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Proceedings

SPIE. LASER
DAMAGE

**LASER-INDUCED DAMAGE
IN OPTICAL MATERIALS: 2014**

**14–17 September 2014
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Editors

Gregory J. Exarhos, Vitaly E. Gruzdev, Joseph A. Menapace, Detlev Ristau, MJ Soileau

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The International Program Committee of the Laser Damage Symposium XLVI: Annual Symposium in Optical Materials

The International Program Committee of the Laser Damage Symposium is an essential part of the conference gathering representatives from many countries active in the field of high power laser components. Presently, the International Program Committee hosts renowned scientists from the United Kingdom, France, China, Japan, Germany and the United States. Besides providing contributions to the conference program, the International Program Committee is also active in promoting the conference and in attracting researchers from around the world. The members of the International Program Committee perform a vital service as an outreach for the conference on the global scale. Individuals with suggestions for the meetings are requested to contact any Committee member who is either in acquaintance or in close proximity. The engagement of the International Program Committee, which initiated participation from around 40 countries during the last several years, is acknowledged here as a major contribution to the success of the conference.

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Detlev Ristau *Committee Chair*, Laser Zentrum Hannover e.V. (Germany)

Symposium Welcome

Detlev Ristau

Laser Zentrum Hannover (Germany)
d.ristau@lzh.de

As a tradition, the Laser Damage Symposium, formerly known as the Boulder Damage Symposium, is opened by a greeting introducing recent hot topics and some statistics about the conference. Consequently, on behalf of my co-chairs, Greg Exarhos, Vitaly Gruzdev, Joe Menepace, and MJ Soileau, and I would like to welcome all presenters and participants to the 46th Annual Symposium on Optical Materials for High-Power Lasers!

For more than 45 years, the NIST-facility in Boulder, Colorado, has been the venue of the Symposium hosting again, in 2014, many representatives from the communities of optical coatings, laser damage and materials. Even though the number of registrants for the conference has declined slightly from last year by a few percent down to 128, the conference can still be considered as the leading platform for the discussion of laser damage and related topics. This is especially reflected by the highest number of contributed presentations ever scheduled for the conference resulting in a very busy program for LD 2014. In total, the conference hosted 90 oral and poster presentations during the relatively short time period of three days. The four main topics of the conference (including Keynote talks) are:

- Fundamental Mechanisms
- Surfaces, Mirrors and Contamination
- Thin Films
- Materials and Measurements.

Special contributions were presented addressing the mini-symposium on “Applications related to laser damage” and the laser damage competition. The mini-symposium, which is following in a long row of Symposia dating back to the year 1992, was organized by Stavros Demos (Lawrence Livermore National Laboratory, USA) and highlighted, among others things, very interesting aspects of laser induced damage in biological tissue. This year, the laser damage competition was dedicated to a dielectric band pass filter for the wavelength 1.064 μm and was initiated by Chris Stolz (Lawrence Livermore National Laboratory, USA) to investigate the fundamental mechanisms of laser damage in these coating systems with high internal field strengths. The contributed papers and posters were focused on recent research activities in the field and indicated the trends in modern materials research for high-power laser applications. For example the topic of Fundamental Mechanisms included studies on damage growth, precursors and defects in coatings and substrates as well as multiple wavelength effects and damage in frequency conversion components. The field of Materials and Measurements was dominated by research work on a further harmonization and standardization of laser damage measurements, ultra-short pulse effects, and accelerated ageing tests. Recent trends in the field of Surfaces, Mirrors and Contamination include the monitoring of contamination and defects on optical surfaces, protection strategies, and the repair of surface defects by different methods. In the research area of Thin Films, mainly continuing research work on rugate systems, different ion processes and material combinations involving Hafnia with focus on the UV-spectral range was reported. These topics stimulated many scientific discussions in the audience and clearly reflect the enormous importance of high-power materials for the future development of photonics, and especially laser technology.

The main program of the Symposium was embedded in a series of social and scientific activities supporting networking and the establishment of international joint research activities. Attendees interested in fundamental aspects of thin film growth and characterization had the opportunity to join the tutorial on “Fundamentals of Growths and Characterization of Amorphous Thin Films” offered by Carmen Menoni (Colorado State University, USA) and Wolfgang Rudolph (The University of New Mexico, USA) on Sunday, the day before the Conference start. This tutorial, which was held for the first time in replacement of the former round table discussion format, attracted more than 60 scientists, clearly indicating the topicality of thin film research in high-power laser technology. Again, the symposium was supported by local industrial companies hosting open house receptions and sponsoring coffee breaks as well as the traditional wine and cheese reception held at the National Center of Atmospheric Research (NCAR) in the beautiful scenery of the Rocky Mountains. Also, during the last day of the Conference, a Facility Tour was organized by the NIST, which gave a very impressive overview of the Atomic Clocks and the Josh Hadler’s Laser Welding Lab.

Financial support for Laser Damage 2014 has been provided by the Conference co-sponsors: Lawrence Livermore National Laboratory (USA), Lasercomponents GmbH (Germany), Spica Technologies, Inc. (USA), and Quantel (USA). Open house receptions, the Wine and Cheese reception and the refreshment breaks were supported by Arrow Thin Films, IDEX Optics and Photonics, and Alpine Research Optics. Also many thanks to the National Institute of Standards and Technology, the Laser Zentrum Hannover e.V., CREOL & FPCE, College of Optics and Photonics, University of Central Florida, Pacific Northwest Laboratory, Office of Naval Research, Laboratory for Laser Energetics of the University of Rochester, and the University of Missouri-Columbia for providing the much needed managerial support during the planning and event operations.

On the basis of worldwide activities in high power laser applications, the Laser Damage Conference has always gathered scientists from many countries. This is also reflected by the International Program Committee of the Conference featuring scientists from many countries strong in laser technology. Presently, the International Program Committee is formed by representatives from the UK, France, Russia, Japan, Germany, China and the US. Besides contributions to the conference programme, the International Program Committee is also active in advertising and gathering contributions for the conference.

