49th ANNUAL LASER DAMAGE SYMPOSIUM
*Proceedings*

SPIE. LASER DAMAGE

# LASER-INDUCED DAMAGE IN OPTICAL MATERIALS 2017

**24–27 September 2017**
**Boulder, Colorado**

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

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# Symposium Welcome

on the occasion of the Annual Laser Damage Symposium - Forty Ninth Annual Symposium on Optical Materials for High Power Lasers

Gregory J. Exarhos
Pacific Northwest National Laboratory, USA

On behalf of the symposium co-chairs, Vitaly Gruzdev, Detlev Ristau, Joseph Menapace, and M. J. Soileau, I extend a hearty welcome to all participants of the Annual Laser Damage Symposium – the Forty Ninth Annual Symposium on Optical Materials for High-Power Lasers. Following a long-term tradition, this meeting continues to be held in Boulder, Colorado. However, this year in accord with last year, meeting participants enjoyed a new venue – the Millennium Harvest House Hotel. This Symposium was founded by Arthur Guenther and Alexander Glass in 1969 to bring together early-career and prominent scientists and engineers within the evolving laser community to both understand and subsequently mediate a specific problem: why and how high energy laser radiation damages otherwise robust substrates and thin films deposited thereon. This "issue", now recognized to be non-trivial, rapidly drove researchers to recognize the need for a multidisciplinary approach that would engage scientists from key technical areas including laser science and optics, solid-state physics, materials science, chemistry, among others. As the damage issue began to be investigated, subtler aspects of the problem were uncovered that were brought to the attention of both fundamental and applied laser researchers and engineers. Within a few years following the first meeting, this conference addressed all aspects of laser-induced damage and became a major international venue for lively discussions and communications among researchers and engineers from academics, industry, national laboratory staff, and the military. The vitality of this problem and of the Conference is evidenced by new participants joining a core of laser damage specialists each year as well as a stable number of papers published annually in the BDS Proceedings. Research in this area is motivated by a quest to fundamentally understand the damage process as laser beam parameters tend toward shorter pulses, shorter wavelengths, and higher powers. R&D also is driven by: the design and development of novel lasers; novel optical materials; and, operation of traditional lasers in challenging ambient environments. Ultrafast laser systems have also enabled the development of novel characterization approaches to understand the transient response of optical materials exposed to high-power incident laser radiation. Rapid progress in materials science has resulted in the discovery and development of new optical materials with potential for use in high-power laser systems. The field of laser damage continues to attract the attention of researchers and funding agencies based upon innovative developments in optics, materials properties modification, and beam-solid interactions.

In view of continuing progress in understanding the laser damage process, it is historically important to review previously published work in this area. The Boulder Damage Symposium (BDS) Proceedings have become the most complete and heavily subscribed resource focused on laser damage and optical physics that has ever been compiled from the development of the first laser to current active research in this area. The 49-year collection of the Proceedings (from 1969 to 2017 inclusive) published by SPIE in a single DVD has recently been supplemented by another DVD with Proceedings papers published from 2009 through 2014 inclusive. Author efforts to prepare original Proceedings manuscripts that contribute to our understanding of the laser damage process in materials and the development of new materials and optical films continues to impact the unique status of the Proceedings. The organizers are grateful to these authors for their contributions to this publication. In addition to the BDS Proceedings, Special Sections on Laser Damage have been published in *Optical Engineering* – the major journal of SPIE – in December 2012, December 2014, and January 2017.

The International Program Committee (IPC) is comprised of eminent researchers within the laser damage community that hail from key international research centres. This committee has been instrumental in developing the content of the symposium program through identification of leading laser damage research topics and associated researchers to speak on them. Presently, the IPC consists of representatives from the United States of America, Germany, France, Japan, China and the UK. Besides providing guidance to developing the conference program, the IPC also promotes the conference and solicits international participation. The engagement of the Committee that elicited participation from more than 30 countries during the last decade is acknowledged as being critical to the multidisciplinary and multinational activities discussed at this symposium. Tremendous efforts of the IPC Chair – Dr. Detlev Ristau of Laser Zentrum Hannover (Germany) – to keep IPC actively engaged are acknowledged.

Earlier this year, the laser-damage community suffered an irrecoverable loss with the passing of Professor Mireille Commandré who was a full professor with Ecole Centrale Marseille (France) and a leader of the ILM (Laser Matter Interactions) research team at the Fresnel Institute (Marseille, France). She served as a member of the BDS International Program Committee of the Laser-Damage Symposium for many years. The laser-damage community highly recognizes and appreciates the outstanding contributions of Mireille to the success of this conference and to the overall progress of research in the fields related to laser damage and optical materials for high-power lasers.

Following the 48-year tradition of this Conference, the symposium continues to address four core topical areas: Materials and Measurements; Fundamental Mechanisms; Thin Films; and, Surfaces, Mirrors and Contamination. One keynote presentation is delivered for each topic to overview a specific research area within that topic and to educate early career scientists and technologists among the conference participants. In order to track current trends in research and further promote scientific dialogue at the meeting, a mini-symposium dedicated to a cogent current topic in laser material interaction has been organised every year since 1992. This year, a mini-symposium "Frontiers of Ultrafast Science: Sources, Basic Effects, and Mechanisms of Ultrafast Laser-Matter Interactions" is chaired by Dr. Vitaly Gruzdev, University of Missouri, USA. The outstanding efforts of Vitaly in preparation of this year's Mini-Symposium and his dedication to this field of research are especially acknowledged here.

Continuing the success of the damage competition held for the first time in 2008, Chris Stolz and Raluca Negres (both of LLNL, USA) have successfully organized another competition that pursues the topic of the previous year. The competition is focused on multilayer coatings for broadband low-dispersion mirrors used in high-power femtosecond lasers. This year's competition considers multilayer laser mirrors for nanosecond pulse operation at 355 nm. Companies and research institutes from China, Japan, Germany, and the United States of America have submitted multiple samples for analysis. As in previous years, Spica Technologies, Inc. (USA) donated an enormous amount of time by evaluating the laser-induced damage threshold of all submitted samples. Efforts of the Spica team and specifically Michael Thomas and Mark Caputo are greatly acknowledged here. This remarkable effort is appreciated by the laser-damage, optical-coating, and high-power-laser communities, and this special contribution by Raluca Negres and Christopher Stolz is acknowledged here. Raluca presented the competition results and has prepared a summary paper that can be found in the present volume of the conference proceedings.

Another tradition of the symposium is to acknowledge two presentations that described significant results at the previous year's meeting. This year, authors received best presentation oral (Alex Glass Award) and poster recognition (Art Guenther Award) awards consisting of honoraria in the amount of $500, and cut-glass pieces of art having the symposium logo, date, and author names embedded into the glass by controlled laser-induced damage produced by a focused Q-switched laser beam. Award criteria include outstanding scientific content, a compelling presentation style, and publication of the manuscript in the conference proceedings. Next year, a special student award will be presented (MJ Soileau Award) based upon these criteria as well.

One of the early traditions of the Symposium involves a pre-conference Sunday event. This year it was a tutorial on femtosecond laser-induced damage. The tutorial was presented by Enam Chowdhury (the Ohio State University, USA). Enam's contribution to the Symposium is gratefully acknowledged.

