Abstract Book

2011 Laser Damage

XLIII Annual Symposium on

Optical Materials for High Power Lasers

18–21 September 2011

National Institute of Standards and Technology (NIST)
Boulder, Colorado, USA

Connecting minds for global solutions

The leading forum on materials 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/ultrafast 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-SYMPOSIA:

- Deep UV Optics
- Meta-Optics/Photonic Band Gap Materials

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XLIII Annual Symposium on
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Special Events

Sunday 18 September

17.00 to 20.30 **Registration Material Pick-up and Mixer at the Boulder Marriott** (2660 Canyon Blvd., Boulder)

17.30 to 19.00 **Roundtable Discussion at the Boulder Marriott**
Definition and Measurement of Laser-Induced Damage in Transparent Materials by Single Short Laser Pulse

The Round-Table discussion is a pre-symposium event that takes place during the registration on Sunday evening. The main purpose of the roundtable is to warm up symposium participants intellectually and to prepare them for active discussions during the Symposium. This year, the Round Table focuses on definition and measurement of laser-induced damage (LID) of transparent materials by single short (nanosecond and shorter) laser pulses, issues lying at the very foundation of the Symposium. The discussion starts with two presentations by the moderators with slightly differing views of how to define laser-induced damage of the transparent materials and how to measure its threshold. The main points to be considered include statistical vs deterministic nature of LID, statistical variations of LID threshold and their origins, characteristic laser-induced phenomena and effects utilized to detect LID, approaches to measure LID threshold.

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

Monday 19 September

18.30 to 20.00 **Precision Optics Open House and Reception**

Tuesday 20 September

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

Wednesday 21 September

11.30 to 12.30 **NIST Facility Tours**

18.00 to 19.30 **Advanced Thin Films Open House and Reception**

Monday AM • 19 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 and 2010 Awards Presentation**
Joseph A. Menapace, Lawrence Livermore National Lab. (United States)

09.00 to 10.00 • SESSION I

Thin Films I

Session Chairs: **Amy L. Rigatti,** Univ. of Rochester (USA); **M. J. Soileau,** Univ. of Central Florida (USA)

09.00: **Using engineered defects to study laser-induced damage in optical thin films with nanosecond pulses** *(Invited Paper)*, Xinbin Cheng, Zhengxiang Shen, Hongfei Jiao, Jinlong Zhang, Bin Ma, Tao Ding, Zhanshan Wang, Tongji Univ. (China) . . . . [8190-01]

09.40: **Low loss, ion beam sputtered optical coatings and their applications,** Ramin Lalezari, Advanced Thin Films (USA) . . . . [8190-02]

Mon. 10.00 to 10.30 • 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.

10.30 to 11.30 • Poster Session and Coffee/Refreshment Break

11.30 to 12.50 • SESSION 2

Thin Films II

Session Chairs: **Jonathan W. Arenberg,** Northrop Grumman Aerospace Systems (USA);
Carmen S. Menoni, Colorado State Univ. (USA)

11.30: **Measurement and calculation of ternary oxide mixtures for ultra short pulse laser thin film optics**, Marco Jupé, Mathias Mende, Detlev Ristau, Laser Zentrum Hannover e.V. (Germany); Laurent Gallais, Institut Fresnel (France) . . . . [8190-03]

11.50: **HfO_2/SiO_2 enhanced diamond turned aluminum mirrors for IR laser optics**, Jue Wang, Horst Schreiber, Corning Tropel Corp. (USA); Scott J. Wilkinson, Robert D. Felock, Corning NetOptix (USA) . . . . [8190-04]

12.10: **Laser damage threshold results for sputtered coatings produced by a remote plasma launch system**, Peter E. MacKay, Mike Wilde, Gooch & Housego Plc (United Kingdom); Steve Wakeham, Plasma Quest Ltd. (United Kingdom); John Allen, AJ Thin Films Consultancy Ltd. (United Kingdom). . . . . [8190-05]

12.30: **Excimer mirror laser damage competition**, Christopher J. Stolz, Lawrence Livermore National Lab. (USA). . . . . [8190-06]

12.50 to 13.40 • Lunch Break

Using engineered defects to study laser-induced damage in optical thin films with nanosecond pulses

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

ABSTRACT TEXT:
Laser-induced damage of optical thin films with nanosecond pulses is complicated due to the existence of micro- or nanoscale extrinsic defects. Systematical study of laser damage initiating from these extrinsic defects is time consuming and quite challenging because of their low density and diverse distribution (including size, location, et al). This situation stimulates the statistical study of laser interaction with engineered defects that have well controlled size, absorption and lodging depth, which can enable a meaningful comparison of experimental results with theoretical modeling, shed more light on mechanisms of damage initiation and guide the coating process optimization.

Low loss, ion beam sputtered optical coatings and their applications

R. Lalezari, Advanced Thin Films (United States)

PRIMARY AUTHOR BIOGRAPHY: Ramin Lalezari is president and cofounder of Advanced Thin Films. Before forming ATFilms in 2002 he worked at various technical management and executive positions at Research Electro Optics.

ABSTRACT TEXT: Continued advances in polishing, thin film coating and metrology have enabled routine production of optical coatings with losses in the few part per million range. Optical components and coatings with extremely low levels of loss and absorption have enabled a number of applications. The presentation will include a brief historical background of ion beam sputtering, substrate requirements, recent results as well as a brief discussion of applications in spectroscopy and high energy lasers.

Keywords: Low loss optical coatings, Ion Beam Sputtering, IBS, CRDS, Cavity ring down spectroscopy

8190-03, Session 2

Measurement and calculation of ternary oxide mixtures for ultra short pulse laser thin film optics

M. Jupé, M. Mende, D. Ristau, Laser Zentrum Hannover e.V. (Germany);
L. Gallais, Institut Fresnel (France)

ABSTRACT TEXT:
The femto-second technology gains of increasing importance in industrial applications. In this context, a new generation of compact and low cost laser sources has to be provided on a commercial basis. Typical pulse durations of these sources are specified in the range from a few hundred femto- up to some pico-seconds, and typical wavelengths are centered around 1030-1080nm. As a consequence, also the demands imposed on high power optical components for this laser sources are rapidly increasing , especially in respect to their power handling capability in the ultra-short pulse range. The present contribution is dedicated to some aspects for improving this quality parameter of optical coating systems. The study is focused on material mixtures to control the band gap of optical coatings. These material mixtures are expected to reveal higher laser damage thresholds which can be adjusted by the band gap energy, and consequently allow for a more sophisticated optimization of the laser stability for complex coating systems. In this context, also models for a prediction of the laser damage thresholds and scaling laws for the dependence on the pulse duration have to be scrutinized and checked.

Keywords: USP-Laser Optics, fs- LIDT, Mixture Oxides, Photoionization, Avalanche ionization

HfO_2/SiO_2 enhanced diamond turned aluminum mirrors for IR laser optics

J. Wang, H. Schreiber, Corning Tropel Corp. (United States);
S. J. Wilkinson, R. D. Felock, Corning NetOptix (United States)

PRIMARY AUTHOR BIOGRAPHY:
Dr. Jue Wang is Principal Scientist of Coating Technology for Advanced Optics - Corning Specialty Materials. His R&D covers Laser Optics, Precision Optics, Aerospace and Defense Optics from LWIR down to EUV.

ABSTRACT TEXT:
Aluminum is an important substrate material for IR mirrors, because of its light weight and suitability to machine into complex shapes. Diamond turned aluminum can be coated with gold and protective silver as high reflective IR optics. Laser durability of the IR mirrors can be further increased by means of dielectric enhanced coatings. In this report, HfO_2/SiO_2 multilayer with a periodic structure was deposited on diamond turned aluminum substrates via modified plasma ion assisted deposition. Surface quality of the HfO_2/SiO_2 coatings as well as the diamond turned aluminum substrates were evaluated via atomic force microscope and VUV- and IR-ellipsometry. Optical performance of the HfO_2/SiO_2 enhanced mirrors at 1064nm was correlated to the substrate surface quality, the film microstructure and the number of periods of the HfO_2/SiO_2 enhancement. Laser durable HfO_2/SiO_2 enhanced IR mirrors at 1064nm was realized on the diamond turned aluminum substrates.

Keywords: Diamond turned aluminum, IR laser optics, high reflective mirror, dielectric enhancement

Laser damage threshold results for sputtered coatings produced by a remote plasma launch system

P. E. MacKay, M. Wilde, Gooch & Housego Plc (United Kingdom);
S. Wakeham, Plasma Quest Ltd. (United Kingdom);
J. Allen, AJ Thin Films Consultancy Ltd. (United Kingdom)

PRIMARY AUTHOR BIOGRAPHY:
Dr. Peter MacKay has been working at Gooch and Housego since 1995, with a three year gap at Nortel Networks. As Principal Technologist he is responsible for developing new production processes throughout the factory from grinding and polishing through to coating and assembly of precision glass and crystalline products.

ABSTRACT TEXT:
In recent years a new coating sputter deposition process has been developed. Using a proprietary plasma source (PLS) a high density but low energy plasma (~1013 ions/cc, 90%) of the target surface, which also therefore provides an ideal basis for running highly stable, high rate reactive sputter deposition processes for dielectric coatings.

Currently the process is being primarily developed to provide high rate, low thermal load coating of large area thin plastic sheets with very low stress, thin films. The process also has the potential to offer high LIDT thin films. This paper will present the results of our initial LIDT trials for both AR coatings and a laser mirror at 1064nm. We will compare the results with those generated using our existing e-beam coating process (as used on waveplates for the NIF program).

In addition, we will characterise the performance of parts produced by e-beam evaporation with ion-assistance using a Commonwealth MKII+ (hollow cathode) ion source. It has the advantage of providing a low energy but high current ion stream without introducing possible contamination from the wire filament common in other ion-source designs.

Keywords: laser damage, thin films, remote plasma

8190-06, Session 2

Excimer mirror laser damage competition

C. J. Stolz, Lawrence Livermore National Lab. (United States);
Heinrich Mädebach, Holger Blaschke, Detlev Ristau,
Laser Zentrum Hannover e. V. (Germany)

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 NationalIgnition 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 80 journal and proceeding articles and 2 book chapters.

ABSTRACT TEXT:
Excimer lasers are a critical technology for the $400 billion in annual manufacturing of integrated circuits. Other applications include medical applications such as laser eye surgery and micro-machining. Ultraviolet mirrors are used for beam steering and high reliability is desired for such commercial industrial applications. A laser damage competition for excimer mirror coatings will create the opportunity to survey private industry, governmental institutions, and university sectors to allow a direct comparison because the samples will be tested under identical conditions. The requirements of the coatings are a minimum reflectance of 97% at 193 nm at normal incidence. Damage testing was performed at a pulse length of 15 ns at the use wavelength. A double blind test assured sample and submitter anonymity so only a summary of the results are presented. In addition to the laser resistance results, details of deposition processes, coating materials and layer count, and spectral results will also be shared.

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

Keywords: lasers

Monday PM • 19 September

13.40 to 15.20 • SESSION 3

Thin Films III

Session Chairs: **Mireille Commandré,** Institut Fresnel (France);
Detlev Ristau, Laser Zentrum Hannover e.V. (Germany)

13.40: **Laser-induced damage of coatings on Yb:YAG crystals at cryogenic condition**, Weili Zhang, He Wang, Hongji Qi, Dawei Li, Kui Yi, Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8190-07]

14.00: **Laser-induced damage of Kapton thin films demonstrating temperature and wavelength dependent absorptance: a case study in remote-sensing material analysis**, William J. Palm, Michael A. Marciniak, Glen P. Perram, Kevin C. Gross, William F. Bailey, Air Force Institute of Technology (USA) . . . . [8190-08]

14.20: **Laser-induced damage thresholds of optical coatings at different temperature**, Katsuhiro Mikami, Shinji Motokoshi, Masayuki Fujita, Takahisa Jitsuno, Kazuo A. Tanaka, Osaka Univ. (Japan) . . . . [8190-09]

14.40: **Investigation of the laser-induced damage of dispersive coatings**, Ivan B. Angelov, Aaron von Conta, Sergei A. Trushin, Max-Planck-Institut für Quantenoptik (Germany); Zsuzsanna Major, Ferenc Krausz, Max-Planck-Institut für Quantenoptik (Germany) and Ludwig-Maximilians-Univ. München (Germany); Vladimir Pervak, Ludwig-Maximilians-Univ. München (Germany) . . . . [8190-10]

15.00: **Characterization of 1064nm laser-induced damage on antireflection coatings grown by atomic layer deposition**, Zhichao Liu, Yaowei Wei, Songlin Chen, Ping Ma, Jianping Hu, Chengdu Fine Optical Engineering Research Ctr. (China) . . . . [8190-11]

15.20 to 16.20 • Poster Session and Refreshment Break

16.20 to 17.40 • SESSION 4

Materials and Measurements I

Session Chairs: **Stavros G. Demos,** Lawrence Livermore National Lab. (USA);
Takahisa Jitsuno, Osaka Univ. (Japan)

16.20: **Characterization of optical losses in transparent YAG ceramics** *(Invited Paper)*, Romain Gaume, Stanford Univ. (USA) . . . . [8190-12]

17.00: **Investigation of bonding interface and effective laser oscillation by advanced composite ceramic**, Tomosumi Kamimura, Yuki Yamana, Haruki Nakagawa, Hiroki Muraoka, Osaka Institute of Technology (Japan); Sawao Honda, Yuji Iwamoto, Nagoya Institute of Technology (Japan); Yan Lin Aung, Akio Ikesue, World Lab Co., Ltd. (Japan) . . . . [8190-68]

17.20: **Subnanosecond bulk damage thresholds of single-crystal YAG and diffusion-bonded YAG structures at 1 micron,** Robert Stultz, Karen E. Yokoyama, Michael Ushinsky, Jeanette Lurier, Raytheon Space & Airborne Systems (USA); Michael D. Thomas, Andrew J. Griffin, Spica Technologies, Inc. (United Kingdom); Robert W. Farley, Mark E. Rogers, Brendan Foran, The Aerospace Corp. (USA) . . . . [8190-14]

17.40 to 17.50 • Closing Remarks

8190-07, Session 3

Laser-induced damage of coatings on Yb:YAG crystals at cryogenic condition

W. Zhang, H. Wang, H. Qi, D. Li, K. Yi, J. Shao,
Shanghai Institute of Optics and Fine Mechanics (China)

PRIMARY AUTHOR BIOGRAPHY:
Weili Zhang received PhD degree at Shanghai University. Her current research interests include laser-induced damage of coatings on Yb:YAG crystals at cryogenic condition.

ABSTRACT TEXT:
As large amounts of heat need to be dissipated during laser operation, some diode pumped solid state lasers (DPSSL), especially Yb:YAG laser, operate at cryogenic condition. This work investigated the laser induced damage of coatings (high-reflective and anti-reflective coatings) on Yb:YAG crystals at cryogenic temperature and room temperature. The results show that the damage threshold of coatings at cryogenic temperature is lower than the one at room temperature. Field-emission scanning electron microscopy (FESEM) and optical profiler were used to obtain the damage morphology, size and depth. Taking alteration of physical parameters, microstructure of coatings and the environmental pollution into consideration, we analyzed the key factor of lowering the coating damage threshold at cryogenic conditions. The results are important to understand the mechanisms leading to damage at cryogenic conditions.

Keywords: laser induced damage, Yb:YAG crystal, cryogenic condition, coating

8190-08, Session 3

Laser-induced damage of Kapton thin films demonstrating temperature and wavelength dependent absorptance: a case study in remote-sensing material analysis

W. J. Palm, M. A. Marciniak, G. P. Perram, K. C. Gross, W. F. Bailey,
Air Force Institute of Technology (United States)

ABSTRACT TEXT: Optical properties and laser damage characteristics of thin-film aluminized Kapton were investigated. Optical absorption of virgin and irradiated samples was measured using a Cary 5000 Grating Spectrophotometer and an ABB/Bomem MB157S FTIR Spectrometer with a combined range of 0.2 to 15 µm at both room-temperature and 150°C. Laser-induced damage mechanisms of penetration time and maximum temperature were collected in a vacuum environment using an IPG Photonics continuous-wave solid-state laser operating at 1.07 µm and an electric-discharge CO_2 laser operating at 10.6 µm. Rather large differences in damage performance at the two wavelengths were observed due to the variability in starting absorption properties between the NIR and LWIR.

A FLIR Systems Quantum Well Infrared Photo-detector camera at 8-9.2 µm was used to remotely examine the thin-film temperature evolution based on a known LWIR band of nearly-constant emissivity. The dual-detector FTIR spectrometer was also employed during testing in order to extract spectral emittance information from high-temperature irradiation scenes. Surface emittance was found to change after the material heated past approximately 500°C and during subsequent post-test cooling. This evolving spectral emittance with temperature successfully predicted increases in absorption credited for the more-rapid penetration times and higher heating rates with the 1.07-µm laser. A simplified one-dimensional conduction and radiation model replicated the remotely-sensed temperature as a function of time in tests with constant absorptance and no material breakdown. With this result of evolving emittance data, this model could be extended to predict more realistic heating trends at high irradiances where damage did occur and spectral absorption properties varied.

Keywords: laser damage, Kapton, imaging, spectroscopy

8190-09, Session 3

Laser-induced damage thresholds of optical coatings at different temperature

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

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

ABSTRACT TEXT: In Institute of Laser Engineering, Osaka university, a new high-power laser system by active mirrors with cryogenic cooled Yb:YAG ceramics have been developed for nuclear fusion driver. Laser-induced damage threshold (LIDT) of optical elements is one of important properties because the output power of laser systems is limited by the LIDTs. However, influences of temperature on LIDT are not known well.

In this study, we measured LIDTs of dielectric and metal coatings with Nd:YAG laser (wavelength 1064 nm, pulse width 4 ns). The purposes are to clear the influences of initial free electron. This study is the first trial to evaluate the temperature dependence of LIDT for optical coatings.

The damage threshold was determined by "N-on-1" method. The damage was detected by plasma emissions and images transferred with co-arraignment He-Ne laser. As experimental samples, SiO_2 and MgF_2 single-layer coatings were prepared on silica and BK7 optical glasses with electron beam evaporation. Copper, silver and gold coatings were also prepared with a magnetron sputtering system.

