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Proceedings

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DAMAGE**

**LASER-INDUCED DAMAGE
IN OPTICAL MATERIALS: 2015**

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Editors

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

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Symposium Welcome

Vitaly E. Gruzdev

University of Missouri-Columbia (USA)

On behalf of co-chairs of this meeting, Gregory Exarhos, Joseph Menapace, Detlev Ristau, and M. J. Soileau, I extend a hearty welcome to all participants of the annual Laser Damage Symposium – the Forty Seventh annual Symposium on Optical Materials for High-Power Lasers held at the NIST facility in Boulder, Colorado. This Symposium was founded by Art Guenther and Alex Glass in 1969 to bring together researchers of the newly emerging laser community to rapidly resolve a specific problem: why and how laser radiation damages materials that are assumed to be highly transparent. The “specific problem” turned out to be very non-trivial and quickly drove researchers to recognition of the need to join the efforts of scientists from optics, solid-state physics, materials science, chemistry, and other areas. The deeper the problem was investigated, the more aspects were brought to the attention of laser researchers and engineers. Within a few years of the first meeting in 1969, this conference became a major international platform for lively discussions and communication between researchers and engineers from academia, industry and military related to all aspects of laser-induced damage. Fluctuating from year to year, the stable number of presentations indicates the enormous vitality of this field and the continuously growing interest in the related topics. Among the motivating factors of research in this field are the continuous extension of the range of available laser parameters towards shorter pulses, shorter wavelengths, and higher powers; development of novel lasers; novel optical materials; and operation of traditional lasers under new environments. The amazing progress in the field of ultrashort laser pulses has provided new unique capabilities for better understanding of the fundamental mechanisms of laser-material interactions that initiate laser damage in optical materials. Ultrafast laser systems have also enabled the development of novel techniques and methods for the characterization of transition response of optical materials for high-power lasers. Rapid progress in material science has resulted in the development of new types of optical materials (e.g., ceramics and nanostructured surfaces) with a high potential of applications in high-power laser systems. All those developments as well as general progress in the field of high-power and high-energy lasers continuously support interest in the field of laser damage that is very likely to stay popular even in the following decades.

In view of those developments, it is important to track the previous research. Proceedings of the Boulder Damage Symposium (BDS) have become the most complete and major resource of information on laser damage and related areas compiled from the early stages of that field onwards. The 40-year collection of the Proceedings (from 1969 to 2008 inclusive) has been published on a single DVD distributed to participants of this symposium in 2009. The tremendous effort of the authors to prepare the manuscripts for this series of Proceedings of SPIE help to maintain the unique status of the Proceedings and are gratefully acknowledged here. In addition to the Proceedings, a special section on Laser Damage was published in *Optical Engineering* – the major journal of SPIE – in December 2012 and 2014. They have attracted significant attention from readers and have received very good feedback from the contributing authors. Those facts have motivated the organizers to prepare and publish another special section on Laser Damage in *Optical Engineering* in January 2017.

Significant contribution to the success of the BDS has been done by the International Program Committee (IPC) representing leading research centres and groups of the laser-damage community worldwide. Presently, the IPC consists of representatives from the United States of America, Germany, France, Japan, China and the UK. Besides providing contributions to the conference program, the IPC is also active in promoting the conference and in attracting researchers from around the world. The engagement of the Committee that initiated participation from more than 30 countries from America, Europe, Asia, Africa and Australia during the last decade is acknowledged here as being very important. Tremendous efforts of the IPC Chair – Dr. Detlev Ristau of Laser Zentrum Hannover e. V. (Germany) – to keep IPC actively working are acknowledged.

Following the 45-year tradition, the conference addresses four core topics including Materials and Measurements, Fundamental Mechanisms, Thin Films as well as Surfaces, Mirrors and Contamination. One invited presentation was delivered for each of the topics to provide overview of the particular research area and educate the younger generation of conference participants. In order to track the current trends in research and further intensify the scientific dialogue at this meeting, a mini-symposium dedicated to a hot current topic in laser material interaction has been organised every year since 1992. This year’s mini-symposium on “Laser-Induced Damage to Multilayers in Femtosecond Regime” was chaired by Dr. Vladimir Pervak from the Ludwig-Maximilians University in Munchen, Germany.

Continuing the success of the damage competition held for first time in 2008, Chris Stolz has kindly organized another competition with the target being to review the present state of the art in multilayer coatings for 150-ps broadband low-dispersion mirrors that are a fluence-limiting components of short-pulse lasers. Samples were submitted by companies and research institutes from China, Japan, Germany, and the United States of America. Femto-Solid Dynamics Laboratory of the Ohio State University accomplished an enormous amount of work by evaluating the laser-induced damage threshold of all the samples. This outstanding effort is appreciated by the community, and the organizers acknowledge this special contribution by Chris Stolz. He delivered a talk about the competition and has prepared a summary paper that can be found in this present volume of the conference proceedings.