Much of the success of this meeting can be attributed to the untiring efforts of the SPIE conference staff and Bobbie Williams of Lawrence Livermore National Lab (Symposium Assistant). We gratefully appreciate our annual co-sponsor, Lawrence Livermore National Laboratory. The contribution of Spica Technologies for performing the laser damage tests for the annual laser-damage thin-film competition is greatly appreciated. We acknowledge the cooperating organizations: Pacific Northwest National Laboratory; School of Optics – CREOL and FPCE, College of Optics and Photonics, University of Central Florida; Laser Zentrum Hannover; University of Missouri, Columbia; Alpine Research Optics; Arrow Thin Films; Quantel Laser USA; LIDARIS LIDT Service; Laser Components. We especially acknowledge support of our sponsors this year: Lawrence Livermore National Laboratory; Spica Technologies Inc.; Materion; ZC Optoelectronic Technologies LTD; Arrow Thin Films; ARO – Alpine Research Optics; Laser Components; LIDARIS LIDT Service; and Quantel Laser.

Participants of the 49th Laser Damage Symposium at the entrance to the National Institute of Atmospheric Research (NCAR) in Boulder, CO on Tuesday, September 26, 2017.

# Tribute to Prof. Mireille Commandre

Vitaly Gruzdev
University of Missouri, USA

Last year the worldwide laser-damage community suffered an irrecoverable loss: Prof. Mireille Commandre passed away on July 11, 2017 at the age of 60. Mireille was a full professor with Ecole Centrale Marseille (France) and a leader of research team ILM (Laser Matter Interactions) at Fresnel Institute (Marseille, France). She is appreciated as a brilliant educator by her graduate and Ph. D. students. Her research group constantly delivered high-level professionals to the laser-damage and optical-materials communities of France and the European Union. Her students have become outstanding researchers and engineers in academia, national laboratories, and industry.

According to Dr. Alexandre Gatto, one of Mireille's students and now a Director of Microstructured Optics, Carl Zeiss Jena GmbH (Germany): "Mireille had been my professor in Marseille as well as my director during my diploma thesis and finally my thesis co-director from 1995 until 1999. Above her outstanding scientific and technical skills in the field of optical coating and materials, above her remarkable cleverness, Mireille's exceptional emotional intelligence remains for me a wonderful quality which made each of our exchanges very truthful and fruitful. Mireille was truly engaged in her research, in her teaching tasks as well as in her mentoring activities. She had put into orbit several students such as me along her successful career and took care of them as much as possible. Her collaborations and networking with the French and international industry was remarkable and recognized in the scientific and industrial community. We had regular contact in the past 20 years, each time with the same pleasure and friendliness."

Mireille worked in the field of laser-induced damage of optical materials and in the area of optical coatings since the beginning of her research career in 1980s. She has contributed to multiple publications in those fields (6 of them were published in SPIE's *Optical Engineering*) as well as numerous invited talks at international conferences on optical coatings, optics characterization for high-power lasers, and laser-matter interactions. Since 2010 she served as a member of International Program Committee of Laser-Damage Symposium. Since 2003, she also served as a member of the Program Committee of another worldwide recognized international conference – Advances in Optical Thin Films. She has also served as session chair and member of program committees of other conferences.

As an active SPIE member, she significantly contributed to promotion of women in optical science and industry. Her profile can be found in 2009 SPIE's Women in Optics Planner:
https://spie.org/membership/women-in-optics/women-in-optics-planner/2009-wio-planner/commandr%C3%A9-mireille?SSO=1


Mireille Commandre at the seaside (left) and in the laboratory by a large-scale optic piece (right).

Her contribution to the Society was recognized by SPIE in 2016 by promoting her to Senior SPIE member: https://spie.org/about-spie/press-room/spie-member-news/memoriam-mireille-commandre

The Co-chairs of the Laser Damage Symposium, members of the International Program Committee of the Laser Damage Symposium, and the entire laser-damage community highly recognize and appreciate the outstanding contributions of Mirielle to the success of this conference and to the overall progress of research in the fields related to laser damage and optical materials for high-power lasers.

We all miss Mireille.

# Summary of Meeting

SPIE Laser Damage Symposium
49th Annual Symposium on Optical Materials for High Power Laser
24-27 September 2017

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## 1. Abstract

These proceedings contain the papers presented as oral and poster presentations at the 49th SPIE Laser Damage Symposium (aka Annual Symposium on Optical Materials for High-Power Lasers). The conference was held at Millennium Harvest House Hotel in Boulder, Colorado on 24-27 September 2017. The symposium was divided into oral and poster sessions following the traditional four major topics: thin films; surfaces, mirrors and contamination; fundamental mechanisms; materials and measurements. A mini-symposium was focused on overview of ultrafast science including ultrafast laser sources, basic effects of ultrafast laser-solid interactions, and ultrafast nonlinear propagation. A tutorial on femtosecond laser damage was held as a pre-symposium event on Sunday evening. The conference was opened by Dr. Gregory Exarhos with a symposium welcome. A brief Tribute was devoted to Dr. Mireille Commandre, member of the International Program Committee who passed away in July 2017. 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.

91 abstracts were submitted to the symposium, of which 87 were included into the conference program and 82 were presented at 12 oral and 4 poster sessions. No parallel sessions were held allowing the opportunity to discuss common research interests with all the presenters. With 149 attendees 66 of which were authors, 11 – students, and 11 more - meeting co-chairs and program-committee members, 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 60% of the presentations and 37% of all attendees coming from Europe and Asia this year. Following the successful experience of 2016, the Symposium was held at Boulder Millennium Harvest House Hotel in Boulder, Colorado for another year. The Hotel offered a setting conductive to effective communications and interchanges between Symposium participants.

In May 2016, a cross promotion relation was established with High Power Laser Ablation international conference (HPLA) held bi-annually in Santa Fe, New Mexico, USA. This year we continued the cross promotion. We consider it as a step towards establishing a supporting collaboration between the two conferences and the two communities with the scopes significantly overlapping over many topics focused on various aspects of laser-material interactions.

The Anniversary 50th Annual Symposium of this series will be held in Boulder, Colorado, 23-26 September 2018. In parallel to the traditional continuous effort to ensure a close liaison between the high-energy, high-peak-power, and high-average-power laser communities, the 50th anniversary will be celebrated with several special events. A mini-symposium will be focused on overview of the history of the Symposium as well as reviews of progress, major developments in all the main research areas associated with laser damage. Several special guests are expected including Dr. Alex Glass – a Co-Founder of the Symposium.

The principal topics to be considered in 2018 do not differ drastically from those enumerated above. We expect to hear more about the impacts of surface contamination, debris, and surface treatment on the laser resistance of optical components. Influence of defects of optical materials continues to generate significant interest over decades. High-

energy laser windows, nonlinear and laser crystals, and optical coatings 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. Laser damage by short-wavelength radiation stays an area of interest stimulated by the demand for laser-resistant UV optics utilized for laser-lithography applications. Short pulse (nanosecond and picosecond) laser optics and damage phenomena surprisingly remain an active area of research over several decades. Recent progress in the fields of ultrashort-pulse (femtosecond) lasers and ultrafast laser-material interactions is a growing area and an expanding part of the symposium. We also expect to hear more about new measurement techniques to improve our understanding of the damage mechanisms and 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 continue to stay another hot topic of the meeting. 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 laser-induced ionization, scaling of damage threshold with laser and material parameters, and nonlinear effects continuously attract a lot of attention due to exploration of novel ranges of laser parameters.

As was initially established in 1992, several distinguished invited speakers will deliver keynote presentations of a tutorial or review nature in 2018. In addition, invited contributors will cover recent breaking developments in the key areas. A tutorial on laser beam characterization is expected to attract significant attention as a pre-symposium event of the meeting in 2018.

