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Proceedings

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LASER-INDUCED DAMAGE IN OPTICAL MATERIALS 2019

22–25 September 2019
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Editors
Christopher Wren Carr, Vitaly E. Gruzdev, Detlev Ristau, Carmen S. Menoni, M.J. Soileau

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Lars O. Jensen, Laser Zentrum Hannover e.V. (Germany)
Enam A. Chowdhury, The Ohio State University (United States)

Symposium Welcome

Detlev Ristau
Laser Zentrum Hannover e.V. (Germany)

Since many decades, the Laser Damage Symposium, which was formerly known as the Boulder Damage Symposium, is opened by a greeting introducing recent hot topics and some statistics of the conference. Consequently, on behalf of my co-chairs, Carmen S. Menoni, Vitaly Gruzdev, Cristopher Wren Carr, and our Emeritus chair, M. J. Soileau, I am very delighted to welcome all presenters and participants to the 51st Annual Symposium on Optical Materials for High-Power Lasers!

For more than 45 years, the Symposium was organized at the NIST-facility in Boulder, Colorado, and moved to Boulder Millennium Hotel in the city center of Boulder for the past years. At this location, also the 50 years Anniversary Symposium was held attracting a very high number of 171 participants as well as more than 80 presentations. At the occasion of the 50th anniversary, it was decided to continue the Symposium also at other locations in the United States of America or even on other continents. Consequently, the recent 51st Laser Damage Conference took place at the Omni Interlocken Hotel in Broomfield, which is not located directly in Boulder but still in the Boulder area. The upcoming Laser Damage Conference 2020 will be held in Rochester, New York, at the Hilton Garden Inn. It was expected that the number of presentation and attendees will decrease after the hype of the 50th Anniversary Symposium. Even though the number of registrants for the conference has declined from the last year down to 122, which corresponds to the average attendance during the last decade, the conference can still be considered as the leading platform for the discussion of laser damage in optical materials and related topics. This is also reflected by the high number of contributed presentations resulting in a busy program of LD 2019. In total, the conference hosted more than 60 oral and poster presentations during the relatively short time period of three days. Besides keynote talks introducing the four main topics of the conference:

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

special contributions were presented within the Minisymposium on “Diffraction gratings in high power lasers: challenges, recent advances, and perspectives” and the laser damage competition. The Minisymposium, which is following in a long row of Symposia dating back to the year 1992, was organized by Jerome Neauport (CEA-CESTA, France) and featured a comprehensive overview on damage effects in diffractive components as well as contributions on large scale gratings and damage effects induced by pulses of different durations. The topic of the damage competition 2019 differed from the former campaigns which were continually dedicated to the production and qualification of optical components with highest laser damage thresholds for specific laser applications. This year, a comparison of the threshold measurement procedure described in the International Standard ISO 21245 to the raster scan technique was performed. The experiment was based on the sample set of high reflecting mirrors for the wavelength 1.064 µm that was already in the focus of the last damage competition 2018. The experiment was organized by Raluca Negres and Christopher Stolz (both with Lawrence Livermore National Laboratory, USA) with voluntary measurement contributions by Spica Technologies, Inc. (New Hampshire, USA) and revealed a significant difference between the two measurement procedures.

Recent trends of talks and posters within the major topics of the Symposium included for instance in the field of optical coatings, investigations in all-silica coatings, laser damage effects induced by ns-pulses and in the sub-ps regime, as well as in the uv-spectral range. Besides a variety of coating materials, especially the oxides HfO_2, SiO_2, In_2O_3 were of interest. Concerning fundamental mechanisms, several studies were concentrated on laser damage growth, time resolved holography and aspects of ultra-short pulse laser damage embracing also few cycle pulses, material modifications, and free carrier dynamics. The field of surfaces, mirrors and contamination was dominated by contributions on microparticle contamination, meta-surfaces for high power laser applications as well as effects of UV/ozone cleaning and polishing. A broad spectrum of contributions addressing spectroscopic methods and direct absorptance measurements, especially considering also the UV/VUV-range, formed a major part of the sessions on materials and measurements. In this context, also specific problems for the measurement of laser damage thresholds for example with cw-lasers but also in view of the standardization and interpretation of raw data as well as comparisons of different measurement methods played an important role. All contributions stimulated vivid discussions in the auditorium and reflected again the importance of high power materials for the future development of photonics and especially laser technology.

The Symposium offers also awards for the best poster and oral presentation, as well as for the leading contribution of a student. In 2016, the annual Best Oral Presentation and the Best Poster Awards were renamed to honor the founding organizers for this meeting. In 2017, the MJ Soileau Best Student Paper Award was added to the annual awards, to appreciate the work of young researchers in the field of laser damage. The awards are supported and approved by the Laser Damage Co-Chairs, with funds matched by SPIE. The bestowal ceremony for the winners of the last conference always takes place at the beginning of the next Symposium. For the 50th Anniversary Symposium 2018, the prices were awarded to the following publications:

THE ALEXANDER GLASS BEST ORAL PRESENTATION AWARD 2018

Revisiting of the laser induced filamentation damage conditions in fused silica for energetic laser systems
Authors: Eyal Feigenbaum, Wade H. Williams, Raluca A. Negres, Mary A. Norton, Christopher F. Miller, Gabriel Mennerat, Clay C. Widmayer, Christopher Wren Carr, Jean-Michel G. Di Nicola, Jeffery D. Bude, Lawrence Livermore National Lab. (USA)

THE ARTHUR GUENTHER BEST POSTER AWARD 2018

Measurement setup for the determination of the nonlinear refractive index of thin films with high nonlinearity
Authors: Morten Steinecke, Tarik Kellermann, Marco Jupé, Detlev Ristau, Lars Jensen, Laser Zentrum Hannover e.V. (Germany)

THE MJ SOILEAU BEST STUDENT PAPER AWARD 2018

Measurement setup for the determination of the nonlinear refractive index of thin films with high nonlinearity
Authors: Amir Khabbazi Oskouei, Sebastian Baur, Luke Emmert, Wolfgang Rudolph, The Univ. of New Mexico (USA); Marco Jupé, Thomas Willemsen, Morten Steinecke, Lars Jensen, Detlev Ristau, Laser Zentrum Hannover e.V. (Germany)

Financial support for Laser Damage 2019 was very much appreciated and has been donated by the Conference co-sponsors: Lawrence Livermore National Laboratory (USA), Arrow Thin Films (USA), KRI 40, (USA), Lidaris (Lithuania), Northtrop Grummon (USA), Spica Technologies, Inc. (USA), Lasercomponents GmbH (Germany), KM Labs (USA), and Edmund Optics (USA). Also, many thanks to the Colorado State University, the Laser Zentrum Hannover e.V., the University of Central Florida, the University of New Mexico, and the Lawrence Livermore National Laboratory for providing the managerial support during planning and event operations. Especially, the important work of the members of the International Program Committee in advertising, gathering contributions for the sessions, and supporting the conference is acknowledged. The International Program Committee of the Conference is featuring scientists from many countries strong in laser technology including representatives from the UK, France, Russia, Japan, Germany, China and the USA.