One of the young traditions of the symposium is to acknowledge authors who presented significant and notable results at previous year's meeting. The authors receive Best Presentation awards consisting of a monetary award in the amount of \$500, and a cut-glass piece of art with symposium emblem and date and names of the authors embedded into the glass by controlled laser-induced damage made with focused beam from a Q-switched laser. Eligibility for this award includes publishing manuscripts of nominated presentations in the conference proceedings.

Much of the success of the meeting can be attributed to the untiring efforts of the SPIE staff: Pat Wight (this year – Conference Program Coordinator), Diane Cline (Symposium Secretary), and Joel Shields (Proceedings Coordinator) as well as Carly Lintiacio of Lawrence Livermore National Lab (Symposium Assistant). The co-chairs acknowledge the support of NIST staff and especially Kent Rochford and James Burrus (NIST) for coordinating activities and arranging for the audio-video facilities in the meeting room. We gratefully appreciate the annual co-sponsoring from the Lawrence Livermore Laboratory which psignificantly supported this meeting. The contribution of Femto-Solid Dynamics Laboratory of the Ohio State University performed the laser damage tests for the annual laser-damage thin-film competition is greatly appreciated. We appreciate support from Pacific Northwest National Laboratory and Office of Naval Research. We also acknowledge the other cooperating organizations: School of Optics – CREOL and FPCE, College of Optics and Photonics, University of Central Florida; and University of Missouri.



Participants of the 47th Laser Damage Symposium inside the National Institute of Atmospheric Research in Boulder, CO.

Damage Competition Summary

Christopher J. Stolz

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There are currently over 50 petawatt class lasers worldwide. These laser systems are used for a number of research projects ranging from inertial confinement fusion, radiography, particle acceleration, studying materials at high temperatures and pressures, radiation therapy, secondary source generation, and medical isotope creation to name a few. There is a huge growth in this field considering that in 1998 the only petawatt class laser in the world was on the NOVA laser at Lawrence Livermore National Laboratory. Pulse compression gratings and short pulse transport mirrors remain one of the fluence limiting components on these laser systems.

Thirty-three samples were submitted by sixteen different participants representing seven different countries. The samples were manufactured by each participant on their own substrates and submitted for laser damage testing and group dispersion delay measurements. Five participants were new to this series of thin film laser damage competitions that started in 2008. Laser Zentrum Hannover remains the only institute that has participated in every competition.

As in previous similar thin film laser damage competitions, there was at least an order of magnitude difference between the most and least laser resistant samples and the winner consisted of hafnia and silica, the material combination of choice for high fluence near infrared multilayer coatings. The winning samples were also deposited by ion beam deposition. An unexpected result of this competition is the significant number of samples that were found not to comply with the challenging GDD specifications over a fairly wide spectral range. No correlation was observed between either GDD or layer count and laser resistance.

Summary of Meeting

SPIE Laser Damage Symposium
47th Annual Symposium on Optical Materials for High Power Laser
27-30 September 2015

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1. Abstract

These proceedings contain the papers presented as oral and poster presentations at the 47th SPIE Laser Damage Symposium (aka 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 27-30 September 2015. The symposium was divided into oral and poster sessions following four major topics: thin films; surfaces, mirrors and contamination; fundamental mechanisms; materials and measurements. A mini-symposium was held this year on laser damage to multilayer coatings for ultrafast lasers. A tutorial on defect-induced damage in nano- and femto-second regime was held as a special pre-symposium event on Sunday evening, September 27. The conference was opened by Dr. Vitaly Gruzdev 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.

84 abstracts were submitted to the symposium, of which 73 were presented at 11 oral sessions and 4 poster sessions. No parallel sessions were held allowing the opportunity to discuss common research interests with all the presenters. With 122 attendees 75 of which were authors and meeting co-chairs, 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 55% of the presentations and 39% of attendees coming from Europe, Asia, and Africa. As usual, the National Institute of Standards and Technology in Boulder, Colorado, offered a setting conducive to effective communications and interchanges between Symposium participants.

The 48th Annual Symposium of this series will be held in Boulder, Colorado, 25-28 September 2016. 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 will be focused on overview of large-scale laser facility projects. Invited talks are also anticipated for the four major topical areas and the mini-symposium. Following multiple feedbacks from symposium participants, the 2016 Symposium is relocated from NIST to Boulder Millennium Harvest House Hotel.