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, fundamental mechanisms of laser-solid interactions, 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 - 49th Annual Symposium on Optical Materials for High-Power Lasers (a.k.a. the Boulder Damage Symposium, because of its Boulder, Colorado, venue) was held on 24-27 September 2017. This symposium continues to be the principal US and International forum for the exchange of information relative to laser-induced damage in all types of optical materials, and the interactions of intense laser light with optical media and components. This year, it was attended by 149 representatives of academia, industry, national research laboratories and centers from 10 countries that was about 16.4% increase in attendance compared to Laser Damage-2016 (Fig. 2). 91 abstracts were submitted to the Symposium, 87 of them were included into the final program, and 82 were delivered within the traditional 3-day format of the meeting including 53 oral and 34 poster presentations. This year 5 presentations were cancelled or not presented. Although, held annually in the US, this is a truly International conference with 37% of the attendees and 60% percent of the presentations coming from abroad this year (Fig. 3). 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 the fundamental effects of matter interactions with femtosecond laser pulses under the title “Femtosecond Laser Damage: Past, Present, and Future”. The tutorial was prepared and held by Dr. Enam Chowdhury (The Ohio State University, USA) on Sunday, 24 September. The tutorial attracted more than 75 participants of the conference. The conference began on Monday, 25 September 2016 with a welcome talk delivered by Gregory Exarhos (Pacific Northwest National Laboratory, USA). A brief Tribute was devoted to Dr. Mireille Commandre, member of the International Program Committee who suddenly passed away in July 2017.

## 3. Symposium Cochairs

The Boulder Damage Symposium was founded by Dr. A. H. Guenther and Dr. Alexander Glass. Over the last 49 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
2017 add C. W Carr; J. A. Menapace 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. It was prepared and held by Dr. Laurent Gallais (Institut Fresnel, France) and featured defect-induced laser damage under the topic "Defect-Induced Damage in Nano- and Femtosecond Regime". In 2016, the tutorial entitled "Advanced Materials for High Laser-Damage Resistance" was prepared and delivered by Dr. Marco Jupe (Laser Zentrum Hannover, Germany). The lecture part was focused on the interplay of three major topics of this Symposium: optical materials, thin films for optical coatings, and fundamental mechanisms of ultrafast laser-material interactions. In 2017, the tutorial was entitled "Femtosecond Laser Damage: Past, Present, and Future" and was delivered by Dr. Enam Chowdhury (The Ohio State University, USA). It was focused on overview of the fundamental research on mechanisms and major effects of the ultrafast laser-induced damage to transparent optical materials, optical coatings, and metal surfaces. The global topic of the tutorial resulted in extended duration of the presentation (about 1.5 hour) that was addressed by attendees in their responses. At the beginning, the tutorial attracted about 70 participants of the conference, but more people joined it soon after finishing the registration. Total attendance was estimated at the level of 85 people.

Each previous year, attendees of the tutorial were asked for feedback by answering 3 questions:
Question 1: How interesting was the Tutorial for you?
Question 2: Was the Tutorial useful and informative for you?
Question 3: Assuming you attend Laser Damage-16, would you attend Tutorial?

In 2014, 22 participants responded to that short questionnaire. In 2015, organizers received 50 responses. In 2017, organizers received 56 responses from the Tutorial attendees summarized in Fig. 1. In spite of some critics, participants expressed high level of satisfaction with the Tutorial in 2017. The success of the Tutorials motivated organizers to continue this novel tradition in 2018. Following the topics suggested by the participants of the survey, the tutorial to be delivered in 2018 will focus on characterization of laser beams.

## 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 stay one of the largest parts of the meeting and receives very significant attention. Besides damage thresholds or sensitivity of particular coatings to high-power laser radiation, the topics of 2017 include improvement

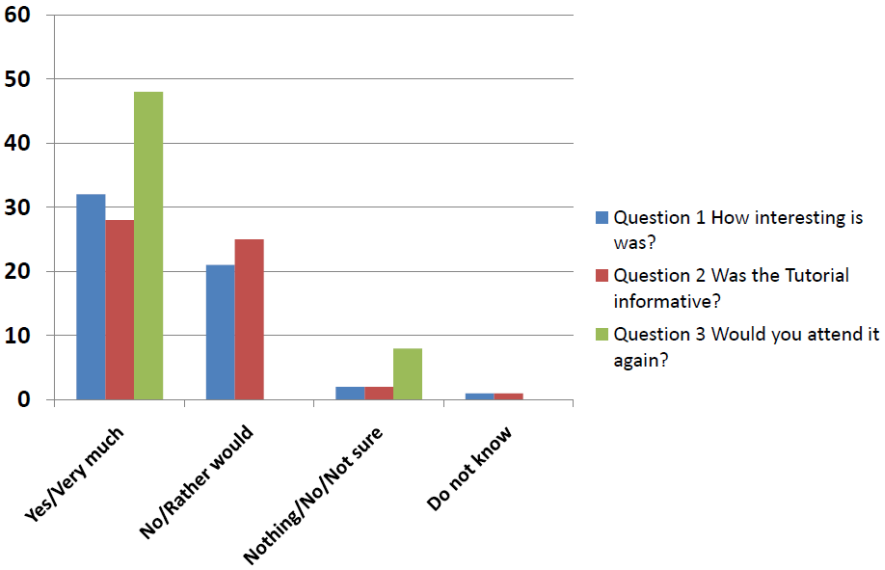


**Fig. 1**. Graphical representation of responses of tutorial participants to the questions listed in Table 1.

of film structure and film design, novel oxide and sol-gel materials for the films, film response to aging, damage threshold and morphology for various optical coatings, structural microscopic defects, 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 and UV (specifically at 355 nm) received increased attention this year. Several talks were devoted to new methods of characterization of nonlinear optical response of the coatings for ultrashort laser pulses (e. g., time resolved digital holography) and use of nanostructured surfaces as high reflectors. Thin-film damage by ultrashort pulses continues to be a rapidly growing field that attracts constantly high attention. This year we heard about laser damage of coatings by few-cycle mid-infrared pulses.

Dense thin films 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 by a variety of deposition techniques to deliver very high laser resistance. As before, thin-film laser damage competition is one of major events of the Thin Film section of the Symposium.

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. We continue to see interest in defect detection and characterization in films and coatings. This year, invited talk of Dr. Selim Elhadj (Lawrence Livermore National Lab, USA) emphasized laser-induced damage of high-performance thin-film transparent electrodes. With total of 16 oral and 10 poster presentations in conference program, the Thin Film section was the largest in the 2017 meeting and confirmed a strong interest of the optical-coating community to laser-damage issues.

## 6. Thin-film laser damage competition

This year the tenth thin-film damage competition was organized by Dr. Christopher Stolz and Dr. Raluca Negres 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, the competition was focused on UV high reflectors tested with 5-nanosecond pulses at wavelength 355 nm. The reflectors tested did have to meet a minimum reflection of 99.5% at 45 degrees incidence angle for P-polarized light at 355 nm. The participants did have total freedom to choose deposition method, coating design, and coating materials. The samples received from several companies in the USA, Europe, and China were damage tested using the rater scan method with 5-nanoscond pulse length laser system operating at 10 Hz in a single longitudinal mode. Experiments were performed at a single testing facility of Spica Technologies, Inc. (USA) to enable direct and reliable comparison among the participants. Details

of the testing procedure and major results of the tests were delivered by Raluca A. Negres in the talk entitled “355-nm Nanosecond laser mirror thin film damage competition”.

