fields. In order to obtain the credible LIDT to evaluate the performance, several test methods have been developed, and the influence of different experimental parameters are analyzed in detail. In this work, the LIDT of HfO2/SiO2 HR films by 1-on-1, S-on-1, R-on-1 and raster scan test modes at 1064nm and 532nm are studied, two types HfO2/SiO2 films are fabricated by reactive electron beam evaporation process which have high reflectance at 1064 nm and 532 nm for P polarization at angle of incidence of 45° respectively. The damage experiment is carried out using a 10 ns for 1064nm and 8 ns for 532 nm pulsed Nd:YAG laser with a repetition rate of 10 Hz, the beam diameter is about 1 mm at 1/e2 of peak intensity, the test points are inspected by an in situ 45X magnification microscope, and verified by an off-line 200X Normaski microscope. Damage is defined as the fluence where damage sites grow upon repeated illumination. All the results are scaled to 1 ns.

It shows that the conditioned test modes, R-on-1 and raster scan, usually have a lager value than unconditioned modes, 1-on-1 and S-on-1, at both 1064 nm and 532 nm. Due to the ramp step illumination, the ideal laser conditioning effect is achieved, so R-on-1 mode gives the maximum value. Moreover, there isn't obvious difference between the 1-on-1 and S-on-1 modes at 1064 nm, but things have changed at 532 nm, S-on-1 mode presents the lowest value. Finally, the raster scan mode has been studied in detail, the influence of scan step in determination of LIDT is discussed, and the relationship between scan parameters and conditioning effect are given.

Keywords: HfO_2/SiO_2, LIDT, laser conditioning, 1-on-1, S-on-1, R-on-1, raster scan

Database on laser-induced damage thresholds for AR and HR coatings in Japan

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PRIMARY AUTHOR BIOGRAPHY:
Primary author is chief researcher at Institute for Laser Technology in Japan. He has developed of high-power lasers and optics for the lasers.

ABSTRACT TEXT:
In Institute for Laser Technology, the measurements of LIDT for optics required from Japanese makers have been opened, by jointing with Osaka university, since 2005. We have been required from about 20 makers and estimated over 100 samples every year. Although the LIDT of each sample was cleared, that of the optics for the other makers was not. The many makers didn't have the goals to improve their samples. For users, the information of LIDTs is also a very important parameter to use the optics and to design the laser systems. The users will desire the comparable data of LIDTs for the using optics.

We had the competitions of LIDT for HR and AR coatings at 1064 nm in 2008s and at 532 nm in 2009s, in cooperation with Japanese optics makers.

In HR coatings for 1064 nm, the highest LIDT of samples was reached to about 300 J/cm^2 (at 10 ns) which was nearly equal to the LIDT in bulk of silica glass. 10 smples for 5 makers had also the LIDTs over than 130 J/cm^2 that was the LIDT of surface for conventional polished silica glass. However, the LIDTs of most samples were leaned toward lower than 60 J/cm^2. As results, it could be considered that over 100 J/cm^2 was a milestone to improve the LIDT for HR coatings at 1064 nm.

Keywords: Damage threshold, Database, HR coating, AR coating

Influence of cleanliness on weak absorption and laser-induced damage of HR coatings at 1064 nm

Z. Shen, T. Ding, X. Wang, X. Ye, B. Ma, X. Cheng, Tongji Univ. (China); H. Liu, Y. Ji, Tianjin Jinhang Institute of Technical Physics (China); Z. Wang, Tongji Univ. (China)

PRIMARY AUTHOR BIOGRAPHY:
Zhengxiang Shen, was born in 1980 and received his PHD in optics from Tongji University, China, in 2008. He is now a teacher lecturer in Institute of Precision Optical Engineering and Department of Physics, Tongji University. His primary interest of study and research focuses on optical fabrication, cleaning technique and optical test.

ABSTRACT TEXT:
The contaminations such as dusts, particles, and organic compound, which are inevitably left on the surface, will affect scattering and act as nuclei for defects in optical coatings. Furthermore, the contaminations will also degrade the performance of the final product by thermal absorption, premature failure in oscillating components, and a reduction in the laser induced damage threshold (LIDT) of high energy optics. It is already a challenge to prevent damage of clean optics under intense laser illumination. In this paper, influence of substrate cleanness on weak absorption and LIDT of HfO_2/SiO_2 high reflecting coatings at 1064 nm is studied.

To investigate the cleaning effect on the roughness of substrate, fused silica substrates (ϕ30×5 mm) are used. The ultrasonic cleaning technique is employed to remove the contaminations on the substrates, and two cleaning process with different solutions (the acid and alkaline solution, and surfactant solution, respectively) are selected. For the determination of the cleaning effect, atomic force microscope (AFM) and dark field microscope is used as quantitative and qualitative methods. Then HfO_2/SiO_2 HR film at 1064nm have been deposited, and damage testing is performed in the '100-on-1' regime, by an automatic Nd:YAG laser test system. The weak absorption of surface is measured by Surface Thermal Lensing technique, and morphologies of defects and laser-induced damage were characterized by Differential Interference Contrast (DIC) microscope and scanning electron microscope (SEM), respectively.

Experiment shows different cleaning processes have different effects on the weak absorption and LIDT of the thin film at 1064nm. The substrate cleaning has no influence on its intrinsic absorption, but has great influence on weak absorption of contamination of the thin film. The smaller sizes and less density of particles distributed on the substrate after efficiently cleaning, the lower absorption peak for contamination on the film, and the less peak number, correspondently the higher laser-induced damage threshold of optical thin-film. Finally, the LIDT of HR film reaches as high as about 38J/cm^2, (the width of the laser pulse is 10ns). It is owing to the sufficient cleanness of removing the micrometer-sized nodular defects on the surface, which is a key factor accounted for the laser-induced damage of high reflecting thin film at 1064nm.

Keywords: cleanliness, weak absorption, laser damage, HR film

Optical properties and LIDT of AR coatings on LBO crystals

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ABSTRACT TEXT:
Non-linear crystal LBO (LiB3O5) is widely used in many Nd:YAG and Nd:YLF laser related applications for generation of the second and third harmonics. One of the most important issues related to efficient LBO application is coating the crystal with single and dual wavelength AR coatings (AR@ 532+1064, AR@ 355) having required laser induced damage threshold (LIDT) and optical properties.

The aim of this work is to investigate ion beam sputtered AR coatings (AR@ 532+1064, AR@ 355), having different designs with ZrO_2, Al_2O_3, SiO_2 and other oxide materials, their mixtures, and optimize their optical, and laser resistance properties. Of special interest is the influence of gradient refractive index profiles on the damage resistance. Besides the spectral properties, the resistance against laser damage is characterized at 355 and 532nm considering practically relevant test parameters. For getting a deeper insight into the damage behavior, the LIDT of LBO crystals and test samples are investigated with regard to their absorptance and defect density, for which laser calorimetry and fast scanning total scattering measuring techniques are employed.

Keywords: Ion beam sputtering, mixture materials, LBO coatings

Exposure of high-reflecting fluoride coatings under high fluence conditions at 193nm

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PRIMARY AUTHOR BIOGRAPHY:

Holger Blaschke received his diploma degree in physics in 1996 from Univ. of Jena, with a thesis written at the Institute of Optics and Quantumelectronics. After a working period at the Fraunhofer Institute Jena (IOF) he joined the Laser Zentrum Hannover (LZH) in 1999 where he currently leads the Characterization group. His research activities cover projects in optics characterization and instrumentation as well as the generation and propagation of laser radiation from the XUV/EUV to the mid infrared range.

ABSTRACT TEXT:

The power-handling capability of optics for micromachining devices, illumination modules, and beam shaping units for research applications in the spectral range below 200 nm is strongly influenced by the large number of possible interaction phenomena of UV photons and the involved material. Generally, fluorides are preferred for substrates and functional coatings at moderate and high fluences.

Especially for the intensive radiation of the ArF laser at 193 nm, the improvement of fluoride multilayer stacks, particularly with regard to optimized long-term performance, is still connected to the quest for the best material combination.

The paper presents results of investigations on evaporated LaF_3/MgF_2 and LaF_3/AlF_3 high-reflecting multilayers deposited on super-polished CaF_2 substrates. In addition to typical spectroscopic inspections up to the band edge of fluoride substances in the VUV spectral range, the work is dedicated to the determination of absorption losses at 193 nm and the test of laser-induced damage threshold at moderate pulse numbers. Further on, dose dependent irradiation tests are performed well below the fluence level of damage onset indicating significant changes for the spectral transfer functions. These experimental observations are discussed in order to find a correlation to the characteristic damage behaviour of both material combinations.

Keywords: 193nm, fluoride coatings, absorption, laser-induced damage, dose effects, ISO 11254-2, ISO 11551

N on 1 testing of AR and HR designs at 1064 and 355 nm

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J. H. Herringer, Arrow Thin Films, Inc. (United States); P. Allenspacher,
A. Ciapponi, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany);
J. W. Arenberg, Northrop Grumman Aerospace Systems (United States)

PRIMARY AUTHOR BIOGRAPHY:

Wolfgang Riede studied physics at the University of Stuttgart, Germany and at the Swiss Federal Institute of Technology (ETH), Zurich, Switzerland. Currently, he is scientist and head of a group involved with optics qualification and adaptive optics at the Institute of Technical Physics, DLR (German Aerospace Center) in Stuttgart. His main interests and working areas are laser damage, laser-induced contamination, and imaging and tracking systems.

ABSTRACT TEXT:

This poster presents test results and involved procedures of a comprehensive test campaign for N on 1 testing of laser optics at wavelengths of 1064 nm and 355 nm. The purpose of the campaign is to gather experimental data for an empirical study of the lifetime of laser optics*.

The optics are designed to operate as anti-reflective or high-reflective at the respective test wavelengths for 0° angle-of-incidence. Both, coatings and substrates (of 2.0 inch diameter) are produced from the same batches to be as identical as possible. There were two different coating technologies used, e-beam and IAD e-beam to explore an effect under vacuum operation.

The laser damage test bench used is operated with a laser source delivering laser pulses in a single longitudinal mode at a repetition frequency of 100 Hz. The beam profile is of a Gaussian-shape and of high spatial quality at the fundamental Nd:YAG laser wavelength and at 355 nm with a pulse duration of 3,5 ns at 1064 nm. Typical beam diameters on the samples were 600 µm (1064 nm) and 300 µm (355 nm), and usually more than 100 test sites are irradiated in one test, to achieve statistical significance. The laser test procedure itself is adapted from the ISO standard 11254-2 for multiple pulse irradiation, and the LIDT evaluation is done accordingly.

The samples are tested under air and vacuum conditions, for comparative purposes, in so-called split areas tests using the same samples. The samples are exposed to vacuum by dynamic evacuation of a stainless-steel chamber with a 2-stage vacuum pump system consisting of an oil-free membrane fore-pump and a main turbo molecular pump.

* An Empirical Investigation of the Laser Survivability Curve, Arenberg et al, these proceedings

Keywords: Laser damage testing, Laser optics qualification, N on 1 testing, Air-vacuum effect

Investigation of laser damage in single layer coatings with pulse durations from 45fs to 24ps

B. Mangote, L. Gallais, Institut Fresnel (France); A. Melninkaitis, J. Mirauskas, Vilnius Univ. (Lithuania); M. Zerrad, Institut Fresnel (France); M. Jeskevic, V. Sirutkaitis, Vilnius Univ. (Lithuania); M. Commandré, Institut Fresnel (France)

ABSTRACT TEXT:
In this paper we describe a series of experiments made on different laser installation at the Vilnius University Laser Research Center and Institut Fresnel in order to study the LIDT of thin films. Samples were single layers of several metal-oxyde materials, namely HfO_2, SiO_2, Nb_2O_5, made by using different deposition techniques : Electron Beam Deposition (EBD), EBD with Ion Assisted Deposition, Dual Ion Beam Sputtering. Four different laser damage set-ups have been used for this study involving near-infrared (1030nm/1064nm) pulses of 45fs, 300fs-700fs, 500-3ps and 24ps.

A model based on the conduction band electron rate equation will be presented for interpretation of measurements. This model is dedicated to the study of sub-ps laser damage in optical interference coating since it takes into account transient interference effects induced by changes in the refractive index during the laser pulse. The theoretical results will be compared to experiments, ie LIDT dependence with the deposition technique and pulse duration observed in the different samples.

7842-20, Poster Session

Stress compensation in HfO_2/SiO_2 multilayer by ion assisted electron beam evaporation

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

PRIMARY AUTHOR BIOGRAPHY:

Tao Ding has graduated from physics department of Yunnan university in 2002, and obtained his PhD degree in condensed matter physics from Fudan University in 2009. Now he is a post-doctor in physics department of Tongji University. He researches on the design and fabrication of optical coatings, characterizes the microstructure and physical properties of the thin films as well.

ABSTRACT TEXT:

HfO_2/SiO_2 high reflective mirrors for 1064nm were fabricated by electron beam evaporation method. The multilayer films were composed of $(LH)^{17}$ stacks on silica. The reflectivity was more than 99.5% for incidence angle 45°. The laser induced damage threshold was tested to be 53J/cm^2 (10ns pulse length) with R-on-1 mode. However, some cracks were found to appear in partial mirrors. The cracks were observed using scanning electron microscopy to detect the cross section, it was found the cracks crossed the whole multilayer and penetrated into the substrate. As the cracks were mainly caused by the excessive tensile stress, we decreased the deposition temperature from 200 to 125 in order to reduce the thermal stress of HfO_2 individual layers, however, the cracks could not be excluded completely.

Furthermore, we employed ion assistance deposition (IAD) method during the SiO_2 individual layers to enhance the compressive stress. According to choose proper IAD parameters, the high reflective mirrors with good flatness were fabricated, and the residual stress of the multilayer got controlled. More specifically, using of surface profiler the residual stresses of multilayer were measured to be –50Mpa and 6Mpa, under air and dry nitrogen atmosphere, respectively. More than 50Mpa difference mainly was contributed by the compressive stress due to the adsorption water molecules into the pores of the film. It demonstrated that the humidity of usage environment must be considered at the stress design. Finally, the damage threshold was tested to be 47J/cm^2 (10ns pulse length), just decrease slightly after the IAD employed.

Keywords: residual stress, multilayer, laser induced damage threshold, ion assistance deposition

07.30 to 08.20 **Poster Placement at NIST**
Poster authors for the Monday poster session are to set up their posters at this time.

08.20 to 10.00 • SESSION 5

Fundamental Mechanisms II

Session Chairs: **M. J. Soileau,** Univ. of Central Florida (United States);
Detlev Ristau, Laser Zentrum Hannover e.V. (Germany)

08.20: **Characterisation of contaminant plumes arising from laser solid target interactions**, James E. Andrew, Katherine A. Wallace, AWE plc (United Kingdom) . . . . [7842-33]

08.40: **Modeling of laser-induced damage in KDP crystals by nanosecond pulses: a hydrodynamic study**, Guillaume Duchateau, Commissariat à l'Énergie Atomique (France); Ludovic Hallo, Univ. Bordeaux 1 (France). . . . . [7842-34]

09.00: **Identification of the laser-induced damage mechanisms in KDP by coupling 355nm and 1064nm nanosecond pulses**, Stéphane Reyné, Guillaume Duchateau, Commissariat à l'Énergie Atomique (France); Jean-Yves Natoli, Institut Fresnel (France); Laurent Lamaignère, Commissariat à l'Énergie Atomique (France). . . . . [7842-35]

09.20: **Frequency dependence in the initiation of ultrafast laser-induced damage**, Jeremy R. Gulley, Kennesaw State Univ. (United States) . . . . [7842-36]

09.40: **The 'vacuum effect' of femtosecond LIDT measurements on dielectric films,** Duy N. Nguyen, Luke A. Emmert, Wolfgang Rudolph, The Univ. of New Mexico (United States); Dinesh Patel, Erik M. Krous, Carmen S. Menoni, Colorado State Univ. (United States) . . . . [7842-37]

10.00 to 10.40 • Tuesday Poster Overview

Poster authors are asked to give 2-minute/2-viewgraph overviews of their posters in the order they appear in the program.