In the results, temperature dependence of LIDTs for optical substrates and all dielectric single-layer coatings indicated same trend as that for bulk silica glasses, which increased linearly with decreasing the temperature. However, all metal coatings had the inverse trend of the dependence for dielectric coatings. The LIDTs decreased linearly with decreasing temperature.

Keywords: Laser-induced damage, Optical coating, Temperature dependence, Dielectric coating, Metal coating

Investigation of the laser-induced damage of dispersive coatings

I. B. Angelov, A. von Conta, S. A. Trushin, Max-Planck-Institut für Quantenoptik (Germany); **Z. Major, F. Krausz,** Max-Planck-Institut für Quantenoptik (Germany) and Ludwig-Maximilians-Univ. München (Germany);
V. Pervak, Ludwig-Maximilians-Univ. München (Germany)

PRIMARY AUTHOR BIOGRAPHY:
Ivan Angelov graduated in 2009 with a master degree in Laser physics and optics at the Department of Quantum Electronics of Sofia University, Bulgaria. Since February 2010 he is working on his PhD degree at the Max-Planck-Institute of Quantum Optics in Garching, Germany.

ABSTRACT TEXT: For the last half century lasers have played an important role in high-field physics as more and more powerful lasers have been developed. In order to increase further the pulse energy and to make pulses shorter, however, it is of crucial importance to produce optical elements, which are able to sustain larger intensities. Thus it is important to understand the mechanisms behind optically induced damage in the domain of ultra-short pulses.

n the sub-picosecond regime the dependence of laser-induced damage threshold (LIDT) on the band gap of the material has been previously investigated [1]. The laser irradiation resistance of thin-film coatings of different mixtures of metal oxides with silica has also been studied [2]. The influence of electric field distribution inside of a multilayer dielectric coating on its damage threshold has been examined as well [3]. Here we combine all these types of investigations in one study in order to assess the influence of the different aspects on the LIDT in the femtosecond domain.

Different dispersive coatings were tested in terms of LIDT by using a Ti:Sapphire laser yielding 1mJ, 45fs pulses at 500Hz repetition rate at 790nm central wavelength. The beam was focused down to 140µm achieving fluences up to 5J/cm^2. Single layer coatings made of Au, Ag, Nb_2O_5, SiO_2, Ta_2O_5 and mixtures of Ta_2O_5 with silica in different concentrations. Different dispersive coatings, consisting of SiO_2 as the low refractive index material and different high refractive index materials (Nb_2O_5, Ta_2O_5, HfO_2) were examined and compared. Each measurement spot was illuminated for 10s with a certain fluence, then the fluence was increased and the same spot was illuminated for another 10s. The procedure was repeated until the scattering signal increased rapidly, indicating damage.

The values yielded by the measurements were within the range from 0.05 to 0.5 J/cm^2. The measured metal coated mirrors showed damage threshold similar to that of the dielectric mirrors. The dispersive mirrors had damage threshold close to that of a single layer of the respective high refractive index material used. Increase of the damage threshold of the single layer mixture coatings was observed in proportion to the concentration of silica in the layer. These results suggest a damage threshold dependence on the band gap of the respective high refractive index material used. On the other hand, no distinctive difference in the damage threshold of the dispersive coatings with respect to that of stack consisted of quarter-wave optical thickness layers, produced with the same high refractive index material was observed. That suggests a weak dependence of the damage threshold on the electric field distribution in the layer stack. Based on these results we conclude that the best approach to increase the damage threshold of thin-film dielectric coatings is to use materials with larger band gap and to mix the high refractive index material with a low refractive index material in an appropriate ratio.

References:
[1] M. Mero et al., Phys. Rev. B 71, 115109 (2005)
[2] M. Jupe et al., Proc. of SPIE Vol. 6403, 64031A-1 (2006)
[3] G. Abromavicius et al., Proc. of SPIE Vol. 6720, 67200Y-1 (2007)

Keywords: laser damage, femtosecond pulses, mixtures, dispersive mirrors, single layer coatings

8190-11, Session 3

Characterization of 1064nm laser-induced damage on antireflection coatings grown by atomic layer deposition

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

PRIMARY AUTHOR BIOGRAPHY:
The author obtained the master's degree in the China Academy of Engineering Physics in 2009, and has been engaged in high-power laser optics material research in Fine Optical Engineering Research Center until now.

ABSTRACT TEXT:
Laser damage experiments were carried out to measure the laser damage resistance of Al_2O_3/TiO_2 and Al_2O_3/HfO_2 antireflection coatings at 1064nm which were deposited by a new coating technology, atomic layer deposition (ALD). Results show that the 1-on-1 qualified damage threshold of Al_2O_3/TiO_2 antireflection coating is between 3J/cm^2 to 6J/cm^2.It is find that deposition temperature may obviously affect damage resistance of coatings. Coatings deposited at 50 or 100 have higher damage threshold than those deposited at 300, which may be due to the crystallization of film material at high temperature. For Al_2O_3/HfO_2 antireflection coatings, the 1-on-1 qualified damage threshold is about 7J/cm^2~8J/cm^2 and the R-on-1 functional damage threshold is 11.7±7%J/cm^2 after annealing process, which indicate that the laser damage resistance of Al_2O_3/HfO_2 antireflection coatings grown by ALD is close to those deposited by traditional e-beam coatings. By using scanning electron microscope (SEM) and atomic force microscope (AFM), the damage morphology has also been discussed. As a result, there are two damage types, “pinpoints” and “melt spots”. Pinpoints are initial damage with a depth of about 180nm~210nm and 5μm ~10μm in diameter, while melt spots are the morphology of damage growth under further laser irradiation. Detailed images indicate that both initial damage and damage growth occur in Al_2O_3 layer. We suggest that residual carbon compounds left by the precursors Al (CH3)3 during deposition process strongly absorb laser energy and cause damage in Al_2O_3 layer.

Keywords: atomic layer deposition, ALD, laser-induced damage, antireflection coatings, damage morphology

8190-12, Session 4

Characterization of optical losses in transparent YAG ceramics

R. Gaume, Stanford Univ. (United States)

NO ABSTRACT AVAILABLE

Subnanosecond bulk damage thresholds of single-crystal YAG and diffusion-bonded YAG structures at 1 micron

R. Stultz, K. E. Yokoyama, M. Ushinsky, J. Lurier,
Raytheon Space & Airborne Systems (United States); **M. D. Thomas, A. J. Griffin,**
Spica Technologies, Inc. (United Kingdom); **R. W. Farley, M. E. Rogers, B. Foran,**
The Aerospace Corp. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Dr. Stultz has been working in the fields of solid-state lasers and nonlinear optics for more than 30 years and is currently an Engineering Fellow at Raytheon Space and Airborne Systems in El Segundo, CA. His professional experiences include the development of various solid-state laser products, as well as Raman and OPO-shifted laser systems. He received his Ph.D. in Electrical Engineering / Electrophysics at the University of Southern California.

ABSTRACT TEXT: Laser bulk damage thresholds were measured for both single-crystal YAG and for diffusion-bonded YAG structures using 600 picosecond pulses at 1064 nm. The tested samples included 3-layer sandwich structures with doped cores of various thicknesses. An undoped-YAG end cap was diffusion-bonded on one end of each of the sandwiches. The 1064 nm laser source was focused to a 13 micron diameter spot at the boundary region between the core and the undoped endcap. Measurements included the evaluation of single- and multiple-pulse damage thresholds at single sites, as well as thresholds for continuous 90%-overlap scans. The single-site thresholds at the diffusion-bonded boundary were close to that of single-crystal YAG. However, the continuous scans revealed isolated microscopic sites where the damage threshold was as much as 4 times lower than that of single-crystal YAG.

We have successfully fabricated ceramic composite structure with extremely strong interface by sinter-bonding of polycrystalline ceramics. High durability was confirmed even in a laser oscillation with high-pumping power density. For that reason, it was demonstrated that polycrystals with different composition are integrated together, and a single ceramic composite with seamless bonding interface is finally formed. The thermo-, mechanical-properties of bonding interfaces is almost equal to those of host material of YAG ceramics due to perfect bonding.(no interstice and defect free) This means our bonding is available to high power laser operation because of higher damage threshold. We demonstrate high power density laser used by advanced composite.

Keywords: YAG, bulk damage threshold, diffusion bonded, subnanosecond damage threshold

Thin Films

10.30 to 11.30 and 15.20 to 16.20

Defect formation in oxide thin films, Lars O. Jensen, Mathias Mende, Laser Zentrum Hannover e.V. (Germany); Céline Gouldieff, Frank R. Wagner, Institut Fresnel (France); Holger Blaschke, Laser Zentrum Hannover e.V. (Germany); Jean-Yves Natoli, Institut Fresnel (France); Detlev Ristau, Laser Zentrum Hannover e.V. (Germany) . . . . [8190-52]

Not all sputtered SiO_2 films are the same, Chris S. Smith, Dinesh Patel, Colorado State Univ. (USA); Ashot S. Markosyan, Roger K. Route, Martin M. Fejer, Stanford Univ. (USA); Carmen S. Menoni, Colorado State Univ. (USA) . . . . [8190-53]

Spontaneous and induced absorption in amorphous Ta_2O_5 dielectric thin films, Ashot S. Markosyan, Roger K. Route, Martin M. Fejer, Stanford Univ. (USA); Dinesh Patel, Carmen S. Menoni, Colorado State Univ. (USA) . . . . [8190-54]

Comparison of femtosecond pulse LIDT in vacuum of oxide films and the effect of a thin capping layer, Duy N. Nguyen, Luke A. Emmert, The Univ. of New Mexico (USA); Dinesh Patel, Carmen S. Menoni, Colorado State Univ. (USA); Wolfgang Rudolph, The Univ. of New Mexico (USA) . . . . [8190-55]

Effects of polishing and cleaning process on laser-induced damage of 355 nm AR coatings, Zhengxiang Shen, Tao Ding, Xiaowen Ye, Bin Ma, Xinbin Cheng, Hongfei Jiao II, Jinlong Zhang, Tongji Univ. (China); Huasong Liu, Yiqin Ji, Tianjin Jinhang Institute of Technology Physics (China); Zhanshan Wang, Tongji Univ. (China) . . . . [8190-56]

Database on damage thresholds of picoseconds pulse for AR and HR coatings, Shinji Motokoshi, Institute for Laser Technology (Japan); Katsuhiro Mikami, Eiji Sato, Osaka Univ. (Japan); Kota Kato, Tomohiro Somekawa, Institute for Laser Technology (Japan); Takahisa Jitsuno, Osaka Univ. (Japan) . . . . [8190-57]

Characterization of hafnia thin films made with different deposition technologies, Wanjun Ai, Shengming Xiong, Institute of Optics and Electronics (China) . . . . [8190-78]

Surfaces, Mirrors, and Contamination

10.30 to 11.430 and 15.20 to 16.20

Full-field simulation of laser-generated ultrasound at the fluid-solid interface, Yan Zhao, Southeast Univ. (China) and Nanjing Univ. of Science & Technology (China); Zhonghua Shen, Jian Lu, Xiaowu Ni, Nanjing Univ. of Science & Technology (China); Yiping Cui, Southeast Univ. (China) . . . . [8190-58]

Formation mechanism of self-organized nanogratings induced by femtosecond laser pulses on titanium surface, Md. S. Ahsan, KAIST (Korea, Republic of) and Khulna Univ. (Bangladesh); Yeong G. Kim, Man S. Lee, KAIST (Korea, Republic of). . . . . [8190-59]

Influence of subsurface defect on anti-damage capability of fused silica at UV laser, Jin Huang, China Academy of Engineering Physics (China) . . . . [8190-60]

Characterization of CO_2 laser-based damage mitigation of SiO_2 surfaces using infrared thermometry and microscopy, Philippe Cormont, Commissariat à l'Énergie Atomique (France); Laurent Gallais, Institut Fresnel (France); Lucile Robin, Commissariat à l'Énergie Atomique (USA); Hebert David, Jean-Luc Rullier, Commissariat à l'Énergie Atomique (France) . . . . [8190-61]

Study of dust-pollution-induced laser damage on fused silica surface, Xinda Zhou, Jin Huang, Xiaodong Jiang, China Academy of Engineering Physics (China) . . . . [8190-62]

Chemical inhibition, mechanisms and detection of contamination-enhanced laser-induced damage, Bruce H. Weiller, Jesse D. Fowler, Randy M. Villahermosa, The Aerospace Corp. (USA) . . . . [8190-63]

Cleaning practices and facilities for the National Ignition Facility, James A. Pryatel, William H. Gourdin, Susan C. Frieders, Lawrence Livermore National Lab. (USA). . . . . [8190-64]

Defect formation in oxide thin films

L. O. Jensen, M. Mende, Laser Zentrum Hannover e.V. (Germany);
C. Gouldieff, F. R. Wagner, Institut Fresnel (France); **H. Blaschke,** Laser Zentrum Hannover e.V. (Germany); **J. Natoli,** Institut Fresnel (France);
D. Ristau, Laser Zentrum Hannover e.V. (Germany)

ABSTRACT TEXT:
In nanosecond laser damage investigations, the specific defect density in the optical component or thin film plays the key role in triggering optical breakdown. UV irradiation can induce additional defects in optical materials before the damaging event takes place. This increased defect density can even be the main cause for UV laser damage as shown before in fused silica.

Moving on to oxide thin films, this contribution will present studies on SiO_2, Al_2O_3, and HfO_2 ion beam sputtered coatings. Pure single layers as well as composite single layers comprised of two oxides have been investigated concerning their tendency to generate additional defects resulting from UV laser irradiation. Within this work, tests at 355nm and 266nm have been performed and are compared.

Keywords: defect formation, UV laser damage, oxide mixtures

Not all sputtered SiO_2 films are the same

C. S. Smith, D. Patel, Colorado State Univ. (United States);
A. S. Markosyan, R. K. Route, M. M. Fejer, Stanford Univ. (United States);
C. S. Menoni, Colorado State Univ. (United States)

ABSTRACT TEXT:
SiO_2 is the material of choice for the low index component of near infrared to near ultraviolet multilayer interference coatings. When amorphous SiO_2 (a-SiO_2) is deposited by sputtering, either metal or oxide targets can be used. Use of an oxide target is generally preferred because it makes the process simple in terms of the chemistry. Instead when using a metal target, the deposition conditions need to be more carefully selected to realize transparent oxide films. In this paper we will present results of Electron Paramagnetic Resonance (EPR) measurements on amorphous and optically transparent SiO_2 thin films deposited under different conditions using a metal (a-SiO_2m) and oxide (a-SiO_2o) target respectively. The EPR signature of a-SiO_2o identifies oxygen interstitials as the dominant defects in the films, while in the a-SiO_2m, the defects are characterized by a g-tensor characteristic of an E' center, prevalent in bulk SiO_2. We will discuss the impact of these defects in the optical properties of the amorphous nanofilms.

This work is supported by ONR grant No. N00014-07-1-1068.

Keywords: ion beam sputtering of oxide films, absorption, electron paramagnetic resonance, defects in amorphous oxides

8190-54, Poster Session

Spontaneous and induced absorption in amorphous Ta_2O_5 dielectric thin films

A. S. Markosyan, R. K. Route, M. M. Fejer, Stanford Univ. (United States);
D. Patel, C. S. Menoni, Colorado State Univ. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Received PhD from M.V. Lomonosov Moscow State University, Till 2006: Laboratory of Magnetism, Moscow State University, Since 2006: E.L. Ginzton Lab, Stanford University

ABSTRACT TEXT:
Tantalum pentoxide (Ta_2O_5) is the high index material most commonly in optical coatings for high average power lasers such as the LIGO project (NSF grant PHY 07-57896), because it is possible to obtain sputtered oxide films with absorption losses at mid-infrared wavelengths of less than a 1 ppm. [1] We have chosen this 'model' oxide to investigate the spontaneous and optically induced absorption.

The photothermal common-path interferometric technique is capable of detecting sub-ppm levels of optical absorption at a given wavelength when a second beam is also incident on the thin film oxide sample. In this work, dual beam experiments are carried out to assess the optical absorption at 1064 nm of a ~ 140 nm thick tantala thin film on fused silica with and without illumination with UV beam of wavelength 266 nm. It will be shown that the presence of UV radiation impacts substantially the absorption value at l = 1064 nm. The data are discussed assuming the main effect of the UV exposure to be the creation of shallow color centers in the tantala thin films.

This work is supported by ONR grant No. N00014-07-1-1068.

[1] G.M. Harry, M.R. Abernathy et al., Class. Quantum Grav. 24 (2007) 405-415.

Comparison of femtosecond pulse LIDT in vacuum of oxide films and the effect of a thin capping layer

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

PRIMARY AUTHOR BIOGRAPHY:

ABSTRACT TEXT: Previously it was shown that for trains of more than 300,000 subpicosecond pulses the damage threshold of hafnium oxide and silicon dioxide thin films drops to just 10% of its single-pulse value when tested under high vacuum conditions (~10^{-7} Torr). It was shown that this effect is related to the water vapor partial pressure of the ambient, and to a smaller extent the partial pressure of oxygen. The shape of this dependence also differs for the two oxides studied. Additional oxides have now been studied and we will show that aluminum oxide exhibits the best laser damage resistance at reduced pressures. In addition the effect of thin (<10 nm) capping layers was also studied. The response of the stack to the ambient water vapor pressure is determined by the surface layer. It was also found that such a capping layer can improve the damage threshold of the underlying film. A model based on the oxygen diffusion in these materials will be presented to explain these data

Keywords: subpicosecond pulse, laser damage, vacuum, water vapor, capping layer, oxygen diffusion

Effects of polishing and cleaning process on laser-induced damage of 355 nm AR coatings

Z. Shen, T. Ding, X. Ye, B. Ma, X. Cheng, H. Jiao II, J. Zhang, Tongji Univ. (China);
H. Liu, Y. Ji, Tianjin Jinhang Institute of Technology 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:
To improve the laser induced damage threshold (LIDT) of laser coatings remains a key problem for high-power optics. The fabrication of laser coatings with high LIDT is a systematic engineering, and we consider it as a chain consisted of some key nodes, such as the material of substrate, polishing methods, cleaning process, deposition material, and deposition techniques et al. In this paper, we pay more attention on polishing and cleaning process of substrates. Our aim is to study the influence of surface preparation steps before coating deposition on the laser damage resistance of 355nm.AR coatings.