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
2016 Broadband low-dispersion femtosecond mirror, wavelength 773 nm, 45 degrees AOI, p-polarization
2017 HR laser mirrors at wavelength 355 nm, nanosecond pulses

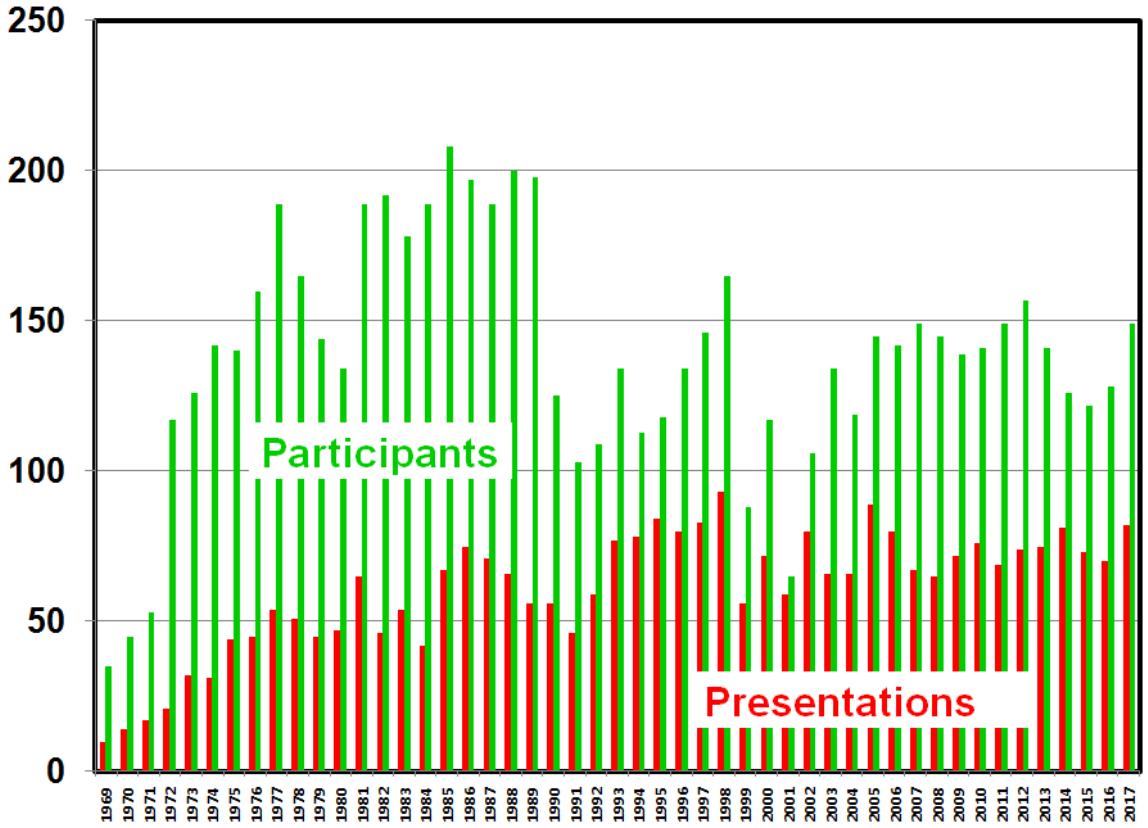


**Fig. 2.** Registered participants (green lines) vs number of presented papers (red lines) since 1969 till 2017 inclusive.

## 7. Fundamental Mechanisms

This section of the Symposium deals with the fundamental effects and mechanisms of the interactions of light with matter. The traditional topics include laser-induced ionization, nonlinear behavior and effects of material response, self-focusing and other propagation effects, 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 basic environmental effects). Also, of great interest are all types of scaling relationships between laser-induced damage thresholds and material/laser/environment parameters that not only afford insight into the fundamentals of the interaction process, but allow extrapolations for engineering and cost-benefit practical evaluations. In many areas, these insights are based on real-world, systems-level tests, as opposed to a frequently pristine laboratory environment. Fundamental mechanisms of laser damage associated with defects continue to be of high interest for researchers of the laser-damage community.

A significant amount of experiments, theoretical calculations, and simulations is now being done in the femtosecond regime as exemplified by the substantial number of submitted papers on ultrafast phenomena. They consider both bulk and surface effects including formation of damage craters. Materials under consideration include typical dielectrics, metals, and semiconductors. Novel simulation approaches, e. g., first-principle simulations by modified particle-in-cell method have been proposed and have demonstrated excellent agreement with experimental data. This year's presentations also featured wavelength dependence of surface-damage threshold for mid-infrared range of optical spectrum.

Continuous efforts are made to characterize the fundamental mechanisms of laser damage in fused silica as the most popular optical material. Simulations of internal stress waves induced by laser damage in dielectric are still of high interest. The invited talk by Dr. Marco Jupe (Laser Zentrum Hannover, Germany) featured the fundamental relation between laser damage and fundamental properties of materials utilized for manufacturing of interference coatings. With 8 oral and 7 poster presentations listed in the conference program, this area is rather stable over last decade.