10.40 to 11.40 • Poster Session and Refreshment Break

11.40 to 13.00 • SESSION 6

Mini-symposium: Fundamentals of Laser Ablation

Session Chair: **Klaus Sokolowski-Tinten,** Univ. Duisburg-Essen (Germany)

11.30: **Insight from molecular dynamics simulation into ultrashort-pulse laser ablation** *(Invited Paper)*, Herbert M. Urbassek, Technische Univ. Kaiserslautern (Germany) . . . . [7842-58]

12.10: **Short-pulse laser induced melting and ablation studied with time-resolved coherent XUV scattering**, Klaus Sokolowski-Tinten, Univ. Duisburg-Essen (Germany); Anton Barty, Deutsches Elektronen-Synchrotron (Germany); Sebastien Boutet, SLAC National Accelerator Lab. (United States); Uladzimir Shymanovich, Univ. Duisburg-Essen (Germany); Henry N. Chapman, Deutsches Elektronen-Synchrotron (Germany); Michael J. Bogan, SLAC National Accelerator Lab. (United States); Stefano Marchesini, Lawrence Berkeley National Lab. (United States); Stefan Hau-Riege, Lawrence Livermore National Lab. (United States); Nikola Stojanovic, Deutsches Elektronen-Synchrotron (Germany); Jörn Bonse, Bundesanstalt für Materialforschung und -prüfung (Germany); Yudi Rosandi, Herbert M. Urbassek, Technische Univ. Kaiserslautern (Germany); Raanan I. Tobey, Henri Ehrke, Univ. of Oxford (United Kingdom); Andrea Cavalleri, Stefan Düsterer, Harald Redlin, Deutsches Elektronen-Synchrotron (Germany); Mathias A. Frank, Lawrence Livermore National Lab. (United States); Sasa Bajt, Joachim Schulz, Deutsches Elektronen-Synchrotron (Germany); Marvin Seibert, Janos Hajdu, Uppsala Univ. (Sweden); Rolf Treusch, Deutsches Elektronen-Synchrotron (Germany); Christoph Bostedt, SLAC National Accelerator Lab. (United States); Mathias Hoener, Lawrence Berkeley National Lab. (United States); Thomas Moeller, Technische Univ. Berlin (Germany). . . . . [7842-59]

12.30: **Modeling of laser-induced ionization of solid dielectrics for ablation simulations: role of effective mass**, Vitaly E. Gruzdev, Univ. of Missouri-Columbia (United States) . . . . . . [7842-60]

12.50 to 14.00 • Lunch Break

Characterisation of contaminant plumes arising from laser solid target interactions

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

PRIMARY AUTHOR BIOGRAPHY:
Jim Andrew is a team leader in the plasma physics department at AWE plc.

ABSTRACT TEXT:
In preparation for experiments on the ORION laser facility, a number of experiments have been performed to characterise debris and shrapnel plumes arising from laser target interactions. These interactions may arise from the use of long [ns] pulse or short [ps] pulse laser beams with mainly solid targets. Plume characteristics depend on the target material and geometry. We will describe interactions with metal or polymer targets and geometries including planar foils, cylinders, wires, washers or complex combinations. Characterisation techniques were based mainly on glass witness plates or aerogel catchers with subsequent analysis by optical or electron microscopy, spectrophotometry, EDAX and image analysis. The implications for the contamination of target chamber optics and plasma diagnostics will also be discussed.

Keywords: Shrapnel, Debris, Plume, Metal, Polymer, Glass, Crater

Modeling of laser-induced damage in KDP crystals by nanosecond pulses: a hydrodynamic study

G. Duchateau, Commissariat à l'Énergie Atomique (France);
L. Hallo, Univ. Bordeaux 1 (France)

PRIMARY AUTHOR BIOGRAPHY:
Guillaume Duchateau earned his Ph'D in 2001. This work was devoted to the modelisation of the interaction of intense and ultra-short laser pulses with atoms. Between 2001 and 2005, he worked for a private company where he developed hydrodynamic schemes. From 2005, Guillaume Duchateau works at CEA. His main topic is the understanding of the laser-induced physical mechanisms leading to damage in KDP crystals.

ABSTRACT TEXT:
A model of laser-induced damage formation and growth in potassium dihydrogen phosphate crystals (KH2PO4 or KDP) irradiated by nanosecond laser pulses is addressed. The wavelength under consideration is 351 nm for which many experimental data are available in the literature. In our modelling approach, a damaged site is assumed to be initiated by a nanometric precursor defect. The latter allows an efficient absorption of the laser energy leading to the damage initiation. Then, the main expected features of the damage scenario are taken into account: the defect-assisted laser absorption and subsequent plasma formation and evolution, the plasma absorption, heat transfer and main hydrodynamic processes. All of these physical mechanisms are coupled in a self-consistent way. In these calculations, a crystal zone is assumed to damage since it undergoes high enough density variations.

Calculations shows that a nanometric precursor defect can effectively lead to damaged site of several tens of micrometers in size as observed experimentally. Also, we demonstrate the reliability of the long-standing assumption regarding the precursor defect size. Further, it is shown that the final damage size is due to the creation of a shock wave which occurs at the beginning of the interaction (less than 100 picoseconds).

The model predictions are compared to various published results as those of Carr et al [Appl. Phys. Lett. 89, 131901 (2006)]. Modeling results show similar trends and are in a good agreement with many experimental observations. In particular, a complex morphology of the damaged site exhibiting three distinct regions is obtained and explained. A linear evolution of the damaged area with respect to the laser energy density is also obtained.

Keywords: laser damage, KDP, model, hydrodynamics

Identification of the laser-induced damage mechanisms in KDP by coupling 355nm and 1064nm nanosecond pulses

S. Reyné, G. Duchateau, Commissariat à l'Énergie Atomique (France); J. Natoli, Institut Fresnel (France); L. Lamaignère, Commissariat à l'Énergie Atomique (France)

PRIMARY AUTHOR BIOGRAPHY:

Stéphane Reyné obtained his MSc and engineering degree in Physics in 2007 at Polytech'Orléans (Engineering School of University of Orléans, France). Specialized in optics and plasmas, he's been working since 2008 on his PhD thesis in the field of laser damage of optical components. He is currently working at the Atomic Energy Commissariat in the Framework of the LMJ Project and collaborates with Fresnel Institute in Marseille, France.

ABSTRACT TEXT:

Nanosecond laser-induced damage (LID) in potassium dihydrogen phosphate (KH2PO4 or KDP) remains an issue for light-frequency converters in large-aperture lasers such as NIF (National Ignition Facility, in USA) and LMJ (Laser MegaJoule, in France). In the final optic assembly, converters are simultaneously illuminated by multiple wavelengths during the frequency conversion. In this configuration, the damage resistance of the KDP crystals becomes a crucial problem and has to be improved. In this study, we propose a refined investigation about the LID mechanisms involved in the case of a multiple wavelengths combination. Experiments based on an original pump-pump set-up have been carried out in the nanosecond regime on a KDP crystal. In particular, the impact of a simultaneous mixing of 351 nm and 1064 nm pulses has been experimentally studied and compared to a model based on heat transfer, the Mie theory and a Drude model. This study sheds light on the physical processes implied in the KDP laser damage. In particular, a three-photon ionization mechanism is shown to be responsible for laser damage in KDP.

Keywords: KDP crystal, multi-wavelength laser-induced damage, wavelength combination effects

Frequency dependence in the initiation of ultrafast laser-induced damage

J. R. Gulley, Kennesaw State Univ. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Jeremy Gulley is an Assistant Professor of Physics at Kennesaw State University near Atlanta, GA. His research in computational ultrafast optics and is concentrated on simulating the propagation of high intensity ultrashort laser pulses through nonlinear optical materials and systems. These simulations are used for prediction of and comparison with laboratory results as well as theoretical investigation into many ultrafast nonlinear optical effects, such as catastrophic self-focusing, plasma generation and ultrafast laser-induced damage.

ABSTRACT TEXT:

Numerous recent studies have investigated the role of photoionization in ultrafast laser-induced damage of bulk dielectrics. These works frequently model the propagation of the laser pulse through the bulk material with a modified nonlinear Schroedinger equation that contains corrective terms that account for the broad bandwidth of ultrafast laser pulses. It has been shown that these corrections are necessary to accurately model the propagation of laser pulses with temporal widths approaching a single optical cycle. It is notable, however, that nearly all of these works use models for photoionization and avalanching that assume a monochromatic laser field. For an ultrafast laser pulse undergoing self-phase modulation, super continuum generation, or plasma-induced blue shifting, the accuracy of such models may become questionable. This study examines the role of spectral width and instantaneous laser frequency in laser-induced damage using a frequency dependent multi-photon ionization model. Specifically, these roles are investigated for a thin fused silica sample with a band gap of 9 eV that must absorb six photons of 800 nm light to photoionize. When the individual photon wavelengths are greater than 845 nm, however, seven photons are required for photoionization, reducing the probability of the event by two or more orders of magnitude. Results of simulations presented in this study suggest that this frequency dependence may significantly affect the processes of laser-induced material damage and filamentation in fused silica for common 800 nm wavelength pulses.

Keywords: Laser-induced damage, Computational optics, Ultrafast pulse propagation, Plasma generation, Fused silica, Nonlinear Schroedinger Equation, Nonlinear optics

7842-37, Session 5

The 'vacuum effect' of femtosecond LIDT measurements on dielectric films

D. N. Nguyen, L. A. Emmert, W. Rudolph, The Univ. of New Mexico (United States);
D. Patel, E. M. Krous, C. S. Menoni, Colorado State Univ. (United States)

ABSTRACT TEXT:
For pulse trains of more than 100,000 pulses, the LIDT of dielectric hafnia and silica films drops continuously as the ambient gas pressure is reduced from atmospheric pressure to about 10-7 torr. A few ten torr of water vapor can recover the LIDT to its atmospheric value. Backfilling the vacuum chamber with oxygen only partially recovers the LIDT. The single pulse threshold is not affected by pressure and these phenomena do not occur with bulk fused silica surfaces. The observations are distinctly different from previous studies involving nanosecond pulses.

The drop in LIDT is associated with a change in damage morphology. At atmospheric pressure damage initiates in the beam center where the fluence is largest as one expects from the current deterministic sub ps pulse damage models. At low pressure we found that damage initiates at sites randomly distributed within the beam spot. The damage sites are investigated using Nomarski and atomic force microscopy.

Our tentative interpretation of these observations involves laser mediated oxygen removal and charging the film surface at sites predisposed by the coating process. Water vapor above a critical pressure can form single layers that neutralize the charged sites, and individual water molecules can replenish the oxygen through dissociative chemisorption into hydroxyl groups at the surface.

Keywords: LIDT, vacuum, damage morphology, subpicosecond laser, water chemisorptions

7842-58, Session 6

Insight from molecular dynamics simulation into ultrashort-pulse laser ablation

H. M. Urbassek, Technische Univ. Kaiserslautern (Germany)

ABSTRACT TEXT:
The materials phenomena occurring after ultra-fast laser irradiation of a metal in the ps- or fs-regime are highlighted. With increasing laser fluence, the film melts, voids are formed, the film tears (spallation), and finally fragments to form a multitude of clusters. These processes are universal in the sense that they occur in widely differing materials such as metals or van-der-Waals bonded materials. We investigate a Lennard-Jones solid as well as four different metals (Al, Cu, Ti, W), which vary widely in their cohesive energy, melting temperature, bulk modulus, and crystal structure. When the energy transfer starting the process is scaled to the cohesive energy of the material, the thresholds of these processes adopt similar - but not identical - values.

For high laser intensities, above the threshold for fragmentation, a homogeneous expansion of the exploding film is observed, in which a mixture of clusters of all sizes is found. The internal temperature of the clusters is constant, independent of space, time, and cluster size. The cluster size distribution can be characterized for small energizations as a bi-exponential distribution, but is better represented for larger energizations by a power law in cluster size. Additionally, we study the dynamics of the phase transitions in their dependence on the laser pulse duration and the temporal structure of the laser pulse.

Keywords: laser ablation, molecular-dynamics simulation, phase transitions, melting, cluster formation

Short-pulse laser induced melting and ablation studied with time-resolved coherent XUV scattering

K. Sokolowski-Tinten, Univ. Duisburg-Essen (Germany); A. Barty, Deutsches Elektronen-Synchrotron (Germany); S. Boutet, SLAC National Accelerator Lab. (United States); U. Shymanovich, Univ. Duisburg-Essen (Germany); H. N. Chapman, Deutsches Elektronen-Synchrotron (Germany); M. J. Bogan, SLAC National Accelerator Lab. (United States); S. Marchesini, Lawrence Berkeley National Lab. (United States); S. Hau-Riege, Lawrence Livermore National Lab. (United States); N. Stojanovic, Deutsches Elektronen-Synchrotron (Germany); J. Bonse, Bundesanstalt für Materialforschung und -prüfung (Germany); Y. Rosandi, H. M. Urbassek, Technische Univ. Kaiserslautern (Germany); R. I. Tobey, H. Ehrke, Univ. of Oxford (United Kingdom); A. Cavalleri, S. Düsterer, H. Redlin, Deutsches Elektronen-Synchrotron (Germany); M. A. Frank, Lawrence Livermore National Lab. (United States); S. Bajt, J. Schulz, Deutsches Elektronen-Synchrotron (Germany); M. Seibert, J. Hajdu, Uppsala Univ. (Sweden); R. Treusch, Deutsches Elektronen-Synchrotron (Germany); C. Bostedt, SLAC National Accelerator Lab. (United States); M. Hoener, Lawrence Berkeley National Lab. (United States); T. Moeller, Technische Univ. Berlin (Germany)

PRIMARY AUTHOR BIOGRAPHY:

Klaus Sokolowski-Tinten works as a senior scientist in the Ultrafast Phenomena in Solids and at Surfaces group of the Physics Department of the University of Duisburg-Essen. His research focuses on high intensity laser - solid interactions (i.e. ultrafast phase transitions, laser ablation, high energy density science) using (and developing) state-of-the-art time-resolved optical and X-ray techniques.

ABSTRACT TEXT:

XUV- and X-ray free-electron-lasers (FEL) combine short wavelength, ultrashort pulse duration, spatial coherence and high intensity. This unique combination of properties opens up new possibilities to study the dynamics of non-reversible phenomena with ultrafast temporal and nano- to atomic-scale spatial resolution. This contribution discusses results of time-resolved experiments performed at the XUV-FEL FLASH (HASYLAB/Hamburg) aimed to investigate the nano-scale structural dynamics of laser-irradiated materials. Thin films and fabricated nano-structures, deposited on Si3N4-membranes, have been excited with ultrashort optical laser pulses. The dynamics of the non-reversible structural evolution of the irradiated samples during laser-induced melting and ablation has been studied in an optical pump - XUV-probe configuration by means of single-shot coherent scattering techniques.

In the first experiment we investigated the formation of laser induced periodic surface structures (LIPSS) on the surface of thin Si-films. Time-resolved scattering using femtosecond XUV-pulses at 13.5 nm and 7 nm allowed us to directly follow the LIPSS evolution on an ultrafast time-scale and with better than 40 nm spatial resolution. The observed scattering patterns show almost quantitative agreement with theoretical predictions and reveal that the LIPSS start to form already during the 12 ps pump pulse.

In the second set of measurements we studied laser induced ablation and disintegration of fabricated nano-structures. Time-dependent auto-correlation functions were obtained from the coherent diffraction patterns measured at various pump-probe time delays and reveal the expansion dynamics of the irraditated samples. Under certain circumstances it became also possible to reconstruct real-space images of the object as it evolves over time.