Fused silica (JGS-1, Chinese code) substrates with different polishing processing, which can introduce different surface topography, are selected to investigate the polishing process. The diameter of the samples is 30 mm and the thickness 5 mm. Then wet chemical cleaning method with ultrasonic technique is employed to remove the contaminations on the substrates. The cleaning protocol is based on the improved RCA cleaning process, which is the most common cleaning technique widely used in the semiconductor industry, but two kinds of solutions are selected. One is the commercial surfactant solution, and the other is the self-confect solution (the mixture of acid and alkaline solution, respectively).Dark field microscope and atomic force microscope (AFM) are adopted as qualitative and quantitative methods to investigate the cleaning effects of substrates. A statistical model of contamination removal rates permits to optimize the cleaning process.

Comparison of all the samples with different treatments, a systematic analysis shows that the damage-free polishing surface and sufficient cleanness of removing the micrometer-sized contamination on the surface, which can introduce nodular defects, play important roles in improving the laser-induced damage of AR coatings.

Keywords: laser damage, polishing, ultrasonic cleaning, laser coating

Database on damage thresholds of picoseconds pulse for AR and HR coatings

S. Motokoshi, Institute for Laser Technology (Japan); **K. Mikami, E. Sato,** Osaka Univ. (Japan); **K. Kato, T. Somekawa,** Institute for Laser Technology (Japan); **T. Jitsuno,** Osaka Univ. (Japan)

PRIMARY AUTHOR BIOGRAPHY:
Chief researcher in Inst. for Laser Tech. He worked on the laser-guide of lightning, SHG for high-average lasers, and solar pumped lasers. His primary work is the developments of high-power lasers and their optics.

ABSTRACT TEXT:
Inst. for Laser Tech. in Japan has opened the examinations of damage threshold for various optical devices required from optics makers since 2005. Many makers do not know the damage thresholds of optics for other makers and cannot compare them with own optics. We have proceeded to construct of database on damage threshold of optics for high-power lasers, cooperating with many Japanese coating makers. It will be connected with the design of laser systems and the improvement of optical technologies. We had presented the database on damage thresholds for HR and AR coatings at each wavelength of 1064 and 532 nm in last symposium[1]). In this time, the damage thresholds for the above 1064-nm samples were estimated by using a glass laser system with 2.2-ps pulse width at 1053-nm wavelength. It was cleared that most of samples had the damage thresholds of about 4.5 J/cm^2. And also, the results were compared with that of 10-ns pulse.

1) S.Motokoshi, et al., Database on Laser-Induced Damage Thresholds for AR and HR Coatings in Japan, Proceedings of SPIE Vol. 7842 (2011) 78420F.

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

8190-78, Poster Session

Characterization of hafnia thin films made with different deposition technologies

W. Ai, S. Xiong, Institute of Optics and Electronics (China)

ABSTRACT TEXT:
In this study, single layer hafnium dioxide thin films were prepared by electron beam deposition (EBD), ion assisted deposition (IAD) with End-Hall and APS ion sources, and ion beam sputtering (IBS). The starting materials for EBD and IAD were hafnium and granulated hafnia, whereas the target for IBS was hafnium. Comprehensive characterization of these films such as structural and optical properties, surface topography and weak absorption have been studied via X-ray diffraction (XRD), Lambda 900 spectrophotometer, variable angle spectroscopic ellipsometry (VASE), scanning electron microscopy (SEM), ZYGO interferometer, and Laser Calorimeter. The results show that thin film properties have a close relationship with deposition technologies. The EBD and IBS films are largely amorphous, however, the IAD films with different ion sources are all polycrystalline but with different crystal structures. Comparison with EBD films, the IAD and IBS films, of which the structures are very compact, represent higher refractive index and weak absorption. RMS roughness and total integrated scattering (TIS) of IAD and IBS films were lower than the EBD films. All of these results are useful to investigate the laser-induced damage threshold (LIDT) of hafnium dioxide thin films and hafnia/silica high reflectors for high power laser applications.

Full-field simulation of laser-generated ultrasound at the fluid-solid interface

Y. Zhao, Southeast Univ. (China) and Nanjing Univ. of Science & Technology (China);
Z. Shen, J. Lu, X. Ni, Nanjing Univ. of Science & Technology (China);
Y. Cui, Southeast Univ. (China)

PRIMARY AUTHOR BIOGRAPHY:
Yan Zhao received her doctor's degree from the department of Measuring and Testing Technologies and Instruments at Nanjing University of Science and Technology in 2007. She is currently a teacher in Nanjing University of Science and Technology. She is devoted to investigating the laser ultrasonics and its applications.

ABSTRACT TEXT:
The analysis of ultrasonic field generated by a pulse laser source load applied on a fluid-solid interface is presented. Based on the thermoelastic theory, the finite element solution for the laser-generated ultrasonic field is derived. The full-field of this ultrasonic field on water-stainless steel interface is presented, which are in very good agreement with the experimental measurement in other literatures. The obtained analytical solutions will provide necessary theoretical background for the optimization of the laser- generation of ultrasonic field on a fluid-solid interface in experiments.

Keywords: Laser ultrasonic, Full-field simulation, Finite element method

Formation mechanism of self-organized nanogratings induced by femtosecond laser pulses on titanium surface

M. S. Ahsan, KAIST (Korea, Republic of) and Khulna Univ. (Bangladesh);
Y. G. Kim, M. S. Lee, KAIST (Korea, Republic of)

ABSTRACT TEXT:
In this paper, we demonstrate the formation of self-organized periodic nanogratings on titanium surface under the irradiation of a single-beam femtosecond laser. We investigate that the direction of the nanogratings is perpendicular to the direction of laser polarization. We also report on the dependence of the formation of nanogratings', produced on titanium surface, on the laser fluence and the number of applied laser pulses in each spot. Furthermore, we investigate the dependence of nanogratings' period on various laser parameters. Besides, we briefly explain the formation mechanism of the self-organized periodic nanogratings, produced on titanium surface. The self-organized nanogratings are mainly produced due to the interaction of the high-intensity incident laser beam and the laser induced plasma waves. Above certain threshold energy, phase explosion takes place, which in turn causes the formation of self-organized nanogratings on titanium surface.

Keywords: Femtosecond laser, Titanium surface, Self-organized nanograting, Phase explosion, Nanostructure

Influence of subsurface defect on anti-damage capability of fused silica at UV laser

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

PRIMARY AUTHOR BIOGRAPHY:
31 years old,a ssistant research fellow, be engaged in research of optics material character in high power solid laser facility.

ABSTRACT TEXT:
In ultraviolet (UV) pulse laser, anti-damage capability of fused silica optics is directly depended on the absorptive impurities and scratches in subsurface, which are induced by mechanical polishing. In the research about influence of subsurface defect on anti-damage capability, a series of fused silica surface with various impurities and various structure scratches were created by HF acid solution etching with different depth. ToF-SIMS and scanning probe microprobe reveals that with increasing etching depth, impurity content in the subsurface layer is decreased, the scratches structure becomes more smooth and diameter to depth ration is increased. Damage test with 355 nm pulse laser shows that when subsurface thickness is removed 600nm by HF acid etching, anti-damage capability of fused silica is enhanced and initial damage threshold is raised by 40 percent. Field enhancement caused by change of scratches structure was calculated by FDTD software, and the calculated results are accordant to the damage test results.

Keywords: fused silica, laser damage, impurity, scraches, HF acid, Tof-sims, Scanning probe microprobe, FDTD

Characterization of CO_2 laser-based damage mitigation of SiO_2 surfaces using infrared thermometry and microscopy

P. Cormont, Commissariat à l'Énergie Atomique (France);
L. Gallais, Institut Fresnel (France); **L. Robin,** Commissariat à l'Énergie Atomique (United States); **H. David, 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:
In order to improve our process of damage growth mitigation based on CO_2 laser, we are studying the silica transformation. In this study, a particular attention was paid to get temperature information during CO_2 laser operation on fused silica surface. Surface temperature was derived from heat flux measured by an infrared camera. The choice of the detection has to be made considering that the silica at the considered spectral range must have, firstly, an optical depth thick compared to the internal temperature gradient and, secondly, an emissivity independent of temperature. For camera calibration, a non-uniform correction (NUC) of the detector pixel matrix was performed and then a correspondence file between numerical levels and blackbody temperatures was created. Three blackbodies were used to establish a calibration file covering the temperature range [400 K - 2500K]. This calibration was also suitable for our special configuration, which gives a high spatial resolution of seventy-five micrometers per pixel. Microscopic observations that have supplemented thermal camera measurements helped us to interpret silica transformations. Notably, we observed that fused silica ejection started at a surface temperature lower than 2000 K. Such evaporation is described by a thermo dynamical approach, and calculations show a very good agreement with experiment.

Keywords: CO_2 laser, damage growth mitigation, temperature measurement

Study of dust-pollution-induced laser damage on fused silica surface

X. Zhou, J. Huang, X. Jiang, China Academy of Engineering Physics (China)

ABSTRACT TEXT:
We report the experiment results of the study on dust pollution initiated damage in optical component of the ICF facilities and evaluate the influence of this kind damage on other optical component. Dust caused by laser-induced damage in optical component in vacuum environment at the ICF facility was collected with fused silica flat optics. The transmission change of the dust polluted optics was observed and analyzed. The damage probability of the dust polluted optics was tested by s-on-1 method using pulsed Nd-YAG solid laser. Results showed that dust polluted sol-gel anti-reflection film coated fused silica optics exhibited lower transmission and higher damage probability than the naked fused silica flat optics. Besides, the dust particle on the input surface will cause severer damage than on the output surface. Electromagnetic field modulating induced by dust particles on surface of fused silica optics was simulated using the FDTD theory. Simulation results suggested that dust particles on the input surface introduced higher light field enhancement than on the output surface.

Keywords: fused silica, vacuum pollution, vacuum pollution

Chemical inhibition, mechanisms and detection of contamination-enhanced laser-induced damage

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. We have developed a test facility that can be used to quantitatively measure contamination enhanced laser induced damage (CELID) thresholds at 1.064 µm for optics in well-controlled and reproducible atmospheres. Using this facility we have developed chemical inhibitors for CELID. We have demonstrated that water or alcohols very effectively inhibit the CELID process and greatly extend the lifetime of fused silica optics under high power laser irradiation in the presence of toluene. In the presence of 300 ppm toluene and synthetic air the damage threshold is 1.8×10^4 laser pulses. With the addition of ~4000 ppm of water, methanol or ethanol, the lifetime is in excess of 1×10^6 pulses with no damage observed. We believe this is due to competitive surface adsorption between contaminant and inhibitor. Temperature dependence of the damage threshold is consistent with this proposal. Other important data will be presented on laser fluence dependence, the development of sensors for damage detection and the effect of optical coatings and other contaminants on damage thresholds.

Keywords: laser, contamination, inhibition, toluene, space, water, methanol, ethanol

Cleaning practices and facilities for the National Ignition Facility

J. A. Pryatel, W. H. Gourdin, S. C. Frieders,
Lawrence Livermore National Lab. (United States)

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

NO ABSTRACT AVAILABLE

Tuesday AM • 20 September

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

Materials and Measurements II

Session Chairs: **James E. Andrew,** AWE plc (United Kingdom);
Joseph A. Menapace, Lawrence Livermore National Lab. (USA)

08.20: **Imaging studies of photodegradation and recovery of DO11(and related dyes) doped into PMMA**, Benjamin R. Anderson, Shiva K. Ramini, Mark G. Kuzyk, Washington State Univ. (USA) . . . . [8190-16]

08.40: **Recent progress in the development of pulse compression gratings**, Jérôme Néauport, Commissariat à l'Énergie Atomique (France); Nicolas Bonod, Institut Fresnel (France); Steve Hocquet, Commissariat à l'Énergie Atomique (France) . . . . [8190-17]

09.00: **Self healing mechanisms in anthraquinone dyes when doped in PMMA polymer**, Shiva K. Ramini, Prabodh Dhakal, Mark G. Kuzyk, Washington State Univ. (USA). . . . [8190-18]

09.20: **Design and testing of optical coatings for laser crystals for HiPER project**, Jindrich Oulehla, Pavel Pokorny, Josef Lazar, Institute of Scientific Instruments of the ASCR, v.v.i. (Czech Republic) . . . . [8190-19]

09.40: **Femtosecond laser micro fabrication in polymers towards memory devices and micro fluidic applications,** Deepak L. N. Kallepalli, Soma Venugopal Rao, Desai Narayana Rao, Sr., Univ. of Hyderabad (India). . . . . [8190-20]

10.00 to 10.30 • 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.

10.30 to 11.30 • Poster Session and Refreshment Break

11.30 to 12.50 • SESSION 6

Materials and Measurements III

Session Chair: **Amy L. Rigatti,** Univ. of Rochester (USA);
Michelle D. Shinn, Thomas Jefferson National Accelerator Facility (USA)

11.30: **Estimation of the Raman cross section in KDP and DKDP at 2w, 3w and 4w**, Stavros G. Demos, Lawrence Livermore National Lab. (USA). [8190-21]

11.50: **The uncertainty analysis of the laser damage threshold measurement based on ISO11254-1**, Jianping Hu, Chengdu Fine Optical Engineering Research Ctr. (China) . [8190-22]

12.10: **Material modification and 3D structure of damage craters in fused silica induced by 355 nm laser pulses irradiation**, Chunhong Li, Xin Ju, Univ. of Science and Technology Beijing (China) . . . . [8190-23]

12.30: **Third harmonic microscopy for optical material characterization**, Reed A. Weber, Cristina Rodriguez, Duy N. Nguyen, Luke A. Emmert, Wolfgang Rudolph, The Univ. of New Mexico (USA); Dinesh Patel, Carmen S. Menoni, Colorado State Univ. (USA) . [8190-24]

12.50 to 13.40 • Lunch Break

8190-16, Session 5

Imaging studies of photodegradation and recovery of DO11(and related dyes) doped into PMMA

B. R. Anderson, S. K. Ramini, M. G. Kuzyk, Washington State Univ. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Benjamin is a graduate student at Washington State University working on his PhD in physics with a specialization in nonlinear optics. He is originally from Detroit and went to undergrad at Valparaiso University in Indiana.

ABSTRACT TEXT:
One of the efficiency limiting factors of optical devices used at high intensities is photo damage to optical components. In devices that use organic dyes, photo damage causes irreversible damage to the chromophores, deteriorating efficiency, and eventually failure. In 2002 we discovered the novel result that Amplified Spontaneous Emission (ASE) in disperse orange 11(DO11) doped into (poly)methyl methacralate(PMMA) will recover after photodegradation, even after complete damage. Our present work focuses on monitoring degradation and recovery of systems such as DO11/PMMA thin films with a digital imaging apparatus. The results are consistent with ASE recovery measurements, but also suggest a dose-dependent response for how much recovery occurs. We have also found several other organic dyes which recover from photodamage when doped into a polymer matrix. These results suggest the possibility of making optical components more resistant to photodamage, and capable of self recovery, removing the necessity to constantly replace components damaged by high intensity light.

Keywords: Photodamage and Recovery, Dye doped polymer thin films, dye laser deterioration, Spatially resolved dye recovery, Photodamage resistant dyes

Recent progress in the development of pulse compression gratings

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

ABSTRACT TEXT:
A Petawatt facility called PETAL (PETawatt Aquitaine Laser) is under development near the LMJ (Laser MegaJoule) at CEA Cesta, France. PETAL facility uses chirped pulse amplification (CPA) technique [1]. This system needs large pulse compression gratings exhibiting damage threshold of more than 4 J/cm² in normal beam at 1.053µm and for 500fs pulses. In this paper, we present our recent progress and developments of such pulse compression gratings. We have shown in previous works that the enhancement of the near electric field inside the pillars of the grating drives the damage threshold [2, 3]. This was evidenced from a macroscopic point of view by means of laser damage testing. We herein demonstrate that damage morphology during damage initiation at the scale of the grating groove is also consistent with this electric field dependence. Some recent grating designs will also be detailed.

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, 124045 (2008)
2. N. Bonod, J. Neauport, "Optical performances and laser induced damage threshold improvement of diffraction gratings used as compressors in ultra high intensity lasers", Opt. Commun. 260 649-655 (2006)
3. J. Neauport, N. Bonod, S. Hocquet, S. Palmier, G. Dupuy, "Mixed metal-dielectric gratings for pulse compression ", Opt. Express 18, 23776-23783 (2010)

Keywords: diffraction gratings, laser induced damage threshold, ultrashort

Self healing mechanisms in anthraquinone dyes when doped in PMMA polymer

S. K. Ramini, P. Dhakal, M. G. Kuzyk, Washington State Univ. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Shiva K. Ramini is currently pursuing his PhD in physics at Washington State University, Pullman, WA. His interests or Optoelectronics, optical damage and recovery.

ABSTRACT TEXT:
Reversible photodegradation of laser dyes is observed in several dye-polymer systems using various experimental techniques [1,2,3]. Howell and Kuzyk[5] first demonstrated that 1-amino-2-methylanthraquinone (disperse orange 11, or DO11) dye-doped polymer would make a full recovery even when the degree of photodegradation was nearly 100%, as measured with amplified spontaneous emission (ASE). However, no recovery of the same dye in liquid solution was observed at any level of decay. This work suggests that the host polymer plays a crucial role in the self-healing process.[4] More recent studies by Embaye et al[5] reported on measurements of the time dependence of decay and recovery of ASE to study the mechanisms responsible for photodegradation and recovery and proposed a general model using a multi-state model.

In this presentation I will discuss recent developments in understanding the effect of temperature and concentration on the rate of photodegradation and recovery using UV-Vis spectroscopy as a probe.