The principal topics to be considered as contributed papers in 2016 do not differ drastically from those enumerated above. We expect to hear more about the impacts 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 the most 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 contamination control are expected in 2016 due to the recent progress of LIGO project and the reported detection of gravitation waves.

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 on advanced materials for high-power lasers is 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.

Key words: laser damage, laser-material interaction, high-power lasers, high-energy lasers, optical components, optical fabrication, optical materials, thin film coatings, contamination, ultrafast laser-matter interactions.

2. Introduction

The SPIE Laser Damage Symposium - 47th Annual Symposium on Optical Materials for High-Power Lasers (a.k.a. the Boulder Damage Symposium, because of its Boulder, Colorado, venue) was held 27-30 September 2015. 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 122 representatives of academia, industry, national research laboratories and centers from 13 countries that was about 1.7% increase in attendance compared to Laser Damage-2014. 84 abstracts were submitted to the Symposium, and 73 of them were included into the final program and were delivered within the traditional 3-day format of the meeting including 44 oral and 29 poster presentations. This year only 3 presentations (2 oral and 1 poster) were cancelled or not presented this year. Although, held annually in the US, this is a truly International conference with 39% of the attendees and 55% 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 from 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, and laser-material interactions. Starting from 2014, the traditional pre-symposium event – a Round-Table discussion held on Sunday evening – was replaced with a tutorial. This year it featured defect-induced laser damage under the topic “Defect-Induced Damage in Nano- and Femtosecond Regime”. The tutorial was prepared and held by Dr. Laurent Gallais (Institut Fresnel, France) on Sunday, 27 September. The tutorial attracted more than 65 participants of the conference. The conference began on Monday, 28 September 2015 with a welcome talk delivered by Vitaly Gruzdev.

3. Symposium Cochairs

The Boulder Damage Symposium was founded by Dr. A. H. Guenther and Dr. Alexander Glass. Over the last 47 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

4. Pre-symposium event: tutorial

Symposium Tutorial is the newest Symposium event introduced for the first time in 2014. That year, the tutorial was focused on the basics of thin films under the topic “Fundamentals of Growth and Characterization of Amorphous Thin Films for Interference Coatings” and was held by Dr. Carmen Menoni (Colorado State University, USA) and Dr. Wolfgang Rudolph (University of New Mexico, USA). In 2015, the Tutorial was held again as pre-symposium event on Sunday evening and featured defect-induced laser damage under the topic “Defect-Induced Damage in Nano- and Femtosecond Regime”. The tutorial was prepared and held by Dr. Laurent Gallais (Institut Fresnel, France). The lecture part focused on fundamental effects and basic physics of defect interactions with nanosecond and femtosecond high-power laser pulses. Correspondingly, two distinct regimes of the interactions – thermal and non-thermal – were overviewed. Special attention was paid to the influence of defects on statistical effects in laser-damage threshold metrology. Implications of defects, including artificial ones, for various applications including studies of laser damage was considered. At the beginning, the tutorial attracted 65 participants of the conference, but more people joined it soon after finishing the registration. Total attendance was estimated at the level of 70 people.

Each year, attendees of the tutorial are asked for feedback. In 2014, 22 participants responded to a short questionnaire that contained 3 questions about the tutorial. In 2015, organizers received 50 responses. Distribution of the responses is summarized in Table 1 and Figure 1. Participants expressed high level of satisfaction with the Tutorial-2015 that motivated organizers to prepare another tutorial in 2016. Following the topics suggested by the participants of the survey, the next tutorial will focus on optical materials for high-power lasers.

Table 1. Summary of a survey of tutorial participants: 2014 vs 2015.

Questions	Very much / Surely yes	Rather interesting / useful	Nothing interesting / useful/ No	Not certain / not sure
Question 1: How interesting was the Tutorial for you?	2014: 1.82% 2015: 68.00%	2014: 63.64% 2015: 32.00%	2014: 0.00% 2015: 0.00%	2014:4.54% 2015:0.00%
Question 2: Was the Tutorial useful and informative for you?	2014: 22.73% 2015: 56.00%	2014: 77.27% 2015: 44.00%	2014: 0.00% 2015: 0.00%	2014:0.00% 2015:0.00%
Question 3: Assuming you attend Laser Damage-16, would you attend Tutorial?	2014: 81.82% 2015: 96.00%	N/A N/A	2014: 0.00% 2015: 0.00%	2014:18.18% 2015: 4.00%

5. 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 improvement of deposition technologies, film structure, film design, oxide materials for the films, film response to environmental attack and aging, and numerous reports on important film properties such as absorption and stability. Attention is traditionally paid to coatings at 1064 nm, 532 nm, 355 nm, and deep-UV (e. g., 193 nm), but coatings for IR have received increased attention this year. Thin-film damage by ultrashort pulses continues to be a hot field emphasized this year by the invited talk of this section and by the Mini-Symposium (see below). The strong increase of interest to this area is attributed to the fast progress in all types of ultrafast/femtosecond lasers.