Keywords: femtosecond laser ablation, free electron lasers, coherent scattering

Modeling of laser-induced ionization of solid dielectrics for ablation simulations: role of effective mass

V. E. Gruzdev, Univ. of Missouri-Columbia (United States)

ABSTRACT TEXT:
Modeling of laser-induced ionization and heating of conduction-band electrons by laser radiation serves as a basis for multiple simulations and experimental studies of laser-induced ablation of dielectric materials. The objective of most of the simulations is to deliver dependence of ablation threshold on laser parameters that can be compared with experimental measurements. Together with band gap and electron-particle collision rate, effective electron mass is one of few material parameters employed for the ionization modeling. Exact value of the effective mass is not known for many materials frequently utilized in experiments, e.g., fused silica and glasses. Because of that reason, value of the effective mass is arbitrary varied around "reasonable values" for the ionization modeling. In fact, it is utilized as a fitting parameter for the modeling to support experimental measurements of dependence of ablation and damage thresholds on laser parameters. In this connection, we study how strong is the influence of variations of the effective mass on the value of conduction-band electron density and related estimations of the thresholds. We consider influence of the effective mass on 1) photo-ionization (multiphoton-ionization) rate; 2) electron-particle collision rate; 3) coefficient of electron impact multiplication; 4) conduction-band electron absorption. In particular, it is shown that the multiphoton-ionization rate can vary by 2-4 orders of magnitude with variation of effective mass by factor of 2 due to strong nonlinear dependence of the rate on effective mass. Impact ionization rate also includes a strong nonlinear dependence on effective mass. Utilizing those results, we demonstrate that variation of effective mass by factor of 1.5-2.5 allows fitting any set of experimental data on threshold of laser-induced damage and ablation within extremely broad range.

Keywords: dielectric solids, laser ablation, laser-induced damage, ionization, simulation, fitting experimental data

Tuesday PM • 28 September

14.00 to 15.00 • SESSION 7

Materials and Measurements I

Session Chairs: **Michelle Shin,** Thomas Jefferson National Accelerator Facility (United States); **Detlev Ristau,** Laser Zentrum Hannover e.V. (Germany)

14.00: **Multiscale analysis: a way to investigate laser damage precursors in materials for high power applications at nanosecond pulse duration** *(Invited Paper)*, Jean-Yves Natoli, Institut Fresnel (France) . . . . [7842-61]

14.40: **Determination of laser damage initiation probability and growth on fused silica scratches**, Mary A. Norton, Christopher W. Carr, David Cross, Raluca A. Negres, Jeffrey D. Bude, William A. Steele, Lawrence Livermore National Lab. (United States) . . . . [7842-62]

15.00 to 16.00 • Poster Session and Refreshment Break

16.00 to 18.00 • SESSION 8

Materials and Measurements II

Session Chairs: **Michelle Shin,** Thomas Jefferson National Accelerator Facility (United States); **James E. Andrew,** AWE plc (United Kingdom)

16.00: **Comparing the use of mid-infrared versus far-infrared lasers for mitigating damage growth on fused silica**, Steven T. Yang, Manyalibo J. Matthews, Selim Elhadj, Diane J. Cooke, Gabriel M. Guss, Vaughn G. Draggoo, Paul J. Wegner, Lawrence Livermore National Lab. (United States) . . . . [7842-63]

16.20: **Impact of the Laser Chemical Processing (LCP) on crystal damage and minority carrier lifetime in silicon solar cells**, Filip Granek, Sybille Hopman, Paul Gundel, Fraunhofer-Institut für Solare Energiesysteme (Germany) . . . . [7842-64]

16.40: **An empirical investigation of the laser survivability curve**, Jonathan W. Arenberg, Northrop Grumman Corp. (United States); Wolfgang Riede, Paul Allenspacher, Alessandra Ciapponi, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Jon H. Herringer, Arrow Thin Films, Inc. (United States). . . . . [7842-65]

17.00: **Programmable defect blocking system for mitigating laser-induced damage growth on the National Ignition Facility**, John E. Heebner, Michael R. Borden, Philip E. Miller, Christopher J. Stolz, Tayyab I. Suratwala, Paul J. Wegner, Mark R. Hermann, Mark A. Henesian, Christopher A. Haynam, Steve Hunter, Kim S. Christensen, Nan Wong, Lynn G. Seppala, Gordon Brunton, Eddy Tse, Abdul A. Awwal, Mark Franks, Ed Marley, Kevin Williams, Michael F. Scanlan, Lawrence Livermore National Lab. (United States). . . . . [7842-66]

17.20: **Laser-induced surface damage density measurements with small and large beams**, Laurent Lamaignère, Commissariat à l'Énergie Atomique (France); Gabriel Dupuy, Thierry Donval, Commissariat à l'Énergie Atomique (United States). . . . . [7842-67]

17.40: **Use of machine learning algorithms and data mining techniques to identify and remove noisy data,** Ghaleb M. Abdulla, Laura M. Kegelmeyer, Zhi M. Liao, Christopher W. Carr, Lawrence Livermore National Lab. (United States) . . . . [7842-68]

18.30 to 20.00 • Wine and Cheese Reception at NCAR

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Multiscale analysis: a way to investigate laser damage precursors in materials for high power applications at nanosecond pulse duration

J. Natoli, Institut Fresnel (France)

ABSTRACT TEXT:
The mechanism of laser induced damage in optical materials under high power nanosecond laser irradiation is commonly attributed to the presence of precursor centers. These precursors initiate a local breakdown process in the material, most often followed by a damage growth, inducing loss in optical performance.

Depending on material and laser source, the precursors could have different origins. Some of them are clearly extrinsic, such as impurities or structural defects linked to the fabrication conditions; others are rather intrinsic as “colored centers”.

In both cases the center size ranging from sub-micrometer to nanometer scale does not permit an easy detection by optical techniques before irradiation. Most often, only a post mortem observation of optics permits to proof the local origin of optical breakdown.

Multi-scale analyzes by changing irradiation beam size have been performed to investigate the density, size and nature of laser damage precursors. Destructive methods such as raster scan, laser damage probability plot and morphology studies permit to deduce the precursor densities. In some cases assumptions on materials and mechanisms (such as absorption) allow through modeling to deduce the index and size of sites responsible for laser damage. Another experimental way to get information on nature of precursors is to use non destructive methods such as photoluminescence and absorption measurements.

The destructive and non destructive multiscale studies are also motivated for practical reasons. Indeed LIDT studies of large optics as those used in LMJ or NIF projects are commonly performed on small samples and with table top lasers whose characteristics change from one to another. In these conditions, it is necessary to know exactly the influence of the different experimental parameters and overall the spot size effect on the final data.

In this paper, we present an overview of recent developments in multiscale characterization and results obtained on optical coatings (surface case) and KDP crystal (bulk case) will illustrate the purpose.

Determination of laser damage initiation probability and growth on fused silica scratches

M. A. Norton, C. W. Carr, D. Cross, R. A. Negres, J. D. Bude, W. A. Steele,
Lawrence Livermore National Lab. (United States)

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 working on adaptive optics, 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:
The manufacture of optical components frequently leaves a variety of surface imperfections including scratches of varying lengths and widths. We have developed methods of engineering subscale parts with a distribution of scratches mimicking those found on full scale fused silica parts. This large number of scratches provides a platform to measure low damage initiation probabilities sufficient to describe damage on large scale optics. In this work, damage probability per unit scratch length was characterized as a function of initial scratch width and post fabrication processing including acid-based etch mitigation processes. The susceptibility of damage initiation density along scratches was found to be strongly affected by the post etching material removal and initial scratch width. We have developed an automated processing procedure to document the damage initiations per width and per length of theses scratches. We show here how these tools can be employed to provide predictions of the performance of full size optics in laser systems operating at 351 nm. In addition we use these tools to measure the growth rate of a damage site initiated along a scratch and compare this to the growth measured on an isolated damage site.

Comparing the use of mid-infrared versus far-infrared lasers for mitigating damage growth on fused silica

S. T. Yang, M. J. Matthews, S. Elhadj, D. J. Cooke, G. M. Guss, V. G. Draggoo, P. J. Wegner, Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Steven T. Yang was born in Taipei, Taiwan in 1963. He received the Bachelor of Science and Master of Science degree in electrical engineering from Massachusetts Institute of Technology in 1987. In 1994, he received the PhD. Degree also in electrical engineering from Stanford University under supervision of Dr. R.L. Byer. His doctoral research was in the area of nonlinear optics using high average power and high coherence solid state lasers. From 1994 to 1996, he worked as a foreign scientist at Sony central research laboratory in Tokyo Japan, where he conducted research related to frequency conversion of diode-pumped solid-state laser for optical disk technology application. From 1996 to 1999, he was a member of the Laser Science & Technology group at the Lawrence Livermore National Laboratory (LLNL). Between the years 1999 to 2002, he worked in the area of optical communication at San Jose CA. Since 2002, he has been at LLNL. His present interest is in the area of high average power lasers, nonlinear optics and laser-induced optics damages.

ABSTRACT TEXT:

Laser-based mitigation of damage growth on fused silica has so far used far-infrared (IR) 10.6 µm CO_2 laser because of the close match between CO_2 laser wavelength and the silica absorption peak. Silica's high absorption at 10.6 µm, however, limits CO_2 laser penetration into the bulk and prevents healing of deep damage sites. It has been suggested that lasers operating in the mid-infrared, where fused silica's absorption is lower, would enable deeper heat penetration and therefore be more suitable for healing deep damage sites. Recently, a custom-built mid-infrared laser operating at 4.6 µm was used in our laboratory to demonstrate the potential of healing deep cracks using mid-infrared lasers. Encouraged by this initial success, we undertook the present study to quantitatively compare the use of the mid-IR (4.6 µm) versus far-IR (10.6 µm) lasers for mitigating damage growths on fused silica optics. Specifically, the temperature distributions on the surface of fused silica when heated with the two different lasers were studied using infrared radiometry. We find that while the linear temperature rise versus incident power due to far-IR laser heating is well described by a surface-heating approximation, the nonlinear temperature rise when heated with the mid-IR laser can only be explained by a volumetric heat model that takes into account the highly temperature dependent absorption coefficient of fused silica at 4.6 µm. The resultant deeper heat penetration when the mid-IR laser is used as compared to the far-IR laser is verified by measuring the glass fictive temperature using confocal Raman microscopy. The advantage of using mid-IR versus far-IR laser for damage growth mitigation is further quantified by defining a figure of merit (FOM) that relates the crack healing depth to laser power required, under minimally-ablative conditions. Based on our FOM, we show that for cracks up to at least 500 µm in depth, mitigation with a 4.6 µm mid-IR laser is more efficient than mitigation with a 10.6 µm far-IR laser. This conclusion is corroborated by direct application of each laser system to the mitigation of pulsed laser-induced damages possessing fractures up to 225 µm in depth.

Impact of the Laser Chemical Processing (LCP) on crystal damage and minority carrier lifetime in silicon solar cells

F. Granek, S. Hopman, P. Gundel,
Fraunhofer-Institut für Solare Energiesysteme (Germany)

PRIMARY AUTHOR BIOGRAPHY:

Dr. Filip Granek received his M.Sc. of electronics degree from Wroclaw University of Technology in Poland in 2004. In 2004 he joined the Silicon Photovoltaics group at Energy Research Centre of the Netherlands (ECN) in Holland. Between 2005 and 2009 he developed high-efficiency back-contact back-junction silicon solar cells at Fraunhofer ISE and in 2009 he received the PhD degree on that topic. Since 2009 he is leading a research group focusing on the Laser Chemical Processing of silicon solar cells at Fraunhofer ISE. He is author and co-author of 35 scientific papers and 6 patent applications.

ABSTRACT TEXT:

Laser Chemical Processing (LCP) [1] offers many new promising processes for improving silicon solar cell manufacturing, e.g. local doping, deep cutting of silicon. In the LCP process laser light is coupled into a hair-thin liquid jet, which guides the liquid media and the laser light to the silicon workpiece.

The local doping of silicon solar cells using LCP process is presently under intensive investigation for the industrial production. However in case of the laser processes the induced crystal damage can cause recombination in the space charge region and disturb the pn-junction, causing significant losses in the solar cell efficiency. In this paper two methods are applied to analyze the damage and its locations for the LCP process.

First, the transmission electron microscopy (TEM) is applied to investigate the crystal dislocations. For this measurement a solar cell which was processed with low laser fluences (0.2 J/cm^2) and one processed with high fluences (2.4 J/cm^2) was chosen to be analysed. For high laser fluence the local dislocations were found which indicate laser induced damage. These kinds of dislocations are found at 2-3 places distributed over the whole width of the laser groove (approx. 80 µm for the 80 µm nozzle at high laser powers). The dislocations extend to approx. 900 nm into the silicon crystal.

Secondly, a local analysis of the minority carrier lifetime at the locations of laser doped lines will be preformed. For that a novel contactless technique [3] based on high injection micro-photoluminescence spectroscopy will be applied. The minority carrier lifetimes with a spatial resolution of few microns will be measured in the LCP affected areas for different laser fluencies. The results will be compared with the TEM analysis.

[1] D. Kray, et al., Applied Physics A, 93,1 (2008).
[2] S. Hopman, et al., Proc. 24th European Photovoltaic Solar Energy Conference, Hamburg, Germany, 1072-6 (2009).
[3] P. Gundel, et al, .Submitted to Journal of Applied Physics (2010)

Keywords: silicon solar cells, crystal damage, laser damage, photovoltaics

7842-65, Session 8

An empirical investigation of the laser survivability curve

J. W. Arenberg, Northrop Grumman Corp. (United States); W. Riede, P. Allenspacher, A. Ciapponi, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); J. H. Herringer, Arrow Thin Films, Inc. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Jon Arenberg is currently the Deputy for Observatory Systems Engineering and Design Integration Lead for the James Webb Space Telescope. He has been with Northrop Grumman over 20 years and working in the optical and laser engineering field for over 27 years. He is a graduate of UCLA in physics and engineering and has worked in a wide variety of optical and space technologies. He is a frequent contributor to these proceedings and holds 11 patents.

ABSTRACT TEXT:
The key to development of a truly universal laser optic life test is identification of universal model of survivability. This universal model must apply over a wide variety of test conditions and test specimens. This paper reports on recent empirical efforts to identify such a survivability model. The results from a recent experiment*, which varies sample type and test wavelengths, are used to test and develop the survivability model.

* N on 1 testing of AR and HR designs at 1064 and 355 nm, Riede et al, these proceedings

Keywords: Laser damage testing, Laser optics qualification, N on 1 testing

Programmable defect blocking system for mitigating laser-induced damage growth on the National Ignition Facility

J. E. Heebner, M. R. Borden, P. E. Miller, C. J. Stolz, T. I. Suratwala, P. J. Wegner, M. R. Hermann, M. A. Henesian, C. A. Haynam, S. Hunter, K. S. Christensen, N. Wong, L. G. Seppala, G. Brunton, E. Tse, A. A. Awwal, M. Franks, E. Marley, K. Williams, M. F. Scanlan, Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Dr. John Heebner completed his Ph.D. in 2003 at the Institute of Optics, University of Rochester. While at the Institute of Optics, he conducted research in ultrafast nonlinear optics under the supervision of Dr. Robert Boyd. His doctoral dissertation involved the use of microresonators for enhancing nonlinear optical propagation effects in integrated waveguides. Currently, at Lawrence Livermore National Laboratory, John is a lead engineer working on front-end laser sources for MegaJoule and Petawatt class fusion laser systems, spatial light modulators for beam sculpting, and ultrafast diagnostics for applications on the National Ignition Facility (NIF). He has co-authored over peer-reviewed 20 articles, written a textbook, and has been granted 2 patents. Currently, he is working a means of mitigating optical damage on the National Ignition Facility at LLNL.