We propose that the molecules are forming a quasi-stable state, dimers being one possible candidate, resulting in quenching of ASE - which is seen as photodegradation. Through a thermodynamic tunneling process, the dimers dissociate to individual molecules in their ground states, which should result in recovery of ASE. Preliminary measurements show that the recovery rate increases with increasing temperature, which is consistent with the dimer hypothesis, in which the dissociation rate should increase with temperature. A combination of time-dependent and temperature-dependent studies under UV-VIS probing provides a window into the decay and recovery process.

[1] G. D. Peng et al, J. Lightwave Technol. 16, 2365 (1998).
[2] B. Howell and M. G. Kuzyk, J. Opt. Soc. Am. B 19, 1790 (2002).
[3] Y. Zhu et al, Opt. Lett. 32, 958 (2007).
[4] B. Howell and M. G. Kuzyk, Appl. Phys. Lett. 85, 1901 (2004).
[5] Embaye et al, J. Chem. Phys., 129, 054504 (2008)

Keywords: amplified spontaneous emission, reversible photodegradation, self healing, disperse orange 11, PMMA, anthraquinone derivatives

Design and testing of optical coatings for laser crystals for HiPER project

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Institute of Scientific Instruments of the ASCR, v.v.i. (Czech Republic)

PRIMARY AUTHOR BIOGRAPHY:
I was Born 1981 in Brno, Czech Republic. In 2008 I finished master's degree in solid state physics at Masaryk University in Brno. Since 2009 I am a Ph.D student and working at the Institute of Scientific Instruments in coherence optics department. My field of interest is design and deposition of thin layer interference coatings.

ABSTRACT TEXT:
In this contribution we present a technology for deposition of interference coatings for optical components designed to operate as active media in power pulsed lasers. The aim of the technology is to prepare crystals for lasers for the HiPER project (High Power laser Energy Research) which should demonstrate the feasibility of laser driven fusion as a future energy source. Diode pumped solid state lasers (DPSSL) are the most likely option for fusion ignition. The choice of material for the lasers active medium is critical. Some of the most important properties include the ability to be antireflection and high reflection coated to reduce the energy losses and increase the overall efficiency. This contribution deals with some of the materials considered to be candidates for slabs serving as the active medium of the DPSSLs. We tested Yb:YAG and Yb:CaF_2 samples. As large amounts of heat need to be dissipated during laser operation, cryogenic cooling is necessary. We designed a special apparatus consisting of a vacuum chamber and a cooling system. The samples were placed into the vacuum chamber which was evacuated and then the samples were cooled down to approximately 120K and illuminated by a pulsed laser. Pulse duration was in the nanosecond region. Multiple test sites on the sample's surface were used for different laser pulse energies. These experiments also served as preliminary tests of laser damage threshold measurement methodology that we plan to use in the future. We combined the investigation with techniques of optical and electron microscopy for coating investigation after the conducted experiments.

Keywords: thin film coatings, HiPER project, laser damage, cryogenic

8190-20, Session 5

Femtosecond laser micro fabrication in polymers towards memory devices and micro fluidic applications

D. L. N. Kallepalli, S. Venugopal Rao, D. Narayana Rao, Sr.,
Univ. of Hyderabad (India)

PRIMARY AUTHOR BIOGRAPHY:

Mr. K L N Deepak is working on laser direct writing in polymers as his PhD program. He obtained his BS Hons and MS degrees in Physics from Sri Sathya Sai University, Puttaparthy in April 2004.

ABSTRACT TEXT:

We investigated femtosecond laser induced microstructures, gratings and craters in four different polymers: poly methyl methacrylate (PMMA), poly dimethyl siloxane (PDMS), polystyrene (PS) and poly vinyl alcohol (PVA) using Ti: Sapphire laser delivering 800 nm wavelength, maximum pulse energy of 1 mJ, 100 femto second (fs) at 1 KHz repetition rate. Local chemical modifications lead to the formation of optical centers, and peroxide radicals which are studied using UV-Vis absorption, emission, confocal micro-Raman and Electron Spin Resonance (ESR), Energy Dispersive Xray Absorption Spectroscopy (EDXAS) spectroscopy techniques. Results and applications towards memory devices and micro fluidics will be presented.

Keywords: emission, memory, optical centers, femtosecond laser direct writing, paramagnetic centers, confocal micro-Raman

8190-21, Session 6

Estimation of the Raman cross section in KDP and DKDP at 2w, 3w and 4w

S. G. Demos, R. N. Raman, R. A. Negres, S.T. Yang, M. A. Henesian and **K. Schaffers,** Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Stavros G. Demos is a physicist and has been involved in the field of Laser Damage since he jointed Lawrence Livermore national Laboratory in 1997 as a post doctoral fellow. He has over 100 journal publications and 20 patents in the fields of lasermatter interactions, laser damage, laser and optical materials, optical diagnostics and, biomedical photonics.

ABSTRACT TEXT:
While laser induced damage in optical components arising from some type of absorbing defect structure (damage precursor) is a well recognized limiting processes in ICF class laser systems, there are other mechanisms that can also damage the optical components. One of these mechanisms is associated with the generation of stimulated Raman scattering (SRS). Spontaneously generated Raman scattered light traveling inside the large aperture components orthogonal to the laser beam propagation direction and following reflections at their edges can experience gain leading to energy conversion via SRS and canlead to adverse effects arising from the interaction of the SRS pulse with the edge surfaces of the optic and the adjacent components (holders etc.). This can lead to damage of the optic and contaminations due to laser ablation of metal or other type of components.

Among the materials used in large aperture laser systems, KDP and DKDP are most vulnerable to SRS effects. A more detailed knowledge of the Raman cross sections in KDP and DKDP is desirable to support estimation of material limits for future ICF laser designs and operational conditions. The problem so far has been addressed using various methods including beveling the edges of the crystal plates to minimize the reflection (and thus amplification) of the SRS back into the optic and by replacing KDP by the much more expensive DKDP, which has lower Raman cross sections of its main Raman peak. But even for DKDP, fourth harmonic generation from the fundamental of an ICF class laser for plasma diagnostic applications can be limited by SRS, especially when considering that intrinsic and impurity defects known to exist in KDP/DKDP crystals could resonantly enhance the Raman cross section.

The SRS gain coefficient can be extracted from the spontaneous Raman cross section. However, the measurement of the absolute value of the spontaneous Raman cross sections has long been a challenge and only a limited set of materials is well characterized. The objective of this work is to measure the absolute value of the Raman cross section of the dominant lines of KDP and DKDP (at various deuteration levels) at the second, third and fourth harmonic frequencies of NIF. This information can support accurate estimation of the SRS gain for these materials as a function of their size, crystal cutting orientation and laser pulse parameters. Our approach is based on performing relative measurements to a suitable material with a known Raman cross section as a wide function of wavelength, covering the second, third and fourth harmonic frequencies of ICF class lasers. This experimental method allowed us to estimate the absolute value of the Raman cross section in KDP and DKDP with an acceptable accuracy to better support the calculation of the SRS gain for different applications such as harmonic generation and the use of KDP/KDDP as large aperture wave plates for polarization smoothing.

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

Keywords: Laser, KDP

The uncertainty analysis of the laser damage threshold measurement based on ISO11254-1

Jianping Hu, Liu Zhicao, Wangjian, Yang liming, Xuqiao
Chengdu Fine Optical Engineering Research Center (China)

ABSTRACT TEXT:
Laser-induced damage test is a method to monitor the damage threshold of optical components for quality assurance. The accuracy of Laser damage threshold is directly related to the output of the laser energy as well as the operation of a high power laser. Considering the measuring result is usually influenced by a lot of factors and the test results are greatly different each other between different laboratories, the international standard ISO11254-1 has been formulated to unify the test procedures for accurate measurement and comparable results of laser damage threshold. Based on the international standard ISO11254-1, the uncertainty of laser damage threshold measurement has been studied in this paper. The analysis shows that the uncertainty, which can be solved by the statistical principles and theories , is mainly induced by the laser energy density measuring and calculation, the damage probability calculation at a energy density, and the linear fit process for the damage probability scheme, etc. The 1064 nm HR coatings tested in this work indicates there are two major factors that may induce the uncertainty of the LIDT, they are the damage probability calculation at an energy density and the linear fit process. The uncertainty induced by the two factors may be around 4% and 18% respectively while the damage threshold of sample is 7.79J/cm^2, and the total relative combined uncertainty of LIDT may reach to 18.72%.

Keywords: uncertainty, laser damage threshold

8190-23, Session 6

Material modification and 3D structure of damage craters in fused silica induced by 355 nm laser pulses irradiation

C. Li, X. Ju, Univ. of Science and Technology Beijing (China)

ABSTRACT TEXT:

Fused silica is an increasingly important material in modern high tech industries, a prominent example being bulk material as transparency optics for large high power output systems such as Laser Megajoule and National Ignition Facility. During the past thirty years, lots of achievements in this field have been obtained to elucidate laser damage process.

In this paper, the amorphous silica samples were specially polished on both surfaces. Pulsed Nd-YAG laser was employed at ambient conditions. The wavelength, pulse length were 355 nm and 6.8 ns, respectively. The examined fluence ranged from 0 to 65 J/cm^2 and the examined frequency was 1/5/10 Hz. Combined advanced analysis methods of synchrotron XRD, synchrotron XRF, synchrotron X-ray CT, positron annihilation technique, FT-IR, XPS and photothermal absorption techniques were employed to analyze the damage mechanism. We report systematic and extensive data about the concentration and spatial distribution variation of surface metal inclusions, structural modifications such as variation of atomic size vacancy defects and variation of bond angle and length of Si-O-Si covalent bond, and the 3-D structure analysis of damage craters after irradiation. The obtained systematic data were used to discuss the role of laser fluence and frequency, the role of metal inclusions, the role of vacancy cluster and the role of structure alteration, and to establish a realistic damage model to acquire a physical insight into UV laser-induced damage process.

Keywords: Fused Silica, Material modification, 3-D structure, Damage crater, Synchrotron radiation, Positron annihilation technique, Vacancy cluster, Damage model

8190-24, Session 6

Third harmonic microscopy for optical material characterization

R. A. Weber, C. Rodriguez, D. N. Nguyen, L. A. Emmert, W. Rudolph, The Univ. of New Mexico (United States); **D. Patel, C. S. Menoni,** Colorado State Univ. (United States)

ABSTRACT TEXT:
As a nonlinear optical technique, third harmonic generation (THG) microscopy is inherently suited for optical material characterization. Femtosecond pulse trains provide sufficient peak intensities at low average power to produce ample TH signal without damaging the material. THG occurs efficiently only when the focal volume of the excitation beam intersects either a material interface or a localized region of material anisotropy. Under linearly polarized illumination the total THG signal is typically dominated by the signal resulting from material interfaces. This makes this technique attractive for surface and thin-film inspection. For symmetry reasons, circularly polarized illumination of an isotropic medium yields zero TH, and prevailing signals originate from localized anisotropic sample sites. Working with isotropic thin films deposited on an isotropic substrate, one can isolate laser induced material modifications that result in anisotropy. Such anisotropy may result from laser induced stress, crystallinity, or birefringence. Pairing THG with complementary imaging techniques, both classical and nonlinear, proves to be a useful diagnostic for investigating intrinsic material defects, damage morphology, vacuum effects in thin-films, and likely pre-damage material modification.

Keywords: nonlinear microscopy, third harmonic, optical materials, damage precursors, anisotropic defects

Tuesday PM • 20 September

13.40 to 15.20 • SESSION 7

Materials and Measurements IV

Session Chairs: **Vitaly E. Gruzdev,** Univ. of Missouri-Columbia (USA); **M. J. Soileau,** Univ. of Central Florida (USA)

13.40: **Modeling max-of-n fluence distribution for optics lifetime**, Zhi M. Liao, John Huebel, John B. Trenholme, Christopher W. Carr, Lawrence Livermore National Lab. (USA). . . [8190-25]

14.00: **Laser damage of the large aperture KDP third harmonic generation crystal due to stimulated Raman scattering**, Bin Feng, Jing Wang, Wei Han, China Academy of Engineering Physics (China) . . . . [8190-26]

14.20: **Deterministic single shot and multiple shot bulk laser damage thresholds of borosilicate glass at 1.064 micron**, Mark W. Kimmel, Sandia National Labs. (USA); Binh T. Do, Ball Aerospace & Technologies Corp. (USA); Arlee V. Smith, AS-Photonics, LLC (USA) . . . . [8190-27]

14.40: **Photo-thermal tomography of optical coatings based on surface thermal lensing technology**, Junhai Xu, Meiping Zhu, Yuanan Zhao, Kui Yi, Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8190-28]

15.00: **Investigation of laser energy and intensity fluctuations of Q-switched nanosecond laser system using second harmonic generation**, Oleg A. Konoplev, Aleksey A. Vasilyev, Steven X. Li, Mark A. Stephen, Anthony W. Yu, Michael A. Krainak, NASA Goddard Space Flight Ctr. (USA) . . . . [8190-29]

15.20 to 16.20 • Poster Session and Refreshment Break

16.20 to 18.00 • SESSION 8

Surfaces, Mirrors, and Contamination

Session Chairs: **Takahisa Jitsuno,** Osaka Univ. (Japan); **Christopher J. Stolz,** Lawrence Livermore National Lab. (USA)

16.20: **Laser-induced contamination on space optics** *(Invited Paper)*, Wolfgang Riede, Helmut B. Schröder, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Denny Wernham, Adrian P. Tighe, Federico Pettazzi, Jorge Alves, European Space Research and Technology Ctr. (Netherlands). . . . . [8190-30]

17.00: **Pulsed ablation of carbon/graphite surfaces and development of plume-kinetics model**, Charles D. Roberts, Air Force Institute of Technology (USA) . . . . [8190-31]

17.20: **Laser-plasma target contaminant plumes and assessment of their potential effects on operational optics**, James E. Andrew, Kathryn A. Wallace, AWE plc (United Kingdom) . . . . [8190-32]

17.40: **Progresses in oil-contamination problem of large-scale pulse-compressor,** Takahisa Jitsuno, Hidetoshi Murakami, Shinji Motokoshi, Eiji Sato, Katsuhiro Mikami, Kota Kato, Tetsuji Kawasaki, Yoshiki Nakata, Hiroyuki Shiraga, Noriaki Miyanaga, Hiroshi Azechi, Osaka Univ. (Japan) . . . . [8190-33]

18.00 to 18.10 • Closing Remarks

18.30 to 20.00 • Wine and Cheese Reception at NCAR

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8190-25, Session 7

Modeling max-of-n fluence distribution for optics lifetime

Z. M. Liao, J. Huebel, J. B. Trenholme, C. W. Carr,
Lawrence Livermore National Lab. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Zhi attended University of Rochester where he obtained his B.S., M.S. and PhD in optical engineering, working under Dr. Govind Agrawal on nonlinear fiber optics before joining Lawrence Livermore National Laboratory (LLNL) in 2001. Zhi's expertise is in nonlinear optics, adaptive optics, and laser-induced damage in optics. He has contributed to many of LLNL's successful laser projects over the years such as the Fiber Laser Guide Star, Alkali Laser, ARC, the Mercury Laser, and NIF (National Ignition Facility). Currently, Zhi's working in developing models for predicting optic lifetime for NIF which he has authored/presented peer-reviewed scientific publications covering these topics. Zhi was also the co-PI for the team that won 2006 R&D award for high-average-power frequency conversion using YCOB crystal.

ABSTRACT TEXT:
Local temporal shot-to-shot variation of high-energy laser system is measured in order to model the maximum fluence any location on the optic will be exposed to after N shots (Max-of-N). We constructed a model to derive an equivalent fluence distribution from a series of shots of differing energy and contrast in order to calculate damage initiation and optics lifetime. This model will allow prediction for Max-of-N effects when direct measurements of the fluence distribution are not available. Comparison to different laser systems will be presented in order to gain insight as to the physical origins of the Max-of-N effect.

Keywords: laser damage, laser contrast, laser dynamic contrast, optics lifetime, statistic optics, Max-of-N effect

Laser damage of the large aperture KDP third harmonic generation crystal due to stimulated Raman scattering

B. Feng, J. Wang, W. Han, China Academy of Engineering Physics (China)

PRIMARY AUTHOR BIOGRAPHY:
Bin Feng was born in Shanxi, China on August 24, 1976. He received the master degree in Haerbin Insitute of Technology of China. In 1999 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:
The large aperture KDP crystals generally used for frequency conversion, polarization rotation and smoothing in laser fusion facilities are vulnerable to laser damage related to transverse stimulated Raman scattering (TSRS) effect. TSRS is anticipated to be an important contributor to KDP damage since the transverse scattering light can get an peak power and fluence density several times of the 351nm laser pulse.

We have observed damage to a 33-cm-diameter KDP frequency tripler subjected to a 29-cm aperture, linearly polarized, flat-in-time laser pulse with a duration of 3 ns and an average third harmonic irradiance about 1.5GW/cm^2. The damage is characterized by bulk damage of a 'both-lungs' pattern with the each lung featuring in the appearance of clusters of cottony opaque areas and the near symmetry axis parallel to the direction of 351nm beam polarization. No obvious damage spots were observed at the center of the crystal aperture.

We find that the peak irradiance of transverse scattering light can exceeds 10 GW/cm^2, when the peak fluence was no larger than 1 J/cm^2, much lower than the damage expectation of KDP crystal. Thus the damage could be intensity-relevant rather than fluence-relevant, as the combination of transverse path length of several centimeters and Stocks irradiance up to several tens GW/cm^2, additive to the third harmonic irradiance, can significantly induce other parasitic nonlinear effect like self-focusing and multiple photon absorption effects, the former leading indirect damage while the later directly bringing on denaturalization in material, both of which can contribute to crystal damage.

Keywords: KDP damage, transverse stimulated Raman scattering, intensity-relevant damage

8190-27, Session 7

Deterministic single shot and multiple shot bulk laser damage thresholds of borosilicate glass at 1.064 micron

M. W. Kimmel, Sandia National Labs. (United States); **B. T. Do,** Ball Aerospace & Technologies Corp. (United States); **A. V. Smith,** AS-Photonics, LLC (United States)

PRIMARY AUTHOR BIOGRAPHY:
Mark Kimmel is laser scientist at Sandia labs.