The co-chairs appreciate and recognize the tireless efforts of the SPIE staff as well as that of Artika Lal, Symposium Assistant from Lawrence Livermore National Laboratory, whose hard work in planning and execution made the event possible. Of course, we are all indebted to Michael Kelley, NIST technical sponsor and James Burrus, who was the prime contact at NIST Boulder, for his continued support, encouragement, and especially for the organization of NIST tours. Also, thank you to Jason Day of Daylight Productions, who managed the audio equipment and made sure the oral sessions ran smoothly. On behalf of all the organizers and attendees, we thank them and also the members of the International Program Committee for their tireless efforts.



Attendees of the Laser Damage Symposium 2014 at the main entrance of the NCAR-building joining for the Wine and Cheese Reception after a busy second day of the Conference.

Summary of Meeting

SPIE Laser Damage
46th Annual Symposium
on Optical Materials for High Power Laser
14-17 September 2014

Vitaly E. Gruzdev
Department of Mechanical and Aerospace Engineering
University of Missouri
Columbia, MO, 65211, USA

Abstract

These proceedings contain the papers presented as oral and poster presentations at the 46th Annual Symposium on Optical Materials for High-Power Lasers. The conference was held at the National Institute of Standards and Technology facility in Boulder, Colorado on 14-17 September 2014. The symposium was divided into the traditional sessions devoted to the following major topics: thin films; surfaces, mirrors and contamination; fundamental mechanisms; materials and measurements. A mini-symposium was held this year on applications related to laser damage. The starting event of the symposium was a tutorial on fundamentals of growth and characterization of amorphous thin films held as a special pre-symposium event on Sunday evening, September 13. The conference was opened by Dr. Detlev Ristau with a symposium welcome. Dr. Gregory J. Exarhos of Pacific Northwest National Laboratory (USA), Dr. Vitaly Gruzdev of the University of Missouri, Columbia (USA), Dr. Joseph A. Menapace of the Lawrence Livermore National Laboratory (USA), Dr. Detlev Ristau of the Laser Zentrum Hannover e.V. (Germany), Dr. M. J. Soileau, of the University of Central Florida (USA) co-chaired the symposium. The founding organizers of the symposium are Dr. Arthur H. Guenther and Dr. Alexander J. Glass.

93 abstracts were submitted to the symposium, of which 81 was presented at 12 oral sessions and 4 poster sessions. No parallel sessions were held allowing the opportunity to discuss common research interests with all the presenters. With 126 participants attending, the meeting offered an outstanding opportunity to make many new acquaintances. Although held annually in the US, Laser Damage symposium continues to be a true international conference with more than 60% of the presentations coming from Europe and Asia. As usual, the National Institute of Standards and Technology in Boulder, Colorado, offered a setting conducive to effective communication and interchange between individuals working in closely related and complementary fields. We look forward to future opportunities to come together again in this setting.

The 47th Annual Symposium of this series will be held in Boulder, Colorado, 27-30 September 2015. A continuous effort will be made to ensure a close liaison between the high-energy, high-peak-power, and high-average-power laser communities, as well as to include damage issues related to various research efforts and commercial laser applications. A mini-symposium focused on multilayer dielectric mirrors for ultrafast lasers is anticipated. Invited talks are also anticipated to open the four major topical areas and the mini-symposium. Following much feedback from symposium participants, relocation of the symposium beginning in 2016 is under active discussion. Several cities in Europe, US, and Asia and re-location regimes (annual or bi-annual) are under consideration now.

The principal topics to be considered as contributed papers in 2015 do not differ drastically from those enumerated above. We expect to hear more about the impact of contamination on the laser resistance of optical components and the influence of defects since both those topics continue to generate significant interest. High-energy laser windows, crystals, and transparent ceramics continue to place limitations on laser systems so remain an active area of research and spirited debate. Refinement of the mitigation strategy consisting of damage initiation followed by arresting damage growth through post-processing techniques while not creating downstream damage is also expected to be a continued focus as a large number of laser-resistant UV optics are manufactured for laser-lithography applications. Short pulse (nanosecond and picosecond) laser optics and damage phenomena remain an active area of research. Recent progress in the fields of ultrashort-pulse (femtosecond) lasers and ultrafast laser-material interactions is believed to be one of the fastest growing area of the future symposium. We also expect to hear more about new measurement techniques to improve our

understanding of the different damage mechanisms or to improve the manufacturing of optical materials and thin films for optical components of greater laser damage resistance. Thin films for a broad range of laser wavelengths and pulse durations will continue to stay one of hot topics of the symposium. Also, new developments in the field of meta-materials and related laser-damage issues will attract growing attention due to their intensive development and potential use in high-power lasers. Fundamental aspects of laser-induced damage including multiphoton and avalanche ionization, scaling of damage threshold with laser and material parameters continuously attract a lot of attention. More presentations on lifetime and optics aging are expected in 2015 due to the significance of those issues for industrial and energy applications of high-power lasers.

As was initially established in 1992, several distinguished invited speakers will deliver keynote presentations of a tutorial or review nature, in addition, other contributors will cover late-breaking developments. Another tutorial is also expected to be delivered as a pre-symposium event on Sunday evening.

The purpose of this series of symposia is to provide an international platform for information exchange about optical materials for high-power / high-energy lasers and a broad range of topics related to laser-induced damage in those materials. The editors welcome comments and criticism from all interested readers relevant to this purpose.

Keywords: laser damage, laser interaction, optical components, optical fabrication, optical materials and properties, thin film coatings, contamination.