Dense thin film processes offer the benefit of environmental stability, and a significant research is proceeding in this direction in the field of thin films. 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 and interfaces 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.

6. Thin-film laser damage competition

This year the eighth 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, broadband low-dispersion mirrors were tested. The requirements included

central wavelength (around 720-820 nm), minimum reflection of 99.5%, and GDD smaller than 100 fs². No requirements were put on deposition method, coating material and design. Sample filters from several companies and institutes from the USA, Europe, and China were tested with 150-ps pulses at 773 nm at the laser-damage test facility of Femto-Solid Dynamics Laboratory of Dr. Enam Chowdhury of the Ohio State University (USA). A multitude of deposition processes, coating materials, and manufacturing techniques submitted to this competition provided highly interesting results that will likely lead to some significant future research.

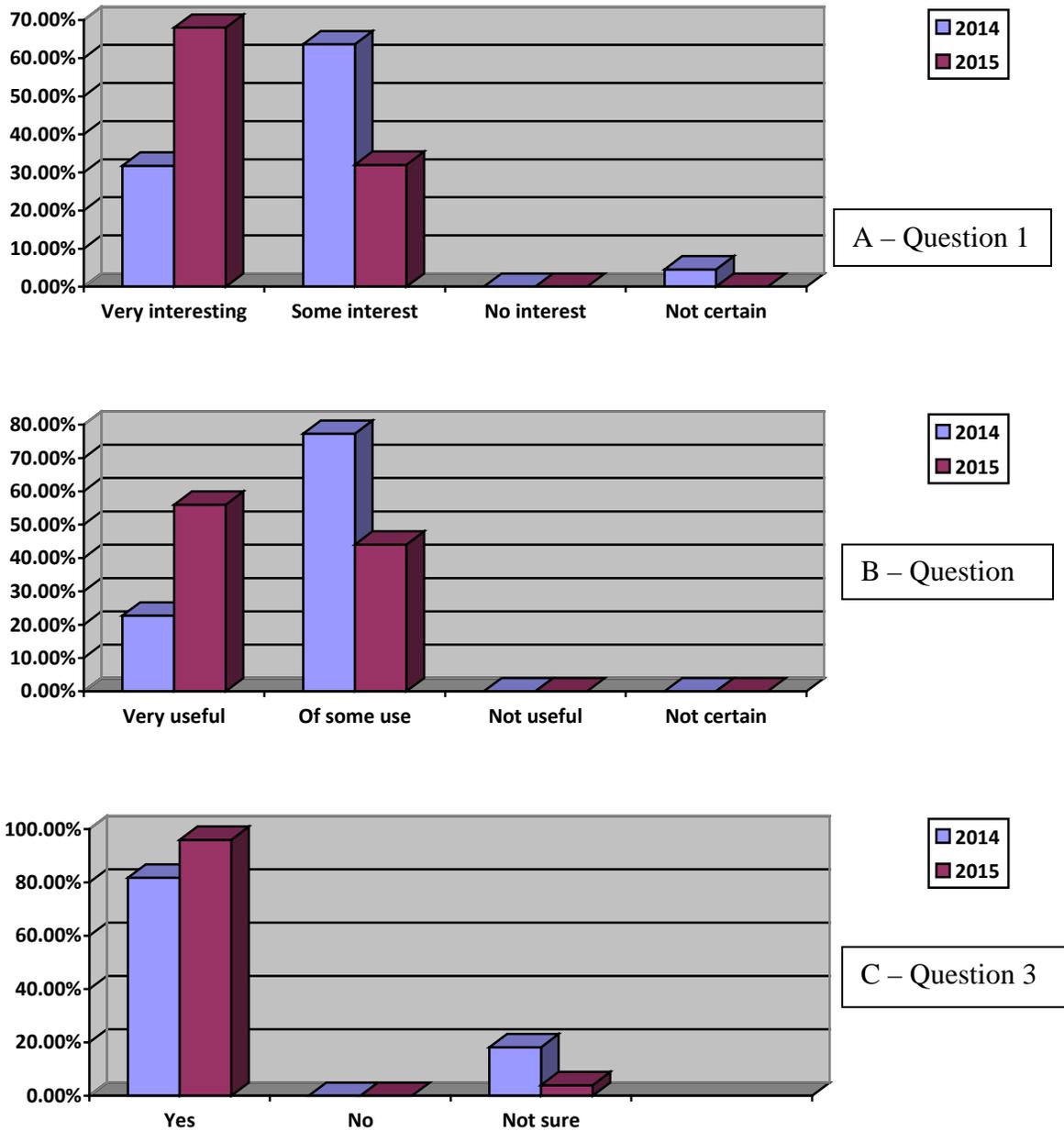


Fig. 1. Graphical representation of responses of tutorial participants to the questions listed in Table 1.