ABSTRACT TEXT:
We used an 8-ns pulsed laser at 1.064 micon, operating with a single-longitudinal-mode and a TEM_{00} spatial mode, tightly focused inside the bulk of Borosilicate glass to measure single-shot and multiple-shot damage thresholds. The radius of the focal spot was 7.5 micron, measured by using the surface third harmonic generation. We tightly focus the laser beam into the Borosilicate glass to keep the damage threshold power below the SBS threshold, and to minimize the effect of self focusing.

We found the single-shot and multiple-shot damage thresholds to be deterministic. The single shot damage of Borosilicate glass occurs on the trailing edge of the laser pulse and the multiple shot damage occurs at the peak of the damaging pulse. This is in contrast to fused silica in which the single shot damage at threshold always occurs at the peak of the laser pulse and the multiple shot damage threshold does not exist.

We find the single-shot damage threshold fluence of Borosilicate glass is at 3919 J/cm^2, and the 2 to 31-shot damage thresholds of this glass are in the range of 3852 to 3157 J/cm^2. We performed multiple tests of 1000 shots at a reduced laser fluence of 2952 J/cm^2 and observed no damage. We also report the damage morphologies in Borosilicate glass generated by nanosecond laser pulses at 1.064 micron.

Keywords: Bulk optical damage, Borosilicate glass, Deterministic, Single shot, Multiple shot

8190-28, Session 7

Photo-thermal tomography of optical coatings based on surface thermal lensing technology

J. Xu, M. Zhu, Y. Zhao, K. Yi, J. Shao,
Shanghai Institute of Optics and Fine Mechanics (China)

PRIMARY AUTHOR BIOGRAPHY:
Junhai Xu is a PhD candidate at Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences. His current research interests include absorption measurement of coatings and laser-induced damage of coatings.

ABSTRACT TEXT:
Surface thermal technology (STL) was developed into an effective apparatus for the measurement and analysis of absorption loss of optical coatings. A high-power laser beam was focused at the surface of the film, inducing a thermal bump which can focus or defocus a second probe laser beam. By detecting the diffraction of the probe beam with a high-sensitivity photoelectrical component, we calculated the absorption of the coating.

Previous work focused in the measurement of the whole sample and was based on the assumption that the film is very thin. In this paper, by changing the modulated frequency of the pump laser from 1Hz to 200MHz, we accurately controlled the thermal diffusion length and got both the amplitude and phase of the photothermal signal at different depth. Based on the comparison of these signals, some analysis of 1) the absorption measurement of thick coatings and 2) the depth localization of strongly absorbing region was performed.

Keywords: Surface thermal technology, absorption loss, absorption measurement

8190-29, Session 7

Investigation of laser energy and intensity fluctuations of Q-switched nanosecond laser system using second harmonic generation

O. A. Konoplev, A. A. Vasilyev, S. X. Li, M. A. Stephen, A. W. Yu, M. A. Krainak,
NASA Goddard Space Flight Ctr. (United States)

PRIMARY AUTHOR BIOGRAPHY:
Dr. Oleg Konoplev received his M.S. and Ph.D. degree from University of Rochester, Rochester, NY. He worked in the area of high peak and high average power lasers and nonlinear optics for about 20 years.

ABSTRACT TEXT:
We analyzed the energy fluctuations of Q-switched multi-kilohertz, nanosecond, milli-Joule level Nd:YAG laser system and compared energy fluctuations of the laser pulses at 1064 nm and 532 nm. The 15 mm long LBO crystal with non-critical phase-matching was used to obtain efficiencies approaching ~ 70%. The investigated system was spectrally multi-moded and exhibited shot-to-shot frequency mode-hopping within ~ 100 pm spectrum . At saturated efficiencies of about 65-70%, the second harmonic energy fluctuations (standard deviation recorded over 10,000 shots) were factor of 3-5 higher than energy fluctuations of fundamental beam. The STDEV of the shot-to-shot energies at 1064 nm were at the level of about 0.5%. The energy fluctuations of the SHG pulses at saturated efficiencies were at the level of 2-3%, while gradually increased to 10% when efficiencies were decreased through beam attenuation. The measurement of pulse duration fluctuations, waist size fluctuations, beam pointing fluctuations and energy fluctuations does not support the large second SHG fluctuations unless there is correlation among some of these parameters. The analysis of SHG efficiency curve and comparison of energy fluctuations at low and high intensities may provide an insight to shot-to-shot intensity fluctuations and correlation of pulse energy, pulse duration and beam waist size which are very important for experiment involving non-linearity and or damage measurements.

Keywords: Laser induced damage tests, Lasers, Q-switched, Lasers, diode pumped, Solid State Lasers, Shot to shot energy fluctuations

Laser-induced contamination on space optics

W. Riede, H. B. Schröder, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany);
D. Wernham, A. P. Tighe, F. Pettazzi, J. Alves,
European Space Research and Technology Ctr. (Netherlands)

PRIMARY AUTHOR BIOGRAPHY:
Wolfgang Riede (Head of Active Optical Systems Department, DLR-TP-AO). 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:
Laser-based systems like LIDAR (Light Detection and Ranging) are widely used in space for detailed earth atmosphere observations as well as planetary surveying. Such systems comprise high energy pulsed lasers in the IR, green or UV spectral range. In the past, several of these missions have suffered from anomalous performance loss or even failure after short operation times. This degradation was due to selective contamination of laser-exposed optical surfaces fed by the outgassing of organic materials and the interaction of the intense laser light with volatile molecules and the surface of the optics. Deposits tend to built up favourably when the laser system is operating in the UV at 355 nm, and even ultra thin molecular layers on the nanometer thickness level reduce the performance and the lifetime of the optical components noticeably. In this paper comprehensive investigations of laser-induced deposit formation are reported. Epoxy, polyurethane and silicone based polymeric materials were used as contamination sources. The onset and dynamic of deposit formation was monitored in-situ and online by UV induced fluorescence imaging. This method turned out to be very sensitive and allowed the detection of nanometer thick depositions. Spatially resolved transmission measurements provided information about the influence of deposits on the optical performance. The growth mechanisms were found to be different for low and high fluence irradiations. The deposit structure was analyzed by White Light Interferometry, Nomarski, Fluorescence, and Atomic Force Microscopy. Time of Flight Secondary Ion Mass Spectroscopy was used for chemical analysis. The influence of the optical surface roughness, coating, and ambient atmosphere on the deposit formation was investigated and mitigation methods are discussed.

Keywords: Laser-induced contamination, Fluorescence monitoring, Deposition

Pulsed ablation of carbon/graphite surfaces and development of plume-kinetics model

C. D. Roberts, Air Force Institute of Technology (United States)

PRIMARY AUTHOR BIOGRAPHY:

Washington State native, graduating with a BS in Physics from Eastern Washington University. Commissioned into the Air Force in 2003 spend profession time in space development and acquisition. Completed M.S. Physics, Cal State Long Beach 2008, and currently PhD class of 2012 student at Air Force Institute of Technology. My area of research is in laser lethality - the char or soot combustion that occurs in various scenarios of high energy laser engagements with targets. I am striving to develop better temperature predictability and increase modeling fidelity.

ABSTRACT TEXT:

Plumes were generated by ablation of graphite using a 248 nm excimer laser in the presence of low-pressure argon at 50-1000 mTorr. The pulsed laser deposition of energy on Carbon/Graphite targets at fluences of 1-5 J/cm^2 in low pressure argon backgrounds yields emissive plumes with large kinetic energies (Estimated between 10-200 eV), driving the formation of a shock front with large Mach numbers (M). The plumes were investigated using element specific imaging (Filtered gated ICCD cameras) , time-of-flight experiments, and IR spectroscopy. We expect to see contributions from atomic carbon as well as the C_{2} diatomic. Studies showed the importance of plume/substrate interaction in causing secondary excitation/interaction phenomena. The propagation of the shock front is independent of ionization species and adequately characterized by the Sedov-Taylor shock model if the dimensionality of the plume is allowed to deviate from ideal spherical expansion. The ideal efficiency of energy conversion from laser pulse to shock expansion is investigated. The low argon background pressures between 100 and 1000 mTorr are sufficient for the generation of a strong shock front with significant thickness, but may be too low to develop three-dimensional flow. It can be shown that shock strength is proportional to the Mach number and inversely dependent on pressure, indicating a thickness limited to approximately the collision mean free path.

Keywords: Carbon, Pulsed Laser Deposition, Fluence, Shock Front, excimer, IR Spectroscopy, ICCD, Mach

8190-32, Session 8

Laser-plasma target contaminant plumes and assessment of their potential effects on operational optics

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

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

ABSTRACT TEXT:
Typical laser targets irradiated by energetic lasers for the study of high temperature plasmas produce shrapnel, debris or radiation directly or indirectly that impact the optics, instruments and surfaces used in the vacuum chambers used for such studies. We describe the various spatial distributions of the target ejecta arising from example targets and indicate how this data can be used to evaluate threats to focussing optics and ancillary instruments in future laser systems. Methods for characterising and measuring contaminant plumes will also be described. The necessity of using different solutions to mitigate degradation in short pulse laser optics, long pulse laser optics and instrument surfaces will also be discussed.

Keywords: Shrapnel, Debris, Radiation, X rays, Protons, Craters, Splats, Glass

8190-33, Session 8

Progresses in oil-contamination problem of large-scale pulse-compressor

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

PRIMARY AUTHOR BIOGRAPHY:
PhD in 1981, Working Institute of laser engineering, Osaka Univ. for 28 years.
Currently a Specially Appointed Professor.
Working on optics for high energy laser.

ABSTRACT TEXT:
We reported a heavy contamination of optical components in the pulse-compressor of LFEX laser system at this symposium in 2010. This contamination was improved largely by the use of the silica-gel in compression chamber. Recently, no fogging was seen on the surface of mirrors or gratings in the compression chamber. Although we detect contamination still on the surface of the optics, the damage threshold is improved to the original value of the sample after placed in the compression chamber. However, we observed some particle contamination in the chamber. This particle contamination came from the charged particle of powder of the silica-gel, and we are trying to reduce this particle contamination using metal mesh to neutralize the charge of the particle.

We are also making efforts to study the effect of oil-contamination on the damage threshold in quantitative manner. We are trying to contaminate mirrors with controlled amount, and measure the damage threshold. In present, we did not succeeded to contaminate the sample in controlled condition. We choose DBP (Di-Butyl Phthalate) as the contaminant because it is easy to identify. However, this material is very difficult to penetrate into the sample mirror. We are now trying to contaminate the sample mirror with DBP in the vacuum condition. First, we will drop a known amount of DBP on the surface of sample mirror, and this sample mirror is evacuated to penetrate the DBP into the coating layers. We will report the result of this quantitative research.

Keywords: LFEX laser, Oil-contamination, Pulse compressor, Damage threshold, Silica-gel

Materials and Measurements

10.30 to 11.30 and 15.20 to 16.20

Effect of laser beam size on laser-induced damage performance, Wei Han, Liquan Wang, Bin Feng, China Academy of Engineering Physics (China) . . . . [8190-13]

Damage effects of filaments on non-transparent materials at long distances, Karsten Diener, Harmut Borchert, Institut Franco-Allemand de Recherches de Saint-Louis (France); Ruediger Schmitt, Institut Franco-Allemand de Recherches de Saint-Louis (Germany); Magali Durand, Ecole Polytechnique (France); Aurélien Houard, Bernard S. Prade, André Mysyrowicz, Ecole Nationale Supérieure de Techniques Avancées (France); Anne Durécu, Didier Fleury, Bernard G. Moreau, Olivier Vasseur, ONERA (France); Francis Théberge, Marc Chateauneuf, Jacques Dubois, Defence Research and Development Canada (Canada). . . . . [8190-65]

Temperature dependences of fluorescence characteristic for Nd/Cr:YAG materials, Yoshiyuki Honda, Minoru Yoshida, Kinki Univ. (Japan); Shinji Motokoshi, Kana Fujioka, Takahisa Jitsuno, Masahiro Nakatsuka, Osaka Univ. (Japan) . . . . [8190-66]

Potential of large diameter MgF_2 single crystal grown by the Czochralski method, Yasuhiro Hashimoto, Yuichi Ikeda, Masao Ariyuki, Naoto Mochizuki, Teruhiko Nawata, Tokuyama Corp. (Japan) . . . . [8190-67]

Characterization of optical materials and coatings for high-power NIR/VIS laser application, Christian Mühlig, Simon Bublitz, Wolfgang Paa, Institut für Photonische Technologien e.V. (Germany); Joachim Hein, Jörg Körner, Friedrich-Schiller-Univ. Jena (Germany); Ivo Zawischa, TRUMPF Laser GmbH & Co. KG (Germany) . . . . [8190-69]

The strategies of laser-induced damage threshold tests for HR and AR coatings at 1064nm, Bin Ma, Yanyun Zhang, Zhengxiang Shen, Hongfei Jiao, Xinbin Cheng, Jinlong Zhang, Tao Ding, Tongji Univ. (China); Huasong Liu, Yiqin Ji, Tianjin Jinhang Institute of Technology Physics (China); Pengfei He, Zhanshan Wang, Tongji Univ. (China) . . . . [8190-70]

Self-laser conditioning of KDP and DKDP crystals, Cédric Maunier, Mathieu Balas, Thierry Donval, Laurent Lamaignère, Guillaume Duchateau, Gabriel Mennerat, Commissariat à l'Énergie Atomique (France) . . . . [8190-71]

An empirical investigation of the laser survivability curve: II, Jonathan W. Arenberg, Northrop Grumman Aerospace Systems (USA); Wolfgang Riede, Alessandra Ciapponi, Paul Allenspacher, Deutsches Zentrum für Luft- und Raumfahrt e.V. (Germany); Jon H. Herringer, Arrow Thin Films, Inc. (USA) . . . . [8190-72]

Complex defects in III-V compound semiconductors, Tinatin Laperashvili, Orest Kvitsiani, Maia Elizbarashvili, Institute of Cybernetics (Georgia) . . . . [8190-73]

A high-power QCW Nd:YAG laser with narrow line width linearly polarized output, Baoshan Wang, Technical Institute of Physics and Chemistry (China) and Changchun Institute of Optics, Fine Mechanics and Physics (China) and Chinese Academy of Sciences (China). . . . [8190-74]

Reflectivity measurement with optical feedback cavity ring-down technique employing a multi-longitudinal-mode diode laser, Zhechao Qu, Yanling Han, Shengming Xiong, Bincheng Li, Institute of Optics and Electronics (China) . . . . [8190-79]

600ps Nd:YAG laser system for damage threshold measurements, Michael D. Thomas, Andrew J. Griffin, Spica Technologies, Inc. (USA). . . . . [8190-80]

Fundamental Mechanisms

10.30 to 11.30 and 15.20 to 16.20

Modeling laser-induced dielectric breakdown: application of the multiple rate equation, Oliver Brenk, Baerbel Rethfeld, Technische Univ. Kaiserslautern (Germany). . . . . [8190-75]

Effect of strain on laser damage and its relation with precursor defects in KDP/DKDP, François P. Guillet, Bertrand Bertussi, Audrey S. Surmin, Guillaume Duchateau, Commissariat à l'Énergie Atomique (France) . . . . [8190-76]

The impact ionization coefficient in dielectric materials revisited, Christian Karras, Duy N. Nguyen, Luke A. Emmert, Wolfgang Rudolph, The Univ. of New Mexico (USA). . . . . [8190-77]

8190-13, Poster Session

Effect of laser beam size on laser-induced damage performance

W. Han, L. Wang, B. Feng, China 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 damge.

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, laser-induced damage of optical components is a major concern. From our operational experience of the prototype of SG-III laser facility, we found that there is a significant difference of laser-induced damage performance between on small-aperture lasers and on large-aperture lasers.

We investigated the influence of laser beam size on laser-induced damage performance, especially damage probability and laser-induced damage threshold (LIDT). It is found that damage probability is beam size dependent when various damage precursors with different potential behaviors are involved. This causes damage probability and LIDTs are different between tested under large-aperture beam and under small-aperture beam. Moreover, fluence fluctuations of large-aperture laser beam bring about hot spots moving randomly across the beam from shot to shot. Thus it leads to the most probable maximum fluence after many shots at any location across components is several times the average beam fluence. These two effects result in difference of damage performance of components in large-aperture lasers and in small-aperture lasers.

Keywords: laser-induced damage, laser damage threshold, damage probability, beam-size effect, hot spot, fluence fluctuation

Damage effects of filaments on non-transparent materials at long distances

Karsten Diener, Harmut Borchert, Institut Franco-Allemand de Recherches de Saint-Louis (France); **Ruediger Schmitt,** Institut Franco-Allemand de Recherches de Saint-Louis (Germany); **Magali Durand,** Ecole Polytechnique (France); **Aurélien Houard, Bernard S. Prade, André Mysyrowicz,** Ecole Nationale Supérieure de Techniques Avancées (France); **Anne Durécu, Didier Fleury, Bernard G. Moreau, Olivier Vasseur,** ONERA (France); **Francis Théberge, Marc Chateauneuf, Jacques Dubois,** Defence Research and Development Canada (Canada)

PRIMARY AUTHOR BIOGRAPHY:

The scientist Karsten Diener has been at the French-German Research Institute of Saint-Louis since 1999. He received his PhD in optics and is specialized on the interaction between high power lasers and explosive devices and on the interaction between ultra short laser beams and optical materials.

ABSTRACT TEXT:

We observed multiple filamentation of a Terawatt fs-laser beam (wavelength: 800 nm, E = 200 mJ/pulse) after 1 km horizontal propagation in the atmosphere. The interaction of these filaments with the non-transparent targets was studied. The filaments were strong enough to damage the surface of optical windows like Ge and ZnSe even at long distances and under turbulent conditions. The damage effects were analysed by studying the modulation transfer function (MTF), the spectral transmission loss, the ablation depth and the damage threshold. LIBS was applied to determine the plasma temperature during the interaction process.

Keywords: femtosecond laser, filament, damage threshold, germanium, zinc selenid

Temperature dependences of fluorescence characteristic for Nd/Cr:YAG materials

Y. Honda, M. Yoshida, Kinki Univ. (Japan);
S. Motokoshi, K. Fujioka, T. Jitsuno, M. Nakatsuka, Osaka Univ. (Japan)

PRIMARY AUTHOR BIOGRAPHY:
Yoshiyuki Honda was born in 1987. He is student of master course in Kinki University.