1. Introduction

The SPIE Laser Damage - 46th Annual Symposium on Optical Materials for High-Power Lasers (a.k.a. the Boulder Damage Symposium, because of its Boulder, Colorado, venue) was held 14-17 September 2014. This symposium continues to be the principal US and International forum for the exchange of information relative to laser-induced damage in optical materials and the interaction of intense laser light with optical media and components. This year, it was attended by 126 representatives of academia, industry, national research laboratories and centers from 14 countries, a 14% reduction in attendance compared to Laser Damage 2013. Among the 93 paper submittals (a record high number of submissions since 1969, reproduced the record level of submissions from 1998), 81 presentations were delivered within the traditional 3-day format of the meeting including 33 oral and 48 poster presentations. The fact that 12 presentations (9 oral and 3 poster) were cancelled or not presented this year did motivate Co-Chairs of the symposium to make steps towards changing some policies of program preparation. Also, continuous visa problems of symposium participants from China were recognized as one of major reasons of presentation cancellations. More active work on the visa issues was proposed and planned for the next Symposium. Although, held annually in the US, this is a truly international conference with almost 50 percent of the attendees and 62.4 percent of the presentations coming from abroad this year. Historically, the meeting has been divided into four broad categories: thin films; fundamental mechanisms; materials and measurements; and surfaces, mirrors, and contamination. Starting in 1992, a mini-symposium is held to highlight hot research topics and areas of active research and special interest in the fields related to high-power/high-energy lasers, laser-induced damage, optical materials, laser-material interactions. Starting from this year, the traditional pre-symposium event – a Round-Table discussion held on Sunday evening – was replaced with a tutorial. This year it featured the fundamentals of thin films under the topic “Fundamentals of Growth and Characterization of Amorphous Thin Films for Interference Coatings”. The tutorial was prepared and held by Dr. Carmen Menoni (Colorado State University, USA) and Dr. Wolfgang Rudolph (University of New Mexico, USA). The tutorial attracted more than 50 participants of the conference. The conference began with a welcome talk delivered by Dr. Ristau and a brief tribute to Dr. Aleksander Manenkov delivered by Dr. Gruzdev.

2. Symposium Cochairs

The Boulder Damage Symposium was founded by Dr. A. H. Guenther and Dr. Alexander Glass. Over the last 46 years many prominent leaders within the high-power laser community have contributed significantly as Co-Chairs to this conference. A historical timeline of their contributions is listed below:

1969	A. H. Guenther, and A. J. Glass (C. M. Stickley)
1979	add H. E. Bennett and B. E. Newnam
1981	add D. Milam; A. J. Glass departs
1987	add M. J. Soileau
1988	D. Milam departs
1989	add L. L. Chase
1994	add M. R. Kozlowski; L. L. Chase departs

1997 add G. J. Exarhos and K. L. Lewis; H. E. Bennett and B. E. Newnam depart
 2001 add C. J. Stolz
 2002 add N. Kaiser; M. R. Kozlowski departs
 2004 N. Kaiser departs
 2005 add D. Ristau
 2007 A. H. Guenther deceased
 2008 K. L. Lewis departs
 2009 add V. Gruzdev
 2010 add J. A. Menapace; C. J. Stolz departs

3. Pre-symposium event: tutorial

This year a new pre-symposium event was held on Sunday evening. It was a tutorial featured the fundamentals of thin films under the topic “Fundamentals of Growth and Characterization of Amorphous Thin Films for Interference Coatings”. The tutorial included two parts of which the first part was prepared and held by Dr. Carmen Menoni (Colorado State University, USA), and the second part - by Dr. Wolfgang Rudolph (University of New Mexico, USA). The science and engineering of state-of-the-art deposition techniques of optical coatings were reviewed in the first part. Special emphasis was given to ion-beam sputtering (IBS) technique. The multi-dimensional parameter space of IBS was introduced and it was explained how the deposition conditions and annealing could affect the film properties. The second part of the tutorial discussed the amorphous versus crystalline state of the films and the expected optical properties. Native, atomic scale defects like oxygen vacancies and interstitials were introduced and corresponding diagnostic techniques were described. Photo-thermal absorption measurements were reviewed from a general point of view and discussed for measurements in transmission and reflection to identify absorption centers due to macroscopic film imperfections.

Attendees of the tutorial were asked for feedback. 22 participants responded to a short questionnaire that contained 3

Table 1. Summary of a survey of tutorial participants.

Questions	Yes, very much / Surely yes	Rather interesting / useful	Nothing interesting / useful/ certainly no	I do not know / not sure
Question 1: How interesting was the Tutorial for you?	31.82%	63.64%	0.00%	4.54%
Question 2: Was the Tutorial useful and informative for you?	22.73%	77.27%	0.00%	0.00%
Question 3: Would you participate in RT Discussion next year?	81.82%	N/A	0.00%	18.18%

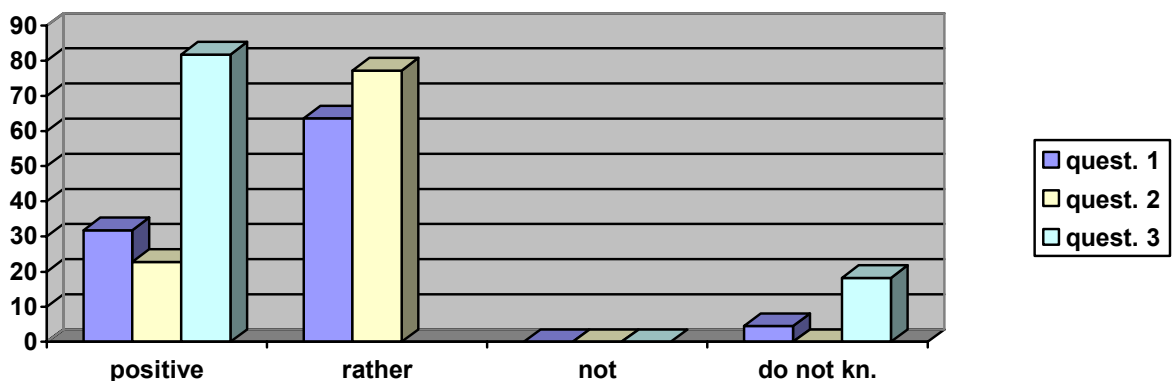


Fig. 1. Graphical representation of responses of tutorial participants to the questions listed in Table 1.

questions listed in Table. 1. Results are presented in Table 1 and in fig. 1. Overall, the participants expressed high level of satisfaction with that tutorial that motivated organizers to prepare another tutorial in 2015. Following the topics suggested by the participants of the survey, the next tutorial will focus on fundamental mechanisms of laser-induced damage in optical materials.