ABSTRACT TEXT:

Customized spatial light modulators have been designed and fabricated to reduce the fluence on optic flaws to increase their operational lifetime and prevent downstream light intensification from optic flaws. By inserting this device in a low-fluence relay plane upstream of the amplifier chain, “blocker” obscurations can be programmed into the beam to shadow downstream optic flaws. In this two stage system, 1920x1080 bitmap images are first imprinted on incoherent, 470nm address beams via pixelated liquid crystal on silicon (LCoS) modulators. To realize defined masking functions with smooth apodized shapes and no pixelization artifacts, address beam images are projected onto custom fabricated optically-addressable light valves. Each valve consists of a large, single pixel liquid crystal cell in series with a photoconductive Bismuth Silicon Oxide (BSO) crystal. The BSO crystal enables bright and dark regions of the address image to locally control the voltage supplied to the liquid crystal layer which in turn modulates the amplitude of the coherent beams at 1053 nm. Valves as large as 24mmx36mm have been fabricated with, low wavefront distortion (<0.5wvs) and antireflection coatings for high transmission (>90%) and etalon suppression to avoid spectral and temporal ripple. This device in combination with a flaw inspection system and optic registration strategy represents a new approach for extending the operational lifetime of high fluence laser optics.

Use of machine learning algorithms and data mining techniques to identify and remove noisy data

G. M. Abdulla, L. M. Kegelmeyer, Z. M. Liao, C. W. Carr,
Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Dr. Abdulla works in the Data Science group at LLNL. His research interests include scientific data management, information organization, information storage and retrieval, text and data mining, and digital libraries. Dr. Abdulla earned his Ph.D. in computer science from Virginia Tech in 1998, and a M.S. degree in computer science from the same institution in 1993. He earned his Bachelor Degree in Electrical and Computer Engineering from Yarmouk University in Jordan. Before joining LLNL, Dr. Abdulla worked for the Dow Chemical Company as an Information Technology Specialist at the business intelligence center. He is a member of ACM, IEEE, Sigma Xi Scientific Research Society, and Upsilon Pi Upsilon Honor Society of the Computer Sciences.

ABSTRACT TEXT:

The Final Optics Damage Inspection System (FODI) on the National Ignition Facility (NIF) can acquire images of the target chamber focus lenses between every system shot. The ~200 images are then examined with an optics inspection analysis package (OI) to identify and track damage sites on the optics. The process of tracking growing damage sites on the surface of an optic can be more effective by removing sites which can be identified as debris or reflections. The manual process to filter these false sites is daunting and time consuming on large laser systems. In this paper we discuss the use of machine learning tools and data mining techniques to help solve this problem. We describe the process to prepare a data set that can be used for training and identifying static reflections in the image data. As a preprocessing step, the images are analyzed and sites with a set of relevant features such as spatial, physical, and luminosity are extracted. A subset of these sites is manually classified to two target classes. A supervised classification algorithm is used to test if the features can predict the class membership of new sites using the training data that we prepared. An open source tool called “Avatar” is used to classify new sites. To verify the accuracy of the classifier we checked classified instances and the accuracy was above 95%.

We are currently working on integrating the model with the online data collection system. Once implemented, Avatar will be able to throw away all sites that are hardware reflections and scientists will not need to examine these sites manually anymore.

Surfaces, Mirrors, and Contamination

10.40 to 11.40 and 15.00 to 16.00

Damage phenomenon of large-aperture fused silica grating, Wei Han, Fuquan Li, Chinese Academy of Engineering Physics (China) . . . . [7842-38]

Inhibition of contamination laser induced damage to optical substrates, Bruce H. Weiller, Jesse D. Fowler, Randy M. Villahermosa, The Aerospace Corp. (United States) . . . . [7842-39]

Effects of characteristic parameters of subsurface defect on anti-damage capability of fused silica, Jin Huang, Chinese Academy of Engineering Physics (China) . . . . [7842-40]

Femtosecond laser microfabrication by axicon lens, Hao Zhang, Jaap I. Dijkhuis, Utrecht Univ. (Netherlands) . . . . [7842-41]

The effect of CO_2 laser annealing on residual stress and on the laser damage resistance for fused silica optics, Philippe Cormont, Commissariat à l'Énergie Atomique (France); Laurent Gallais, Institut Fresnel (France); Laurent Lamaignère, Thierry Donval, Jean-Luc Rullier, Commissariat à l'Énergie Atomique (France) . . . . [7842-42]

Investigation of scratch and pits for large polished mirror surface, Etsuo Fujiwara, Nozomu Araki, Univ. of Hyogo (Japan) . . . . [7842-43]

Long-term laser induced contamination tests of optical elements under vacuum at 351nm, Uwe Leinhos, Klaus Mann, Armin Bayer, Jens-Oliver Dette, Matthias Schöneck, Laser-Lab. Göttingen e.V. (Germany); Martin Endemann, Denny Wernham, Federico Petazzi, Adrian P. Tighe, Jorge Alves, European Space Research and Technology Ctr. (Netherlands); Dominique Thibault, EADS Astrium (France) . . . . [7842-44]

Materials and Measurements

10.40 to 11.40 and 15.00 to 16.00

Explanation of laser-induced damage behavior of fused silica in a large-aperture laser using a small-aperture damage test, Fuquan Li, Wei Han, Chinese Academy of Engineering Physics (China) . . . . [7842-45]

Studies on the emission and Electron Spin Resonance spectroscopic properties of microstructures in polymer films achieved using femtosecond laser direct writing, Lakshmi Narayana D. Kallepalli, Venugopal R. Soma, Kuladeep Rajamudili, Praveen K. Velpula, Narayana R. Desai, Univ. of Hyderabad (India) . . . . [7842-46]

Positron lifetime and coincidence Doppler broadening study of vacancy-type defects in fused silica induced by ultraviolet laser pulses, Chunhong Li, Univ. of Science and Technology Beijing (China); Jin Huang, Xinda Zhou, Xiaodong Jiang, Weidong Wu, Chinese Academy of Engineering Physics (China); Zhuoxin Li, Baoyi Wang, Institute of High Energy Physics (China); Xin Ju, Univ. of Science and Technology Beijing (China) . . . . [7842-47]

Characterization of fiber preforms for high power lasers using LID absorption measurement technique, Christian Mühlig, Simon Bublitz, Stephan Grimm, IPHT Jena (Germany); Andreas Langner, Gerhard Schötz, Heraeus Quarzglas GmbH & Co. KG (Germany) . . . . [7842-48]

Piezoelectric resonance spectroscopy of laser induced damage in nonlinear-optical crystals, Aleksei V. Konyashkin, Daniil V. Myasnikov, Institute of Radio Engineering and Electronics (Russian Federation) and Moscow Institute of Physics and Technology (Russian Federation); Valentin A. Tyrtyshnyy, Moscow Institute of Physics and Technology (Russian Federation); Aleksei V. Doronkin, Oleg A. Ryabushkin, Institute of Radio Engineering and Electronics (Russian Federation) and Moscow Institute of Physics and Technology (Russian Federation) . . . . [7842-49]

Dual wavelength laser damage testing for high energy lasers, Mark Kimmel, Patrick K. Rambo, Jens Schwarz, John C. Bellum, Briggs W. Atherton, Sandia National Labs. (United States) . . . . [7842-50]

Development of free designable ceramic fiber and its laser property, Tomosumi Kamimura, Osaka Institute of Technology (Japan); Takayuki Okamoto, Okamoto Optics Co., Ltd. (Japan); Yan Lin Aung, Akio Ikesue, World Lab Co., Ltd. (Japan) . . . . [7842-51]

Influence of ion implantation on damage threshold and optical properties of thin metal films on lithium niobate used as photodetector of high-power laser radiation, Viktor O. Lysiuk, V. Lashkaryov Institute of Semiconductor Physics (Ukraine); Vasyl S. Staschuk, National Taras Shevchenko Univ. of Kyiv (Ukraine); Mykola I. Kluy, V. Lashkaryov Institute of Semiconductor Physics (Ukraine) . . . . [7842-52]

Population kinetics of the fluorescing M center state in CaF_2 upon fs laser excitation at 392 nm and 262 nm, Christian Karras, Christian Muehlig, Herbert Stafast, Wolfgang Triebel, Thomas Zeuner, Wolfgang Paa, IPHT Jena (Germany) . . . . [7842-53]

Linear and nonlinear absorption of $Ti_xSi_{1-x}O_2$ mixtures, Marco Jupé, Laser Zentrum Hannover e.V. (Germany); Kai Starke, Cutting Edge Coatings GmbH (Germany); Detlev Ristau, Laser Zentrum Hannover e.V. (Germany) . . . . [7842-54]

Effects of thermal annealing on KDP and DKDP on laser damage resistance at 3w, François P. Guillet, Bertrand Bertussi, Laurent Lamaignère, Cédric Maunier, Commissariat à l'Énergie Atomique (France) . . . . [7842-55]

Study of relation between crystallinity and laser damage of calcium flouride, Minako Azumi, Eiichiro Nakahata, Nikon Corp. (Japan) . . . . [7842-56]

The image processing for single-shot measurement of laser damage threshold, Jianping Hu, Zhichao Liu, Songlin Chen, Ping Ma, Qiao Xu, Chengdu Fine Optical Engineering Research Ctr. (China). . . . . [7842-57]

Damage phenomenon of large-aperture fused silica grating

W. Han, F. Li, Chinese Academy of Engineering Physics (China)

PRIMARY AUTHOR BIOGRAPHY:
Wei Han was born in Hubei, China, on June 21, 1982. He received the master degree in Laser Fusion Research center, China Academy of Engineering Physics, China. In 2006, he joined the Laser Fusion Research center as an assistant researcher. His research interests include nonlinear optics, high-power lasers and laser-induced damage.

ABSTRACT TEXT:
In the context of large high-power laser facilities such as the National Ignition Facility in the United States, the Laser Megajoule in France and the prototype of SG- laser facility in China, the lifetime of optical components is a major concern. A main cause of lifetime reduction is laser-induced damage. It is believed that material imperfections, self-focusing and contaminations are the causes of laser-induced damage, especially the surface damage.

Our recent laser experiment performed on the prototype of SG- laser facility at 351 nm has caused severe damage on a large-aperture fused silica grating. And the damage on the grating is distinctly different from those occurred at other fused silica optics such as the lens and the windows. There are three bizarre facts about the damage on the grating. First, the deterioration of the grating surface always started with the appearance of ash-like material on the four corners. The foggy area gradually expanded inward. Afterwards, the craters appeared on the front surface and its number was increasing with the shots. Second, unlike other optics, the damage is mainly on its front surface. In common belief, the nonlinearity caused by strong light would make the fluence on the rear surface higher than on the front surface, therefore the damage tends to happen on the rear surface. Third, the six long cracks located alternately at the front and the rear surface appeared together after one shot (the sixth shot, 3.1J/cm^2, 351nm, 3ns flat-top, 1.0GW/cm^2). They are basically arrayed at the same 20mm interval and the right-most crack is outside the border of the light.

We believe that the characteristic surface corrugation of the grating has seeded strong Stimulated Brillouin Scattering (SBS) and the grating's damage is mainly due to SBS.

Keywords: laser-induced damage, fused silica grating, stimulated Brillouin scattering

Inhibition of contamination laser induced damage to optical substrates

B. H. Weiller, J. D. Fowler, R. M. Villahermosa, The Aerospace Corp. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Bruce Weiller is a Senior Scientist at the Aerospace Corporation. He received a B.A. in Chemistry from Clark University in 1981 and a Ph.D. from Cornell in 1986, followed by postdoctoral research at Argonne National Laboratory and the University of California at Berkeley. He has published over 80 publications and patents. He has been a visiting scientist at the Institute of Microtechnology at the University of Neuchatel, Switzerland and serves as a reviewer for NSF, NASA and numerous chemistry journals.

ABSTRACT TEXT:

Optics that have been shown to last well over 1 million laser pulses, in a “clean” environment, can exhibit laser induced damage in as few as 8,000 pulses in the presence of contaminants, reducing the survivability of space-based laser systems by a factor of 100 or more. The mechanism of contamination laser induced damage (C-LID) is not well known, however it has been shown that it can be caused by trace levels of various contaminants. C-LID occurs in vacuum or in sealed enclosures filled with nitrogen or air. Only certain types of contaminants cause C-LID but once damage occurs laser power rapidly decays leading to premature failure.

We have examined several high vapor pressure molecules and found that they very effectively inhibit the C-LID process and greatly extend the lifetime of fused silica optics under high power laser (Nd:YAG, 1064 nm, 1×10^{-8} s) irradiation in the presence of toluene. We have characterized the thresholds for the C-LID process using toluene as a model contaminant by varying oxygen and toluene concentrations. In the presence of 300 ppm toluene and nitrogen, the damage threshold is $(7.8 \pm 1.9) \times 10^3$ laser pulses, in synthetic air the damage threshold is $(18.0 \pm 2.1) \times 10^3$ laser pulses. With the addition of ~4000 ppm of various vapor phase inhibitors, the lifetime is in excess of 1×10^6 laser pulses with no damage observed. Possible mechanisms and applications will be discussed.

Keywords: contamination, toluene, YAG, inhibition, space, silica, lifetime

Effects of characteristic parameters of subsurface defect on anti-damage capability of fused silica

J. Huang, Chinese Academy of Engineering Physics (China)

PRIMARY AUTHOR BIOGRAPHY:
Jin Huang is a Research Assistant, engaged with study of optics material damage mechanism and life evaluation of fused silica optics at high power laser

ABSTRACT TEXT:
Anti-damage capability of fused silica optics was directly depended on the absorbent impurities in the subsurface layer and scratches introduced by mechanical polishing. A series of fused silica surface with various contents of impurities and various morphologies scratches were created by different level HF acid etching. ToF-SIMS and scanning probe microprobe reveals a decreasing level of impurities in the subsurface layer as increasing etching level. The smoothing of structure, increasing diameter to depth ration and decreasing space wave frequency was revealed for the scratches created by increasing level HF acid etching. Damage test results anti-damage capability of etching fused silica was enhanced, the initial damage threshold was raised by 40 percent as the level of subsurface layer removed 600nm by HF acid etching. The enhancement of field caused by the spatial structure of scratches was calculated by FDTD software, and the calculated results were accordance to the damage test.

Keywords: UV pulsed laser irradiation, impurity, scratch, ToF-SIMS, damage threshold, field enhancement

Femtosecond laser microfabrication by axicon lens

H. Zhang, J. I. Dijkhuis, Utrecht Univ. (Netherlands)

PRIMARY AUTHOR BIOGRAPHY:

Hao Zhang is currently a first year PhD student of Nanophotonics group,Debye Institute under the supervision of prof. Jaap Dijkhuis.His reserch interest include laser ablation, femtosecond laser microfabrication, ultrafast dynamics in laser machining process and photonic crystals. He has obtained master degree of optical engineering in University of Electronic Science and Technology of China and has began his PhD research in Debye institute, Utrecht University since 2009.

ABSTRACT TEXT:

We use axicon and vortex plates to create ring shaped foci. A α=1° axicon was inserted inside a Galileo telescope, and moved along the telescope axis, to vary the effective cone angle continuously. A Hurricane (Spectra Physics) amplified Ti-sapphire laser is used in the experiments generating 800nm 120fs laser pulses with 1kHz repetition rate. A microscope objective (NA=0.8) is used to focus the beam. The fabrication process is monitored by a CCD camera. CCD images of the foci show that ring foci of different diameter from ~50 μm down to less than 10μm can be realized. Reflection microscope image and laser-induced fluorescence microscope image of the ring pattern burned by the laser in a ruby crystal indicate a ring-shaped void of ~30μm diameter and ~1μm width surrounded by highly compressed material was created. We plan confocal microscopy and electron microscopy to uncover more details of the fabricated structure.In order to investigate a photonic application of a ring structure, we show a full vector 2D FDTD simulation on a long 2μm diameter ruby cylinder core cavity surrounded by a 4μm diameter 1μm width ring shaped vacuum void which can be fabricated by the above method. The cavity resonances for wavelength (~1.5μm to 8μm) in the order of the cavity size.