ABSTRACT TEXT:
Nd/Cr:YAG is very useful for the flashlamp or solar pumped laser through the energy transfer is efficiently caused from Cr^{3+} to Nd^{3+}. The sensitizer Cr^{3+} ions have broad absorption bands in the visible region, and their spectra overlap with the emission spectra of Xe flashlamp or solar. But the process of the energy transfer from Cr^{3+} to Nd^{3+} is not understood well. It is also a problem that the absorption at near infrared is appeared with changes of Cr^{3+} to Cr^{4+}. So we measured fluorescence characteristic on the Nd/Cr:YAG ceramics at different temperature to analyze the energy transfer between Cr^{3+} and Nd^{3+} ions. And also, the spectral changes of transmittance and excitation-fluorescence by UV laser irradiation were estimated.

6 samples with different doping amounts were prepared in a crystal, ceramics and powders. The each sample was mounted in a cryostat (Oxford lab), and measured at the temperature from 77 K to 450 K.

The peak of fluorescence by Nd^{3+} ions shifted to long wavelength with increase the temperature in spite of Cr^{3+} ions concentration. However, the excitation-fluorescence of Cr ions, which was a range of 350 to 700 nm, increased at high temperature. The fluorescence lifetimes excited at Cr ions were short with increase the temperature although that excited at Nd ions were a constant. The sample irradiated by KrF excimer laser pulse at 248 nm was appeared the absorption in visible region.

Keywords: Nd/Cr:YAG, temperature dependence, fluorescence, transmittance

Potential of large diameter MgF_2 single crystal grown by the Czochralski method

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Tokuyama Corp. (Japan)

PRIMARY AUTHOR BIOGRAPHY:
Yasuhiro Hashimoto has been at Tokuyama Corporation since 2007. He has been working on crystal growth and laser damage such as MgF_2 or CaF_2.

ABSTRACT TEXT:
Magnesium fluoride (MgF_2) single crystal is expected as the alternative of Quartz for polarizing materials in high power lithography system. MgF_2 is anisotropic crystal and its physical properties are different along each crystal axes. Therefore it is difficult to make large diameter single crystal by using Bridgman method which is mainly used for growth of fluoride crystals.

We have been studying on making large diameter and high quality single crystal by using Czochralski method [1,2]. Previously we reported the stable growth of it with 150mm diameter. This time we succeeded to grow the crystal with over 200mm diameter.

Additionally, by improving the purification process and growth process, we succeeded to reduce 75 percent of the amount of color center induced by irradiation of ArF laser.

[1] N. Mochizuki et al “Fluoride single crystals for the next generation lithography”, Proc. SPIE 6924 69242L
[2] M. Ariyuki et al “Development of Large Size MgF_2 Single Crystal Grown by the CZ method”, Proc. SPIE 7504 75041Q

Keywords: large diameter, polarizing material, magnesium fluoride, Czochralski method

8190-69, Poster Session

Characterization of optical materials and coatings for high-power NIR/VIS laser application

C. Mühlig, S. Bublitz, W. Paa, Institut für Photonische Technologien e.V. (Germany);
J. Hein, J. Körner, Friedrich-Schiller-Univ. Jena (Germany);
I. Zawischa, TRUMPF Laser GmbH & Co. KG (Germany)

ABSTRACT TEXT:
We report on the characterization of optical materials and coatings used in high power NIR/VIS laser applications, mainly by means of LID (laser induced deflection) absorption measurements. The characterization covers laser active materials like Yb doped silica and Yb doped CaF_2, optical materials for beam shaping and the at-wavelength characterization of their photo-thermal properties, AR coatings and nonlinear crystals like LBO for second harmonic generation.

Regarding direct absorption measurements an emphasis is placed on the importance of the independent calibration procedure. As example, LBO crystals and fused silica are taken to show the complexity and the existing diversity of the material's photo-thermal response and its influence on choosing the appropriate measurement concept. Furthermore, a new concept is introduced to significantly increase the LID sensitivity for optical materials featuring a low photo-thermal response like in the case of LBO.

Keywords: High power lasers, laser active materials, optical materials, nonlinear crystals, absorption, optical coatings

The strategies of laser-induced damage threshold tests for HR and AR coatings at 1064nm

B. Ma, Y. Zhang, Z. Shen, H. Jiao, X. Cheng, J. Zhang, T. Ding, Tongji Univ. (China);
H. Liu, Y. Ji, Tianjin Jinhang Institute of Technology 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. After two years post-doctor experience, now he is a young lecturer in Tongji University. He researches on the laser induced damage threshold (LIDT) test of optical elements.

ABSTRACT TEXT:
The accurate evaluation of laser induced damage threshold (LIDT) is the foundation of improving and optimizing the deposition process and coating technology. In order to provide the quality assurance of our HfO_2/SiO_2 high reflectance (HR) and anti-reflectance (AR) coatings fabricated by reactive electron beam evaporation process at 1064 nm, an improved test system with micron-scale damage events automated detection, location and the growth study of each damage sites have been developed to obtain a more reliable LIDT. In our system, a Q-switched Nd:YAG laser with a 10 Hz frequency and 10 ns duration is used. The test sample is observed by a digital microscope illuminated in dark field with an adjustable 70~700X of total magnification. The damage principle is the appearance of the image difference before and after the laser irradiation in 1-on-1, S-on-1 and R-on-1 measurements, and the sample will be considered damage when the variation between the current defects and the pre-defects is more than an accepted tolerance in raster scan measurement. The improved test facility is able to implement the popular tests according to the relevant standards, reduce test time and the influence of operators.

Keywords: LIDT, HR coating, AR coating, damage testing

Self-laser conditioning of KDP and DKDP crystals

C. Maunier, M. Balas, T. Donval, L. Lamaignère, G. Duchateau, G. Mennerat,
Commissariat à l'Énergie Atomique (France)

PRIMARY AUTHOR BIOGRAPHY:
Cedric Maunier has received a Ph.D in Physics from the University of Caen (France) in 2001 for his work on rare earth-doped laser materials. Since 2002, he is working at CEA-CESTA on large optics manufacturing and laser damage resistance for Laser Megajoule facility.

ABSTRACT TEXT:
One of the key factors limiting the energy produced by megajoule-class high power lasers such as Laser Megajoule is the resistance of the large optical components to laser damage. It is notably the case for KDP and DKDP crystals, which are used as frequency converters. It is known for a long time that the exposure of such optical components to a series of laser shots with increasing fluences improves their resistance to laser damage. This process, known as laser conditioning, is generally carried out using a single dedicated setup at a specific wavelength (mostly 351 nm) both for SHG and THG. But indeed, the frequency converters are submitted to several wavelengths in operational conditions, and as an example, the SHG is not exposed to 351 nm light.

It is thus interesting to evaluate the behaviour of crystals conditioned thanks to the harmonics they generate themselves from the fundamental incoming pulse, with respect to monochromatic laser conditioning. To do so, we have laser conditioned a couple of KDP SHG and DKDP THG samples in frequency conversion regime using the Alisé setup, which can produce centimetric nanosecond laser pulses > 100 joules at 1,053 nm. Once conditioned, the resistance to laser damage of the frequency converters has been measured using setups with sub-millimetric beams, at wavelengths corresponding to the working conditions of the crystals. The influence of several parameters on the efficiency of laser conditioning has been evaluated and the results have been compared to those previously obtained using monochromatic laser conditioning.

Keywords: laser damage, KDP, DKDP, laser conditioning, frequency conversion

An empirical investigation of the laser survivability curve: II

J. W. Arenberg, Northrop Grumman Aerospace Systems (United States);
W. Riede, A. Ciapponi, P. Allenspacher, 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 fi eld 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:
In this paper, we report on a continuing empirical investigation into the nature of the laser survivability curve. The laser survivability curve is the onset threshold as a function of shot number. This empirical investigation is motivated by the desire to design a universal procedure for the measurement of the so-called S on 1 damage threshold. Analysis is carried on the test results from a large set of planned measurements from identical samples produced for this investigation and DLR archival data. The sample set and test conditions which include a number of wavelengths, coating designs and ambient pressure conditions.

Keywords: Laser damage testing, laser optics qualification, S on 1 testing, ISO 11254-2, ISO 21254-2

8190-73, Poster Session

Complex defects in III-V compound semiconductors

T. Laperashvili, O. Kvitsiani, M. Elizbarashvili, Institute of Cybernetics (Georgia)

PRIMARY AUTHOR BIOGRAPHY:
Born in 1948, Georgia; Higher education: Iv. Javakhishvili Tbilisi State University (Georgia); Working at: Department of Optically Driven Anisotropic Systems, V. Tchavtchanidze Institute of Cybernetics, Georgian Technical University. Head of the Georgian National Optician-Technologist Alliance (GNOTA).

ABSTRACT TEXT:
Structural defects-related deep levels in compound semiconductors play a role in determining important parameters of semiconductor devices. Although many theoretical approaches have been applied to the study of electronic structure of various lattice defects in III - V compounds some controversies over the properties of the structural and anti-structural defect centers remain to be not resolved. Structural defects-related deep levels in compound semiconductors play a fundamental role in determining the physical properties of an oxygen impurity in GaAs, GaP. Here presented the results of experimental study of the electrical and optical properties of the GaP:O system. Investigation the nature of the interactions between structural defect states and O atomic orbitals are important to interpret experimental data taken on the GaP:O system. The heat treating of the Chokhralsky grown GaP crystal was carried out in the closed ampoule where Ga_2O_3 and Zn were put. Prepared samples had a high resistivity (107-108) ohm. Ohmic contacts were fabricated by alloying Indium in inert gas (N_2) atmosphere. The structures have high photosensitivity and were lighting in visual region. It was investigated double injection current and determined defect levels in semiconductor band gap.

Keywords: Compound semiconductor, Structural defects, Antistructural defects, Deep levels, Double injection

A high-power QCW Nd:YAG laser with narrow line width linearly polarized output

B. Wang, Technical Institute of Physics and Chemistry (China) and Changchun Institute of Optics, Fine Mechanics and Physics (China) and Chinese Academy of Sciences (China)

PRIMARY AUTHOR BIOGRAPHY:

2008.7~today, Key Lab of Functional Crystal and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, research assistant, all solid state laser technology engineer 2003.7~2008.6, Changchun Institute of Optics, Fine Mechanics and Physics,CAS Master and Doctor degree of Science, major in all solid state laser and nonlinear optical frequency conversion.

ABSTRACT TEXT:

Ring cavity is the traditional method to achieve narrow line width especially single frequency laser. A novel design in this report is the FP was placed in big beam waist of the symmetric cavity, the goodness is apparent that the thermal effect in this area is weaker than in another smaller beam waist. Differently with traditional CW pump mode in this experiment, the QCW LD with pulse repetition frequency of 500Hz and pulse width of 200us is used for the virtue of weak thermal lens effect and high pump intensity. We use the FP with reflectivity of 70% in this experiment, for it affects the output power only little but narrow the line width greatly. When the laser operates at the point so called unsteady cavity, the output power is 63W which is a litter lower than the status of no FP. The laser pulse width is 160μs, which is narrower than the 200us drive current pulse width. The line width and frequency maintenance were measured by wavelength meter WS7 (HighFinesse). The line width is <0.1GHz which is operation at single frequency mostly and the frequency maintenance fluctuate within ±1GHz in 30 minutes. The beam quality is measured by M2-200 (Spiricon, Inc.), the M2 is 1.15 both in the x direction and y direction. To scaling the laser power, a pair of pump laser module same with the oscillator pump module is used as the amplifier. From double pass amplification, the output power increase to 125W with M2=1.24.

Keywords: Nd:YAG 1064nm laser, Ring cavity, Narrow line width, Quasi continuous wave, High power, MOPA, Good beam qualiy, Linearly polarizer

Reflectivity measurement with optical feedback cavity ring-down technique employing a multi-longitudinal-mode diode laser

Z. Qu, Y. Han, S. Xiong, B. Li, Institute of Optics and Electronics (China)

ABSTRACT TEXT:
Cavity ring-down (CRD) techniques based on measuring the decay rate of light intensity inside the optical cavity, are widely used for trace gas analysis and high reflectivity measurement. In this presentation a filtered optical feedback CRD (FOF-CRD) technique employing a multi-longitudinal-mode continuous-wave diode laser is investigated for measuring high reflectivity of highly reflective mirrors. The original spectrum of the diode laser without the effect of the FOF has two longitudinal modes covering tens of the free spectral ranges (FSR) of the ring-down cavity (RDC). Due to the relatively broadband spectrum, the theoretical efficiency of coupling the laser power into the RDC is less than 0.05%. In the FOF-CRD scheme, on the other hand, the FOF induced overall spectral broadening is experimentally observed, with the diode laser running with several longitudinal modes. However the bandwidth of each longitudinal mode is significantly reduced. The coupling efficiency of the laser power into the RDC is higher than 20% in FOF-CRD technique. The enhancement of the coupling efficiency induced by the FOF effect is nearly three orders of magnitude. High accuracy measurements of high reflectivity are achieved with this simple FOF-CRD scheme.

Keywords: Cavity ring-down, filtered optical feedback, coupling efficiency, high reflectivity

600ps Nd:YAG laser system for damage threshold measurements

M. D. Thomas, A. J. Griffin, Spica Technologies, Inc. (United States)

ABSTRACT TEXT:
This paper describes the construction of a 600ps Nd:YAG based laser and damage detection system for short pulse damage threshold measurements of substrate and coating materials. The system integrates a single frequency, high repetition rate diode pumped microchip laser with a series of both diode pumped and flashlamp pumped amplifiers to provide upwards of 20 mJ at a repetition rate of 20 Hz. This represents a gain of greater than 1x103 in the laser amplifier stage. Excellent beam quality and energy stability is maintained. In addition to the laser, a damage detection system based on laser scatter was able to accurately measure the number of pulses at which damage occurred for a particular site. This allowed generation of damage threshold statistics at fluence levels approaching the single shot damage threshold limit.

Modeling laser-induced dielectric breakdown: application of the multiple rate equation

O. Brenk, B. Rethfeld, Technische Univ. Kaiserslautern (Germany)

PRIMARY AUTHOR BIOGRAPHY:
Born 09.09.1977, Abitur 1997, Begin of university studies: 2003, Diploma in Physics: 2010, PhD student since 2010

ABSTRACT TEXT:
During irradiation with an intense ultrashort laser pulse breakdown of a dielectric medium can occur. Applying the multiple rate equation (MRE), introduced in [Rethfeld, PRL, 92:187401 (2004)], we shed light on absorption and breakdown.

The MRE is a numerical tool to simulate the effects of ultrashort laser pulse irradiation on dielectrics and allows to investigate the temporal evolution of the electronic density in the conduction band. The model includes photoionization and traces the energy change of an electron in the conduction band due to single photon absorption, allowing us to determine when an electron can perform impact ionization.

The results for the temporal evolution of the increasing electronic density in the conduction band are in very good agreement to a full kinetic approach applying Boltzmann collision integrals [Kaiser et. al., PRB, 61(17):11437 (2000)], however, with considerably less computational effort.

We included optical parameters which depend on the free electron density. They determine the reflectivity at the material surface and the absorption of the laser energy inside the material. Having these parameters at hand we investigate breakdown, which is usually assumed to happen at a certain critical density of electrons in the conduction band. Knowledge of optical parameters and the electronic density enables us to follow breakdown independent of the assumption of a critical density criterion.

Our approach allows us to estimate the depth up to which material modification can occur, similar to [Christensen et. al., PRB, 79, 155424 (2009)].

Keywords: ultrashort laser pulses, dielectrics, breakdown, multiple rate equation, modelling

Effect of strain on laser damage and its relation with precursor defects in KDP/DKDP

F. P. Guillet, B. Bertussi, A. S. Surmin, G. Duchateau,
Commissariat à l'Énergie Atomique (France)

ABSTRACT TEXT:
Although many studies have been devoted to identification of the defects responsible for laser damage in KDP/DKDP optics, an accurate description of these precursor defects is yet to come. Defects in crystals can be classified in terms of dimension: 0D (punctual defects), 1D (dislocations) 2D (eg stacking faults) or 3D (eg particles or inclusions). As precursor defects density ranges from a few per cubic millimetres (for the most critical ones) to several hundreds for high laser fluences, 1D and 2D defects can be ruled out as they do not match this criterion. Punctual defects can create states in the gap and can thus account for photonic absorption and subsequent laser damage. However, physical models show that absorbers have a 3D extension of several tens of nanometers, a characteristic incompatible with dimensionless 0D punctual defects. One has then to consider aggregates of punctual defects, a combination which would account for both defect assisted photonic absorption and 3D dimension of the absorbing precursor defect. These clusters would then anchor around structural defects as a result from minimisation of free energy. It is reasonable to think that strain resulting from the presence of structural defects plays a role in the existence of these point defect clusters. As dislocations induce a strain field which extends far beyond the dislocation core, they are good candidates for studying the effect of strain on precursor defects. Moreover, they can be easily identified in KDP crystals using X-Ray topography. This study reports laser damage resistance measurements on areas affected by strain resulting from dislocations. Implications on precursor defects will be discussed.

Keywords: KDP, precursor defects, strain, laser damage

The impact ionization coefficient in dielectric materials revisited

C. Karras, D. N. Nguyen, L. A. Emmert, W. Rudolph,
The Univ. of New Mexico (United States)

ABSTRACT TEXT:
Multiphoton ionization and avalanche ionization have been long recognized as the processes responsible for laser-induced damage in dielectrics. Rate equations of the form

dn/dt=W(I)+A(I)In-n/T,

where n is the electron density of the conduction band and the three terms are the multiphoton ionization rate, the impact ionization rate, and a unimolecular relaxation rate, respectively, have been successful in modeling the main features of sub-picosecond laser damage behavior [1]. These models typically assume a constant value for the impaction ionization parameter A(I). However, because of the complexity of processes associated with high-field ionization including changes of the band structure and electrons far above the band edge, it is likely that the impact parameter depends on the intensity I or the fluence F of the excitation pulse.