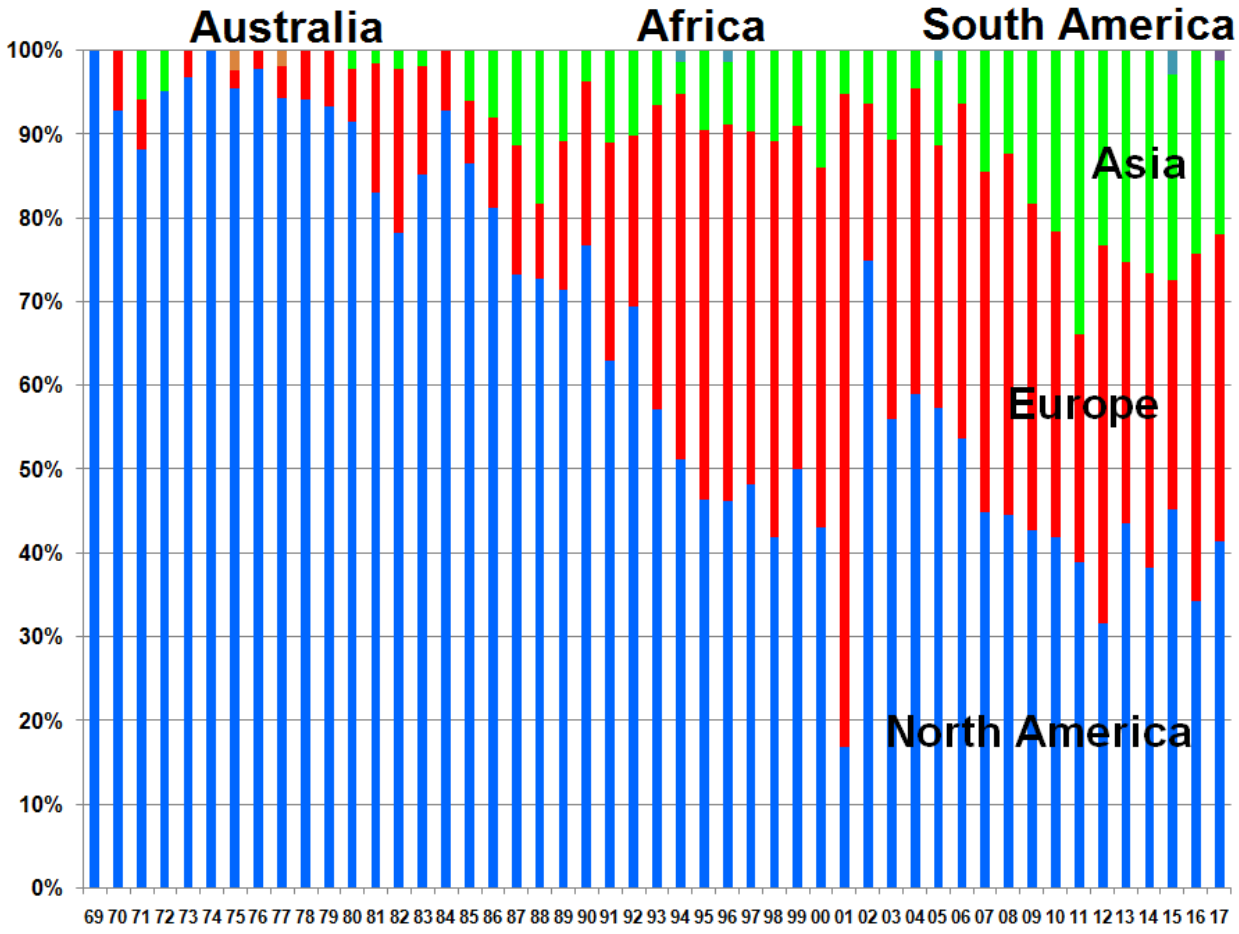


**Fig. 3.** Continent-distribution chart of the presentations delivered at the conference from 1969 till 2017 inclusive.

## 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 real-life environments. There is a significant amount of work needed in understanding what contamination is acceptable, what contamination is a threatening issue for 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 by particles deposited on a surface. A fair amount of papers deals with substrate preparation prior to thin-film deposition, and laser-damage mitigation, and surface micro- and nano-structuring to enhance surface reflection without depositing any kind of optical coatings. The problem of resistance to laser radiation becomes prevalent for application of those reflection-enhancing nanosctructuring techniques in high-power laser systems. Decontamination and refining of optical surfaces and the impact of contamination on laser resistance still stay the topics of active research and discussion. Significant attention was paid to damage initiation by scratches and to influence of polishing techniques. The invited talk by Dr. Christopher W. Carr (Lawrence Livermore National Laboratory, USA) featured the surface contamination by micro-particles and approaches to mitigate their influence on surface damage in high-energy lasers. With 8 oral and 4 poster presentations, this key are shows increased representation in 2017 compared to 2016.

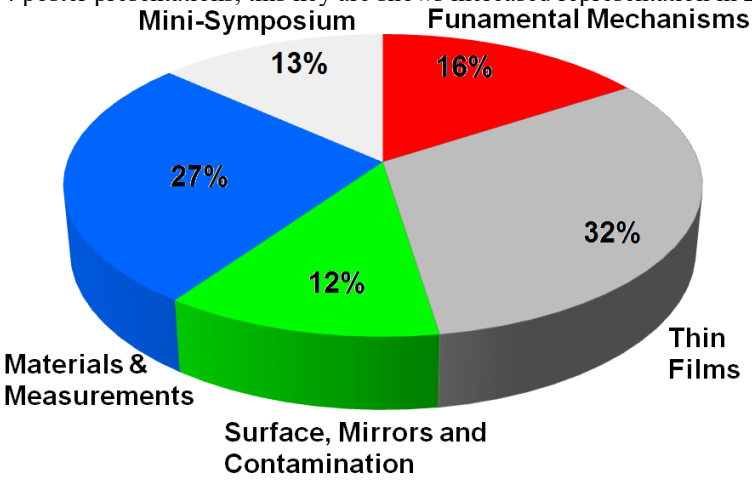


**Fig. 4.** Distribution of presentations of the 49th Laser Damage Symposium (2017 only) by key topics.

## 9. Materials and Measurements

Among the four main sections of the conference, this one continuously stays the largest over last decade (Figs. 4 and 5). This section deals with protocols and setups 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, 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, several presentations covered photo-thermal effects with applications to absorption measurements and laser conditioning.

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 novel methods (e. g., STERIO-LID) for detection of damage precursors and defects. Continuous efforts have been reported on measurement of absorption for UV optics and specifically – for fused silica optics. 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. The invited talk by Dr. Frank Wagner (Institut Fresnel, France) featured characterization of defects in bulk materials and their influence on multiple-pulse laser damage. With 16 oral and 10 poster presentations, this section of the conference was among the two largest sections in 2017.

## 10. Mini-Symposium

This year the meeting hosted the mini-symposium on Frontiers of Ultrafast Science: Sources, Basic Effects, and Mechanisms of Ultrafast Laser-Matter Interactions was chaired by Dr. Vitaly Gruzdev, University of Missouri, USA. With 8 invited talks and 3 regular oral presentations, the Mini-Symposium spread over three oral sessions and truly represented the breakthrough developments in this field of modern science. The topics included generation of attosecond pulses, sub-cycle dynamics of electron excitation in semiconductors and dielectrics, ultrafast nonlinear propagation effects in transparent materials, ultrafast energy deposition in dielectrics, and specific distortions of energy bands of dielectrics. Those talks provided an excellent overview of the current frontier research that paves a road towards future developments in lasers and laser applications. Repeating the story of femtosecond lasers that emerged as exotic laboratory tools in 1980s, the attosecond and sub-cycle effects can become routine fundamentals of laser developments in just few decades. The Mini-Symposium became one of the brightest events of this conference. The Mini-Symposium of Laser Damage 2018 will be devoted to the overview of the 50 years of Laser Damage Symposium. It will be chaired by Dr. Detlev Ristau.

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

| *Year* | *Chair* | *Topic* |
|---|---|---|
| 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<br>Hideo Hosono | Defects in Glass |
| 2001 | Mark Kozlowski | Optical Materials for Telecommunications |
| 2002 | Detlev Ristau | Optics characterization – joint with 7th 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<br>Herve Bercegol | Fused Silica |
| 2009 | Wolfgang Rudolph | Femtosecond Laser-Induced Damage |
| 2010 | Klaus Sokolowski-Tinten | Fundamentals of Laser Ablation |
| 2011 | Holger Blashke,<br>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 |
| 2016 | Stefan H. Borneis<br>Christopher J. Stolz | Review of Large-Scale, High-Power Laser Facility Projects |
| 2017 | Vitaly Gruzdev | Frontiers of Ultrafast Science: Sources, Basic Effects, and Mechanisms of Ultrafast Laser-Matter Interactions |

## 11. Keynote and Invited Presentations

As per usual, the 49th Laser Damage Symposium is highlighted by four keynote presentations in the major areas:

1. "Optical Damage of High Performance Thin Film Transparent Electrodes", **Selim Elhadj,** Lawrence Livermore National Lab (USA) – area of Thin Films.
2. "Particle damage sources and their mitigation on high energy laser systems", **Chrostopher W. Carr**, Lawrence Livermore National Lab. (USA) Lawrence Livermore National Laboratory (USA) – the area of Surfaces, Mirrors, and Contamination.
3. **Marco Jupe**, "Virtual and real materials for interference coatings", Laser Zentrum Hannover (Germany)– the area of Fundamental Mechanisms.
4. **Frank Wagner,** "Nanosecond multiple pulse measurements and the different types of defects", Institut Fresnel (France) – the area of Materials and Measurements.