Finally we are preparing pump-probe experiments to study the dynamics of the laser machining process and monitor the plasmon resonances and electron densities during the ablation process.

Keywords: femtosecond laser microfabrication, axicon lens, pump-probe

The effect of CO_2 laser annealing on residual stress and on the laser damage resistance for fused silica optics

P. Cormont, Commissariat à l'Énergie Atomique (France); L. Gallais, Institut Fresnel (France); L. Lamaignère, T. Donval, J. Rullier, Commissariat à l'Énergie Atomique (France)

PRIMARY AUTHOR BIOGRAPHY:
Philippe Cormont has been at CEA since 1987 working in optical components characterizations, first for the Atomic Vapor Laser Isotope Separation and later in the Laser Megajoule facility. He is currently in charge of the fabrication of the phase plates and the flat windows for LMJ. His research interests are in ways to increase the lifetime of optical components.

ABSTRACT TEXT:
The CO_2 laser is used to prolong the lifetime of large optics for high power lasers such as the NIF and LMJ. Indeed, on silica optical components, damaged sites, whose diameter is in the order of tens of microns, appear at high UV laser fluence, and the size of such sites increases exponentially with each UV laser shot. An intense heat by CO_2 laser ejects the material from the surface of the optical component and removes all fractures around the damaged site so that this site will not be damaged at fluences of operation of the UV laser. A crater is formed at the site of initial damage. But the intense heat creates debris and residual stress around this crater. Due to these debris and stress, the optical component is again weakened. We show here that a second heating process, done with different settings of the CO_2, named here laser annealing, eliminates the debris and reduce stress. The results presented here establish that annealing significantly improves the resistance of laser optics.

Keywords: fused silica, laser damage, laser mitigation, stress, CO_2 laser

Investigation of scratch and pits for large polished mirror surface

E. Fujiwara, N. Araki, Univ. of Hyogo (Japan)

PRIMARY AUTHOR BIOGRAPHY:

Etsuo Fujiwara received B.E. degree in 1976 from Osaka University and the Dr. Eng. Degree in 1981 from Osaka University. He joined Institute of Laser Engineering Osaka University in 1982, Kansai Electric Power Company from 1993 to 1998 for isotope separation, Himeji Institute of Technology in 1998, and University of Hyogo as a professor from 2009. His major interests are on laser applications and on high speed droplet applications.

ABSTRACT TEXT:

Scratches and pits defects are usually checked over by human eyes in dark clean rooms. We discuss inspection equipment for scratch and pits on large polished mirror surface. The inspection method is as same as that of surveyors, in which an oblique bright light irradiate a mirror surface and a surveyor looks for scattered light at defects from vertical direction. The instrument developed has a compact detector, which includes a line laser diode and measurement optics with a USB camera and photo detector. The field of vision of the USB camera is as small as 2.5mm*2mm. The compact detector is set on a motor controlled linear drive unit with encoders to decide the coordinates of the detector. When the detector catches a strong scattered light from a defect during scanning measurements, the PC records the coordinates of the detector without motor stopping and keeps measurements for next defects. A mirror polished metal pipe was used for a test with 210mm in diameter and 300mm in length. The detector moves on the motor controlled linear guide to search on the fast rotating pipe surface for spiral scanning without omission. The maximum search speed has been 1m/s with 2mm laser width, resulting in less than 10 minutes/m^2 for measurements. After the end of sequence measurements, the detector can jump to selected defect points. A present minimum detection size has been 20um for pits and less than 10um for scratch. The developed measurement system will be also useful for a large polished glass surface for defects scattered by light.

Keywords: scratch, pit, mirror surface, inspection

Long-term laser induced contamination tests of optical elements under vacuum at 351nm

U. Leinhos, K. Mann, A. Bayer, J. Dette, M. Schöneck, Laser-Lab. Göttingen e.V. (Germany); M. Endemann, D. Wernham, F. Petazzi, A. P. Tighe, J. Alves, European Space Research and Technology Ctr. (Netherlands); D. Thibault, EADS Astrium (France)

ABSTRACT TEXT:
No abstract available

Explanation of laser-induced damage behavior of fused silica in a large-aperture laser using a small-aperture damage test

F. Li, W. Han, Chinese Academy of Engineering Physics (China)

PRIMARY AUTHOR BIOGRAPHY:

Fuquan Li was born in Sichuan, China on December 24, 1974. He received the master degree in University of Electronic Science and Technology of China. In 2000 he joined the Laser Fusion Research center. Now he is an associate researcher. He has published over 30 papers in journals and conferences. His research interests include high-power solid-state laser, nonlinear optics, and laser-induced damage.

ABSTRACT TEXT:

Laser-induced damage is a key lifetime limiter for optics in high-power laser facility. A main cause of lifetime reduction is laser-induced damage. It is believed that material imperfections, self-focusing and contaminations are the causes of laser-induced damage, especially surface damage. More worrisomely, the initial damage would grow rapidly with repetitive pulses.

A large fused silica component was tested on a high-power laser facility and was damaged most severely on the input surface. In order to figure out the damage reason, we have examined the damage behavior of the fused silica component with a small-aperture laser and compared it to results we obtained at the large-aperture laser facility. The acid etch can not effectively increase the threshold fluence. The in-situ threshold fluence can be predicted by threshold data obtained on the small-aperture test with a statistics-based model. This model is instructional and useful in practice. It enables us to predict the damage performance of optics by testing the large-aperture optics offline with a small laser.

Keywords: Laser-induced damage, fused silica, acid etch

7842-46, Poster Session

Studies on the emission and Electron Spin Resonance spectroscopic properties of microstructures in polymer films achieved using femtosecond laser direct writing

L. N. D. Kallepalli, V. R. Soma, K. Rajamudili, P. K. Velpula, N. R. Desai,
Univ. of Hyderabad (India)

ABSTRACT TEXT:
Spectroscopic studies of the femtosecond (fs) laser modified regions were systematically performed after fabricating several gratings and micro-channels in polymers including Poly(methylmethacrylate) [PMMA], Polydimethylsiloxane [PDMS], Polystyrene [PS], and Polyvinyl alcohol [PVA]. Ultrashort pulses (~100 fs duration) at 800 nm were used for writing the microstructures in various polymers in the transverse writing geometry. We observed emission from the fs laser modified regions of these polymers when excited at different wavelengths during the confocal microscopic studies. Pristine polymers are not paramagnetic, but exhibited paramagnetic behavior upon fs irradiation. Lifetime of the free radicals observed in fs irradiated PMMA, PS, and PVA was nearly one day, but fs irradiated PDMS showed an unusual behavior of exhibiting Electron Spin Resonance (ESR) signal even after 6 months. The ramifications of such a behavior for applications of these microstructures in photonics and microfluidics will be discussed.

Keywords: femtosecond direct writing, PMMA, PDMS, micro-channels, gratings

7842-47, Poster Session

Positron lifetime and coincidence Doppler broadening study of vacancy-type defects in fused silica induced by ultraviolet laser pulses

C. Li, Univ. of Science and Technology Beijing (China); J. Huang, X. Zhou, X. Jiang, W. Wu, Chinese Academy of Engineering Physics (China); Z. Li, B. Wang, Institute of High Energy Physics (China); X. Ju, Univ. of Science and Technology Beijing (China)

PRIMARY AUTHOR BIOGRAPHY:
Chunhong Li received his bachelor's and master's degree in materials science from university of science and technology beijing.He is interested in the field of laser-material interaction and related science. Recently, his work is focus on the study of damage mechanism in fused silica induced by UV laser pulses.

ABSTRACT TEXT:
The generation and depth distribution of ultraviolet laser-induced vacancy-type defects in fused silica has been determined using positron annihilation lifetime spectrum and coincidence Doppler broadening spectrum with Beijing Intense Slow Positron Beam. The employed Nd-YAG 355 nm laser beam profile was near Gaussian with a 1/e2 diameter of 0.5 mm at the sample plane and a pulse length (FWHM, full width at half maximum) of 6.8 ns. The silica samples were irradiated by 355 nm laser with various fluences, frequencies and numbers of pulses. Deconvolution of the positron lifetime spectrum obtained by general software POSITRONFIT suggested that laser-induced defects can be analyzed into three components: monovacancy, double vacancy and vacancy clusters. The longer lifetime showed that the irradiation introduced larger vacancy clusters as a result of vacancy combination. In all the cases studied, the lifetime representing vacancy clusters increased as the irradiation fluence elevated from 0.5 to 2 J/cm2, the frequency shifted from 1 to 10 Hz and pulses number increased from 30 to 1200. However, the corresponding concentration for vacancy clusters gradually decreased during this increasing irradiation process. The behavior of the S-parameter and W-parameter with the variation of incident positron beam energy was used to analyze the depth distribution of defects. The value of S-parameter increased up to 5% as the incident positron beam energy increased. The CDB results showed that the concentration of defects rapidly increased to a maximum of about 1500 nm depth from the surface which was followed by slightly decreased concentration distribution.

Keywords: Laser-material interaction, Vacancy-type defects, Fused silica, Depth distribution, PALS, CDBS, Slow Positron Beam

Characterization of fiber preforms for high power lasers using LID absorption measurement technique

C. Mühlig, S. Bublitz, S. Grimm, IPHT Jena (Germany); A. Langner, G. Schötz, Heraeus Quarzglas GmbH & Co. KG (Germany)

ABSTRACT TEXT:
Laser induced deflection (LID) technique is applied to measure directly residual absorption in undoped and doped fused silica fiber preforms at 1550nm. The investigations are performed to analyze the minimal achievable attenuation for a fiber preform material based on the pure absorption effects (specific absorbing impurities or imperfections) especially without scattering phenomena before starting the whole process of fiber drawing.

Typically, doped fiber preforms are characterized by optical inspections before the drawing process starts. Often, any initial spectrometric preform evaluation fails since the intense scattering, which accounts for the dominant losses in doped fiber preform materials for high power fiber lasers, is drastically reduced during the drawing process. This reduction allows to build kilowatt fiber lasers from laser active fibers with attenuations < 50 dB/km. Therefore, the possible use of the preform material for high power fiber lasers is investigated in the end once the fiber is manufactured. To reduce costs and save time it would be helpful to at least partly sort out inappropriate material before the drawing process. For the first time to our knowledge, this is done by measuring directly and absolutely the residual absorption in fiber performs by the laser induced deflection (LID) technique. Although the measurements can not predict the final attenuation of the fiber, they will give a lower fiber attenuation limit that allows preselecting of materials before starting the fiber drawing process.

In this work we report on different LID strategies to handle the strong scattering in the materials to enable the measurement and absolute calibration. Furthermore, results for different preform materials are presented and compared to final attenuation values of the produced fibers. The sensitivity for the realized setup is estimated and compared to the aspired fiber attenuation values required for the realization of multi-kW fiber lasers.

Keywords: High power fiber laser, fiber preform, laser active materials, absorption

Piezoelectric resonance spectroscopy of laser induced damage in nonlinear-optical crystals

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PRIMARY AUTHOR BIOGRAPHY:

Graduated from Moscow State University in 2006, physics department. Now is getting PhD degree in Russian Academy of Sciences. Live in Fryazino, Moscow Region, Russia.

ABSTRACT TEXT:

Laser induced damage (LID) of optical materials is the main limiting factor for its performance in high-power laser systems. Nonlinear-optical crystals used for laser frequency conversion slightly suffer from the laser damage due to the optical absorption properties. Most common approaches for the optical material LID metrology are standardized procedures, which are destructive inherently [1]. We propose piezoelectric resonance spectroscopy technique for the real-time observation of the LID processes in the nonlinear-optical crystals. It is based on the registration of variations of the amplitude and phase of the complex electrical impedance of the crystal in condition of piezoelectric resonance.

Crystal's piezoelectric resonances are strongly temperature dependent. In order to observe piezoelectric resonance one has to measure the dependence of the electrical impedance of the crystal on the external electric field frequency f. Nonlinear-optical crystal is placed between the electrodes, and is connected in series with the load resistor R and RF generator. For each frequency value the crystal complex electrical impedance Z(f) is calculated from the voltage data measured by lock-in amplifier [2]. The piezoelectric resonance is characterized by the following parameters: Rf - resonance frequency, Rfi - maximum of the impedance phase, RZ - maximum of the impedance amplitude |Z(f)|. At a given laser power the non-uniform crystal temperature distribution can be characterized by the equivalent temperature directly obtained from the piezoelectric resonance frequency shift [2]. It can be clearly seen that at certain power value the dependencies of the piezoelectric resonance phase and amplitude decline from the linear law. Analysis of the nonlinear behavior of these parameters reveals the possibility for the LID examination.

[1] Hildenbrand, A., Wagner, F. R., Akhouayri, H., Natoli, J.-Y. and Commandre, M., "Accurate metrology for laser damage measurements in nonlinear crystals," Opt. Eng. 47(8), 083603 (2008).

[2] Konyashkin, A.V., Doronkin, A.V., Tyrtyshnyy, V.A., Myasnikov, D.V., Ryabushkin, O.A., "Resonant acoustic spectroscopy of the interaction of the single-mode high-power laser radiation with crystals," J. Phys.: Conf. Ser. 214, 012064 (2010).

Keywords: nonlinear-optical crystals, impedance spectroscopy, piezoelectric resonance, calorimetry, equivalent temperature

Dual wavelength laser damage testing for high energy lasers

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PRIMARY AUTHOR BIOGRAPHY:
Mark Kimmel is a Senior Member of Technical Staff at Sandia National Labs. His background includes optical damage testing, laser development, and the development and application of short-pulse laser diagnostics.

ABSTRACT TEXT:
As high energy laser systems evolve towards higher energies, fundamental material properties such as the laser-induced damage threshold (LIDT) of the optics limit the overall system performance. The Z-Backlighter Laser Facility at Sandia National Laboratories uses a pair of such kiljoule-class Nd:Phosphate Glass lasers for x-ray radiography of high energy density physics events on the Z-Accelerator. These two systems, the Z-Beamlet system operating at 527nm/ 1ns and the Z-Petawatt system operating at 1054nm/ 0.5ps, can be combined for some experimental applications. In these scenarios, dichroic beam combining optics and subsequent dual wavelength high reflectors will see a high fluence from combined simultaneous laser exposure and may even see lingering effects when used for pump-probe configurations. Only recently have researchers begun to explore such concerns, looking at individual and simultaneous exposures of optics to 1064 and third harmonic 355nm light from Nd:YAG [1]. However, to our knowledge, measurements of simultaneous and delayed dual wavelength damage thresholds on such optics have not been performed for exposure to 1054nm and its second harmonic light, especially when the pulses are of disparate pulse duration.

The Z-Backlighter Facility has an instrumented damage tester setup to examine the issues of laser-induced damage thresholds in a variety of such situations [2] . Using this damage tester, we have measured the LIDT of dual wavelength high reflectors at 1054nm/0.5ps and 532nm/7ns, separately and spatially combined, both co-temporal and delayed, with single and multiple exposures. We found that the LIDT of the sample at 1054nm/0.5ps can be significantly lowered, from 1.32J/cm^2 damage fluence with 1054/0.5ps only to 1.05 J/cm^2 with the simultaneous presence of 532nm/7ns laser light at a fluence of 8.1 J/cm^2. This reduction of LIDT of the sample at 1054nm/0.5ps continues as the fluence of 532nm/7ns laser light simultaneously present increases. The reduction of LIDT does not occur when the 2 pulses are temporally separated. This paper will also present dual wavelength LIDT results of commercial dichroic beam-combining optics simultaneously exposed with laser light at 1054nm/2.5ns and 532nm/7ns.