The co-chairs very appreciatively recognize the enthusiastic support of the SPIE staff Diane Cline as event manager, Kirsten Anderson as conference program coordinator, and Josh Henry as meting manager, as well as of Heather Thomas, Symposium Assistant from the Lawrence Livermore National Laboratory, whose hard work in planning and execution made the event possible. On behalf of all the organizers and attendees, we thank them and also the members of the International Program Committee for their tireless efforts.

Attendees of the Laser Damage Symposium 2019 at the main entrance of the NCAR-building joining for the Wine and Cheese Reception after a busy second day of the Conference.

Summary of Meeting

Annual Laser Damage Symposium:
51st Annual Symposium on Optical Materials for High Power Laser
(aka Boulder Damage Symposium)
22-25 September 2019

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Albuquerque, NM, 87131, USA

ABSTRACT

These proceedings contain the papers presented as oral and poster presentations at the 51st Annual Laser Damage Symposium (aka Annual Symposium on Optical Materials for High-Power Lasers, also Boulder Damage Symposium). The conference was held at OMNI Interlocken Hotel in Broomfield, Colorado on 22-25 September 2019. 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 devoted to overview of the diffraction gratings for high-power lasers. A Tutorial on optical coatings for large-aperture laser systems was held by Jim Oliver as a pre-symposium event on Sunday evening. The conference was opened by Detlev Ristau with a symposium welcome. Christopher Wren Carr of Lawrence Livermore National Laboratory (USA), Vitaly Gruzdev of the University of New Mexico (USA), Carmen S. Menoni of the Colorado State University (USA), Detlev Ristau of the Laser Zentrum Hannover e.V. (Germany), and M. J. Soileau of CREOL - The College of Optics and Photonics, 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.

63 abstracts were submitted to the symposium and included into the conference program, of which 55 were presented at 10 oral and 4 poster sessions demonstrating the lowest number of presented submissions since 1991. No parallel sessions were held allowing the opportunity to discuss common research interests with all the presenters. With 121 attendees, 42 of which were authors, 12 – students, and 16 more – meeting co-chairs and program-committee members, the meeting attendance was at the lowest level since 2004. In spite of that, the conference offered attendees a traditional outstanding opportunity to make many new acquaintances. Although held annually in the US, Laser Damage Symposium continues to be a true international conference with 49% of all presentations and 31.4% of the attendees coming from Europe and Asia this year. Following active discussions from previous years, the Symposium was held for the first time outside its mother city (Boulder, Colorado) – at OMNI Interlocken Hotel in Broomfield, Colorado.

The 52nd Annual Symposium of this series will be held in Hilton Garden Inn Rochester / University and Medical Center in Rochester, New York, 13-16 September 2020. In response to feedback of conference participants, the 52nd meeting will be held in another US city. A traditional continuous effort will be made to ensure a close liaison between the high-energy, high-peak-power, and high-average-power laser communities. Topic of a mini-symposium of the 2020 meeting is still under consideration and will be announced in 2020 Call for Papers of Lase r Damage Symposium in later January 2020.

The principal topics to be considered in 2020 do not appreciably deviate from those enumerated above. We expect to hear more about the impacts of surface contamination, debris, and surface treatment on the laser resistance of laser optics. Growing attention is paid to surface nano-structuring for production of inti-reflection effect without use of optical coatings. Influence of various defects of optical materials on laser damage continues to generate a significant interest over decades. Nonlinear and laser crystals, surfaces, and optical coatings continue to place major limitations on laser systems and remain the most active areas of laser-damage research and spirited debate. Recent progress in improvement and revision of the international standards on laser-induced damage will continue to attract significant

attention of conference participants. 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 in laser-lithography applications. Short pulse (nanosecond and picosecond) laser optics and damage phenomena surprisingly remain an active area of research over several decades. Constant progress in the fields of ultrashort-pulse (femtosecond) lasers and ultrafast laser-material interactions continues to substantially contribute to the conference. We also expect to hear more about new measurement techniques to improve our understanding of the fundamental damage mechanisms and to advance the manufacturing of optical materials and thin films for optical components. Thin films for a broad range of laser wavelengths and pulse durations continue to stay another hot topic of the meeting. Also, recent developments in the fields of surface nano-structured and meta-optical materials, and related laser-damage issues 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, dynamics of the damage processes, transient material responses, generation of free-carrier plasma, and various 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 and review nature in 2020. Invited contributors will cover recent breaking developments in the 4 key areas of the research on laser-induced damage and optical materials for lasers. Continuing the recent conference traditions, a tutorial on preparation and materials of of substrates for coating deposition will be held by Walter Siehlein, Blue Ridge (USA) 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, fundamental mechanisms of laser-induced damage and relevant laser interactions with optical materials, improvement of optical coatings, studies of contamination effects, laser-damage standards, and a broad range of topics related to laser-induced damage in various optical materials. Co-chairs welcome relevant comments and criticism from interested readers.

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

1. Introduction

The Annual Laser Damage Symposium – 51st Annual Symposium on Optical Materials for High-Power Lasers (a.k.a. the Boulder Damage Symposium, because of its original venue in the city of Boulder, Colorado, USA) was held on 22-25 September 2019. 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 121 representatives of academia, industry, national research laboratories and centers from 9 countries that was about 41% decrease in attendance compared to the anniversary 50th Symposium of 2018 (Fig. 1). Countries of North America, Europe, and Asia were represented at the conference in 2019 with no participants from other continents (Fig. 2). 63 abstracts were submitted to the Symposium, they were all included into the final program, and 55 were delivered within the traditional 3-day format of the meeting including 33 oral and 22 poster presentations. The reduced number of presentations has resulted in a relaxed conference schedule with increased time of the poster sessions and lunch breaks. The conference schedule received positive feedbacks of meeting attendees. Following the critics of the busy schedule of the anniversary Laser Damage Symposium in 2018, conference program continues to observe the limitation on the number of invited talks: one per each of the 4 major topical areas plus one for Mini-Symposium.