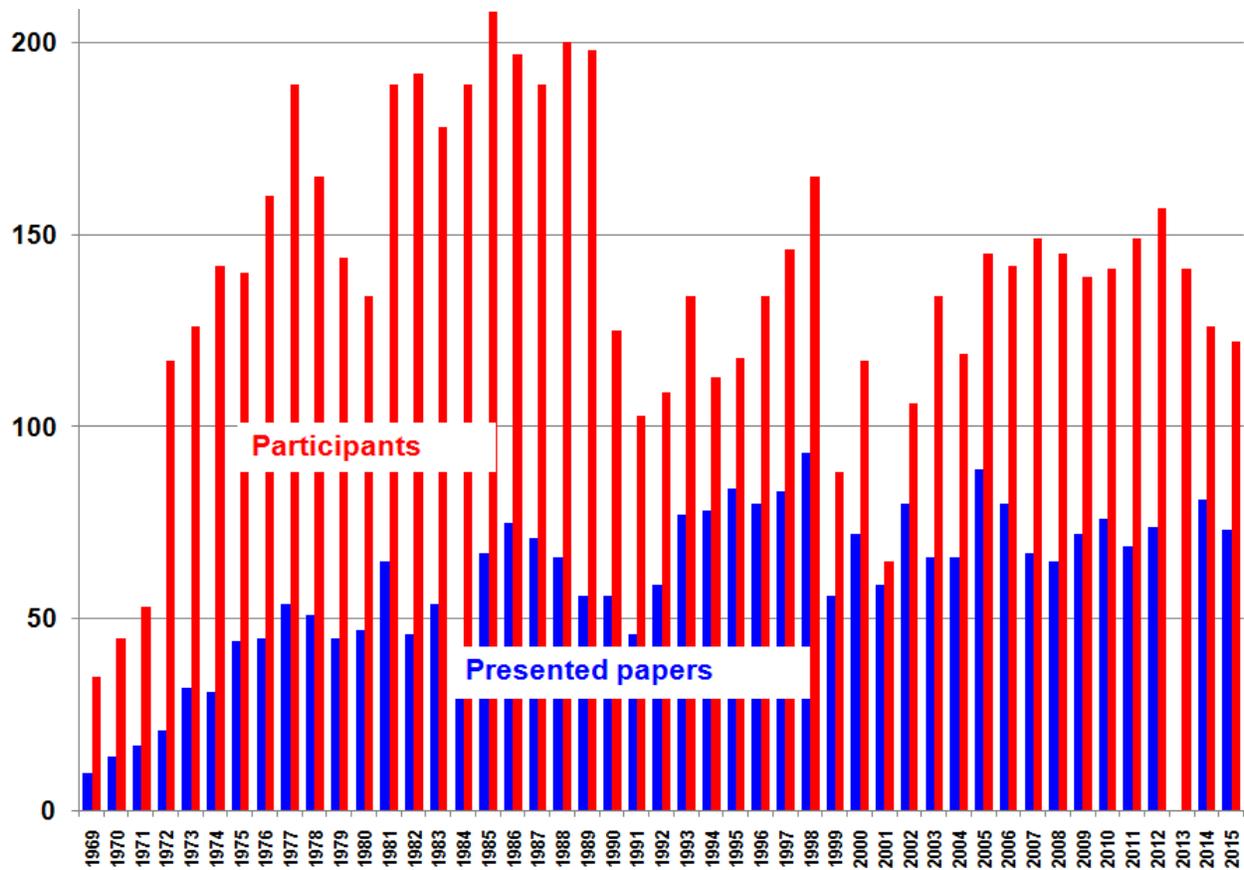


Fig. 2. Registered participants (red lines) vs number of presented papers (blue lines) since 1969 till 2015 inclusive.