Boulder conference attendance statistics

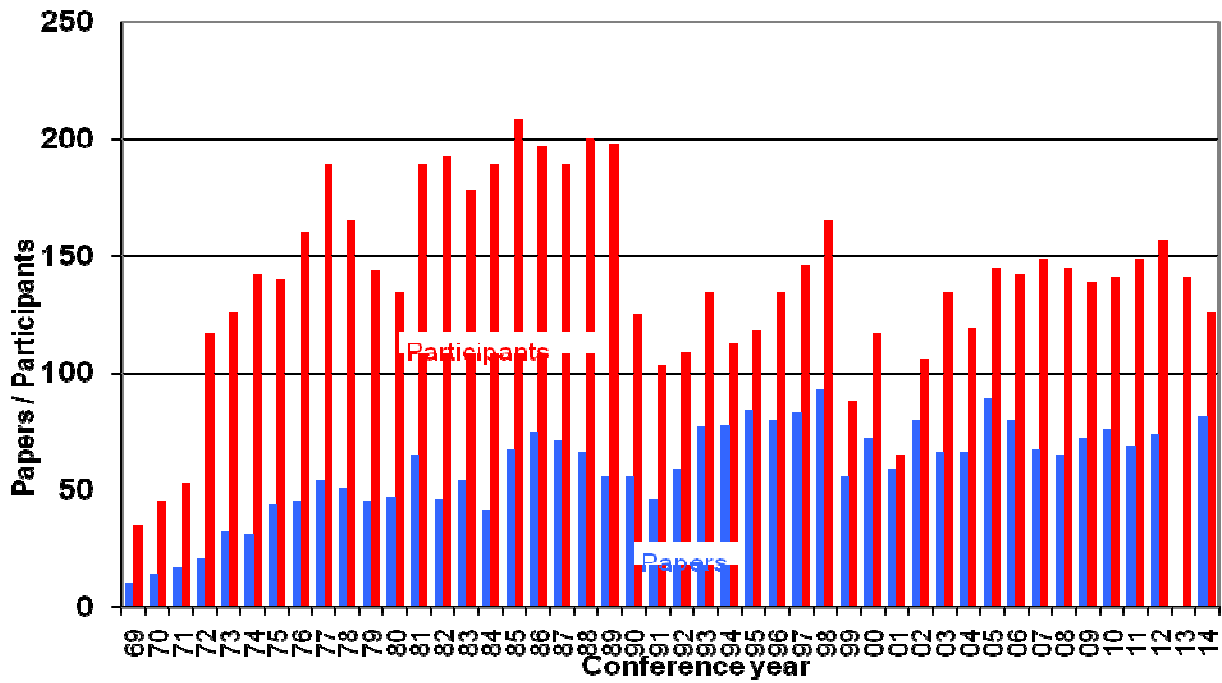


Fig. 2. Registered participants (red lines) vs number of presented papers (blue lines) since 1969 till 2014 inclusive.

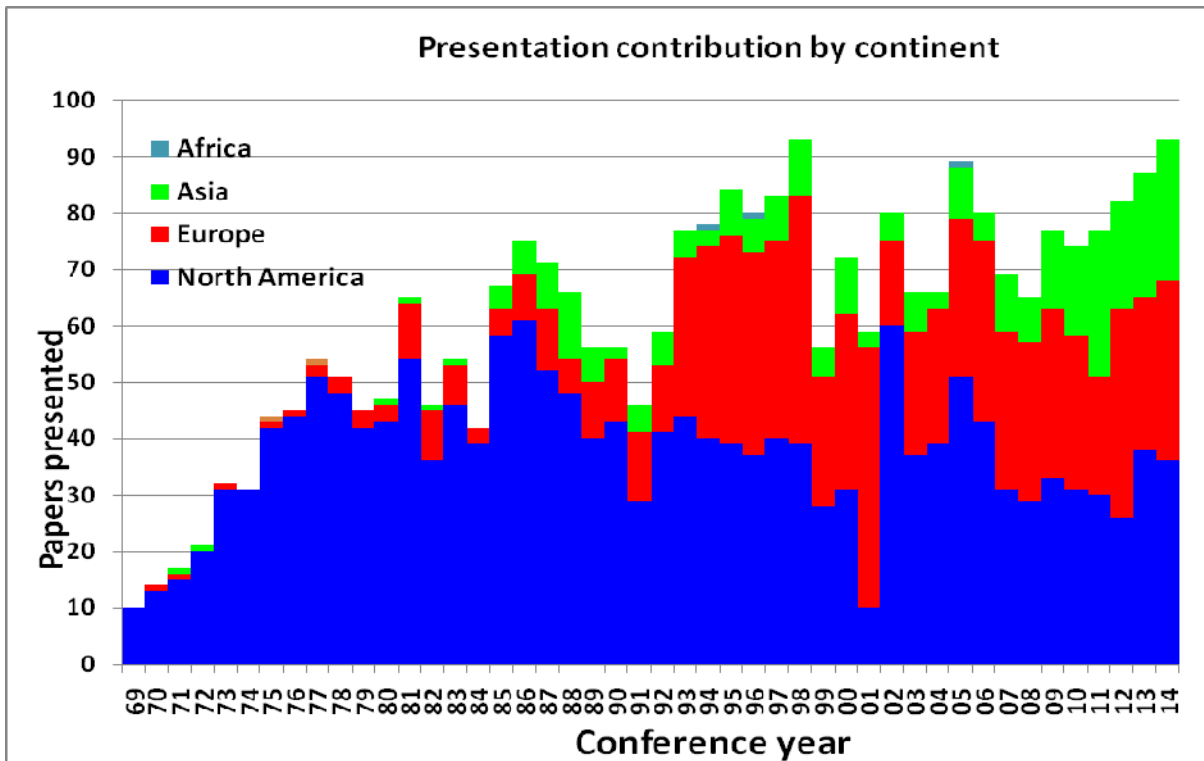


Fig. 3. Distribution of contributed papers by continents from 1969 till 2014 inclusive.

4. Thin Films

Because of the tremendous range of applications of optical multilayer coatings for modifying the optical performance of elements (e.g., reflectivity, wavelength sensitivity, polarization, or simply protection), this category continues to receive very significant attention. Besides damage thresholds or sensitivity of particular coatings, topics include advanced thin deposition technologies (atomic-layer deposition, ion-beam sputtering and e-beam evaporation), film structure, film design, film response to environmental attack and aging, and numerous reports on important film properties such as absorption and stability. Special attention is paid to coatings at 1064 nm, 532 nm, 355 nm, and deep-UV coatings (e. g., 193 nm). This year, the problem of thin-film damage by ultrashort pulses received the highest attention with almost 35% presentations of this section devoted to that topic. The strong increase of interest to this area is attributed to fast progress in all types of ultrafast/femtosecond lasers.