Although, held annually in the US, this is a truly International conference with 31.4% of the attendees and 48% of the presentations coming from abroad this year (Figs. 3 and 4). 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, and optical materials. Starting from 2014, a traditional pre-symposium event – a Round-Table discussion held on Sunday evening – was replaced with a Tutorial. This year it featured deposition, optical performance, and laser-induced damage threshold of multilayer optical coatings for large-aperture pieces of optics and was entitled "Optical Coatings for Large-Aperture Laser Systems". The tutorial was brilliantly delivered by Dr. Jim Oliver (Laboratory for Laser Energetics, University of Rochester, USA) in the evening of Sunday, 22 September. It attracted more than 70 conference participants and was accepted very well. The conference began on Monday, 23 September 2019 with a welcome talk delivered by Dr. Detlev Ristau (Laser Zentrum Hannover eV, Germany) and awarding the Best Oral, Best Poster, and Best Student presentations from Laser Damage Symposium 2018.

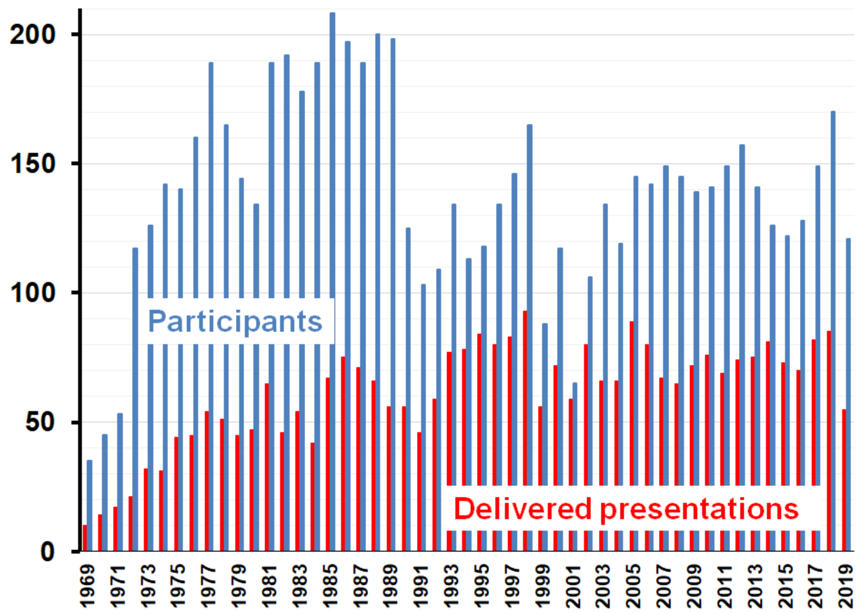

Fig. 1. Registered participants (blue columns) and number of presented papers (red columns) vs year from 1969 through 2019 inclusive. The vertical axis shows absolute number of participants/presentations.

2. Symposium Co-Chairs

The Boulder Damage Symposium was founded by Dr. A. H. Guenther and Dr. Alexander Glass. Over the last 51 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 in Table 1.

Table 1. Co-chairs of Laser Damage Symposium.

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. E. Gruzdev
2010	add J. A. Menapace; C. J. Stolz departs
2017	add C. W. Carr; J. A. Menapace departs.
2018	add C. S. Menoni; G. J. Exharhos departs; M. J. Soileau departs and becomes a honorary co-chair.

3. International Program Committee

Program of the Symposium is traditionally built with the assistance of the International Program Committee. Detlev Ristau has chaired the Committee and coordinated its work since 2005. Tremendous work of Committee members results in inviting high-level key-note, invited, and plenary speakers. In 2019, the Committee consisted of 17 experts with research expertise covering all major fields and sub-fields of laser damage. They represented major research centers of 7 countries conducting research relevant to various aspects of laser-induced damage (Table 2).

Table 2. Members of International Program Committee of Laser Damage Symposium in 2019.

Jonathan W. Arenberg	Northrop Grumman Aerospace Systems	USA
Enam A. Chowdhury	The Ohio State University	USA
Stavros G. Demos	Laboratory for Laser Energetics, University of Rochester	USA
Leonid B. Glebov	The College of Optics and Photonics, University of Central Florida	USA
Lars O. Jensen	Laser Zentrum Hannover e. V.	Germany
Takahisa Jitsuno	Osaka University	Japan
Klaus Mann	Laser-Laboratory Gottingen e. V.	Germany
Andrius Melninkaitis	Vilnius University	Lithuania
Masataka Murahara	Tokai University	Japan
Jean-Yves Natoli	Institut Fresnel	France
Jerome Neauport	CEA-Cesta	France
Raluca A. Negres	Lawrence Livermore National Laboratory	USA
Semyon Papernov	Laboratory for Laser Energetics, University of Rochester	USA
Jonathan Phillips	STFC Rutherford Appleton Laboratory	United Kingdom
Wolfgang Rudolph	The University of New Mexico	USA
Jianda Shao	Shanghai Institute of Optics and Fine Mechanics	China
Christopher Stolz	Lawrence Livermore National Laboratory	USA

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). Following highly positive response of tutorial attendees, another Tutorial was held again in 2015 as a 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 that tutorial resulted in extended duration of the presentation (about 1.5 hour) that was addressed by attendees in their responses. In 2018, the Tutorial featured basic and advanced approaches to characterize laser beams and measure their basic parameters. It was entitled “Laser Beam Characterization”. The tutorial was prepared and held by Dr. Bernd Eppich (Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany).

The Tutorial of 2019 entitled “Coatings for Large-Aperture Laser Systems” detailed important aspects of deposition process, optical performance, coating stresses, and laser-damage thresholds of optical coatings for large-aperture laser systems. For meter-scaler optic sizes and substrate masses in excess of 100 lb, specialty coating processes to provide spatially uniform, low-stress, and high-damage-threshold performance were overviewed. The Tutorial was brilliantly delivered by Jim Oliver (Laboratory for Laser Energetics, University of Rochester, USA) – an internationally recognized expert in the field. The Tutorial received exceptionally positive feedback from more than 70 conference participants attended the lecture and was recognized as one of the brightest events of the Symposium.