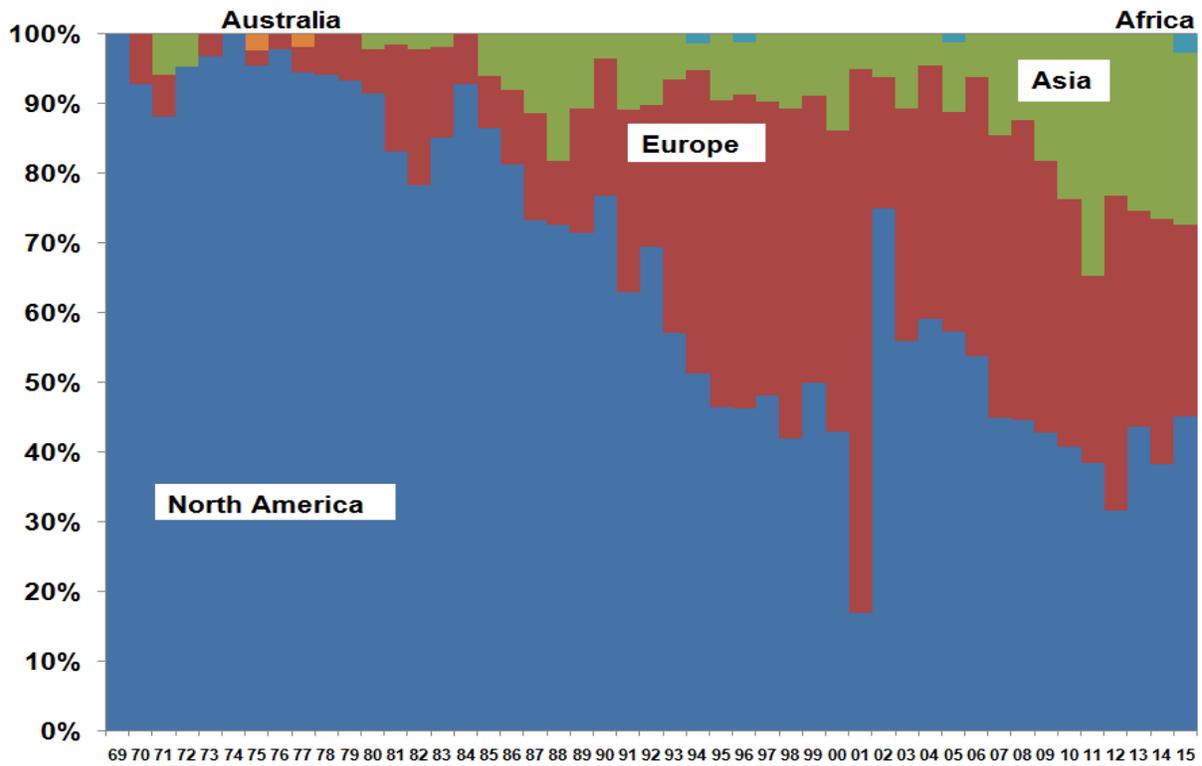


Fig. 3. Distribution of contributed papers by continents from 1969 till 2015 inclusive.

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
2015	Broadband low-dispersion mirror, wavelength 773 nm, picosecond pulses

7. Fundamental Mechanisms

This area deals with the fundamental effects and mechanisms 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 were mainly focused on two topics: a) ultrafast laser-material interactions including laser-induced ionization, propagation effects, and material response; and b) laser action on fused silica including the fundamental influence of defects on laser-induced damage threshold and linear vs non-linear absorption.

8. Surfaces and Mirrors

Presentations of this category are devoted to surface preparation, 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 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 lasers.

This year, significant number of presentations is devoted to laser-induced contamination on optics operating 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 substrate preparation prior to thin-film deposition, laser-damage mitigation, and surface micro- and nano-structuring to enhance surface resistance to laser radiation. Decontamination and refining of optical surfaces and the impact of contamination on laser resistance still stay the topics of active research and discussion.

9. 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. This year, presentations covered a very broad range of optical materials including fused silica, KDP crystals, calcium fluoride, and Nd-doped ceramics focusing on characterization of their properties.

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. Impressive 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. Continuous efforts are made to verify and improve ISO standards on laser damage threshold and determine the most effective stochastic approaches to evaluation of laser-damage threshold.

10. Mini-Symposium

This year the meeting hosted the mini-symposium on Laser-Induced Damage to Multilayers in Femtosecond Regime chaired by Dr. Vladimir Pervak of UltraFast Innovations GmbH, and the Ludwig-Maximilians University in Munchen, Germany. With 1 plenary presentation and 3 more regular talks spread over one oral session, the mini-symposium was intended to cover one of the most dynamic and demanded areas – the area of multilayer optical coatings for femtosecond laser pulses. The plenary talk gave an excellent excursion and brilliant introduction into the challenges and recent progress in the field of optical coatings for ultrafast lasers.