Dense thin film processes offer the benefit of environmental stability, and most of the research in the field of thin films is proceeding in this direction. Laser interaction studies uncover areas where dense films offer advantages over traditional e-beam coatings. Also as shown in the thin film damage competition there are a number of companies that are manufacturing dense coatings from a variety of deposition techniques with very high laser resistance.

Coating defects continue to be an area of active interest in both process of optimization to minimize defect density and formation as well as mitigation techniques such as laser conditioning. This year we continue to see interest in defect detection and characterization in films and coatings for IR and deep UV pulsed lasers. As before, thin-film laser damage competition is one of major events of Thin Film section of the Symposium.

5. Thin-film laser damage competition

This year the seventh thin-film damage competition was organized by Dr. Christopher Stolz of Lawrence Livermore National Laboratory (USA). It started in 2008 to sample the industrial, government, and academic sectors producing high laser resistant optical coatings. This year, narrow-bandwidth Fabry-Perot filters were tested. The requirements included central wavelength (1064 nm), minimum transmission (75%), and NGLE TUNING RANGE (10-30 DEGREES). Sample filters from several companies and institutes from the USA, Europe, and China were tested with 5 ns pulses at the 1064 nm at the laser-damage test facility of Spica Technologies Inc. (USA). A multitude of deposition processes, coating materials, and manufacturing techniques submitted to this competition provided some intriguing results that will likely lead to some significant future research.

2008	HR mirrors for Nd-YAG lasers, wavelength 1064 nm, nanosecond pulses
2009	HR mirrors for Ti-sapphire lasers, wavelength 780 nm, femtosecond pulses
2010	AR coatings for excimer lasers, wavelength 351 nm, nanosecond pulses
2011	HR mirrors for excimer lasers, wavelength 193 nm, nanosecond pulses
2012	Brewster-angle thin film polarizer, wavelength 1064 nm, nanosecond pulses, p-polarization
2013	Brewster-angle thin film polarizer, wavelength 1064 nm, nanosecond pulses, s-polarization
2014	Narrow-bandwidth Fabry-Perot transmission filters, wavelength 1064, nanosecond pulses

6. Fundamental Mechanisms

This area deals with the fundamental effects of interactions of light with matter. Topics include laser-induced ionization, nonlinear behavior and effects, self-focusing and scattering, modeling of thermal and non-thermal processes, and experimental data reduction protocols (e.g. effects of pulse width, repetition rate or duty cycle, spot size, wavelength, temperature, ionizing radiation, and other environmental effects). Also, of great interest are all types of experimental or material variable scaling relationships for laser-induced damage thresholds that not only afford insight into the fundamentals of the interaction process, but allow extrapolations for engineering and cost-benefit evaluations. In many areas, these insights are based on real-world, systems-level tests, as opposed to a frequently pristine laboratory environment.

A significant amount of experimental and simulation work is now being done in the femtosecond regime as exemplified by the significant number of submitted papers on ultrafast phenomena. They consider both bulk and surface effects including formation of periodic surface ripples. Novel simulation approaches have been proposed and demonstrated excellent agreement with experimental data. This year's presentations show stable growth of scientific interest and

research activity in that field. Significant number of presentations also focuses on the fundamental influence of defects on laser-induced damage threshold in transparent materials, linear and non-linear absorption, laser-induced ionization, and material response to high-power laser action.

7. Surfaces and Mirrors

Presentations of this category are devoted to surface preparation (including MRF technology for large-aperture optics, plasma pre-treatment, aqueous HF-based etching), subsurface damage characterization, roughness and scattering, environmental degradation and aging, as well as substrate material properties, including cooling techniques, and, of course, damage measurement and the cleaning of surfaces. The crux of the contamination problem is fundamentally that damage experiments done in controlled clean laboratory settings do not necessarily yield the same results as laser operations in less pristine operating environments. There is a significant amount of work needed in understanding what contamination is acceptable, what contamination is threatening to optic survivability, and how fluence-limiting or lifetime-limiting contamination can be eliminated or mitigated from operating laser systems.

This year, significant number of presentations is devoted to cleaning and protection of mirror surfaces in laser interferometric gravitation observatories (LIGO). Special cleaning procedures have been developed for LIGO optics to meet the hard requirements to sensitivity of those unique devices. Other hot topics of this category are related to laser-induced contamination on optics operating in space at laser-equipped satellites and in reaction chambers of fusion setups. Mapping of scattering continues to stay one of effective non-contact tools to detect surface contamination and defects. A fair amount of papers deals with laser-damage mitigation demonstrating pronounced success in that field. Decontamination and refining of optical surfaces and the impact of contamination on laser resistance still stay the topics of active research and discussion. Influence of scratches on laser-induced damage threshold also continues to stay of high interest for researchers in this field.

8. Materials and Measurements

Among the four main sections of the conference, this one continuously stays the largest over last decade. This section deals with protocols and setups (e.g., automated stations) for measurements of laser damage to the bulk of transparent optical media whether amorphous, polymeric, polycrystalline, or crystalline; reports on material properties of importance for their optical function and/or the damage process, e.g., linear and nonlinear absorption coefficients, thermal conductivity, stress-optic coefficients, moduli, scattering, and various defects. Also included are new techniques for measuring these quantities, which present a continuing challenge as materials are improved in quality and diversity. Among the novel directions are intensive developments in applications of optical ceramics, meta-materials, and nano-structured materials for production of specific optics with engineered responses for high-power lasers.

There is always interest in improved measurement systems or new instruments particularly in the areas of non-destructive characterization and defect detection. Laser damage measurements are difficult, and work continues on developing tests that address large area versus small area and the difficulties of obtaining data with high space resolution. Significant efforts are reported on investigation of damage precursors and initiators, their identification and elimination. Impressing reports are delivered on automated programmable systems for defect identification and blocking for mitigating laser-induced damage. Continuous efforts have been reported on measurement of absorption for deep-UV optics, characterization of nonlinear absorption, and separation of bulk and interface contributions to the total absorption of optics with single or multiple interfaces.