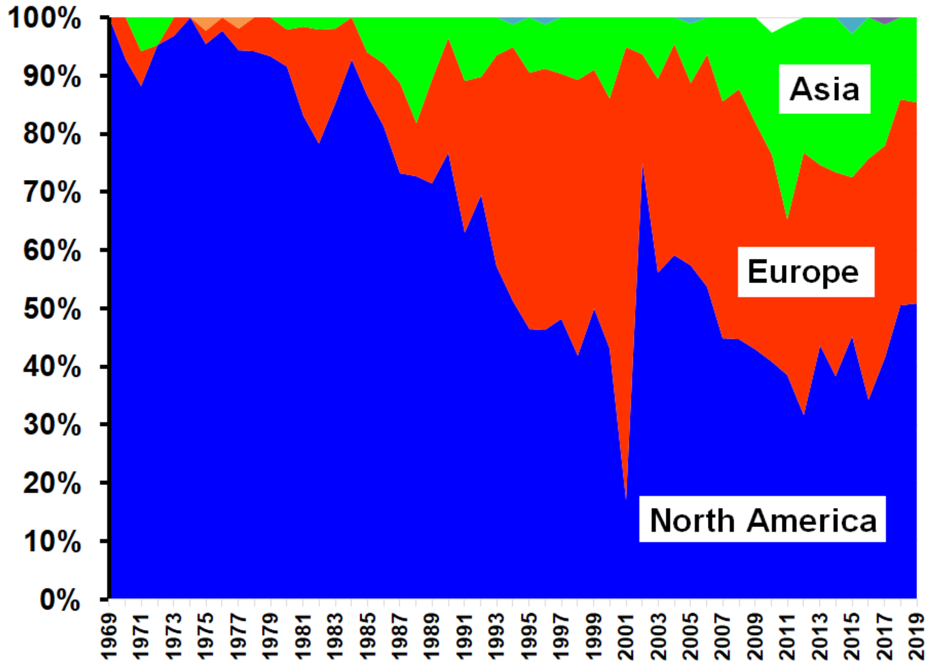

Fig. 2. Continent-distribution chart of the presentations delivered at the conference vs year from 1969 through 2019 inclusive. Tiny areas at the top part of the chart depict minor representations from Africa and Australia.

5. Thin Films

Due to 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 continued to be one of the largest parts of the meeting and received very significant attention. Thin films and optical coatings are known to demonstrate the lowest thresholds of laser-induced damage compared to those of bulk materials. Besides the traditional focus on damage thresholds or sensitivity of particular optical coatings to high-power laser radiation, the specific topics of 2019 included fatigue effects by nanosecond and ultrashort (femtosecond and picosecond) laser pulses, comparison of high (500 MHz) vs low (kHz) repetition rates, improvement of film structure, novel film and substrate materials, film response to aging, influence of substrate preparation on film quality, film contamination and defects, and specific features of damage morphology on various optical coatings. Oxide films including hafnia and silica continued to attract major attention in the field of thin-film materials, but this year we also heard about laser damage of indium-tin-oxide (ITO) and polyimide films, all-silica multilayer coatings produced byGlancing Angle Deposition (GLAD) technique, and use of LaF_3 – AlF_3 layers in multilayer stacks for vacuum ultraviolet. Major attention was traditionally paid to coatings at 1064 nm, 1030 nm, 800nm, 780 nm, 532 nm, and 355 nm. Damage of multilayer mirrors and anti-reflection coatings by ultrashort pulses was another significant focus of this section. This year we heard about damage of coatings by few-cycle (less than 4 cycles) laser pulses 766 nm. A lot of attention was paid to comparison of different damage techniques, e g., 1-on-1 vs S-on-1 traditionally utilized in damage tests of optical multilayer coatings.

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 from 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 was one of the major events of the Thin Film section.

Defects and interfaces continued to be a traditional area of high interest for this field. They were approached by deposition optimization to minimize defect density, optimization of film composition, specific vacuum conditions, and laser-conditioning mitigation techniques. We continued to see interest in defect detection and characterization in various films and coatings. Special consideration received redistribution of laser-pulse electric field in coatings produced by scattering from nanometer-sized impurities. This year, invited talk of Tomas Tolenis (Center for Physical Sciences and Technology, Lithuania) was devoted to all-silica multilayer coatings produced by GLAD method. Layer-to-layer variations of refractive index are achieved by deposition of specific columnar structures and tailoring the coating thickness. With total of 8 oral and 8 poster presentations delivered at the conference, the Thin Film section was the largest in the 2019 meeting and confirmed a strong non-decaying interest of the optical-coating community to various laser-damage issues (Figs. 3 and 4).

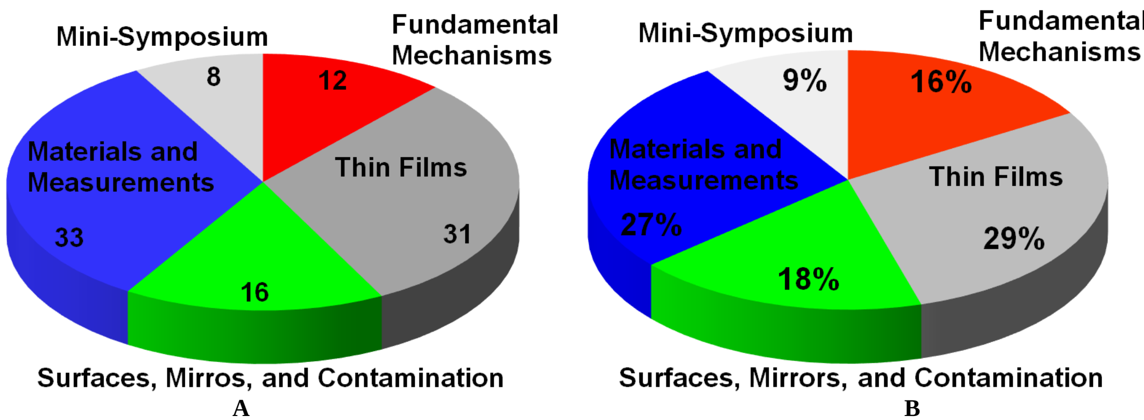

Fig. 3. Distribution of presentations of the 50th Laser Damage Symposium in 2018 (A) and 51st Symposium in 20197 (B) by key topics. Numbers show percentage of presentations of specific topics.