[1] M. Zhou et al., Optics Communications 282, 3132 (2009).
[2] M. Kimmel et al., edited by J. E. Gregory et al. (SPIE, 2009), p. 75041G.

Keywords: laser-induced damage, damage threshold, nanosecond laser pulses, femtosecond laser pulses

Development of free designable ceramic fiber and its laser property

T. Kamimura, Osaka Institute of Technology (Japan); T. Okamoto, Okamoto Optics Co., Ltd. (Japan); Y. L. Aung, A. Ikesue, World Lab Co., Ltd. (Japan)

ABSTRACT TEXT:
In most of the high-power fiber lasers, silica fibers measuring several tens of meters in length are usually used. It is impractical for such lasers to be integrated into very compact devices. The maximum output power of a centimeters long fiber lasers is limited for the most part to the watt level because of the difficulty of increasing active ions doping concentrations in the fibers. By solving these problems, we have fabricated Nd:YAG ceramic fibers by using an advanced ceramic technology.

There are several methods for the fabrication of fiber. In this experiment, an extrusion process which is similar to the making of pasta was applied to produce an elongated green powder compact. After sintering under vacuum at 1750ºC for 5 h, a transparent polycrystalline simple Nd:YAG ceramic fiber with 0.4at% Nd doping (65mm in length, and 1.0mm and 0.5mm in diameter) was obtained. Recently, we have also succeeded not only in the fabrication of a very thin ceramic fiber with 100-200μm in diameter, but also in the fabrication of the ceramic fiber having end-cap structure. Almost perfect optical quality was confirmed by the measurement of polarizer and Fizeau interferometry. The laser oscillation was carried out by using simple structure and end-cap structure. Output power of 12 W for the input power of 50W was achieved by using the end-cap type fiber core. 8W/cm is the highest output power of a centimeter length.

Influence of ion implantation on damage threshold and optical properties of thin metal films on lithium niobate used as photodetector of high-power laser radiation

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PRIMARY AUTHOR BIOGRAPHY:
Viktor Lysiuk is graduated with Master's degree at Taras Shevchenko National University of Kiev in 2003 on Laser and Optoelectronic Engineering. Now is prepering to defend PhD thesis. Speciality Optics, Laser Physics.

ABSTRACT TEXT:
Thin metal films on pyroelectrics lithium niobate and lithium tantalate are used for increase absorption of pyroelectric detectors to rise sensitivity of device. But all absorbing materials: metal films and populat golden black have very low adhesion to the substrate - pyroelectric. This circumstance make impossible to register high-power laser radiation by pyroelectric photodetectors with such absorbing films. Special design of photodetectors (conical, spherical etc) increase time constant that is not acceptable for precision investigation.

Implantation of thin Ni, Mo or Pd thin 40-nm films on lithium niobate or lithium tantalate (pyroelectric) by Ar+ ions is allowed to increase radiation stability of the samples in 2-3 orders. Adhesion of thin film to substrate rise strongly because of atoms intermixing at the interface film-substrate as result of cascade of atom collisions. Ions energy and dose were selected to have maximal number of ions and atoms stopped just at the interface film-substrate. To use this idea for Ni< Mo or Pd films with thickness of 40 nm, it is necessary to select Ar+ ions energy 100 keV. This result was calculated by Monte-Carlo method (programm TRIM).

Spectral sensitivity of thin Pd films on lithium niobate becomes nonselective owing to crater-like blisters creation by ion implantation. It happens because of exit Ar gas outside from films depth during thermal annealing usually take place to relax systems from defects and stress.

Absorption of such systems increase what helps to rise sensitivity of pyroelectric photodetectors. It is explained by dimension of blisters (Mi theory).

Thin metal films on lithium niobate or lithium tantalate may be used as sensitive elements of pyroelectric photodetectors for detection of low or high-power laser radiation in wide spectral area 0.25 - 15 microns. Investigation and comparison of optical, electrical and mechanical characteristics with analogs have shown that presented pyroelectric photodetector on the base of implanted systems has the best characteristics among thermal photodetectors.

Keywords: ion implantation, pyroelectric photodetector, thin films, adhesion, blisters formation, ion intermixing, spectral sensitivity, damage threshold

Population kinetics of the fluorescing M center state in CaF_2 upon fs laser excitation at 392 nm and 262 nm

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PRIMARY AUTHOR BIOGRAPHY:
Dipl.-Physicist Studies at the Friedrich-Schiller-University, Jena Diploma work at the Institute of Photonic Technology (IPHT), Jena

ABSTRACT TEXT:
Optical CaF_2 emission at 740 nm with a time constant of approximately 20 ns is attributed to the fluorescence of the M center, a typical crystal defect. It is observed upon optical M center excitation in a broad wavelength range from 193 nm (ArF laser) up to 630 nm (He/Ne laser). Evidently the primary (highly) excited states M**, which cover a huge range in the energy spectrum from 2 to 6.4 eV above the M ground state, relax in each case to the same low lying fluorescent level M*. This relaxation process is fast and cannot be resolved by typical excimer laser irradiation and photomultiplier detection on the 10 ns time scale.

Here we report on femtosecond laser experiments yielding the time constants τrel for the relaxation from the primary M** to the fluorescent M* state. The obtained values amount to τrel (262 nm) = (3.0 ± 0.3) ps and to τrel (392 nm) = (1.0 ± 0.1) ps upon excitation of M centers by the third and second harmonics of the Ti:Sapphire fs laser, respectively.

Keywords: UV/DUV, CaF2, Calcium fluoride, M center, laser pulses, Femtosecond pulses, radiationless transition, fluorescence

Linear and nonlinear absorption of $Ti_xSi_{1-x}O_2$ mixtures

M. Jupé, Laser Zentrum Hannover e.V. (Germany); K. Starke, Cutting Edge Coatings GmbH (Germany); D. Ristau, Laser Zentrum Hannover e.V. (Germany)

ABSTRACT TEXT:
The application of the fs-technology for the investigation in dielectric optics led to a fundamental understanding of the electron excitation and relaxation processes in solids. Usually, pump probe experiments and experiments for the investigation of the interaction of intensive laser pulses with dielectrics are in the focus of the investigation. An alternative approach for high power experiments is LIDT testing and investigations in non linear absorption. The non linear absorption is directly correlated to the density of the free carrier and consequently, to the damage threshold.

The presented study displays the results of the linear and non linear absorption measurements of $Ti_xSi_{1-x}O_2$ -single layers coated by ion beam sputtering. For the determination of the linear absorption behaviour the wavelengths 532nm and 1064nm applying a quasi CW-Laser were considered. The non linear absorption is measured by a Ti:Sapphire CPA-Laser at 790nm.

The investigation indicates a clear correlation of the linear absorption as well as the non linear absorption and the silica concentration in the mixture layer.

Keywords: non linear absorption, linear absorption, Ultra fast phenomena, ISO11551

Effects of thermal annealing on KDP and DKDP on laser damage resistance at 3w

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Commissariat à l'Énergie Atomique (France)

PRIMARY AUTHOR BIOGRAPHY:
The author obtained a PhD in material science in 1993. He has been involved in studies on laser damage in KDP since 2002.

ABSTRACT TEXT:
It has been shown at BDS XL [1] that thermal annealing affects laser damage resistance of KDP at 3ω. Effect of thermal annealing, though, depends strongly on the pulse length: whereas marked improvement of laser damage resistance is observed at 12ns, no improvement at all is observed at 3ns.

The second part of this former study was to combine thermal annealing with laser conditioning. At 12 ns, the combination led to a markedly better resistance than any of the two processes considered separately. At 3ns, even though thermal annealing by itself does not increase laser damage resistance, combination of the two processes was found to yield a better resistance than laser conditioning alone. This result was however found to be dependant on the order with which the processes were applied to KDP, i.e. laser conditioning first or thermal annealing first.

Since the crystals most concerned with laser damage are the DKDP third harmonic generators, it was necessary to check if these results are valid for deuterated KDP. The growth processes used to grow KDP and DKDP crystals are different (resp. fast and slow growth processes) and thus laser damage precursors may differ in such a way that the response to thermal annealing varies from KDP to DKDP. Another point for concern is the quadratic to monoclinic transition, the temperature of which is quite below the 170°C considered for the thermal annealing of KDP. In situ X-Ray diffraction studies have shown that the transition temperature is about 135°C for the 70% deuterated DKDPs considered in this study. The annealing temperature was thus set to 125°C so as to avoid the phase transition which breaks the crystals into polycrystalline splinters. Measured effects of thermal annealing on DKDP at 3ω will be discussed on the poster.

References:

[1] François Guillet, Bertrand Bertussi, David Damiani, Laurent Lamaignère, Audrey Surmin , K. Vallé and Cédric Maunier, « Effect of thermal annealing on laser damage resistance of KDP at 3ω » 2008 SPIE proceedings, 7132, 713211-1 (2009)

Keywords: KDP, thermal annealing, laser damage, laser conditioning

Study of relation between crystallinity and laser damage of calcium flouride

M. Azumi, E. Nakahata, Nikon Corp. (Japan)

ABSTRACT TEXT:
The artificially grown calcium fluoride is one of key materials for microlithography and is used as for excimer laser optics etc. Such calcium fluoride is required high laser durability and laser induced bulk damage threshold (LIDT). However, the artificially grown calcium fluoride is not a complete crystal, and there are a lot of sub-grain boundaries inside the crystal that have the possibility of causing degradation of laser durability and LIDT. Moreover, mechanical properties of calcium fluoride are different according to the crystal axis, therefore there is a possibility that mechanical properties influence LIDT. In this study, we examined the relation between crystallinity and laser durability and LIDT.

First, we examined the relation between the crystal axis and LIDT. The ArF excimer laser and the fifth high harmonic of the Nd:YAG laser at 213nm were used for the irradiation source of light. We prepared samples that optical axes were , and from the same crystal. Moreover, mechanical properties of these samples were measured, and we examined the relation between mechanical properties and LIDT. In addition, we examined the ArF excimer laser durability and the solid-state 193 nm laser durability of these samples.

Next, we examined the relation between the sub-grain boundary and LIDT. The laser was irradiated at the sub-grain boundary, and LIDT was measured, and it compared with LIDT of the part without the sub-grain boundary. We observed the distribution of the sub-grain boundary of the sample by X-ray reflection topography.

The image processing for single-shot measurement of laser damage threshold

J. Hu, Z. Liu, S. Chen, P. Ma, Q. Xu,
Chengdu Fine Optical Engineering Research Ctr. (China)

ABSTRACT TEXT:
A high efficient laser damage measurement has been investigated experimentally by use of binary phase grating. With a periodic binary phase grating, a laser beam is transformed into an ensemble array of Gaussian-like spots, which is known as the Fresnel image of the grating. Use a scientifical CCD to monitor and image the laser spot array and damage, process the image data to obtain a peak fluency distribution of laser spot array and the damage of coating sample, the damage threshold of test sample can be determined by use of the data from single shot of laser.

Keywords: damage threshold measurement, image processing, binary phase grating

Wednesday AM • 29 September

08.20 to 10.00 • SESSION 9

Materials and Measurements III

Session Chairs: **Stavros G. Demos,** Lawrence Livermore National Lab. (United States); **Jianda Shao,** Shanghai Institute of Optics and Fine Mechanics (China)

08.20: **Risk mitigation for laser-induced contamination on the ADM-Aeolus satellite**, Denny Wernham, Federico Pettazzi, Jorge Alves, Adrian P. Tighe, European Space Research and Technology Ctr. (Netherlands) . . . . [7842-69]

08.40: **HEL-generated extinction effects and extinction along extended atmospheric paths: implications for USAF-ABL and HEL-missile exhaust plumes interactions**, Clifford A. Paiva, BSM Research Associates (United States) . . . . [7842-70]

09.00: **High-intensity fibre laser design for micro-machining applications**, David I. Ortiz-Neria, Fernando Martinez-Pinon, Jose A. Alvarez-Chavez, Ctr. de Investigación e Innovación Tecnológica (Mexico) . . . . [7842-71]

09.20: **Improvement of laser damage resistance and diffraction efficiency of multilayer dielectric diffraction gratings by HF-etchback linewidth tailoring**, Hoang T. Nguyen, Cindy C. Lasron, Jerald A. Britten, Lawrence Livermore National Lab. (United States) . . . . [7842-72]

09.40: **Mode-selection in novel high-intensity Yb^{3+}-doped fiber laser cavities**, Jose A. Alvarez-Chavez, Solange I. Rivera-Manrique, Fernando Martinez-Piñon, Ctr. de Investigación e Innovación Tecnológica (Mexico); Herman L. Offerhaus, Univ. Twente (Netherlands). . [7842-73]

10.00 to 10.30 • Coffee Break

10.30 to 12.30 • SESSION 10

Surfaces, Mirrors, and Contamination I

Session Chairs: **Carmen S. Menoni,** Colorado State Univ. (United States); **Mireille Commandré,** Institut Fresnel (France)

10.30: **Developing MRF technology for the manufacture of large-aperture optics in mega-joule class laser systems** *(Invited Paper)*, Joseph A. Menapace, Lawrence Livermore National Lab. (United States) . . . . [7842-74]

11.10: **Impact of substrate surface scratches on laser damage resistance of multilayer coatings**, Siping R. Qiu, Justin E. Wolfe, Anthony M. Monterrosa, Nick E. Teslich, Michael D. Feit, Thomas V. Pistor, Christopher J. Stolz, Lawrence Livermore National Lab. (United States) . . . . [7842-26]

11.30: **Damage testing of critical optical components for high power ultra fast lasers**, Enam Chowdhury, Brittany Taylor, Rebecca Daskalova, Patrick Poole, Linn D. Van Woerkom, Richard Freeman, The Ohio State Univ. (United States); Douglas J. Smith, Plymouth Grating Lab. (United States) . . . . [7842-76]

11.50: **Damage threshold measurements of AR microstructures, and microstructure-based high reflectors and polarizers in the near UV**, Douglas S. Hobbs, Curtis A. Lockshin, Bruce D. MacLeod, TelAztec LLC (United States) . . . . [7842-77]

12.10: **An improved method of mitigating laser-induced surface damage growth in fused silica using a rastered, pulsed CO_2 laser**, Isaac L. Bass, Gabriel M. Guss, Michael C. Nostrand, Paul J. Wegner, Lawrence Livermore National Lab. (United States) . . . . [7842-78]

12.30 to 14.00 • Lunch Break

7842-69, Session 9

Risk mitigation for laser-induced contamination on the ADM-Aeolus satellite

D. Wernham, F. Pettazzi, J. Alves, A. P. Tighe,
European Space Research and Technology Ctr. (Netherlands)

PRIMARY AUTHOR BIOGRAPHY:
Denny Wernham has been working in high power laser and space optics for the last 18 years in the areas of nonlinear optics, thin film optical coatings for high power lasers and optics for satellite power and thermal control. He joined The European Space Agency in 2003 working in contamination control and is currently the Product Assurance Manager for the ADM-Aeolus satellite.

ABSTRACT TEXT:
Laser-induced contamination (LIC) is a phenomenon that can lead to the degradation of the properties of optical components in vacuum due to the formation of a deposit in the area irradiated by a UV laser beam. The deposit growth is proposed to be the result of photochemical and photothermal mechanisms triggered by the interaction of UV laser radiation and outgassing species from polymeric materials on the surface of the optics.

In the framework of ESA's ADM-Aeolus satellite mission, a successful test campaign has been performed, which has demonstrated the efficiency of several mitigation techniques against LIC for the ALADIN laser. These include the standard contamination control methods of identification of materials with particular propensity to cause LIC, reduction of the outgassing of organic materials by vacuum bakeout and shielding of optical surfaces from contamination sources as well as novel methods such as in-situ cleaning. These methods have now been applied at satellite level in order to guarantee the success of the mission.