9. Mini-Symposium

This year the meeting hosted the mini-symposium on applications related to laser damage chaired by Dr. S. Demos of Lawrence Livermore National Lab (USA). With 4 plenary presentations and 2 more regular talks spread over two oral sessions, the mini-symposium was intended to cover a tremendous range of laser-damage applications in industry and science (e. g., laser peening and nano-patterning), medicine (from tissue damage to micro-scale operations at cellular level), military, and even in security of quantum keys for computing systems. Unfortunately, four of the presentations were cancelled due to various and highly unexpected reasons, but the two delivered invited talks were excellent excursions and brilliant introductions into the laser-damage applications for laser peening and nano-patterning .

A brief summary of the past mini-symposium topics starting from 1992 and the organizing chairs is listed below.

<i>Year</i>	<i>Chair</i>	<i>Topic</i>
1992	Brian Newnam	Damage Issues for Lithographic Optics
1993	Karl Guenther	Quest for the Invincible Laser Coating – Critical Review of Pulse Laser-Induced Damage to Optical Coatings: Causes and Cures
1994	Claude Klein	Diamond for Optics Applications in Adverse Environment
1995	Floyd Hovis	Contamination and the Laser Damage Process
1996	Robert Setchell	Laser-Induced Damage in Optical fibers
1997	David Welch	Damage and Lifetime Issues for Laser diodes
1998	Norbert Kaiser	Optics for Deep UV
1999	David Sliney	Laser Damage Processes in the Eye and Other Biological Tissue
2000	Mark Kozlowski Hideo Hosono	Defects in Glass
2001	Mark Kozlowski	Optical Materials for Telecommunications
2002	Detlev Ristau	Optics characterization – joint with 7 th International Workshop of Laser Beam and Optics characterization
2003	William Latham	Understanding Optical Damage with Ultra-short Laser Pulses
2004	Keith Lewis	Damage Issues in Fiber Laser systems
2005	Leon Glebov	Petawatt Lasers
2006	Alan Stewart	Optics in a Hostile Environment
2007	Stan Peplinski	Lifetime Issues for CW and Quasi-CW Lasers
2008	Christopher Stolz Herve Bercegol	Fused Silica
2009	Wolfgang Rudolph	Femtosecond Laser-Induced Damage
2010	Klaus Sokolowski-Tinten	Fundamentals of Laser Ablation
2011	Holger Blashke, Carmen Menoni	Deep-UV Optics
2011	Michelle Shin	Meta-Optics/Photonic Band Gap Materials
2012	Stavros Demos	Laser-Induced Plasma Interactions
2013	Leonid Glebov	High-Power Fiber Lasers
2014	Stavros Demos	Applications Related to Laser Damage

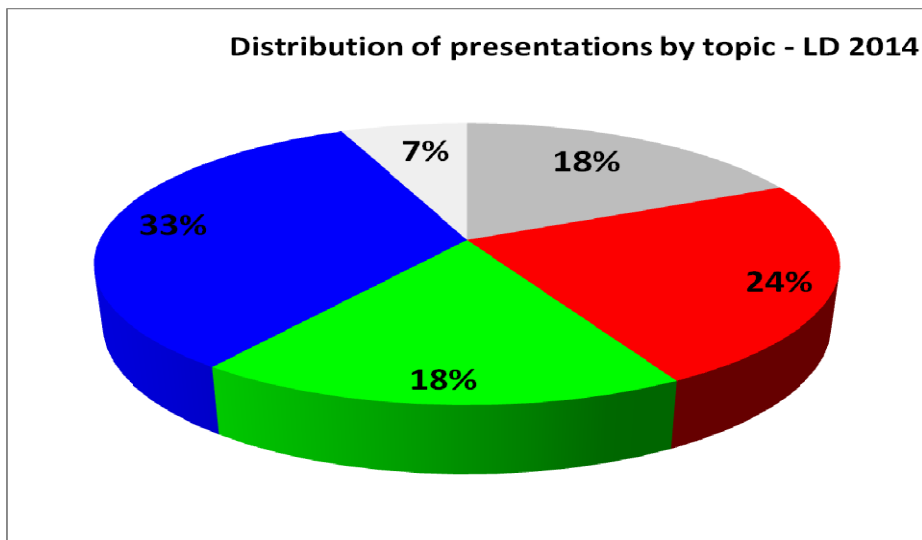


Fig. 4. Distribution of presentations of Laser Damage-2014 by topics: dark grey - Fundamental Mechanisms; red - Thin Films; green - Surface, Mirrors, and Contamination; blue - Materials and Measurements; light grey - Mini-Symposium.

10. Keynote Presentations

As usually, the 46th Laser Damage Symposium is highlighted by four keynote presentations in the major areas:

1. “Contamination of optical components: protecting optics installed in advanced LIGO from particulate contamination”, Calum I. Torrie, California Institute of Technology (USA) and Scottish Univ. Physics Alliance (United Kingdom).
2. “Large-aperture plasma-ion-assisted coatings for femtosecond-pulsed laser systems”, James B. Oliver, J. Bromage, Ch. Smith, D. Sadowski, University of Rochester (USA).
3. “Silica laser damage mechanisms, precursors, and their mitigation”, Jeffrey D. Bude, Lawrence Livermore National Laboratory (USA).
4. “Experimental tools for nonlinear spectroscopy: absorption and refraction”, David J. Hagan, Eric W. Van Stryland, T. R. Ensley, M. C. Reichert, CREOL, The College of Optics and Photonics, University of Central Florida (USA).

11. Conference Awards

Beginning with the meeting in 2000, the organizers instituted a best paper award in the oral and poster categories. The awards appropriately take the form of laser-induced art in an optical glass plaque. (see, e.g., paper by I. N. Trotski, Proc. SPIE 4679, 392-399 (2001)).