Earlier attempts to determine this functional dependence with fused silica [2] were hampered by the fact that relaxation out of the conduction band during the excitation pulse masked the pulse-induced change in A. We report measurements that attempt to isolate the avalanche term in the rate equation.

First, we investigate sapphire (α - Al_2O_3), which has a conduction band lifetime of 3 ps [3], so that relaxation during the pulse can be ignored. Second, we use pump-probe experiments to isolate the effect of multiphoton ionization. In the first of these, a pump pulse of fixed fluence promotes electrons to the conduction band while the transmission of a weak second pulse is measured that probes the “free” carrier absorption leading to impact ionization. The detection system is sensitive to 0.2% changes in the transmission. In a second experiment a two-pulse (energies E1 and E2), two-color experiment is performed that maps the damage fluence in the space (E1,E2) for different pulse durations.

Care is taken in both experiments to avoid multiple pulse accumulation effects by moving the sample after each excitation. A model taking into account multi-photon ionization and impact ionization is compared to the experimental data to evaluate the impact ionization parameter A(I,F).

[1] M. Mero, J. Liu, W. Rudolph, D. Ristau, and K. Starke, “Scaling laws of femtosecond laser pulse induced breakdown in oxide films,” Phys. Rev. B 71, 1115109 (2005).
[2] P. P. Rajeev, M. Gertsvolf, P. B. Corkum, and D. M. Rayner, “Field dependent avalanche ionization rates in dielectrics,” Phys. Rev. Lett. 102, 083001 (2009).
[3] S. Guizard, P. Martin, P. Daguzan, G. Petite, P. Audebert, J.P. Geindre, A. Dos Santos, and A. Antonnetti, “Contrasted behavior of an electron gas in MgO, Al2O3 and SiO2,” Europhys. Lett. 29, pp. 401-406 (1995).

Keywords: impact ionization, sapphire, subpicosecond pulses, field-enhanced ionization, pump probe

Wednesday AM • 21 September

08.20 to 10.00 • SESSION 9

Mini-symposium: Deep UV Optics

Session Chairs: **Holger Blaschke,** Laser Zentrum Hannover e.V. (Germany);
Carmen S. Menoni, Colorado State Univ. (USA)

08.20: **Absorption measurement of HR coated mirrors at 193nm with a Shack-Hartmann wavefront sensor**, Byungil Cho, Edward J. Danielewicz, J. Earl Rudisill, Newport Corp. (USA) . . . . [8190-34]

08.40: **Comparative study of fused silica materials for deep UV laser applications**, Christian Mühlig, Simon Bublitz, Institut für Photonische Technologien e.V. (Germany); Helmut Bernitzki, JENOPTIK Optical Systems GmbH (Germany) . . . . [8190-35]

09.00: **Adhesion and coating with photo-oxidized silicone oil for deep ultraviolet optic materials**, Masataka Murahara, Tokai Univ. (Japan) and Tokyo Institute of Technology (Japan) and Okamoto Optics Co., Ltd. (Japan); Yuji Sato, Tokyo Institute of Technology (Japan); Yoshiaki Okamoto, Okamoto Optics Co., Ltd. (Japan) . . . . [8190-36]

09.20: **Absolute measurement of absorptance in DUV optics from laser-induced wavefront deformations**, Klaus Mann, Uwe Leinhos, Julian Sudradjat, Bernd Schäfer, Laser-Lab. Göttingen e.V. (Germany) . . . . [8190-37]

09.40: **Impact of SiO_2 and CaF_2 surface composition on the absolute absorption at 193nm**, Istvan Balasa, Holger Blaschke, Lars O. Jensen, Detlev Ristau, Laser Zentrum Hannover e.V. (Germany) . . . . [8190-38]

10.00 to 10.30 • Coffee Break

10.30 to 11.30 • SESSION 10

Mini-symposium: Meta-Optics/Photonic Band Gap Materials

Session Chairs: **Michelle D. Shinn,** Thomas Jefferson National Accelerator Facility (USA);
Christopher J. Stolz, Lawrence Livermore National Lab. (USA)

10.30: **3D meta-optics for high-power laser applications** *(Invited Paper)*, Eric G. Johnson, The Univ. of North Carolina at Charlotte (USA) . . . . [8190-39]

11.00: **Thermal conduction in optical coatings and interfaces: a key to high-power meta-optics** *(Invited Paper)*, Joseph J. Talghader, Univ. of Minnesota, Twin Cities (USA) . . . . [8190-40]

11.30 to 13.00 • Lunch Break

11.30 to 12.30 • NIST Facility Tours

NIST has generously offered to provide 2 limited tours of the facility, including the NIST-F1 and NIST-F2 Atomic Clocks. Space is limited. Sign-up onsite by 2:00 pm Tuesday to reserve your place. First come, first served for Laser Damage attendees only. A sign-up sheet will be at the registration desk.

Absorption measurement of HR coated mirrors at 193nm with a Shack-Hartmann wavefront sensor

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, coating deign, 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:

All-dielectric HR mirror coatings consisting of AlF_3/LaF_3/Oxide layers were deposited on DUV grade fused silica and CaF_2. A novel technique was employed to measure the absorption of these mirrors during irradiation by a 193nm ArF excimer laser source. The method involves the application of a photothermal measurement technique. The setup uses a Shack-Hartmann wavefront sensor to measure wavefront deformation caused by the heating of the coating by the ArF beam. Laser calorimetric measurements of absorption were used to calibrate the wavefront sensor. Gage R&R measurements were done to show that this is a practical test technique for use in production.

The new test setup was used to investigate HR mirror coatings both before and after exposure to high average power ArF laser beams. HR mirror samples were irradiated by a 193 nm kilohertz laser source for either 500 million or 20 billion pulses. The spatial resolution is sufficient to make wavefront deformation measurements both inside and outside of the laser beam footprint. The differences between wavefront deformation measured inside the beam footprint compared to measured outside the beam footprint can be explained by compaction of the coating in the area heated by the ArF laser.

Interesting wavefront distortion results from testing mirrors with either fused silica or CaF_2 substrates can be explained by considering the figure of merit of these materials for excimer laser mirror substrates.

Keywords: absorption, 193 nm HR mirror, fluoride, oxide, photothermal measurement, wavefront deformation, Shack-Hartmann sensor, Excimer laser coatings

Comparative study of fused silica materials for deep UV laser applications

C. Mühlig, S. Bublitz, Institut für Photonische Technologien e.V. (Germany);
H. Bernitzki, JENOPTIK Optical Systems GmbH (Germany)

ABSTRACT TEXT:
We report on a comparative study of different fused silica materials for ArF laser applications. Laser induced deflection (LID) technique is applied to measure directly and absolutely the absorption coefficient in fused silica materials at 193 nm as a function of the incident laser fluence in the range 1...3 mJ/cm^2 before and after applying up to 40 million shots at a fluence of 5 mJ/cm^2. In addition the laser induced refractive index change is detected after the prolonged irradiation for all samples. The obtained results, e.g. fluence dependent absorption dk/dH and absorption increase, are used to distinguish in general between two different fused silica types for ArF laser applications. Together with numerical simulations it is demonstrated how the results can be applied to select the appropriate fused silica material for a particular application.

Keywords: Fused silica, ArF laser, Absorption, laser induced degradation, Compaction

Adhesion and coating with photo-oxidized silicone oil for deep ultraviolet optic materials

M. Murahara, Tokai Univ. (Japan) and Tokyo Institute of Technology (Japan) and Okamoto Optics Co., Ltd. (Japan); **Y. Sato,** Tokyo Institute of Technology (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 five 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 no vacuum ultraviolet (UV) permeable adhesive on the market. The conventional adhesive is called “UV-curing adhesive”, which is the one a curing agent is added in its mother agent to absorb ultraviolet rays and construct a bridge; the curing agent remains in the mother agent after the chemical reaction is completed, and the UV rays of 250 nm or less do not penetrate. We, thus, took note of a synthetic fused silica that is transparent up to 170 nm and have studied on the method of using silicone oil, whose chemical structure of the main chain is siloxane bond same as the fused silica’s, as an adhesive by the process of its photo-oxidizing in an atmosphere of an oxidizing agent. So far, our study has been focused on driving the methyl group of the silicone oil that absorbs UV rays out of the chemical reaction system after the photo-oxidation. And, it has been also focused on substituting oxygen for the methyl group gone to form the same chemical structure of a main chain as the fused silica.

When accomplishing the study, the trouble encountered in experiment was that the absorption region of the methyl group in the silicone oil was close to that of oxygen as an oxidizing agent. Ultraviolet rays had to be irradiated to the silicone oil applied on the substrate surface in oxygen atmosphere for photo-oxidation, but the UV rays were consumed by the photo-dissociation of oxygen only and did not reach the important silicone oil when it tried to irradiate vacuum UV rays to the sample in oxygen atmosphere; that is to say, the oxidation reaction did not take place. Then, UV rays were irradiated to the silicone oil from the other side of the substrate, and the photo-curing reaction took place. Photo-curing reaction did not occur when photo-irradiating from the side of the silicone oil applied. After having the substrate exposed to oxygen plasma beforehand for oxygen adsorption and applying silicone oil to it, the substrate was photo-irradiated; curing started from the part where it touched the substrate. The silicone oil film, however, blackened when continued more powerful irradiation. This phenomenon was caused by the oxidizing agent deficiency and by the free carbon photo-dissociated that remained behind in the silicone oil. After several attempts on the method to provide oxygen in proper quantities in order to convert the organic silicone oil in a liquid state into amorphous fused silica in a solid state, the following became clear: it is necessary 1) to keep the temperature of the atmosphere at a constant value, and 2) always to observe the transmission of the vacuum UV light to the substrate and control the intensity of irradiation. The breakthrough findings are reported at the conference.

Keywords: photo-oxidized silicone oil, coating, adhesion, deep UV optics material, Xe2 excimer-lamp, hydroxyl groups, fused silica glass, carbon contamination

Absolute measurement of absorptance in DUV optics from laser-induced wavefront deformations

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

PRIMARY AUTHOR BIOGRAPHY:

Klaus R. Mann received his M.S. degree in physics in 1981 and the PhD in 1984 from Univ. of Göttingen, the latter with a thesis written at the Max-Planck-Institut für Strömungsforschung. After a post-doctoral appointment at IBM Yorktown Heights (USA) and work in industry (Alcan Deutschland GmbH) he joined Laser-Laboratorium Göttingen in 1988, where he currently leads the ´Optics / Short Wavelengths´ group. His research activities cover projects in UV optics characterization, laser beam propagation, wavefront analysis, as well as generation and application of EUV/XUV radiation. He is author of more than 100 scientific publications.

ABSTRACT TEXT:

A photo-thermal measurement system for quantitative determination of absorptance in DUV optics is presented. It is based upon a Hartmann-Shack wavefront sensor with extreme sensitivity, accomplishing spatially resolved monitoring of faint thermally induced wavefront distortions in both transmissive or reflective optical elements. Since the extent of deformation is directly proportional to the absorption losses, the new parallelized photo-thermal technique can be employed for a rapid assessment of the material quality. For instance, monitoring the fluence dependence of the thermal lens induced under ArF excimer laser irradiation in fused silica accomplishes evaluation of both single- and two-photon absorption coefficients. Moreover, fast monitoring of degradation phenomena (e.g. laser-induced color center formation) is accomplished, as well as a separation of surface and bulk absorptance. Along with a description of the new technique we present results from photo-thermal measurements on fused silica, CaF_2 and dielectric coatings (both AR and HR) under 193nm irradiation. The data are compared with theoretical results obtained from a solution of the heat diffusion equation.

In addition, we present also examples for application of the new photothermal technique in other wavelength regimes, including pump-probe experiments of highly loaded hard x-ray beamline optics at the ESRF / Grenoble, as well as quantitative determination of the focus shift in optics for high power solid-state lasers in the near IR range. Employing a collinear geometry of heating and probe beam, thermal wavefront distortions can be precisely characterized also for complex optical systems, as e.g. F-theta objectives used for material processing.

Keywords: deep UV, photo-thermal measurement, Hartmann-Shack, wavefront sensor, fused silica, CaF_2

Impact of SiO_2 and CaF_2 surface composition on the absolute absorption at 193nm

I. Balasa, H. Blaschke, L. O. Jensen, D. Ristau,
Laser Zentrum Hannover e.V. (Germany)

ABSTRACT TEXT:
Significant effort is pursued for the development and optimization of lithography grade materials aiming for ultra-low optical losses. Nowadays very sophisticated crystal growing techniques are available. The surface finish of these DUV substrates has to be considered in an analogous manner, as the performance of thin film optical coatings may directly be influenced by the surface composition.

Using laser calorimetry according to ISO 11551, the treatment-dependent surface contribution to the overall absorptance of lithography grade substrate materials is deduced. The sensitivity enhanced test setup allows for a detailed study at ultra-low fluences - typical for current deep ultraviolet lithography applications. The results on absorption measurements are supported by common and innovative surface qualification methods, deriving characteristics on roughness, stoichiometry, and contamination, which are the footprints of applied polishing methods and, further, handling conditions on the one hand side, and a consequence of cleaning procedures and dose dependent exposure to DUV-radiation on the other side.

Keywords: DUV/VUV, ISO 11551, surface absorption, CaF_2, SiO_2, laser calorimetry, contamination, polishing

8190-39, Session 10

3D meta-optics for high-power laser applications

E. G. Johnson, The Univ. of North Carolina at Charlotte (United States)

PRIMARY AUTHOR BIOGRAPHY:
Director of Optoelectronics Center and Professor of Electrical Engineering and Optics

ABSTRACT TEXT:
High energy laser systems span a variety of technologies including optical sources for pumping of solid state media, resonators for oscillators, amplifiers for additional gain and beam clean up, and the eventual spatial and spectral beam combining for eventual laser target interactions. Each of these elements forming the laser device and beam control require a number of passive optical elements for spatial, spectral and beam conditioning functions. These optical elements must withstand high average powers, thus pushing the damage limits of most optical coatings. Moreover, additional functionality for spatial, spectral and polarization control is highly desired at different points in the system, without an increase in the number of components and with a minimal impact on system cost and complexity. Numerous forms of 2D and 3D Meta-Optics can be envisioned, these include spectral filters based on Guided Mode Resonances, where the incident wave is coupled to a leaky mode in the structure, auto-cloned structures for spatially varying polarization converting optics, low index of refraction materials, and hybrid composite structures which exploit dispersive properties and resonance effects for novel optical functions. One of the major facets of Meta-Optics is the ability to tune the optical properties across the optical element or wafer - this spatially varying feature opens up new possibilities for manipulating the laser beams for spatial or spectral conditioning prior to amplification and/or beam delivery. This talk will highlight recent results in the field and provide example structures for High Energy Laser components.

Keywords: Gratings, Optical coatings, Metaoptics, passive optics, mirrors

Thermal conduction in optical coatings and interfaces: a key to high-power meta-optics

J. J. Talghader, Univ. of Minnesota, Twin Cities (United States)

PRIMARY AUTHOR BIOGRAPHY:
Joseph Talghader obtained his B.S. in electrical engineering from Rice University in 1988. He was awarded and NSF Graduate Fellowship and studied at UC-Berkeley to obtain his M.S. and Ph.D. in 1993 and 1995, respectively. After a short period in Silicon Valley, Dr. Talghader joined the University of Minnesota, where he is now a Full Professor. He has been extensively involved in infrared and hyperspectral technologies, optical coatings materials science, and the miniaturization of optical systems. Dr. Talghader has received 3M Faculty Awards on three occasions and he has numerous patents and peer-reviewed papers in the fields of micro- and nano-sensors. He has served as General Chair and Program chair of the 2006 and 2003 IEEE/LEOS Optical MEMS and Nanophotonics Conference and as Guest Editor of the IEEE JSTQE 2004 and 2007 Special Issues on Optical Micro- and Nanosystems.

ABSTRACT TEXT:
The ability of metamaterials to withstand high optical powers is largely dependent on the thermal properties of the materials and interfaces used to construct them. In this paper, we will discuss the thermal conductivities of dielectric optical materials with an emphasis on films deposited by the relatively new technique of atomic layer deposition (ALD) but applicable to all films. The thermal interaction of a coating and a high-power laser begins with coating absorption, so we will review the fundamental absorption spectra of dielectrics across much of the infrared and visible spectrum. Upon laser heating, this spectra can change. For example, the spectral signature of OH at =3.4 m in a film can be reduced when the film is exposed to a high-power laser beam. Once the film is heated, its thermal properties become critical to understanding failure mechanisms. At the University of Minnesota, we have investigated the conductivities of ALD films that were constructed as nanolaminates, that is, heterogeneous films constructed primarily of one material but with occasional insertions of a monolayer(s) of another material. We find that the thermal conductivities of these films are dependent almost wholly on how the nanolaminate controls the crystal structure of the films, while the number and position of the interfaces seems to play almost no role. The measurement techniques used to find the thermal conductivities, and, more importantly, the implications of these results to patterned films and metaoptics will be discussed.