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	Defects in Glass
	Hideo Hosono	
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	Fused Silica
	Herve Bercegol	
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
2015	Vladimir Pervak	Laser-Induced Damage to Multilayers in Femtosecond Regime

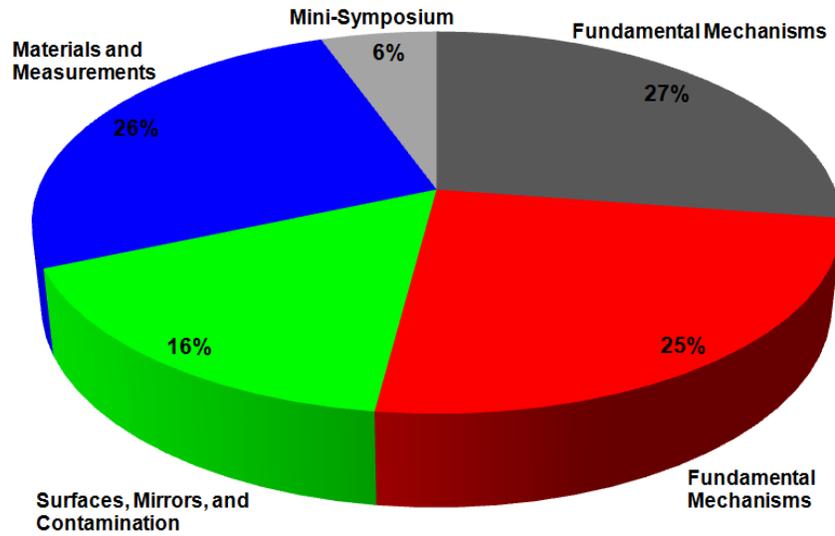


Fig. 4. Distribution of presentations of Laser Damage-2015 by topics.