There were several outstanding posters and oral papers, however, the following papers were selected for 2014:

Best oral paper:

“Ultrafast optical breakdown of multilayer thin films at kHz and MHz repetition rates: a direct comparison”, presented by Olga Razskazovskaya, Max-Planck-Institut für Quantenoptik (Germany); coauthors include Ivan B. Angelov, Max-Planck-Institut für Quantenoptik (Germany), Michael K. Trubetskov, Max-Planck-Institut für Quantenoptik (Germany) and Moscow State University (Russia), Vladislav S. Yakovlev, Max-Planck-Institut für Quantenoptik and Ludwig-Maximilians-Univ. München (Germany), Martin Gorjan, Max-Planck-Institut für Quantenoptik and Ludwig-Maximilians-Univ. München (Germany), Helena G. Barros, Ludwig-Maximilians-Univ. München (Germany), Ferenc Krausz, Max-Planck-Institut für Quantenoptik and Ludwig-Maximilians-Univ. München (Germany), Vladimir Pervak, Ludwig-Maximilians-Univ. München and Ultrafast Innovations GmbH (Germany)

Best poster paper:

“Repair of a mirror coating on a large optic for high laser-damage applications using ion milling and over-coating methods”, Ella S. Field, John C. Bellum, Damon E. Kletecka, Sandia National Laboratory (United States).

12. Publications

Concerns were previously expressed by Laser Damage authors regarding copyright issues appeared when results presented at Laser Damage Symposium and published in the Symposium Proceedings were submitted for publication in non-SPIE peer-reviewed journals. To address those concerns, Dr. Michelle Shinn and Dr. Vitaly Gruzdev volunteered as guest editors of Special Section on Laser Damage published in flagman peer reviewed SPIE journal *Optical Engineering*. The first Special Section was published in volume 51, issue 12 and contained 18 papers selected by peer-reviewers for publication out of 21 submitted manuscripts. The papers covered various aspects of laser damage including fundamental mechanisms, influence of defects, measurements of laser-damage thresholds, statistical laws of damage threshold, damage of thin films and optical coatings. Many of those publications were based on the results presented at Laser Damage and on manuscripts published in the Proceedings of Laser Damage Symposium. Other manuscripts were submitted independently via general submission procedure of SPIE journals. That Special Section was recognized as highly successful with multiple downloads and many citations. That fact motivated the International Program Committee of Laser Damage Symposium to coordinate another Special Section on Laser Damage with editors of *Optical Engineering*. Result of that effort is the Special Section on Laser Damage–II that has been published in volume 53, no. 12 of *Optical Engineering* in 2014. It contains 16 papers selected out of 21 submissions and covers a broad spectrum of topics related to laser-induced damage.

All interested readers are welcome to visit the web pages of those two Special Sections of *Optical Engineering*.

13. In Conclusion

The location in Boulder, Colorado, during autumn at the venue of the National Institute of Standards and Technology and its outstanding facilities and support staff were appreciated by all. All attendees of Laser Damage were easily accommodated with ample opportunity to mingle and socialize.

This year the sunny and warm weather in Boulder encouraged to take a group picture of all symposium participants by the staircase of the National Institute of Atmospheric Research (Boulder, CO) where the traditional Wine and Cheese Reception was held on Tuesday, September 15.

The organizers of the Boulder Damage Symposium look for opportunities to join with other related groups for joint meetings in the future. For example, in 2002 we had a joint meeting with the 7th International Workshop on Laser Beam and Optics Characterization (LBOC), again with no parallel sessions. Also, starting from 2009, Pacific Rim Laser Damage (PLD) symposium is held annually in spring in Shanghai, P. R. China with the topics and the scope completely similar to the topics and scopes of this meeting. We are looking forward to develop fruitful collaboration with PLD meeting in order to join our efforts for better serving the laser-damage community worldwide.

We must also note tireless assistance of SPIE who handle the administrative functions of the symposium. Their presence, experience, resources, and professionalism clearly were made manifest with on-line reservations, payment by credit cards, badges, preparation of the abstract book and pocket programs, preparation and printing this volume of Symposium Proceedings, and on-line document service, to which we may add the social functions – thanks to them, “A good time was had by all.”

14. Acknowledgments

A number of volunteers help tirelessly with some of the administrative duties necessary to put on a conference of this magnitude. Diane Cline from SPIE took care of all the administrative planning and on-site tasks including setup, registration, and general questions. Carle Limtiaco from Lawrence Livermore National Lab helped with the registration pick up and at front desk through the entire meeting. Pat White from SPIE took care of program preparation, invitation letters for international participants, and provided much on-line support for the conference. Joel Shields also from SPIE was responsible for preparation of this volume of the conference proceedings and the publication of the manuscripts into it. Artika Arpana from Lawrence Livermore National Laboratory assisted with the thin-film competition.

This year we acknowledge support from Lawrence Livermore National Laboratory (USA) and several companies: ATFilms, Arrow Thin Films (USA); Alpine Research Optics (USA); IDEX Optics & Photonics (USA); Spica Technologies Inc. (USA); Laser Components GmbH (Germany), and Quantel Laser (USA) for supporting social events and refreshments of this meeting. They are separately acknowledged in this volume of conference proceedings. Special acknowledgement is for Spica Technologies for their support of laser-damage competition.

Of course, we are all indebted to Kent Rochford, Division Chief of the Optoelectronics Division, who was the prime contact at NIST, for his continued support and encouragement, and Jason Day, also of NIST, who together made it possible to hold a seamless meeting. On behalf of all the organizers and attendees, we thank them for their tireless efforts and support of Laser Damage Symposium.

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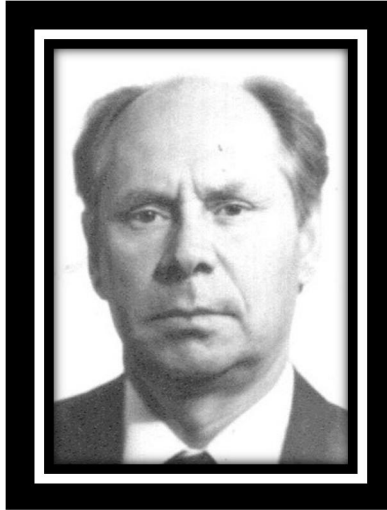
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Tribute to Dr. Alexander A. Manenkov

Vitaly E. Gruzdev
Univ. of Missouri (United States)



This tribute is devoted to an outstanding researcher, one of the most significant contributors to the field of Laser Damage, Professor Dr. Alexander A. Manenkov. He passed away on 26 March 2014 in Moscow, Russia.