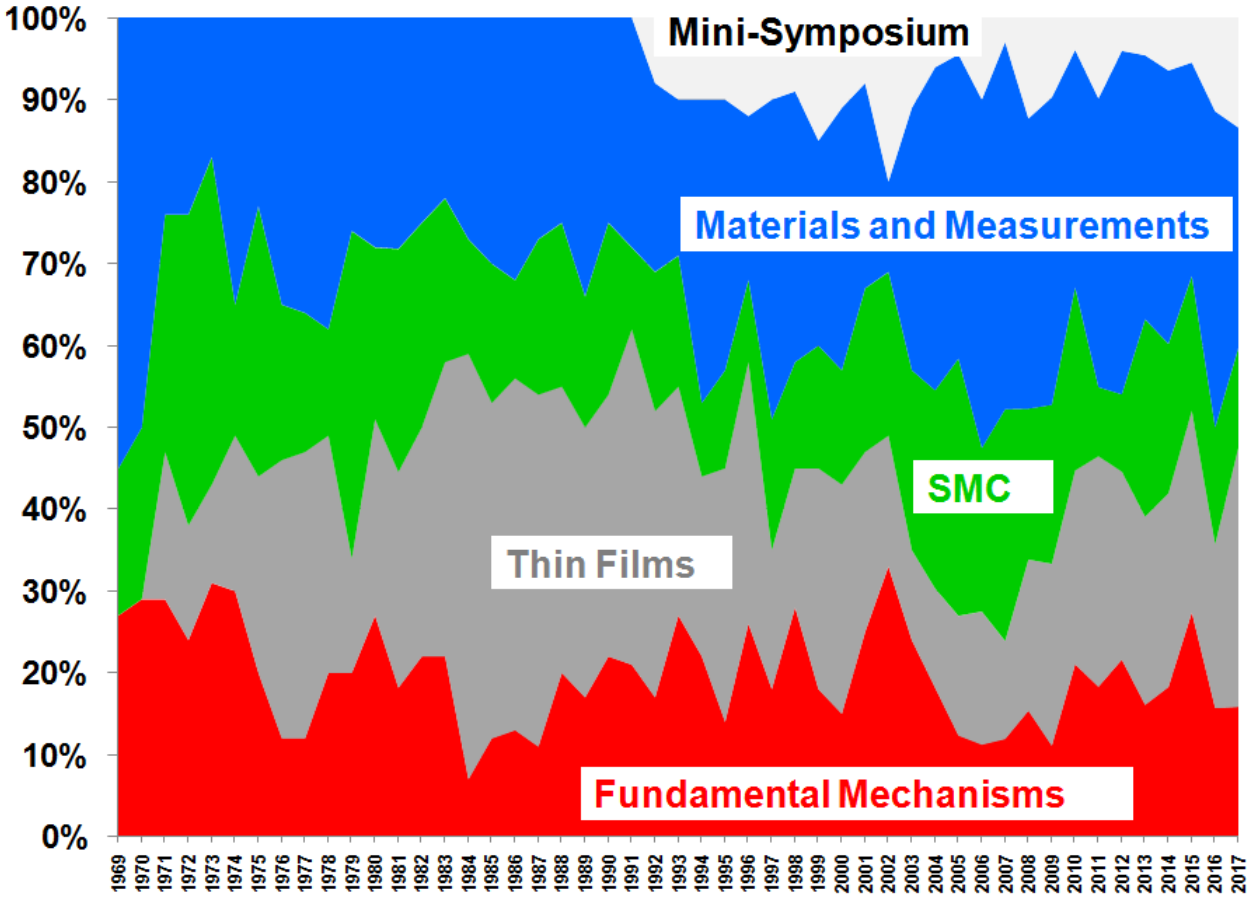


**Fig. 5**. Distribution of presentations over four major topics and mini-symposium since 1969 through 2017 inclusive.

Also, the Mini-Symposium hosted 8 invited talks this year:

**Louis DiMauro** (The Ohio State University, USA), "Atomic and molecular dynamics in mid-infrared fields"
**Zhenghu Chang** (The University of Central Florida, USA), "Attosecond X-rays generated with intense, few-cysle MIR lasers"
**Arnaud Couairon** (Ecole Polytechnique, France), "Self-consistent modeling of laser energy deposition in photoionized dielectrics"

**Mac Kira** (University of Michigan, USA)**, Stephan W. Koch (**University of Marburg, Germany), "Ultrafast strong-field effects in semiconductors"
**Martin Schultze** (Max Plank Institute of Quantum Optics, Germany), "Attosecond energy transfer dynamics in band-gap materials"
**Gunter Steinmeyer** (Max Born Institute, Berlin, Germany), "Interferometric frequency-resolved optical gating for probing optical nonlinearities as the verge of multiphoton-induced breakdown"
**Kazuhior Yabana** (University of Tsukuba, Japan), "First-principles calculations for ultrafast energy transfer from laser pulse to solids"
**Vladislav Yakovlev** (Max Plank Institute of Quantum Optics, Germany), "Electron dynamics just below the damage threshold and a dream of petahertz electronics"

## 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)). All the awarded papers can be found in this volume of Laser Damage Proceedings.

Starting from 2017, Co-Chairs of this Symposium establish three awards:
- Alexander Glass Best Oral Presentation Award;
- M. J. Soileau Best Student Paper Award;
- Arthur Guenther Best Poster Award.

There were several outstanding posters and oral papers nominated for those awards,, however, the following papers were selected by Co-Chairs for 2017:

*Alexander Glass Best Oral Presentation Award:*
**"Revealing the relative contribution of photo- and impact-ionization in ultrashort pulse laser-induced damage in solid dielectrics"**, Peter Jürgens, Anton Husakou, Mikhail Ivanov, Marc J. J. Vrakking, Alexandre Mermillod-Blondin, Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Germany); SPIE paper number [10447-21].

*M. J. Soileau Best Student Paper Award:*
"**Time-resolved investigations of laser-dielectric interaction mechanisms**", Allan Bildé, Stéphane Guizard, Ecole Polytechnique (France); Sergei M. Klimentov, A. M. Prokhorov General Physics Institute of the Russian Academy of Sciences (Russian Federation); Andrius Melninkaitis, Julius Vaicenavicius, Balys Momgaudis, Vilnius Univ. (Lithuania); Alexandros Mouskeftaras, Ecole Polytechnique Fédérale de Lausanne (Switzerland); SPIE paper number [10447-27].

*Arthur Guenther Best Poster Award:*
**"A method for the determination of the defect density distribution from standard damage frequency measurements"**, Jonathan W. Arenberg, Northrop Grumman Aerospace Systems (United States); Carmen S. Menoni, Colorado State Univ. (United States); SPIE paper number [10447-66].

## 13. Cross promotion with High Power Laser Ablation conference

In May 2016, a cross-promotion agreement was signed between Laser Damage Symposium (LD) and High Power Laser Ablation international conference (HPLA). HPLA is held each other year (2016 – most recent) in April or May in Santa Fe or Taos, NM. With average number of attendees about 150 and number of presentations varying from 80-100, HPLA is very close to LD (average number of attendees about 125, and number of presentations about 80). Very strong international representation (more than 50% of speakers and attendees from Europe, Asia, and Australia) is characteristic of HPLA. Invited speakers are the top experts of laser-ablation and high-power-laser communities. For example, Prof. G. Mourou – the father of the Chirped-Pulse Amplification method now employed in majority of commercial femtosecond lasers – delivered an invited talk at HPLA meeting in April 2016. Major topics of this conference include:
- FUNDAMENTAL PHYSICS: fundamental physics of laser-material interactions; Theory and simulation of laser-

matter interaction; basic mechanisms of laser ablation; ultrafast material modification by femtosecond pulses; ultrafast X-ray and complimentary electron scattering measurements in solids; imaging materials and plasma plumes at the limits of spatial and time resolution; ultrashort-pulse laser effects; fundamentals of laser ablation and nanoparticle formation in liquids;
- ABLATION APPLICATIONS: ultrafast materials processing by lasers; biological applications of lasers and laser ablation; laser direct writing in bulk of transparent materials; MAPLE and other laser methods of materials processing;
- HIGH-POWER LASERS: new results in high power lasers and their applications; promising new laser and optical technologies; new results in diode pumped alkali lasers (DPALS), exciplex pumped alkali laser (XPALS), and noble-gas lasers; advances in microstructured optical fibers and fiber lasers; advances in free electron laser technology;
- NOVEL MATERIALS AND MEASUREMENTS: research facilities and measurement techniques; metamaterials for short-pulse photonic and microwave pulse generation;
- LASER NANO-TECHNOLOGIES: nanoengineering & materials processing at nanoscale;
- BEAM PROPAGATION AND SPACE APPLICATIONS: microwave and laser power beaming; space debris removal and beyond; phased pulsed fiber laser array applications in space;
- LASER PROPULSION: advanced BEP propulsion concepts; laser ablation propulsion: macro & micro.