The subject of this paper is to summarise the various mitigation techniques from the large number of studies that have been performed and is applicable to any use of high power pulsed lasers in vacuum in the presence of organic contaminants.

Keywords: Lasers and laser optics, Optical Materials, Environmental effects, Contamination

HEL-generated extinction effects and extinction along extended atmospheric paths: implications for USAF-ABL and HEL-missile exhaust plumes interactions

C. A. Paiva, BSM Research Associates (United States)

PRIMARY AUTHOR BIOGRAPHY:
Executive Summary: Missile Defense Physicist; Electro-Optics and Millimeter Wave Technologies; Advanced Image Processing Techniques Applied to Target Detection, Tracking, Classification and Identification (ATDCI); SM3-Block 1-A Naval BMD System; System Integration Engineering and Sensitivity Analysis Methods for High Energy Laser Program (HEL); Missile Hardbody and Exhaust Plume Interactions; Exoatmospheric/Endoatmospheric Applications of HEL Weapons

ABSTRACT TEXT:
This research addresses missile exhaust plume ionization as a function of altitude variable water vapor concentrations (including missile exhaust plume) increases, rocket plume expansions in H20 environments, reverse flows and HEL-generated plasmas, cumulatively as these processes affect USAF-AB (Airborne Laser) Advanced Tracking Illuminator (ATILL) and adaptive optics Beacon Illuminator Laser (BILL). Boost-phase missile exhaust plumes have been shown to generate a variety of very challenging exhaust-plasma and HEL electromagnetic extinction effects. The overall engagement event results in HEL plasma-/missile plume (also a plasma near the exhaust exit plane). This results in reducing returned energy to the sensor suite aboard USAF-ABL when considering missiles plume LOS penetration by ATILL and BILL. Specifically such exhaust plasma/HEL/plume interactions generate a reduction in coherence due to engagements with LOS missile exhaust reverse flows. This requires changes in automatic target detection, classification and identification (ATDCI) components and the primary HEL weapon system (USAF Airborne Laser). Missile expanded and reversed exhaust H2Ovapor plumes are shown to generate very severe propagation extinction fields within the Prandtl-Meyer reverse flows and HEL engagement regimes. This further results in inadequate automatic target recognition and pattern reference library efficiencies of USAF-ABL ATILL and BILL.

Keywords: HEL exhaust absorption scatter extinction, Airborne Laser Ship Borne Laser, High Power Solid State Laser, THAAD Theater Missile Defense, Cruise Missile Prandtl Meyer Reverse Flow, Maxwell Field Equations Absorption Extinction, ATILL BILL Oxygen De Excitation Fluence, Asymmetric Missile Exhaust Plumes

High-intensity fibre laser design for micro-machining applications

D. I. Ortiz-Neria, F. Martinez-Pinon, J. A. Alvarez-Chavez,
Ctr. de Investigación e Innovación Tecnológica (Mexico)

PRIMARY AUTHOR BIOGRAPHY:
Mr. Ortiz-Neria holds a BEng in Mechatronics from IPN. He is pursuing a MSc in Advance Technology by the supervision of Jose A. Alvarez-Chavez, PhD.

ABSTRACT TEXT:
This work is focused on the design of a 250W high-intensity continuous-wave fibre optic laser with a 15u beam spot size and BPP of 1.8 for its use on Laser-assisted Cold Spray process (LCS) in micro-machining.

The metal-powder deposition process LCS, is a novel method based on Cold Spray (CS) assisted by laser. It can reduce the cost by the use of high-pressure gas to achieve a very fast impact velocity on substrate like in CS. In LCS, the critical velocity of impact is less while the powder particle is heated before the deposition by a laser beam. Furthermore, LCS does not heat the powder to achieve the high temperature as it happens in plasma processes. This property puts aside cooling problems which normally happen in sintered processes with high oxygen/nitrogen concentration levels.

This technique will be used not only in deposition of thin layers. It will be feasible to perform micro-machining precise work with the use of the high-intensity fiber laser presented in this work, and selective deposition of particles, in a similar way to the known Direct Metal Laser Sintering process (DMLS).

The fiber laser cavity consists on a large-mode area, Yb^{3+}-doped, semi-diffraction limited, 25-m fiber, operating in continuous wave regime. The fiber shows an arguably high slope-efficiency with no signs of roll-over. The measured M2 value is 1.8 and doping concentration of 15000 ppm. It was made with a slight modification of the traditional MCVD technique. A full optical characterization will be presented.

Keywords: fiber laser, large mode area, ytterbium, micro-machining, laser-assisted cold spray, metal deposition

7842-72, Session 9

Improvement of laser damage resistance and diffraction efficiency of multilayer dielectric diffraction gratings by HF-etchback linewidth tailoring

H. T. Nguyen, C. C. Lasron, J. A. Britten,
Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Mr. Hoang Nguyen is currently a Senior Scientist in the Advanced Optical Components and Technology Group in NIF & Photon Science Directorate, where he is the grating production and development manager. Hoang has responsible for the design, execution and testing of novel gratings for unique applications requested by end users. He heads the optical design efforts, the testing and qualification of advanced optical systems to improve lithography. He is responsible for process development on the large reactive ion beam etcher that is a unique component of LLNL's world leading fabrication facility for critical optics used in pulse compression and other high-energy laser applications.

ABSTRACT TEXT:
Multilayer dielectric (MLD) diffraction gratings for Petawatt-class laser systems possess unique laser damage characteristics. Details of the shape of the grating lines (1,2) and the concentration of absorbing impurities on the surface of the grating structures (3) both have strong effects on laser damage threshold. For instance, It is known (1,2) that electric field enhancement in the solid material comprising the grating lines varies directly with the linewidth and inversely with the line height for equivalent diffraction efficiency. Here, we present an overview of laser damage characteristics of MLD gratings, and describe a process for post-processing ion-beam etched grating lines using very dilute buffered hydrofluoric acid solutions. This process acts simultaneously to reduce grating linewidth and remove surface contaminants, thereby, in theory, improving laser damage thresholds through 2 pathways. Laser damage resistance of several small witness gratings measured at LLNL at 1053 pulses at nominal 10 ps, 76.5°, 10 Hz showed an increase in small-spot damage initiation fluence from 0-50% after the etchback process. The HF etchback process also allows the ability to easily modify ion-milled profiles to recover or tailor performance if linewidths are larger than optimal, resulting in a processing tool that can increase yield as well as improve performance.

Mode-selection in novel high-intensity Yb^{3+}-doped fiber laser cavities

J. A. Alvarez-Chavez, S. I. Rivera-Manrique, F. Martinez-Piñon, Ctr. de Investigación e Innovación Tecnológica (Mexico); H. L. Offerhaus, Univ. Twente (Netherlands)

PRIMARY AUTHOR BIOGRAPHY:
Dr. Jose Alfredo Alvarez-Chavez is currently a tenured Research Fellow and Lecturer at the National Polytechnic Institute in Mexico. His work involves research and development of high-power, continuous wave (CW), and pulsed, narrow line-width and broad-band, diffraction-limited, high-energy, large mode area, rare-earth doped fiber lasers and amplifier systems. He started working in this field at the Optoelectronics Research Centre of the Southampton University. The ORC was one of the first research centers working in the field. Dr. Jose Alvarez-Chavez was a key individual in the team that set the world record of CW Gaussian output power in a single fibre while working at the Optoelectronics Research Centre and Southampton Photonics Ltd. UK

ABSTRACT TEXT:
High-power, cladding pumped with novel laser and cavity structures are becoming a suitable option for a wide range of applications in the military, medical, telecomm and scientific areas. Real applications of such devices depend on a few main parameters such as: M2 value (beam quality), intensity, wavelength, energy per pulse and pulse duration in the case of pulsed sources. In this work we shall present a full set of results regarding a higher order mode selection technique for improving the beam quality in high-intensity rare-earth-doped cores for the development of novel fiber structures and laser cavities. Both CW and Q-switched fiber laser cavities are fully studied and characterized for applications in medicine and range finding, respectively. This is only our first steps towards new lines of research at the National Polytechnic Institute in Mexico city.

Keywords: fiber lasers, beam quality, mode supression, beam parameter product, high-energy, diffraction limited

7842-74, Session 10

Developing MRF technology for the manufacture of large-aperture optics in mega-joule class laser systems

J. A. Menapace, Lawrence Livermore National Lab. (United States)

ABSTRACT TEXT:
No abstract available

7842-26, Session 10

Impact of substrate surface scratches on laser damage resistance of multilayer coatings

S. R. Qiu, J. E. Wolfe, A. M. Monterrosa, N. E. Teslich, M. D. Feit, T. V. Pistor, C. J. Stolz, Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:

S. Roger Qiu is a physicist at the Lawrence Livermore National Laboratory (LLNL). He received his Ph.D. (2000) in physics and joined LLNL in 2002. His research is centered on understanding interactions at the surface/interface of materials. Roger has served as a symposium chair/co-chair for many conferences including the Materials Research Society annual meetings and the International Conference on Crystal Growth. He has coauthored over 30 peer-reviewed journal articles including two cover articles and two invited reviews. Currently, he works on projects aimed to improve laser damage resistance of optics at the National Ignition Facility in LLNL.

ABSTRACT TEXT:

Substrate scratches can limit the laser resistance of multilayer mirror coatings on high peak power laser systems. To date, the mechanism by which substrate surface defects affect the performance of coating layers under high power laser irradiation is not well defined. In this study, we combine experimental approaches with theoretical simulations to delineate the correlation between laser damage resistance of coating layers and the physical properties of the substrate surface defects including scratches. A focused ion beam technique is used to reveal the morphological evolution of coating layers on surface scratches. Preliminary results show that coating layers initially follow the trench morphology on the substrate surface, and as the thickness increases, gradually overcoat voids and planarize the surface. Simulations of the electrical field distribution of the defective layers using the finite difference time domain (FDTD) method show that there exists field intensification mostly near the top surface region of the coatings near convex focusing structures. The light intensification could be responsible for the reduced damage threshold. Damage testing under 1064 nm, 3ns laser irradiation over coating layers on substrates with designed scratches show that damage probability and threshold of the multilayers depend on substrate scratch density and width. Our preliminary results argue for further investigation to determine the nature of the substrate scratches that lead to multilayer coating damage.

Damage testing of critical optical components for high power ultra fast lasers

E. Chowdhury, B. Taylor, R. Daskalova, P. Poole, L. D. Van Woerkom, R. Freeman,
The Ohio State Univ. (United States); D. J. Smith, Plymouth Grating Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Enam Chowdhury is the Lead Scientist building a short pulse PW class laser at the Ohio State University SCARLET High Energy Density Physics Laboratory. His research includes short pulse laser technology, ultraintense atomic and plasma physics. He is well known for conducting atomic physics experiments at Ultra-high intensities.

ABSTRACT TEXT:
Mirrors and gratings used in high power ultra fast lasers require a broad bandwidth and high damage fluence, which is essential to the design and construction of petawatt class short pulse lasers. Damage fluence of several commercially available high energy broad band dielectric mirrors with over 100 nm bandwidth at 45 degree angle of incidence, and pulse compression reflection gratings with gold and silver coating with varying processing conditions is studied using a well characterized 25 femtosecond ultra-fast laser. Results will be presented and damage fluences in air vs in vacuum will be compared.

Keywords: laser induced damage, ultrafast lasers, dielectric mirror, pulse compression grating, damage fluence, damage threshold

Damage threshold measurements of AR microstructures, and microstructure-based high reflectors and polarizers in the near UV

D. S. Hobbs, C. A. Lockshin, B. D. MacLeod, TelAztec LLC (United States)

PRIMARY AUTHOR BIOGRAPHY:
Douglas S. Hobbs is President and co-Founder of TelAztec, a small research and development company specializing in the design and fabrication of microstructure-based optical components and devices. Mr. Hobbs has worked in the industry for 28 years including 2 years at Grumman, 8 years at Raytheon, 5 years at HLS (a startup he founded in 1995), and the last 10 years at TelAztec. Mr. Hobbs holds an M.S. degree in Optical Engineering from Tufts University and a B.S. degree in Physics from Bucknell University. He has 14 U.S. Patents and has published numerous journal articles.

ABSTRACT TEXT:
Microstructures etched in the surface of fused silica windows can provide high performance optical functionality such as anti-reflection (AR), wavelength selective high reflection (HR), and polarization filtering. In 2007, the pulsed laser induced damage threshold (LiDT) of AR microstructures built in fused silica and glass was shown to be up to three times greater than the LiDT of single-layer thin-film AR coatings, and at least five times greater than multiple-layer thin-film AR coatings. Surface structure resonant (SSR) laser mirrors, consisting of microstructures that are first etched in the surface of a fused silica window and subsequently coated with a thin metal oxide layer, were investigated for their laser damage properties at three discrete wavelengths and the results were given at the 2008 symposium. Building upon this earlier work, LiDT measurements at a single wavelength of 351nm in the near UV will be presented for AR, HR, and polarizing microstructures built in fused silica windows. Scanning Electron Microscope (SEM) analysis of the microstructure variants will be shown, along with spectral transmission and reflection data that is matched to theoretical models. Samples of AR microstructures in fused silica will be entered in the 2010 Symposium's Thin Film Damage Competition focusing on AR treatments for 351nm.

Keywords: Anti-Reflection, AR, Microstructures, HR, Polarizer, LiDT, Near UV, Pulsed Laser Damage

An improved method of mitigating laser-induced surface damage growth in fused silica using a rastered, pulsed CO_2 laser

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Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Isaac Bass received his bachelor's degree in math and chemistry from the University of California, Berkeley in 1960, and his Ph.D. in physics from Columbia University in 1965. He has taught physics at Sonoma State University, worked in the laser industry, and has been in the Laser Programs at the Lawrence Livermore National Laboratory since 1984. He has worked on mitigation of laser induced damage in optical materials for the National Ignition Facility since 2003.

ABSTRACT TEXT:
A new method of mitigating (arresting) the growth of large (> 200 um deep) laser induced surface damage on fused silica has been developed that successfully addresses several issues encountered with our previously-reported large site mitigation technique [1]. As in the previous work, a tightly-focused 10.6 um CO_2 laser spot is scanned over the damage site by galvanometer steering mirrors. In contrast to the previous work, the laser is pulsed instead of CW, with the pulse length and repetition frequency chosen to allow substantial cooling between pulses. This cooling has the important effect of reducing the heat-affected zone capable of supporting thermo-capillary flow from scale lengths on the order of the overall scan pattern to scale lengths on the order of the focused laser spot, thus preventing the formation of a raised rim around the final mitigation site and its consequent down-stream intensification. Other advantages of the new method include lower residual stresses, and improved damage threshold associated with reduced amounts of re-deposited material. The raster patterns can be designed to produce specific shapes of the mitigation pit including cones and pyramids. Details of the new technique and its comparison with the previous technique will be presented.