6. Thin-film laser damage competition

This year, the eleventh thin-film damage competition was organized by Dr. Raluca Negres and Dr. Christopher Stolz of Lawrence Livermore National Laboratory (USA). The competition started in 2008 as a double-blind laser-damage competition to sample the government, industrial, and academic sectors producing high laser resistant optical coatings. The competition continued every year since then and focused on different coating types and/or use conditions including high reflectors for nanosecond laser pulses at all popular wavelengths from 193 nm to 1064 nm, polarizers, Fabry-Perot interference filters, and broadband dispersion-controlled high reflectors for ultrashort pulses. This year's competition was a continuation of the competition from 2018 and focused on the same multilayer mirrors and irradiation conditions tested in 2018: zero-degree-of-incidence high reflecting coatings were tested using

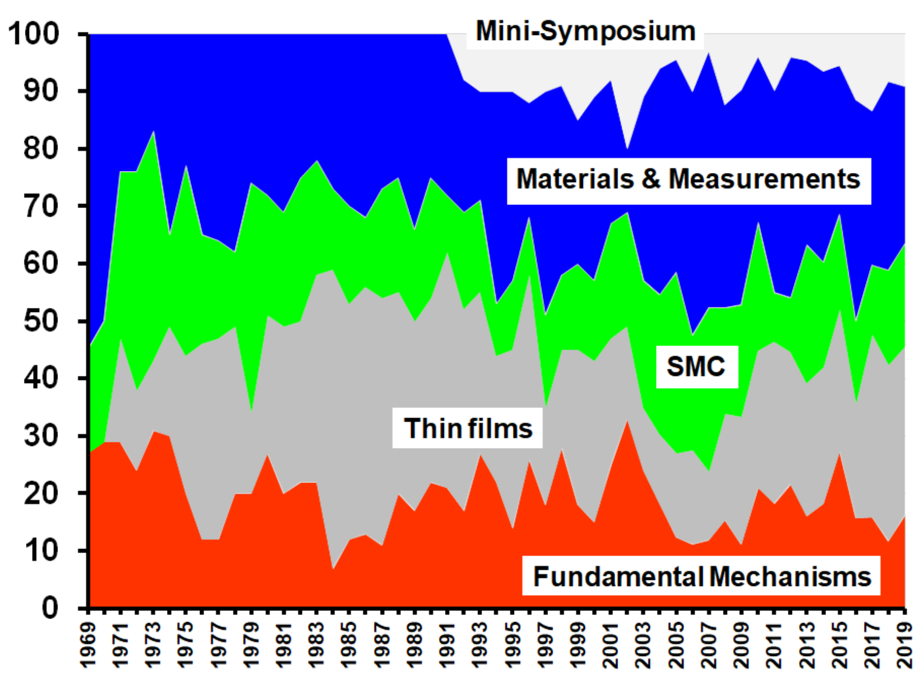

Fig. 4. Distribution of presentations over four major topics and mini-symposium vs year from 1969 through 2019 inclusive. The vertical axis shows percentage of presentations of the major conference section.

a raster scan method at 1064 nm wavelength with 5-ns laser pulses at 10 kHz repetition rate in a single longitudinal mode regime. The mirror specifications exactly reproduced those announced in 2008. The participants from the USA, Europe, and Asia selected coating materials coating design, and deposition method on their own. The samples were tested at the same damage-testing facility of Spica Technologies Inc. (USA) that was utilized for the damage tests in 2008 to enable direct and reliable comparison among the participants. The major objective of the 2019 competition was to compare two methods that currently dominate in laser-damage testing: rater scan (from 2018) vs ISO-standard protocol (2019). The rankings and damage performance was compared and demonstrated a clear difference between the two methods. Details of the testing procedure, deposition processes, cleaning method, coating materials, and layer count as well as major results of the tests were delivered by Raluca A. Negres on Tuesday afternoon (September 24) in the talk entitled “1064-nm mirror thin film damage competition”.

The Table 3 below summarizes the 11 damage-test competitions performed from 2008 to 2019 inclusive.

Table 3. List of topics of thin-film laser damage competition from 2008 through 2019.

2008	HR mirrors for Nd-YAG lasers, wavelength 1064 nm, 0-degree incidence, 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
2018	HR Nd:YAG laser mirrors , wavelength 1064 nm, 0-degree incidence, nanosecond pulses, raster scan
2019	HR Nd:YAG mirrors, wavelength 1064 nm, 0-degree incidence, nanosecond pulses; ISO vs raster scan

7. Fundamental Mechanisms

This section traditionally deals with the fundamental effects and mechanisms of interactions of high-intensity light with matter. General topics of this field include laser-induced ionization, nonlinear behavior and effects of material response, self-focusing and other nonlinear propagation effects, modeling of thermal and non-thermal laser-material interactions, experimental data reduction protocols (e.g. effects of pulse width, repetition rate, spot size, wavelength, temperature, ionizing radiation, and other basic environmental effects). 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. The fundamental mechanisms of defect-initiated laser damage continues to be of extremely high interest for a large part of the laser-damage community.

This year, 8 of 9 presented submissions of this topical area were devoted to ultrafast/sub-picosecond laser-material interactions and ultrashort-pulse laser effect. They included bulk and surface effects including formation of damage craters, generation of periodic surface ripples on ZnSe surface, modification of optical properties in bulk glasses, a transition from intrinsic to defect-driven damage morphology in multilayer high reflectors, ablation of thin films by few-cycle laser pulses, variations of nonlinear absorption by high-repetition-rate femtosecond laser pulses, and fatigue effects in multi-pulse femtosecond laser-material interactions. Materials under consideration were multilayer stacks as well as typical dielectrics and semiconductors. This year’s presentations also featured use of time-resolved digital holography to identify specific contributions and effects in multi-pulse ultrafast laser interactions with transparent materials. Continuous efforts were made to characterize the fundamental mechanisms of laser damage in fused silica, hafnia, and titania as the most popular optical materials. Traditional high attention was paid to modeling laser-induced nonlinear absorption and free-carrier generation. The invited talk by Laurent Gallais (Institut Fresnel, France) overviewed experimental data and major mechanisms of laser-induced damage growth on optical coatings produced by multiple sub-picosecond laser pulses. Damage of reflective coatings at wavelength 1030/1053 nm was specifically addressed with emphasis on contribution of nano-scale defects. With 2 poster and 7 oral presentations delivered at the meeting, this area was the smallest among the 4 major topics of the Symposium (Figs. 3, 4).