There are several significant motivations for establishing the cross promotion of the two conferences. First, there is a significant overlapping of the topics of two conferences especially in the fields of fundamental mechanisms of laser damage/ablation; laser-surface interactions; high-power lasers. However, the community of LD overlaps with the community of HPLA just a little bit. Therefore, the communities of the two conferences can benefit from information exchange between on conferences and publication plans. Moreover, the cross promotion can assist with increase of attendance of both LD and HPLA conferences. Overall, direct contacts with the HPLA organizers and the cross-promotion can help to establish a good bridge between the two research communities.

With the positive results already obtained form this cross promotion of the two conferences, the organizers of Laser Damage Symposium are quite optimistic regarding the high potential of mutual support of LD and HPLA conferences that can benefit the both meetings.

## 14. 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. Vitaly Gruzdev and Dr. Michelle Shinn 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:
http://opticalengineering.spiedigitallibrary.org/Issue.aspx?JournalID=92&issueID=24711&direction=P
and contained 18 papers selected by peer-reviewers for publication out of 21 submitted manuscripts (Table 1). 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 (Fig. 6). 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 was published in volume 53, no. 12 of *Optical Engineering* in December 2014:
http://opticalengineering.spiedigitallibrary.org/Issue.aspx?JournalID=92&issueID=930112&direction=P
It contained 16 papers selected out of 21 submissions and covers a broad spectrum of topics related to laser-induced damage. Due to increasing requirements to scientific quality and content of submitted manuscripts, 5 manuscripts were rejected during preparation of that Special Section (Table 1).

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. This Special Section was published in January 2017 in volume 56, no. 1:
http://opticalengineering.spiedigitallibrary.org/issue.aspx?journalid=92&issueid=935413
It contains record-high number of submissions (33 total) of which 28 were published. This success of the Special Section on Laser Damage III is partly due to the cross promotion with HPLA conference as discussed above.

In 2018, another Special Section on Laser Damage IV will be prepared and published by *Optical Engineering*. Guest Editors of that Special Sction are Vitaly Gruzdev and Jonathan Arenberg. Detailed Call for Papers and submission information can be found on the web site of Optical Engineering:
https://www.spiedigitallibrary.org/journals/optical-engineering/call-for-papers?SSO=1#divLaserDamageIV

**Table 1.** Submission overview of the three Special Sections of *Optical Engineering* on Laser Damage.

| Special Section issue | Total submissions | Published | Rejected |
|---|---|---|---|
| Laser Damage (v. 51, no. 12, 2012) | 21 | 18 | 3 |
| Laser Damage II (v.53, no. 12, 2014) | 21 | 16 | 5 |
| Laser Damage III (v. 56, no. 1, 2017) | 33 | 28 | 7 |

## 15. In Conclusion

The location in Boulder, Colorado, during autumn at the venue of the Boulder Millennium Harvest House Hotel 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. The new venue was highly supportive for fixing the repeating problems with access of registered conference participants to the NIST facilities experienced in 2013-2015

This year the nice weather in Boulder encouraged to take a group picture of all symposium participants outside the National Institute of Atmospheric Research (Boulder, CO) where the traditional Wine and Cheese Reception was held on Tuesday, September 26.

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.”

## 16. Acknowledgments

A number of volunteers help tirelessly with some of the administrate 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. Bobbie Williams of 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. Assistance of James Bell (meeting manager) and Jeff Braswell (Marketing) of SPIE is greatly appreciated by organizers of this Laser Damage meeting.

The contribution of Spica Technologies for performing the laser damage tests for the annual laser-damage thin-film competition is greatly appreciated. We acknowledge the cooperating organizations: Pacific Northwest National Laboratory (USA); School of Optics – CREOL and FPCE, College of Optics and Photonics, University of Central Florida (USA); Laser Zentrum Hannover (Germany); University of Missouri, Columbia (USA); Alpine Research Optics (USA); Arrow Thin Films (USA); Quantel Laser USA (USA); LIDARIS LIDT Service (Lithuania); Laser

Components (USA). We especially acknowledge support of our sponsors this year: Lawrence Livermore National Laboratory; Spica Technologies Inc.; Materion; ZC Optoelectronic Technologies LTD; Arrow Thin Films; ARO – Alpine Research Optics; Laser Components; LIDARIS LIDT Service; and Quantel Laser for supporting the social events, WiFi access, and refreshments of this meeting. They are separately acknowledged in this volume of conference proceedings.