14.00 to 15.00 • SESSION 11

Surfaces, Mirrors, and Contamination II

Session Chairs: **Leonid B. Glebov,** CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); **Masataka Murahara,** Tokai Univ. (Japan)

14.00: **Oil-contamination problem in large-scale pulse-compressor**, Takahisa Jitsuno, Hidetosi Murakami, Shinji Motokoshi, Eiji Sato, Katsuhiro Mikami, Kota Kato, Tetsuji Kawasaki, Yoshiki Nakata, Nobuhiko Sarukura, Toshihiko Shimizu, Hiroyuki Shiraga, Noriaki Miyanaga, Osaka Univ. (Japan). . . . . [7842-79]

14.20: **Investigation of surface damage initiation and growth on KDP third harmonic generation crystals**, Paul P. Demange, Mary A. Norton, Zhi M. Liao, John J. Adams, Ghaleb M. Abdulla, Christopher W. Carr, Lawrence Livermore National Lab. (United States) . . . . [7842-80]

14.40: **Results of applying a non-evaporative mitigation technique to laser-initiated surface damage on fused silica**, John J. Adams, Jeffrey D. Bude, Masoud Bolourchi, Gabe M. Guss, Ibo J. Matthews, Michael C. Nostrand, Lawrence Livermore National Lab. (United States) . . . . [7842-81]

15.00 to 15.30 • Coffee Break

15.30 to 16.50 • SESSION 12

Surfaces, Mirrors, and Contamination III

Session Chairs: **Leonid B. Glebov,** CREOL, The College of Optics and Photonics, Univ. of Central Florida (United States); **Semyon Papernov,** Univ. of Rochester (United States)

15.30: **Plasma pre-treatment effect for photo-oxidized coating and adhesion to optical glass surface**, Masataka Murahara, Tokai Univ. (Japan); Yuji Sato, Tokyo Institute of Technology (Japan); Takahisa Jitsuno, Osaka Univ. (Japan); Yoshiaki Okamoto, Okamoto Optics Co., Ltd. (Japan) . . . . [7842-83]

15.50: **Aqueous HF-based etch process for improving laser damage resistance of fused silica optics**, Tayyab I. Suratwala, Phillip E. Miller, Jeffrey D. Bude, William A. Steele, Nan Shen, Marcus V. Monticelli, Michael D. Feit, Ted A. Laurence, Mary A. Norton, Christopher W. Carr, Lana L. Wong, Lawrence Livermore National Lab. (United States) . . . . [7842-84]

16.10: **How to polish fused silica to obtain surface damage threshold equals to the bulk damage threshold**, Binh T. Do, Sandia National laboratories (United States); Arlee Smith, AS photonics (United States); Rod Schuster, Peter Allard, Troy Alley, David Collier, Alpine Research Optics (United States); Alice Kilgo, Sandia National Laboratories (United States) . . . . [7842-85]

16.30: **Precision grinding for rapid fabrication of fused silica for laser applications,** Xavier Tonnellier, Paul Morantz, Paul Shore, Kevin Howard, Cranfield University Precision Engineering Centre (United Kingdom) . . . . [7842-86

16.50 to 17.10 • Closing Remarks

17.30 to 19.00 • Open House: Precision Photonics Corp.

Oil-contamination problem in large-scale pulse-compressor

T. Jitsuno, H. Murakami, S. Motokoshi, E. Sato, K. Mikami, K. Kato, T. Kawasaki, Y. Nakata, N. Sarukura, T. Shimizu, H. Shiraga, N. Miyanaga, Osaka Univ. (Japan)

PRIMARY AUTHOR BIOGRAPHY:
Born in 1948. Working for Osaka University since 1982. Main field is high power laser system.

ABSTRACT TEXT:
Heavy contamination of optical components has been observed in the pulse-compressor-chamber of LFEX laser system. The source of contamination was found at the inner-wall of chamber as the machining oil (paraffin oil) which included DBP from the outer-wall of chamber. The damage thresholds of optical components drop to 5 to 10 J/cm^2 at 1 ns pulse duration which was about 1/3 of original value. We also found this contamination is commonly seen for large-scale vacuum chambers which we have.

Finally, we found a very simple method to reduce the contamination in the compressor chamber by using the silica-gel. The damage threshold of a mirror sample was increased up to 45 J/cm^2 when the sample was evacuated inside a small chamber with carefully processed silica-gal. We introduced several pallets filled with the silica-gel at the floor of the compressor chamber, and after evacuated the chamber, we found the damage threshold was recovered to the original value without the contamination. According to the commonness of this contamination, this method should be very useful for many compression chambers for short-pulse lasers.

Keywords: large-scale pulse compressor, CPA laser system, Fast-Ignition driver

7842-80, Session 11

Investigation of surface damage initiation and growth on KDP third harmonic generation crystals

P. P. Demange, M. A. Norton, Z. M. Liao, J. J. Adams, G. M. Abdulla, C. W. Carr,
Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Paul DeMange is a physicist with research interests in lasers and material science. Paul has been at Lawrence Livermore National Laboratory since 2002 and is in the PLS directorate.

ABSTRACT TEXT:
KH2PO4 (KDP) crystals used for frequency conversion in large-aperture laser systems are expected to perform for a wide range of exposure conditions that span fluence, frequency, pulse duration, and number of pulses. However, the formation of laser-induced damage sites on the surface of these optical materials sets constraints on the acceptable range of these exposure parameters. Furthermore, the possibility that surface damage sites can grow with further exposure, to cause undesirable intensity variations in the beam profile seen both by optics downstream as well as at the site of the experiment, is an area of primary focus.

To understand the surface conditions leading to damage, growth and the governing exposure parameters, we analyze online data and perform offline experiments to investigate surface damage initiated at pre-existing defects and growth of existing damage sites from exposure to variable fluence, frequency, pulse duration, and number of laser pulses. Specifically, we examine mechanically-initiated defect sites that mimic the morphology of both surface damage and mechanical defects observed on online optics as well as monitor existing defects upon subsequent exposure. Experiments for KDP third harmonic generation optics are compared with experiments performed on SiO_2. The results show that defect sites made in a similar fashion and under similar exposure conditions on these two materials behave differently. Analysis of the online data indicates that only ~1% of surface damage sites on KDP exhibit significant growth compared to most of surface damage sites for SiO_2.

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

7842-81, Session 11

Results of applying a non-evaporative mitigation technique to laser-initiated surface damage on fused silica

J. J. Adams, J. D. Bude, M. Bolourchi, G. M. Guss, I. J. Matthews, M. C. Nostrand,
Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:
John Adams is a physicist at the Lawrence Livermore National Laboratory working in the NIF Optics group. He earned his Ph.D. in Engineering-Applied Science from the University of California, Davis. John's research interests include characterization and mitigation of laser damage on fused-silica surfaces, laser damage in crystalline materials, and laser physics.

ABSTRACT TEXT:
Numerous authors have reported using a CO_2 laser, primarily through ablation, to mitigate surface damage sites on fused-silica. We report on a new approach using a single application of a CO_2 laser operating at 10.6 microns with a relatively large beam (2mm diameter) to locally heat a damage site on the surface of a fused-silica optic to a temperature at which the fused-silica will soften and somewhat flow (~2000K) but at which material removal from evaporation is not significant (<2500K). By reflowing a damage site, it can be rendered benign to further growth or re-initiation. This non-evaporative approach is further attractive due to minimal rim formation and lack of re-deposited debris around the damage site. For instance, rim formation is one feature that can lead to potentially problematic downstream intensification whereas re-deposited debris can cause re-initiation and growth on or near the mitigated damage site. Another consideration when optimizing a mitigation protocol is the amount of residual stress left behind in the substrate due to the heating associated with the mitigation. Residual stress can lead to an unacceptable amount of additional fracture following subsequent nearby initiations. We report on our study aimed at optimizing a non-evaporative mitigation technique for treating fused-silica surface damage against re-initiation while minimizing downstream intensification and residual stress issues. The effectiveness of the protocol in terms of probability for re-initiation as well as the morphological changes of the damage sites will be discussed.

Plasma pre-treatment effect for photo-oxidized coating and adhesion to optical glass surface

M. Murahara, Tokai Univ. (Japan); Y. Sato, Tokyo Institute of Technology (Japan); T. Jitsuno, Osaka Univ. (Japan); Y. Okamoto, Okamoto Optics Co., Ltd. (Japan)

PRIMARY AUTHOR BIOGRAPHY:

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

ABSTRACT TEXT:

There is the method to form microscopic roughness on the surface of a sample in order for a film or adhesive hard to peel off, but it is unsuitable to optical material surfaces. We, thus, demonstrated the undamaged surface by chemically substituting the functional groups that a coating agent or adhesive had on an optical material. A few thin films were successfully deposited, but many were not according to the kinds of materials and came off if wiped. Then, hydrophilic groups (-OH) were substituted on the sample surface beforehand, and photo-adhesion or coating was carried out. The sample surface was firstly treated by discharge plasma for promoting efficiency of hydroxyl group substitution, and hydroxyl groups were substituted on the sample surface by photochemical reaction of the modification side and water when the material presented high wettability temporarily; as a result, the interface of adhesion or coating was united persistently.

The contact angle with water of fused silica is 40 degrees; that of sapphire is 72 degrees; that of BK7 glass is 31 degrees. When those surfaces were irradiated by glow discharge plasma of DC2 pole sputtering system for five minutes, all of the surfaces dropped to five degrees. Under this condition, silicone oil was applied on each pretreated sample surface and irradiated with excimer lamp light (172nm) for 60 minutes. The adhesive strength of the silica glass plates with plasma pretreatment improved to 25M pascal when compared with that of the silica glass plates without pretreatment, which was 18M pascal.

Keywords: photo-oxide coating, photo-oxide adhesion, plasma pre-treatment, silicone oil, Xe2 excimer-lamp, hydroxyl groups, fused silica glass, contact angle

Aqueous HF-based etch process for improving laser damage resistance of fused silica optics

T. I. Suratwala, P. E. Miller, J. D. Bude, W. A. Steele, N. Shen, M. V. Monticelli, M. D. Feit, T. A. Laurence, M. A. Norton, C. W. Carr, L. L. Wong, Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:

Tayyab Suratwala received his Ph.D. in Materials Science & Engineering from the U. of Arizona and his B.S. in Ceramic Engineering from U. of Illinois at Urbana-Champaign. He has been at Lawrence Livermore National Laboratory since 1997 and is currently the Science & Technology lead in Optic-Targets for the National Ignition Facility. He has author 50+ journal and proceedings articles in areas of glass grinding and finishing, chemical and thermal based mitigation of damage precursors and damage sites, fracture behavior in glasses, slow crack growth, glass chemistry, optical properties of glasses, and sol-gel chemistry.

ABSTRACT TEXT:

The past 10-15 years has seen dramatic improvement in the damage resistance of fused silica optics used in high-peak-power laser systems through the application of improved finishing processes and new post-fabrication mitigation techniques. The post-fabrication mitigation strategies include local CO_2 laser treatments to 'repair' a damage site to prevent it from growing larger, and treating the optic with a new chemical etching technique (referred to as Advanced Mitigation Process or AMP) that can significantly suppress the initiation of pre-existing surface fractures and increase the overall damage resistance of the silica surface. In the current work, a review of the development of the AMP process is described. A critical step enabling AMP development was first the identification of the laser damage precursors which are fracture surfaces, impurities in the polishing layer, and re-deposited material from the etching process. All of these precursors lead to a localized optical absorption below the bulk silica glass band gap causing laser damage well below the bulk damage threshold of fused silica. The AMP process uses aqueous HF-based etching which isotropically removes silica from the entire surface. This process removes both the impurities in the polishing layer that can lead to laser initiation and removes the absorbing precursors on fracture surfaces making them much less likely to initiate. The etching process has been optimized to minimize re-deposition of the SiF62- reaction product (through solubility control, agitation, optimized rinsing, and optimized etched amounts). With the optimized etch process, laser damage resistance increase dramatically; the average threshold fluence for damage initiation for 30 m wide scratches as measured by R/1 small beam testing increased from 7 to 41 J/cm^2, and the statistical probability of damage initiation at 12 J/cm^2 of an ensemble of scratches measured by large beam damage testing decreased from ~100 mm^{-1} of scratch length to ~0.001 mm^{-1}. The AMP process is currently being used to treat fused silica optic in high fluence lasers such as the National Ignition Facility.

How to polish fused silica to obtain surface damage threshold equals to the bulk damage threshold

B. T. Do, Sandia National laboratories (United States); A. Smith, AS photonics (United States); R. Schuster, P. Allard, T. Alley, D. Collier, Alpine Research Optics (United States); A. Kilgo, Sandia National Laboratories (United States)

PRIMARY AUTHOR BIOGRAPHY:
Binh Do is a test engineer.

ABSTRACT TEXT:
We polished fused silica windows by three different techniques:

1. The conventional polishing technique, a loose abrasives lapping process using Alumina follows by a fine Cerium oxide polish.
2. The fused silica windows were polished by an alumina polishing process.
3. The fused silica windows polished by the second process were polished further by silica until they are super polished.

We employed the same measurement technique that have proven successful for the bulk damage threshold measurement to measure the damage thresholds of bare silica surfaces polished by the above three polishing techniques. We used an 8-nanosecond, single transverse and longitudinal mode pulsed laser, from a Q-switched Nd:YAG laser. We used the surface third harmonic generation technique to precisely place the focus of the laser beam on the surface of the fused silica window. We also used the technique to measure the laser focus spot size and it was found to be 8 μm in radius. Key findings include:

a. The surface damage threshold can be made equal to the bulk damage threshold. There is a large difference in single-pulse damage thresholds of bare silica surfaces polished using ceria, alumina, and alumina followed by silica. The ceria polished samples have a statistical damage threshold ranging from 50 to 450 GW/cm^2. The alumina polished surfaces damage at 200-500 GW/cm^2, with half the spots damaging at the bulk threshold of 500 GW/cm^2. The windows polished by alumina followed by silica damage almost universally at the bulk damage threshold of 500 GW/cm^2.
b. There are strong conditioning effects for these surfaces. The ceria polished surfaces have reduced thresholds for multiple pulses. The alumina polished surfaces attain the bulk damage threshold at most locations using multiple pulse annealing.
c. We found there was no beam size variation of the damage threshold irradiance for the bare alumina/silica polished samples.
d. By measuring the bulk damage threshold powers at different depth from the front surface, we have found the experimental evidence of self focusing effect which gives the correction factor for the measured bulk damage threshold.
e. We showed that air breakdown does not limit the surface irradiance, silica breakdown does.
f. We recorded damage morphologies for the different surfaces.

Keywords: polishing techniques, damage threshold

Precision grinding for rapid fabrication of fused silica for laser applications

X. Tonnellier, P. Morantz, P. Shore, K. Howard, Cranfield University Precision Engineering Centre (United Kingdom)

PRIMARY AUTHOR BIOGRAPHY:

Xavier Tonnellier is a Research Fellow in Ultra Precision Technologies and he is currently researching on effective manufacturing technologies for large freeform optics. He joined Cranfield University Precision Engineering Centre in November 2004. He obtained his PhD in Precision Engineering from Cranfield University entitled 'Precision Grinding for Rapid Manufacturing of Large Optics'. He obtained his MSc in the mechanical and manufacturing engineering from the Ecole Nationale d'Ingénieur de Tarbes (ENIT), France.

ABSTRACT TEXT:

A new ultra precision large optics grinding machine, BoX®, was developed and commissioned at Cranfield University. BoX® offers a rapid and economic solution for grinding large off-axis aspherical and free-form optical components [1]. The efficient grinding process stage is provided in order to reduce necessary polishing stages through achievement of high surface form accuracy, good surface quality and low subsurface damage [2]. The BoX® grinding machine process has demonstrated a low level of subsurface damage in ULE and Zerodur [3].

This paper presents an analysis of grinding a 430mm fused silica off axis “wedge” optic. This optical element is representative of aspherical optics within a number of high power laser systems [4-5]. The grinding experiments have been conducted using diamond resin bond wheels with 25µm grit sizes. The material removal rate used demonstrates the unique capability of the BoX® grinding process in rapid fabrication of large optical components for high power laser systems. The surface profile was measured using a large scale Leitz CMM machine. The subsurface damages were revealed using a sub aperture polishing process [3] in combination with an etching technique on smaller representative parts.

These experiments point out the applicability of the developed rapid grinding process from laser optics to large telescope mirror segments up to 1.5m. The use of an in-situ measurement technique and error correction procedure permitted to improve initial ground form achieve a form accuracy of 1 µm p-v over 1 metre. The results highlighted the effect of grinding parameters and machine dynamics on form accuracy and induced levels of subsurface damage.

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