8. Surfaces and Mirrors

Presentations of this category are devoted to surface preparation, surface and subsurface damage characterization, surface roughness, scattering, environmental degradation, surface aging, substrate material properties including cooling techniques, polishing techniques, and cleaning of surfaces. The crux of the contamination problem is that the damage experiments done in controlled clean laboratory settings do not necessarily yield the same results as laser operations in less pristine real-life environments. A novel aspect of this field is the research on surface degradation of space optic that is to transfer millions-to-billions of laser pulses. There is a significant amount of work needed to understand what type and level of 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.

This year, presentations of this topical area addressed interaction of 1053-nm picosecond and sub-picosecond laser pulses with microparticle contamination of reflective optics, creation of high-fluence precursors by 351-nm nanosecond laser pulses on fused-silica surfaces, front and rare surface damage of optical pieces due to particulate contamination, use of novel water-free etching fluids for water-sensitive crystals, damage performance of fused-silica debris shield at the National Ignition Facility, laser-damage performance of various metasurfaces, use of UV/ozone cleaning for removal of laser-induced contamination on optical surfaces, studies of surface laser-induced damage of novel strontium-borate crystals, influence of magnetic field-assisted finishing on morphology of laser-induced damage, and dependence of morphology of UV-laser-induced contamination on chemical and physical parameters. A very remarkable amount of papers dealt with fused-silica surfaces subjected to action of multiple (from 2 to billion) laser pulses. Fair amount of papers was focused on influence of surface contamination of various types (e. g., by metal or polymer micro- and nano-particles) of surface laser-induced damage. Invited talk by Kyle R. P. Kafka (Laboratory for Laser Energetics, University of Rochester, USA) entitled "Short-pulse laser irradiation of microparticle contamination on reflective optics" featured the interaction of high-fluence picosecond and sub-picosecond laser pulses with metal, polymer, and glass micro-scale particles on surface of reflective optics, e. g., diffraction gratings and high-reflective coatings. Depending on laser parameters and microparticle material, the interaction can vary from particle removal with minor damage to irradiated surface to severe surface damage. The brilliant style of the presentation and high-class scientific content of this talk were appreciated by a majority of conference attendees who recognized it as one of the best presentations of the conference. With 12 oral and 3 poster presentations, this key area shows slightly increased representation in 2019 compared to 2018 (Fig. 3) with a steady trend to growth over last 4 years (Fig. 4).

9. Materials and Measurements

Among the four main sections of the conference, this one continuously stays one of the largest over the last decade (Figs. 3 and 4). In general, 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 native defects. Also included are new techniques for measuring these quantities, which stay a continuing challenge as materials are improved in quality and diversity. There is always a strong 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 the work continues on developing tests that address the difficulties and improve existing ISO protocols.

This year, major presentation topics of this area were large-scale laser facilities, theory for evaluation of the quality of laser-damage metrics, arrest of laser-induced-damage growth on the exit surfaces of silica optics, measurement of laser-induced damage threshold by high-repetition-rate ArF lasers at 193 nm, damage of liquid crystals by 1-ns laser pulses at 1053, 527, and 351 nm wavelengths, use of spectra of filament-induced luminescence to assess optical purity in bulk transparent materials, lasing from rare-earth-ion doped ZnO micro-spheres, Monte Carlo analysis of ISO and raster-scan laser-damage protocols, progress in revision of the ISO Laser Damage Standard, use of Markov-Chain Monte Carlo simulations for interpretation of S-on-1 damage statistics, measurement of damage thresholds in infrared-grade chalcogenide glasses by continuous-wave radiation, 6-year statistics of laser-induced damage at 1-Hz 1-PW laser system, measurement of absorption of typical optical materials at UV and IR spectral regions, use of third-harmonic generation for time-resolved characterization of transient optical response of dielectrics near damage threshold, and final-optics performance at Laser Mega Joule laser facility. As usually, multiple presentations were focused on measurements of laser-damage threshold in various materials including bulk fused silica, sapphire, CaF_2 and MgF_2 crystals, chalcogenide glasses, liquid crystals, and multilayer high reflectors. A fair amount of talks was devoted to revision or improvement of the protocols utilized to measure laser-induced damage threshold. Laser damage of optics of large-scale high-power laser facilities continues to attract significant attention worldwide. Methods to assess optical properties, e. g., absorption continue to be a substantial topic of this area. Also, time-resolved characterization of transient optical response is another important sub-field for ultrafast lasers. The major range of laser parameters of interest includes nanosecond and femtosecond pulses at 1070, 1064, 1053, 1030, 355, and 193 nm. Substantial attention was again paid to UV lasers. Among novel methods, use of the third-harmonic generation in experiments and use of Markov-Chain Monte-Carlo simulations should be mentioned. The invited talk entitled "The state-of-the-art and the art of possible in high-power lasers, in context of challenges and opportunities of optical damage" was delivered by Craig W. Siders (Lawrence Livermore National Laboratory, USA) and featured the current state of the large-scale laser facilities worldwide as well as outline of the most significant laser-damage issues associated with operation of those facilities. With 7 oral and 8 poster presentations delivered at the meeting, this topical section was the second largest in the conference program of 2019 (Fig. 3).

10. Mini-Symposium

This year, the Mini-Symposium was focused on various aspects of diffraction gratings for high-power laser systems including characterization of damage resistance of multi-layer dielectric gratings to nanosecond laser pulses, damage initiation and growth of multilayer dielectric gratings by laser pulses of various pulse widths, and morphology and mechanisms of damage of the multilayer gratings. Terrance J. Kessler from Laboratory for Laser Energetics, University of Rochester, USA brilliantly performed to organize this Mini-Symposium and contributed a lot of his energy and enthusiasm. The invited talk of this Mini-Symposium delivered by Jerome Neauport from CEA-Cesta, France was focused on diffraction gratings for high-power laser systems and addresses major challenges, issues, recent advances, and future perspectives in this field.

A brief summary of the past mini-symposium topics starting from 1992 and the organizing chairs is listed below in Table 4. A topic of Mini-Symposium of the 2020 conference is still under discussion, and there are options in the areas of meta-optics, mid-infrared lasers, and non-glass materials. The topic will be announced in the Laser Damage 2020 Call for Papers in late January 2020.