| Vol | Issue | Month | Paper # | Author(s) | Paper Type | Published Online | CID | Downloads | Citations |
|---|---|---|---|---|---|---|---|---|---|
| 51 | 12 | Dec-12 | OE GED-DEC2012 | Gruzdev and Shinn | Guest Editorial | 11/9/12 | 121801 | 1,081 | 0 |
| 51 | 12 | Dec-12 | 120400SSR | Palm (Marciniak) | Article | 7/10/12 | 121802 | 639 | 3 |
| 51 | 12 | Dec-12 | 120367SSPR | Cho | Article | 7/10/12 | 121803 | 318 | 0 |
| 51 | 12 | Dec-12 | 120366SSPR | Cho | Article | 7/10/12 | 121804 | 256 | 0 |
| 51 | 12 | Dec-12 | 120405SSPR | Gulley | Article | 6/27/12 | 121805 | 475 | 5 |
| 51 | 12 | Dec-12 | 120382SSPRR | Wagner | Article | 7/13/12 | 121806 | 268 | 17 |
| 51 | 12 | Dec-12 | 120493SSPR | Weber | Article | 7/9/12 | 121807 | 211 | 6 |
| 51 | 12 | Dec-12 | 120375SSRR | Apostolova | Article | 8/3/12 | 121808 | 324 | 8 |
| 51 | 12 | Dec-12 | 120381SSR | Han (Li) | Article | 7/19/12 | 121809 | 598 | 7 |
| 51 | 12 | Dec-12 | 120406SSPR | Brenk (Rethfeld) | Article | 8/22/12 | 121810 | 354 | 4 |
| 51 | 12 | Dec-12 | 120468SSR | Manenkov | Article | 9/18/12 | 121811 | 497 | 5 |
| 51 | 12 | Dec-12 | 120401SSPRR | Muehlig | Article | 9/14/12 | 121812 | 289 | 6 |
| 51 | 12 | Dec-12 | 120411SSRR | Nikiforov | Article | 9/20/12 | 121813 | 96 | 1 |
| 51 | 12 | Dec-12 | 120377SSRR | Lu | Article | 9/26/12 | 121814 | 399 | 5 |
| 51 | 12 | Dec-12 | 120396SSPRRRR | Ahsan | Article | 9/26/12 | 121815 | 331 | 9 |
| 51 | 12 | Dec-12 | 120620SSPR | Komolov | Article | 10/10/12 | 121816 | 319 | 2 |
| 51 | 12 | Dec-12 | 120486SSPRR | Shen | Article | 10/10/12 | 121817 | 560 | 19 |
| 51 | 12 | Dec-12 | 120617SSPR | Stolz | Article | 11/28/12 | 121818 | 543 | 3 |
| 51 | 12 | Dec-12 | 120616SSPRR | Arenberg | Article | 12/10/12 | 121819 | 102 | 3 |
| | | | | | | | TOTAL | 7660 | 103 |
| 53 | 12 | Dec-14 | OE-2014-1208-GED | Gruzdev and Shinn | Guest Editorial | 12/22/14 | 122501 | 615 | 0 |
| 53 | 12 | Dec-14 | 140177SSPR | Carreon | Article | 6/11/14 | 122502 | 193 | 1 |
| 53 | 12 | Dec-14 | 140405SSPR | Balasa | Article | 7/1/14 | 122503 | 117 | 3 |
| 53 | 12 | Dec-14 | 140509SSPR | Papernov | Article | 6/25/14 | 122504 | 1,544 | 2 |
| 53 | 12 | Dec-14 | 140527SSR | Lu (Ma) | Article | 7/1/14 | 122505 | 290 | 3 |
| 53 | 12 | Dec-14 | 140398R | Rubenchik (Wu) | Article | 7/17/14 | 122506 | 306 | 5 |
| 53 | 12 | Dec-14 | 140456SSPR | Mitchell | Article | 7/23/14 | 122507 | 345 | 3 |
| 53 | 12 | Dec-14 | 140541SSPR | Muehlig | Article | 8/11/14 | 122508 | 116 | 0 |
| 53 | 12 | Dec-14 | 140718SSR | Douti (Gallais) | Article | 8/6/14 | 122509 | 298 | 9 |
| 53 | 12 | Dec-14 | 140531SSR | Baumann (Perram) | Article | 8/12/14 | 122510 | 153 | 3 |
| 53 | 12 | Dec-14 | 140437SSPRR | Hildenbrand (Petrov) | Article | 8/21/14 | 122511 | 310 | 8 |
| 53 | 12 | Dec-14 | 140532SSPR | Gonschior (Klein) | Article | 9/2/14 | 122512 | 118 | 0 |
| 53 | 12 | Dec-14 | 140540SSR | Stratan(Zorila) | Article | 10/8/14 | 122513 | 188 | 4 |
| 53 | 12 | Dec-14 | 140712SSRR | Ding(Wang) | Article | 10/6/14 | 122514 | 169 | 0 |
| 53 | 12 | Dec-14 | 140793SSR | Gruzdev | Article | 10/27/14 | 122515 | 352 | 0 |
| 53 | 12 | Dec-14 | 140754SSPRR | Field | Article | 11/6/14 | 122516 | 1,510 | 3 |
| 53 | 12 | Dec-14 | 140756SSR | Arenberg | Article | 12/2/14 | 122517 | 500 | 1 |
| | | | | | | | TOTAL | 7124 | 45 |
| 56 | 1 | Jan-17 | OE-2017-0111-GED | Shinn and Gruzdev | Guest Editorial | 1/23/17 | 011000 | 376 | 0 |
| 56 | 1 | Jan-17 | 151769SSR | Hervy (Gallais) | Article | 6/30/16 | 011001 | 284 | 0 |
| 56 | 1 | Jan-17 | 160321SSPR | Field | Article | 7/8/16 | 011002 | 886 | 0 |
| 56 | 1 | Jan-17 | 160429SSPRR | Zhu | Article | 7/11/16 | 011003 | 197 | 0 |
| 56 | 1 | Jan-17 | 160551SSPR | Papernov | Article | 7/15/16 | 011004 | 192 | 0 |
| 56 | 1 | Jan-17 | 160320SSPR | Field | Article | 7/15/16 | 011005 | 727 | 0 |
| 56 | 1 | Jan-17 | 160594SSPR | Muehlig | Article | 7/18/16 | 011006 | 86 | 0 |
| 56 | 1 | Jan-17 | 160631SSR | Scharring | Article | 8/1/16 | 011007 | 2,862 | 2 |
| 56 | 1 | Jan-17 | 160697SSPR | Negres | Article | 8/1/16 | 011008 | 1,018 | 3 |
| 56 | 1 | Jan-17 | 160565SSRR | Shen (Jiang) | Article | 8/3/16 | 011009 | 143 | 0 |
| 56 | 1 | Jan-17 | 160739SSR | Lorbeer | Article | 8/15/16 | 011010 | 712 | 0 |
| 56 | 1 | Jan-17 | 160549SSR | Han (Feng) | Article | 9/8/16 | 011011 | 147 | 0 |
| 56 | 1 | Jan-17 | 160635SSPRR | Bellum | Article | 8/25/16 | 011012 | 732 | 2 |
| 56 | 1 | Jan-17 | 160694SSR | Phillips (Perram) | Article | 8/26/16 | 011013 | 97 | 2 |
| 56 | 1 | Jan-17 | 160835SSR | Bardy | Article | 8/29/16 | 011014 | 182 | 1 |
| 56 | 1 | Jan-17 | 160848SSR | Raemer | Article | 9/8/16 | 011015 | 150 | 0 |
| 56 | 1 | Jan-17 | 160617SSPR | Demos | Article | 9/8/16 | 011016 | 452 | 2 |
| 56 | 1 | Jan-17 | 160914SSR | Bauer (Perram) | Article | 9/20/16 | 011017 | 70 | 1 |
| 56 | 1 | Jan-17 | 160686SSPR | Field | Article | 9/21/16 | 011018 | 1,264 | 2 |
| 56 | 1 | Jan-17 | 160810SSRR | Xu (Emmert) | Article | 10/12/16 | 011019 | 137 | 0 |
| 56 | 1 | Jan-17 | 160636SSPRR | Bellum | Article | 10/12/16 | 011020 | 465 | 2 |
| 56 | 1 | Jan-17 | 161045SSPR | Jiao | Article | 10/13/16 | 011021 | 95 | 1 |
| 56 | 1 | Jan-17 | 160864SSR | Doualle (Gallais) | Article | 10/17/16 | 011022 | 133 | 2 |
| 56 | 1 | Jan-17 | 160796SSR | Gehring | Article | 10/25/16 | 011023 | 86 | 0 |
| 56 | 1 | Jan-17 | 160863SSPR | Durak (Velpula) | Article | 11/4/16 | 011024 | 125 | 0 |
| 56 | 1 | Jan-17 | 161048SSR | Saripalli | Article | 11/7/16 | 011025 | 76 | 0 |
| 56 | 1 | Jan-17 | 160970SSRR | Sun | Article | 11/30/16 | 011026 | 142 | 1 |
| 56 | 1 | Jan-17 | 160821SSRR | Ma (Cheng) | Article | 12/8/16 | 011027 | 94 | 1 |
| 56 | 1 | Jan-17 | 160855SSPR | Qiu | Article | 10/24/16 | 011108 | 515 | 1 |
| | | | | | | | TOTAL | 12445 | 23 |
| | | | | | | | GRAND TOTAL | 27229 | 171 |

**Figure 6.** A photocopy of a table with download and citation data for the Special Sections on Laser Damage published in 2012, 2014, and 2017. Made according to the data provided by the Publishing Department of SPIE as of September 12, 2017.

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