Dr. Manenkov was born on 2 January 1930 in the Tartar Region (previously the Soviet Union, now – Russia). He received his M. S. Degree from Khazan State University in 1952 in Khazan, Russian Federation. In 1952 he began his first year of Ph. D. studies at Khazan Physical-Technical Institute, one of the major research centres of the former Soviet Union. In 1953 he was transferred to Lebedev Institute of Physics in Moscow, Russian Federation from which he received his Ph. D. in Physics and Math Sciences. In 1983 he joined the newly opened General Physics Institute. His career progressed from Laboratory Fellow (during the Ph. D. studies) to Assistant Research Professor, to a group leader, Laboratory Chair, and finally to a Chair of the department of General Physics Institute. Starting from the early steps of his independent research, he closely worked with the Academician of the Russian Academy of Sciences, Noble Prize Winner, Dr. A. M. Prokhorov.

Dr. Manenkov has made highly significant contributions to multiple fields of research and technology related to lasers. First, he began with studies of electron paramagnetic resonance that was focused on applications for quantum electronics and masers. With development of a maser based on his results, Dr. Manenkov focused on applications of the maser for radio-spectroscopy and radio-astronomy. Soon after the invention of lasers in 1965, he switched to the area of laser-material interactions and began research on fundamental mechanisms of the interactions with special emphasis on laser-induced damage (LID) of transparent solids, self-focusing, nonlinear laser-pulse propagation, and laser interactions with absorbing defects and impurities.

Starting from the early 1970s, laser-induced damage of transparent materials became one of the major research areas for Dr. Manenkov. He was leading the first LID research group in the former Soviet Union starting from 1971. Since that time, he has made very essential contributions to the field of LID mainly by theoretical and experimental studies of the fundamental mechanisms of LID. Development of theoretical models of laser-induced avalanche (also known as impact) ionization was one of the hot topics for the LID community during the early period of LID development. Dr. Manenkov significantly contributed to detailed evaluations of electron-phonon collisions to the avalanche ionization for specific types of phonons in particular materials.¹⁻³ His group derived several relations for LID thresholds from those models of the electron avalanche ionization. He also studied the role of seed electrons in impact-ionization development that was one of the basic challenging points in the 1970s. As a reminder, the earliest electron-avalanche models completely neglected considerations of the seed electrons in solids assuming that thermal effects always provide some electrons to seed the avalanche development. Some

models considered even avalanche development from a single “lucky” electron assuming a negligible role of the density of seeding electrons in the solids. It took almost a decade to figure out the essential contribution of the photo-ionization in the production of enough seed electrons to start up the avalanche development.

Another highly significant contribution was made by Dr. Manenkov to the field of defect-induced LID. He developed multiple models of LID initiated by microscopic-size absorbing and low-absorbing impurities and defects. Starting from the simple model of local heating and thermal phase transition, he proposed a variety of advanced models including various thermal instabilities (following the concept of S. I. Anisimov), temperature-stimulated enhancement of the ionization, and local thermo-mechanical stresses around the defects.^{3,4}

Surprisingly, less known are the other pivotal contributions of Dr. Manenkov to the field of LID and materials for high-power lasers. In particular, he studied the dynamics of valence electron transitions of various ion groups in sapphire and ruby in attempt to improve gain materials for solid-state lasers. His research on the influence of mechanical properties (viscosity) of polymers on LID threshold resulted in development of novel materials for high-power Q-switchers.

His outstanding contributions to the research have been awarded with two highly prestigious awards:

- USSR State Prize for the development of masers and their application in radio-astronomy and long-distance open-space communications - in 1976 (it was the highest award in the former Soviet Union);
- In 2010 he received Prokhorov Gold Medal of the Russian Academy of Sciences for his contribution to radio-spectroscopy, quantum electronics a laser physics.

Since the late 1970s, Dr. Manenkov has attended the annual Boulder Damage Symposium (later – SPIE Laser Damage Symposium) and made regular presentations of the results of theoretical and experimental investigations of his research group. In 2009 he presented an invited talk reviewing the fundamental mechanisms of LID at the anniversary of the 40th Laser Damage Symposium.

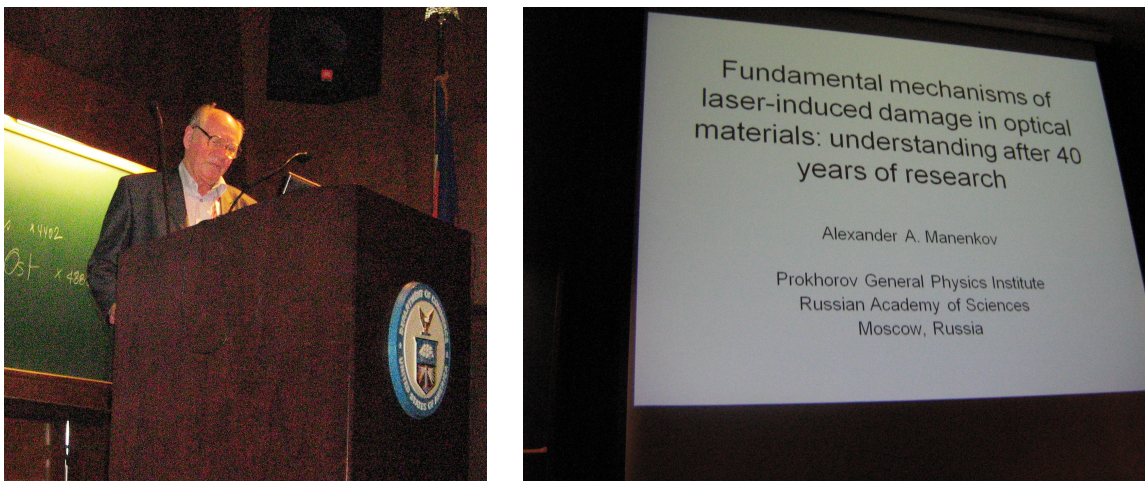


Fig. 1. Presentation of the review talk by Dr. Manenkov at the anniversary Laser Damage Symposium in 2009.

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