11. Keynote and Invited Presentations

As usually, the 51th Laser Damage Symposium was highlighted by four keynote presentations in the four major topical areas of the conference:

1. "All-silica coatings for high-power laser applications", **Tomas Tolenis,** Center for Physical Sciences and Technology (Lithuania) – area of Thin Films.
2. "Short-pulse laser irradiation of microparticle contamination on reflective optics", **Kyle R. P. Kafka**, Laboratory for Laser Energetics, University of Rochester (USA)– the area of Surfaces, Mirrors, and Contamination.
3. "Phenomenology and mechanisms of laser damage growth on optical coatings in the sub-ps pulse regime", **Laurent Gallais,** Institut Fresnel (France) – the area of Fundamental Mechanisms.
4. "The state-of-the-art and the art of possible in high-power lasers, in context of challenges and opportunities of optical damage", **Craig W. Siders**, Lawrence Livermore National Laboratory (USA) – the area of Materials and Measurements.

Also, the Mini-Symposium hosted the following invited talk this year:

"Diffraction gratings in high-power lasers: challenges, recent advances, and perspectives", **Jerome Neauport**, CEA-Cesta (France).

In 2020, plenary talks will be introduced into conference program. They are planned for the first morning session of each conference day and will be focused on general topics of common interest for the laser-damage community.

Table 4. Mini-Symposium topics and chairs from 1992 through 2019 inclusive.

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 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 Herve Bercegol	Fused Silica
2009	Wolfgang Rudolph	Femtosecond Laser-Induced Damage
2010	Klaus Sokolowski-Tinten	Fundamentals of Laser Ablation
2011	Holger Blashke, Carmen Menoni	Deep-UV Optics
2011	Michelle Shin	Meta-Optics/Photonic Band Gap Materials
2012	Stavros Demos	Laser-Induced Plasma Interactions
2013	Leonid Glebov	High-Power Fiber Lasers
2014	Stavros Demos	Applications Related to Laser Damage
2015	Vladimir PErvak	Laser-Induced Damage to Multilayers in Femtosecond Regime
2016	Stefan H. Borneis 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
2018	M. J. Soileau	50th Anniversary Conference Overview
2019	Terrance J. Kessler	Diffraction gratings for High-Power Laser Systems

12. Conference Awards

Beginning with the meeting held in 2000, the conference co-chairs instituted a Best Presentation 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)). Starting from 2015, a small monetary honorarium was added to the glass plaque to support the awarded researchers.

In 2017, Symposium Co-Chairs re-named and expanded the award categories in honor of the symposium's founding organizers and key chairs. Starting from 2017, in honor of the symposium's founding organizers and key chairs, one presentation is selected in each of three categories – oral, poster, and student presentation – by conference co-chairs on the basis of scientific excellence and quality of presentation and is warded with one of the following awards:

- Alexander Glass Best Oral Presentation Award;
- M. J. Soileau Best Student Paper Award;
- Arthur Guenther Best Poster Award.

Since submission of a manuscript to the conference proceedings is a mandatory condition of receiving an award, all awarded papers of 2019 can be found in this volume of Laser Damage Proceedings. In 2019, the following papers were selected by Co-Chairs for the awards:

Alexander Glass Best Oral Presentation Award:
"Non-localized creation of high-fluence precursors by 351-nm laser exposure", David Cross, Christopher W. Carr, Lawrence Livermore National Laboratory (USA); SPIE paper No. 11173-44.

M. J. Soileau Best Student Paper Award:
"Single-shot femtosecond laser-induced damage and ablation of HfO2/SiO2-based optical thin films: A comparison between few-cycle pulses and 110 fs pulses", **Noah Talisa, Michael Tripepi, Abdallah AlShafey, Brandon Yarris, Jacob Krebs,** The Ohio State University (USA), **Aaron Davenport, Emmett Randel, Carmen S. Menoni,** Colorado State University (USA), **Enam A, Chowdhury,** The Ohio State University (USA) SPIE paper No. 11173-25.

Arthur Guenther Best Poster Award:
"Direct comparison of laser-induced damage threshold testing protocols on dielectric mirrors: effect of nanosecond laser pulse shape at NIR and UV wavelengths", Ruta Pakalnyte, Vilnius University (Lithuania), **Egidijus Pupka,** LIDARIS Ltd. (Lithuania), **Andrius Melninkaitis**, Vilnius University (Lithuania) SPIE paper No. 11173-42.

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, Vitaly Gruzdev and Michelle Shinn volunteered as guest editors of Special Section on Laser Damage published in the flagman peer reviewed SPIE journal *Optical Engineering*. The first Special Section was published in volume 51, issue 12:
https://www.spiedigitallibrary.org/journals/optical-engineering/volume-51/issue-12#SpecialSectiononLaserDamage
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:
https://www.spiedigitallibrary.org/journals/optical-engineering/volume-53/issue-12#SpecialSectiononLaserDamageII
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 and success of the two previous Special Sections on Laser Damage motivated Vitaly Gruzdev and Michelle Shinn to volunteer again in editing another Special Section on Laser Damage III. That Special Section was published in January 2017 in volume 56, no. 1:
https://www.spiedigitallibrary.org/journals/optical-engineering/volume-56/issue-01#SpecialSectiononLaserDamageIII
It contains a record-high number of submissions (33 total) of which 28 were published. This success of the Special Section on Laser Damage III was partly due to the highly fruitful cross promotion with High Power Laser Ablation conference (HPLA) in 2016-2017. Of the 28 published papers, 8 were submitted by the HPLA authors. Of the entire Special Section, the paper of Stefan Scharring et al "Laser-based removal of irregularly shaped space debris":
https://www.spiedigitallibrary.org/journals/Optical-Engineering/volume-56/issue-01/011007/Laser-based-removal-

of-irregularly-shaped-space-debris/10.1117/1.OE.56.1.011007.full
was featured by the journal and appreciated among the best downloads.