Keywords: metamaterials, optical coatings, thermal conductivity, laser damage

Wednesday PM • 21 September

13.00 to 15.00 • SESSION 11

Fundamental Mechanisms I

Session Chairs: **James E. Andrew,** AWE plc (United Kingdom);
Joseph A. Menapace, Lawrence Livermore National Lab. (USA)

13.00: **Electron dynamics in transparent materials under high-intensity laser irradiation** *(Invited Paper)*, Barbel Rethfeld, Technische Univ. Kaiserslautern (Germany) . . . . [8190-41]

13.40: **Spatially resolved spectral emission following rear surface fused silica damage event with ns pulses**, Michael D. Feit, R. N. Raman, Raluca A. Negres, Stavros G. Demos, Lawrence Livermore National Lab. (USA) . . . . [8190-42]

14.00: **The early material response during nanosecond laser-induced breakdown in bulk fused silica**, Paul P. DeMange, Raluca A. Negres, Rajesh N. Raman, Jeffrey D. Colvin, Stavros G. Demos, Lawrence Livermore National Lab. (USA). . . . . . [8190-43]

14.20: **Laser ablation mechanism of transparent layers on semiconductors with ultrashort laser pulses**, Tino Rublack, Stefan Hartnauer, Markus Muchow, Michael Mergner, Gerhard Seifert, Martin-Luther-Univ. Halle-Wittenberg (Germany) . . [8190-44]

14.40: **Growth mechanism of laser-induced damage in fused silica**, Guohang Hu, Kui Yi, Xiaofeng Liu, Yuanan Zhao, Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8190-45]

15.00 to 15.30 • Coffee Break

15.30 to 17.10 • SESSION 12

Fundamental Mechanisms II

Session Chairs: **Stavros G. Demos,** Lawrence Livermore National Lab. (USA); **Detlev Ristau,** Laser Zentrum Hannover e.V. (Germany)

15.30: **Luminescence of different surface flaws in high purity silica glass under UV excitation**, Jessica Fournier, Commissariat à l'Énergie Atomique (France) and Univ. Bordeaux 1 (France); Jérôme Néauport, Pierre Grua, Commissariat à l'Énergie Atomique (France); Véronique Jubera, Evelyne Fargin, David Talaga, Stéphane Jouannigot, Univ. Bordeaux 1 (France) . . . . [8190-47]

15.50: **Modeling free-carrier absorption and avalanching by ultrashort laser pulses**, Jeremy R. Gulley, Kennesaw State Univ. (USA) . . . . [8190-48]

16.10: **On the cooperativeness of nanosecond-laser induced damage during frequency doubling of 1064 nm light in $KTiOPO_4$**, Frank R. Wagner, Institut Fresnel (France); Guillaume Duchateau, Commissariat à l'Énergie Atomique (France); Anne Hildenbrand, Jean-Yves Natoli, Mireille Commandré, Institut Fresnel (France) . . . . [8190-49]

16.30: **Carrier dynamics in KDP and DKDP crystals illuminated by intense femtosecond laser pulses**, Guillaume Duchateau, Commissariat à l'Énergie Atomique (France); Ghita Geoffroy, Univ. Bordeaux 1 (France); Cédric Maunier, Anthony D. Dyan, Hervé Piombini, Stephane Guizard, Commissariat à l'Énergie Atomique (France) . . . . [8190-50]

16.50: **Pulse-width scaling of laser-damage threshold and dominating ionization mechanisms,** Vitaly E. Gruzdev, Univ. of Missouri-Columbia (USA). . . . . [8190-51]

17.10 to 17.20 • Closing Remarks

8190-41, Session 11

Electron dynamics in transparent materials under high-intensity laser irradiation

B. Rethfeld, Technische Univ. Kaiserslautern (Germany)

ABSTRACT TEXT:
The energy of a laser beam, irradiating a surface, is primarily absorbed by electrons within the solid. In actual transparent materials, absorption is low. High-intensity lasers may, however, be absorbed by initially bounded electrons through nonlinear processes. The increase of free electron density leads eventually to dielectric breakdown and the material becomes highly absorbing.

In this talk I present theoretical studies on the dynamics of electrons in dielectrics and semiconductors during and after irradiation with an ultrashort laser pulse. We study microscopic processes determining absorption, re-distribution of the energy among electrons and transfer of energy to the crystal lattice. We review different aspects of electronic excitation, studied with time-resolved models as the multiple rate equation, Monte Carlo simulation or Boltzmann kinetic approach.

The density of free electrons in the conduction band of the solid is a crucial parameter for laser damage. The density can be estimated for the case of VUV laser irradiation with the recently introduced "effective energy gap" [Medvedev and Rethfeld, EPL 88, 55001 (2009)]. It depends on the properties of material (like the band structure and the density of states) and photon energy, but not on the intensity of the laser pulse.

For the case of irradiation with visible light, we investigate criteria for damage thresholds. Two concepts compare, namely a change of optical parameters leading to an increased photon absorption and the melting threshold of the lattice. We show that in dielectrics both criteria are fullfilled simultaneously, while for semiconductors both thresholds may differ.

Moreover, we show the influence of pulse shape on damage thresholds.

Spatially resolved spectral emission following rear surface fused silica damage event with ns pulses

M. D. Feit, R. N. Raman, R. A. Negres, S. G. Demos,
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.

ABSTRACT TEXT:
The spectral and spatial characteristics of the emission generated during and following fused silica rear surface damage initiation with ns 1 or 3 laser pulses was studied using spectral imaging and spatially resolved point spectroscopy measurements. These measurements were complemented by time resolved shadowgraphs and time integrated light scattering images to record the spatial distribution and trajectories of the ejected material and compare to that of the generated emission.

The emission apparently has two sources. The first source is confined to within about 1.5 mm from the surface and is characterized by the presence of atomic lines attributable to oxygen and silicon, an indication of strong plasma emission which correlates with the visual "flash" seen at the surface. Outside this near surface region the emission intensity is broadband with no lines and logarithmically decreases and red shifts with distance. The experimental results suggest that this second source of emission may be due to hot ejected particles streaming away from the surface.

Both sources of emission give insight into the dynamics of the post damage initiation material response, allowing estimates of plasma extent and temperature and estimates of ejected particle distributions, temperatures and sizes. A theoretical model describing the cooling of hot particles by evaporation and radiation as a function of their original temperature and size is employed to better quantify the original temperature of the ejected particles. The results are suggestive that the temperature of the particles decreases with respect to their ejection delay time reflecting on the rate at which the hot modified material in the developing and post initiation crater is cooling down via material ejection and other processes.

Keywords: fused silica, laser damage, spectral emission, particle emission

The early material response during nanosecond laser-induced breakdown in bulk fused silica

P. P. DeMange, R. A. Negres, R. N. Raman, J. D. Colvin, S. G. Demos,
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.

ABSTRACT TEXT:
Laser induced damage in the bulk of optical materials is associated with localized energy deposition that is accompanied by a sequence of transient material modifications leading to the formation of a void and a network of cracks. We have previously shown that for the case of ns bulk damage in fused silica, the return to the “solid” phase takes place at ~70 ms delay but the entire network of cracks is formed within the initial 25 ns from the initiation of the damage process. However, the processes taking place during the initial 25 ns of the damage event were not resolved due to limited temporal resolution. It has been shown that modified material is exposed to temperatures on the order of 1 eV and pressures on the order of 10 GPa or larger but the dynamics occuring within the first 25 ns following these extreme initial conditions is limited to modeling and hydrocode simulations. As such, images capturing the early material response would greatly enhance our knowledge regarding the governing physical mechanisms and the origin of the subsequently developing material modifications as well as help optimize and validate existing modeling tools.

In this work, we have performed direct imaging with adequate temporal resolution to resolve of the localized dynamics of material response in bulk fused silica following laser-induced breakdown (damage) via nanosecond pulses. Hydrocode simulations are also performed to assess the pressure and temperature dynamics by a best match to the experimental results. The time-resolved images reveal the initial build up of an electronic excitation followed by the launch of a shockwave, the expansion of the modified material (absorption front) and, the development of phase instabilities at the modified material interface. The experimental results indicate that the shock propagates at ≈12 km/sec for about 1 ns, followed by decay into an acoustic wave. Phase instabilities appear to play an important role and are responsible for a faster expansion of the modified region by a factor of ~2 compared to the hydrocode simulations. These phase instabilities also act as precursors to crack formation. The instabilities are observed to grow at a speed of ≈4.6 km/sec during the first 2 ns transitioning thereafter into crack propagation at ≈1.7 km/sec until the termination of the process at ~20 ns delay.

Keywords: Laser-induced damage, bulk damage, SiO_2

8190-44, Session 11

Laser ablation mechanism of transparent layers on semiconductors with ultrashort laser pulses

T. Rublack, S. Hartnauer, M. Muchow, M. Mergner, G. Seifert,
Martin-Luther-Univ. Halle-Wittenberg (Germany)

PRIMARY AUTHOR BIOGRAPHY:
Tino Rublack was born 28 October, 1978, in Berlin (Germany). He received his diploma in Physics from the University of Hamburg in 2009. Now he is doing his PhD at Halle University in the group of Dr. Gerhard Seifert.

ABSTRACT TEXT:
Transparent dielectric layers on semiconductors are being used as anti-reflection coatings both in photovoltaic applications and for mid-infrared optical elements. We have shown recently that selective ablation of such layers is possible using ultrashort laser pulses at wavelengths being absorbed by the semiconductor [1]. To get a deeper understanding of the ablation mechanism we have done ablation experiments for different transparent materials, e.g. SiO_2 and SiNx on silicon, using a broad range of wavelengths and pulse durations between 50 and 2000 fs. The characterization of the ablated regions was done by light microscopy, atomic force microscopy (AFM), Raman spectroscopy and scanning electron microscopy (SEM).

Utilizing laser wavelengths above the silicon band gap, selective ablation of the dielectric layer without noticeable damage of the opened silicon surface is possible. In contrast, ultrashort pulses (1-2 ps) at mid-infrared wavelengths always damage silicon already at lower intensities than the dielectric, even when a vibrational resonance (e.g. at 9.26µm for SiO_2) is addressed. The physical processes behind this, on the first glance counterintuitive observation, will be discussed.

References

[1] T. Rublack, S. Hartnauer, P. Kappe, C. Swiatowski and G. Seifert, Selective ablation of thin SiO_2 layers on silicon substrates by femto- and picosecond laser pulses ", Appl. Phys. A DOI 10.1007/s00339-011-6352-x (2011).

Keywords: ablation mechanism, silicon, Raman, ultrashort laser

8190-45, Session 11

Growth mechanism of laser-induced damage in fused silica

G. Hu, K. Yi, X. Liu, Y. Zhao, J. Shao,
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:
Growth of laser induced damage plays a major role in determining optics lifetime in high power laser systems. Previous studies have demonstrated that the size of crater increased under successive laser shots, but that of the gray haze and CO2 laser mitigation spot remained constant. In this study, scanning electron microscopy (SEM) and focus ion beam (FIB) were applied to observe the microstructure of vertical and horizontal cross sections of the crater, gray haze and mitigation spot. X-ray photoelectron spectroscopic (XPS) and X-ray Diffraction (XRD) were used to measure their composition. Time finite difference domain (FDTD) was applied to calculate the light intensity distribution around the mitigation and damage spots. Results showed that the crater had several cracks and a slightly oxygen deficient composition, which did not occur in the gray haze and mitigation spot. Furthermore, the peak light intensity around the crater was much higher. Based on the above analysis, a growth mechanism of laser induced damage in fused silica was proposed.

Keywords: growth mechanism, crack, oxygen deficient composition, light intensity distribution

8190-47, Session 12

Luminescence of different surface flaws in high purity silica glass under UV excitation

J. Fournier, Commissariat à l'Énergie Atomique (France) and Univ. Bordeaux 1 (France); **J. Néauport, P. Grua,** Commissariat à l'Énergie Atomique (France); **V. Jubera, E. Fargin, D. Talaga, S. Jouannigot,** Univ. Bordeaux 1 (France)

PRIMARY AUTHOR BIOGRAPHY:

Jessica Fournier is a phD student at CEA/CESTA in collaboration with the Institute of Condensed Matter and Chemistry of Bordeaux. She is working on laser damage in high purity silica for the Laser MegaJoule Facility. She is studying defects present in silica using luminescence spectroscopy in order to understand laser damage mecanism.

ABSTRACT TEXT:

Laser damage on silica optics for 3 nanoseconds pulse durations at 351 nm wavelength takes place for fluences of a few J/cm². The defects responsible for the damaging process are likely microfractures created during polishing . In order to get new insights about optical material elaboration, photoluminescence experiments have been performed on high purity silica glass optics. Investigations have been carried out for three kinds of sites on these optics: pristine silica, laser damage, and indented areas. In silica glasses, two luminescent defects are well known : the ODC (Oxygen Deficient Center) with an emission band at 450nm (2.75eV) and the NBOHC (Non Bridging Oxygen Hole Center) with an emission band at 650nm (1.9eV). The surface flaws like indentations and laser damage yield different spectroscopic behaviours, but in the two cases, a luminescence band at 2.25 eV is found. This band is not yet attributed to a well characterized defect. In order to get the spatial distribution of the different defects, luminescence mappings have been realized. Luminescence experiments for different temperatures have been made to investigate the possible role of several luminescent objects, emitting around 550 nm (2.25 eV).

Keywords: Laser damage, Luminescence microscopy, Silica glass

8190-48, Session 12

Modeling free-carrier absorption and avalanching by ultrashort laser pulses

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 plasma generation, pulse filamentation, and ultrafast laser-induced damage.

ABSTRACT TEXT:

In the past decade it was demonstrated experimentally that negatively chirped laser pulses can lower the surface LIDT for wide band-gap materials by decreasing the number of photons required for photoionization on the leading edge of the pulse. Similarly, simulations have shown that positively chirped pulses resulting from self-focusing and self-phase modulation in bulk dielectrics can alter the onset of laser-induced material modifications by increasing the number of photons required for photoionization on the leading edge of the pulse. However, the role of multi-chromatic effects in free-carrier absorption and avalanching has yet to be addressed. In this work a frequency-selective model of free-carrier dynamics is presented, based on a recently extended multi-rate equation for the distribution of electrons in the conduction band. In this model free-carriers gain energy from the field by single-photon absorption at the instantaneous frequency, which varies as a function of space and time. For cases of super-continuum generation it is shown that a Drude-type absorption can vary from 50% to over 200% the absorption rate as evaluated at the central pulse frequency only. Simulations applying this model to ultrafast laser-plasma interactions in fused silica explore how pulse chirps may be used as a distinguising parameter for LID resulting from otherwise identical pulses.

Keywords: ultrashort laser, laser-induced damage, ionization, simulation, dielectric solids, chirped laser pulse, pulse propagation, nonlinear optics

8190-49, Session 12

On the cooperativeness of nanosecond-laser induced damage during frequency doubling of 1064 nm light in $KTiOPO_4$

F. R. Wagner, Institut Fresnel (France);
G. Duchateau, Commissariat à l'Énergie Atomique (France);
A. Hildenbrand, J. Natoli, M. Commandré, Institut Fresnel (France)

PRIMARY AUTHOR BIOGRAPHY:
Frank Wagner obtained his MSc degree in Physics 1997. (University of Göttingen, Germany). He finished his PhD thesis on the surface properties of excimer laser ablated polymers in 2000 (EPFL, Lausanne, Switzerland). He then developed the water-jet guided laser as R&D Engineer at Synova SA (Switzerland) until 2004. Finally, he joined the high power photonics group of the Fresnel Institute in Marseille, France, as an assistant professor.

ABSTRACT TEXT:
Due to its high nonlinear coefficients, KTP ($KTiOPO_4$) is one of the most important nonlinear optical materials for frequency doubling of Nd:YAG lasers. Former studies suggest a certain cooperativeness of the laser induced damage mechanism between the 1064 nm and the 532 nm wavelengths present during SHG. We will report experiments that allow confirming and quantifying the cooperativeness of the laser damage mechanism in this material and compare it to known data from KDP. A simple model based on the formation of color centers, which are also responsible for the gray tracking effect, will be presented. The experimental data allows determining reasonable ranges for the main parameters of the model.

Keywords: Laser damage, cooperative damage mechanism, $KTiOPO_4$, KTP, second harmonic generation, SHG

Carrier dynamics in KDP and DKDP crystals illuminated by intense femtosecond laser pulses

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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:
The dynamics of electrons and holes in potassium dihydrogen phosphate (KH2PO4 or KDP) crystals and its deuterated analog (KD2PO4 or DKDP) induced by femtosecond laser pulses is investigated at λ = 800 nm. To do so, experiments based on a femtosecond time-resolved interferometry technique have been carried out. It is shown that two relaxation dynamics exist in KDP and DKDP crystals. In particular, it appears that one dynamics is associated with the migration of proton/deuteron in the crystalline lattice. Both of the dynamics correspond to physical mechanisms for which the multiphoton order required to promote valence electrons to the conduction band is lower than the one of a defect-free crystal. These results suggest the presence of states located in the band gap that may be due to the presence of defects existing before any laser illumination or created in the course of interaction. In order to interpret the experiments, a model based on a system of rate equations has been developed. Modeling results are in good agreement with the experimental data, and allow one to obtain fundamental physical parameters governing the laser-matter interaction as multiphoton absorption cross sections, capture cross sections, recombination times, and so forth. Finally, it will be shown how these results can be used to the understanding of laser-induced damage by nanosecond pulses in inertial confinement fusion class laser aperture.

Keywords: KDP, femtosecond laser interferometry, carrier dynamics, modeling

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Pulse-width scaling of laser-damage threshold and dominating ionization mechanisms

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ABSTRACT TEXT:
This presentation considers scaling of intrinsic laser-induced damage threshold (LIDT) with pulse width depending on particular dominating mechanism of laser-induced ionization. The range of considered pulse width is small enough to eliminate thermal mechanisms. The simplest model of flat-top laser pulse is utilized to derive pulse-width dependence of LIDT from solutions to rate equation for conduction-band electron density. The criterion of LID is based on reaching certain critical conduction-band electron density. Three ionization mechanisms are analyzed separately: multiphoton, tunneling, and avalanche ionizations. The obtained results show that LIDT expressed in terms of laser intensity (W/cm^2) decreases with pulse width for all the considered ionization mechanisms. Rate of the decrease depends on particular mechanism. We provide a transparent physical interpretation of this general trend of the pulse-width scaling. If LIDT is expressed in terms of laser fluence (J/cm^2), the pulse threshold demonstrates monotonous increase with pulse width for multiphoton ionization. For the tunneling and avalanche ionizations, LIDT switches from decrease for extremely short pulses to increase for longer pulses with a pronounced minimum at certain pulse width. We compare obtained results with available experimental data and show that some data do not correspond to the obtained theoretical predictions even qualitatively. In this connection, we discuss the approximations underlying the ionization models. Among the possible reasons of the disagreement between the theoretical and experimental data there are mentioned: 1) the monochromatic approximation for laser pulses that becomes wrong for ultrashort pulses; 2) possible participation of another ionization mechanism; and 3) oversimplified models of electronic bands for the transparent materials.

Keywords: laser-induced damage threshold, intrinsic laser-induced damage, laser damage mechanisms, laser-induced ionization, avalanche ionization, photo-ionization, multiphoton ionization, dielectric solids

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