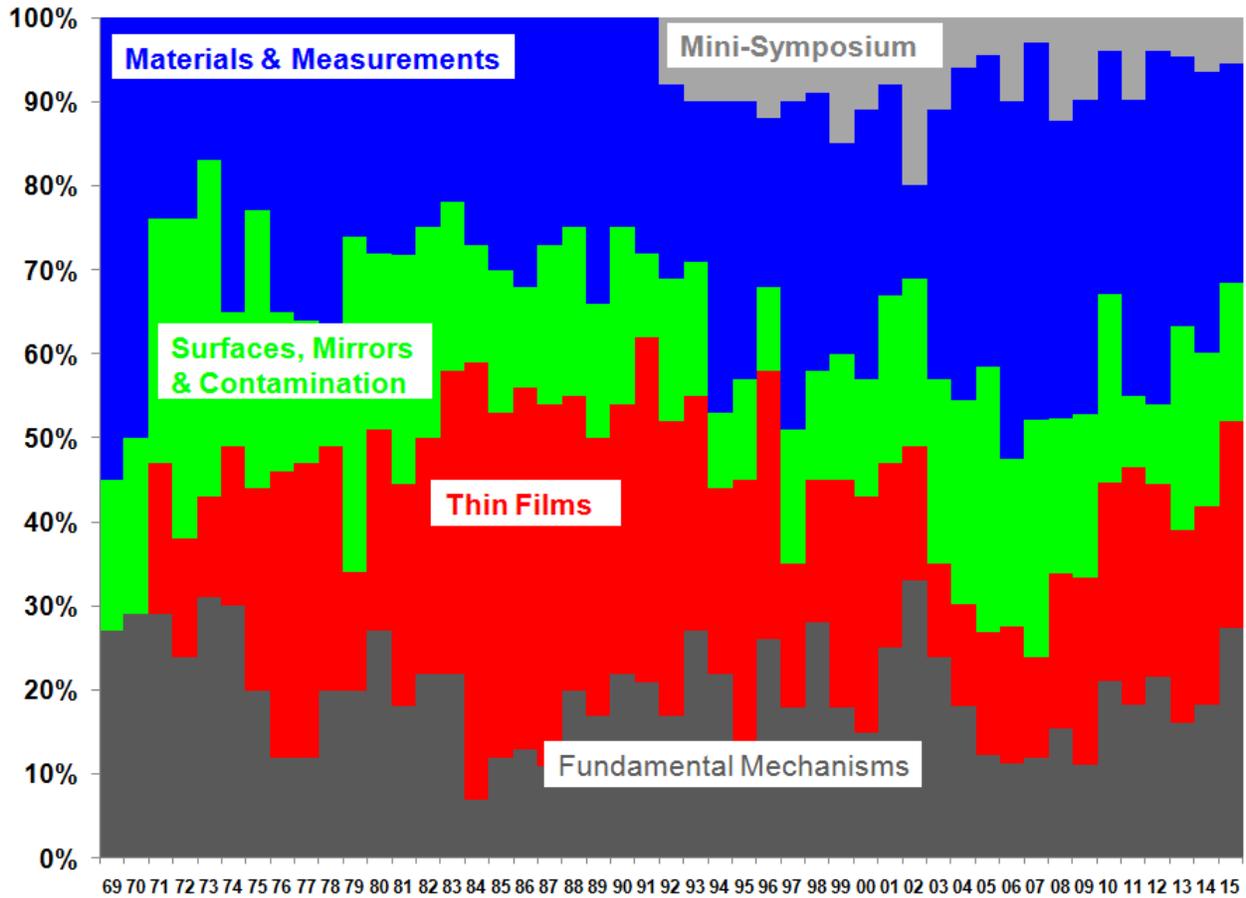


Fig. 5. Distribution of presentations over four major topics and mini-symposium since 1969 through 2015 inclusive.

11. Keynote Presentations

As usually, the 47th Laser Damage Symposium is highlighted by four keynote presentations in the major areas:

1. “Dispersive dielectric mirror for ultrashort-pulse laser at high intensity”, Vladimir Pervak of UltraFast Innovations GmbH, and the Ludwig-Maximilians University in Munchen (Germany) – area of Thin Films.
2. “Volume holographic elements for high-power laser applications”, Leonid B. Glebov, CREOL, The College of Optics and Photonics, University of Central Florida (USA) – the area of Surfaces, Mirrors, and Contamination.
3. “What time-resolved measurements tell us about femtosecond laser damage?”, Andrius Melninkaitis, Vilnius University, and LIDARIS Ltd. (Lithuania); N. Siaulyis, B. Momgaudis, J. Vaicenavicius, S. Barkauskaite, V. Sirutkaitis, Vilnius University (Lithuania); L. Gallais, Ecole Centrale Marseille (France); S. Guizard, CEA (France) – the area of Fundamental Mechanisms.
4. “Characterization of extremely high-purity optical materials for solid state laser cooling”, Mansoor Sheik-Bahae, Nathan Giannini, the University of New Mexico (USA) – the area of Materials and Measurements.

12. 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 2015:

Best oral paper:

What time-resolved measurements tell us about femtosecond laser damage? Andrius Melninkaitis, Vilnius Univ. (Lithuania), LIDARIS Ltd. (Lithuania); Nerijus Šiaulyis, Balys Momgaudis, Julius Vaicenavicius, Simona Barkauskaite, Valdas Sirutkaitis, Vilnius Univ. (Lithuania); Laurent Gallais, Ecole Centrale Marseille (France); Stéphane Guizard, Commissariat à l’Énergie Atomique (France), Ctr. National de la Recherche Scientifique (France), Ecole Polytechnique (France) [9632-23]

Best poster paper:

Bulk damage and absorption in fused silica due to high-power laser applications, Frank Nuernberg, Heraeus Quarzglas GmbH & Co. KG [9632-65]

13. 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 contained 16 papers selected out of 21 submissions and covers a broad spectrum of topics related to laser-induced damage.

Strong interest of the Laser-Damage community to and success of the two previous Special Sections on Laser Damage motivated Vitaly Gruzdev and Michelle Shinn to volunteer in editing another Special Section on Laser Damage-III. With the deadline for manuscript submissions on May 1, 2016, this Special Section is planned to be published in January 2017. All interested readers are welcome to visit the web page of *Optical Engineering* and check the Call for Paper Submission to this Special Section..

14. 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. However, repeating problems with access of registered conference participants to the NIST facilities have forced Co-Chairs to change location of Laser Damage 2016 from NIST to Boulder Millennium Harvest House Hotel in Boulder, Colorado.

This year the rainy weather in Boulder encouraged to take a group picture of all symposium participants inside the National Institute of Atmospheric Research (Boulder, CO) where the traditional Wine and Cheese Reception was held on Tuesday, September 29.

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.”

15. 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 (USA), Arrow Thin Films (USA); Alpine Research Optics (USA); IDEX Optics & Photonics (USA); Spica Technologies Inc. (USA); Laser Components GmbH (Germany), Quantel Laser (USA), KMLabs (USA), LIDARIS (Lithuania), and REO (USA) for supporting social events and refreshments of this meeting. They are separately acknowledged in this volume of conference proceedings. Special acknowledgement is for Femto-Solid Dynamics Laboratory of Dr. Enam Chowdhury of the Ohio State University (USA) for their support of laser-damage competition.

Of course, we are all indebted to Kent Rochford, Division Chief of the Optoelectronics Division of NIST in Boulder, 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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