In 2018, another Special Section on Laser Damage IV was prepared in the connection with the 50th anniversary of the conference. It was published by *Optical Engineering* in volume 57, no. 12:
https://www.spiedigitallibrary.org/journals/optical-engineering/volume-57/issue-12#SpecialSectiononLaserDamageIV
Guest Editors of that Special Section were Vitaly Gruzdev and Jonathan Arenberg. Of the 12 submissions to that Special Section, 10 were published including 3 review papers: "Laser-induced damage of nodular defects in dielectric multilayer coatings" by Jinlong Zhang et al
https://www.spiedigitallibrary.org/journals/Optical-Engineering/volume-57/issue-12/121909/Laser-induced-damage-of-nodular-defects-in-dielectric-multilayer-coatings/10.1117/1.OE.57.12.121909.short
"Ten year summary of the Boulder Damage Symposium annual thin film laser damage competition" by Christopher Stolz and Raluca Negres:
https://www.spiedigitallibrary.org/journals/Optical-Engineering/volume-57/issue-12/121910/Ten-year-summary-of-the-Boulder-Damage-Symposium-annual-thin/10.1117/1.OE.57.12.121910.short
and "Discussing defects related to nanosecond fatigue laser damage: a brief review" by Frank Wagner et al:
https://www.spiedigitallibrary.org/journals/Optical-Engineering/volume-57/issue-12/121904/Discussing-defects-related-to-nanosecond-fatigue-laser-damage--a/10.1117/1.OE.57.12.121904.full

Submission data on those published special sections on Laser Damage are summarized in Table 5. Data on citation and downloads of specific papers of those four published special sections on Laser Damage can be found in Fig. 5.

In March 2020, it is panned to publish another special section of *Optical Engineering* on Laser Damage V. Vitaly Gruzdev and Jonathan Arenberg serve as Guest Editors for this special section. The special section is open for submissions beginning mid-December 2019:
https://www.spiedigitallibrary.org/journals/optical-engineering/call-for-papers?SSO=1#LaserDamageV
As in 2018, several invited review papers will be arranged by the Guest Editors.

Table 5. 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	5
Laser Damage IV (v. 57, no. 12, 2018)	12	10	2

14. In Conclusion

The location in Broomfield, Colorado, USA at the Omni Interlocken Hotel, its facilities and support staff were appreciated. While attendees of the 51st Laser Damage Symposium were accommodated with ample opportunity to mingle and socialize, some concerns were expressed regarding that conference venue. To address them, the 52nd Symposium will be held at Hilton Garden Inn Rochester / University and Medical Center in Rochester, New York, 13-16 September 2020. By departing from the traditional location in the Boulder area of Colorado, the conference begins a cycle of nation-wide tour with a prospect of returning to Boulder, Colorado each third or fourth year. The organizers of the conference are focused on keeping the fundamental traditions of the conference while maintaining its reputation and status among the laser-damage community worldwide. The organizers hope the new venue will be highly supportive for addressing the concerns from conference attendees received from previous years.

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 in the evening on Tuesday, September 24.

The organizers of the Boulder Damage Symposium look for opportunities to join with other related groups for joint meetings in the future. Also, starting from 2009, Pacific Rim Laser Damage (PLD) conference is held annually in spring with the topics and the scope completely similar to the topics and scopes of this Symposium. We are looking forward to develop fruitful collaboration with PLD meeting in order to join our efforts.

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	1,691	0
51	12	Dec-12	120400SSR	Palm (Marciniak)	Article	7/10/12	121802	767	6
51	12	Dec-12	120367SSPR	Cho	Article	7/10/12	121803	406	1
51	12	Dec-12	120366SSPR	Cho	Article	7/10/12	121804	318	2
51	12	Dec-12	120405SSPR	Gulley	Article	6/27/12	121805	592	10
51	12	Dec-12	120382SSPRR	Wagner	Article	7/13/12	121806	318	32
51	12	Dec-12	120493SSPR	Weber	Article	7/9/12	121807	273	11
51	12	Dec-12	120375SSRR	Apostolova	Article	8/3/12	121808	381	16
51	12	Dec-12	120381SSR	Han (Li)	Article	7/19/12	121809	692	12
51	12	Dec-12	120406SSPR	Brenk (Rethfeld)	Article	8/22/12	121810	397	8
51	12	Dec-12	120468SSR	Manenkov	Article	9/18/12	121811	544	17
51	12	Dec-12	120401SSPRR	Muehlig	Article	9/14/12	121812	333	11
51	12	Dec-12	120411SSRR	Nikiforov	Article	9/20/12	121813	100	0
51	12	Dec-12	120377SSRR	Lu	Article	9/26/12	121814	420	7
51	12	Dec-12	120396SSPRRRR	Ahsan	Article	9/26/12	121815	351	15
51	12	Dec-12	120620SSPR	Komolov	Article	10/10/12	121816	335	5
51	12	Dec-12	120486SSPRR	Shen	Article	10/10/12	121817	607	24
51	12	Dec-12	120617SSPR	Stolz	Article	11/28/12	121818	601	5
51	12	Dec-12	120616SSPRR	Arenberg	Article	12/10/12	121819	111	2
							TOTAL	**9237**	**184**
53	12	Dec-14	OE-2014-1208-GED	Gruzdev and Shinn	Guest Editorial	12/22/14	122501	1,174	0
53	12	Dec-14	140177SSPR	Carreon	Article	6/11/14	122502	217	7
53	12	Dec-14	140405SSPR	Balasa	Article	7/1/14	122503	159	5
53	12	Dec-14	140509SSPR	Papernov	Article	6/25/14	122504	2,728	13
53	12	Dec-14	140527SSR	Lu (Ma)	Article	7/1/14	122505	329	7
53	12	Dec-14	140398R	Rubenchik (Wu)	Article	7/17/14	122506	502	21
53	12	Dec-14	140456SSPR	Mitchell	Article	7/23/14	122507	384	4
53	12	Dec-14	140541SSPR	Muehlig	Article	8/11/14	122508	131	0
53	12	Dec-14	140718SSR	Douti (Gallais)	Article	8/6/14	122509	372	26
53	12	Dec-14	140531SSR	Baumann (Perram)	Article	8/12/14	122510	196	6
53	12	Dec-14	140437SSPRR	Hildenbrand (Petrov)	Article	8/21/14	122511	375	15
53	12	Dec-14	140532SSPR	Gonschior (Klein)	Article	9/2/14	122512	175	1
53	12	Dec-14	140540SSR	Stratan(Zorila)	Article	10/8/14	122513	256	19
53	12	Dec-14	140712SSRR	Ding(Wang)	Article	10/6/14	122514	213	0
53	12	Dec-14	140793SSR	Gruzdev	Article	10/27/14	122515	422	7
53	12	Dec-14	140754SSPRR	Field	Article	11/6/14	122516	2,262	13
53	12	Dec-14	140756SSR	Arenberg	Article	12/2/14	122517	1,478	2
							TOTAL	**11373**	**146**
56	1	Jan-17	OE-2017-0111-GED	Shinn and Gruzdev	Guest Editorial	1/23/17	011000	1,017	0
56	1	Jan-17	151769SSR	Hervy (Gallais)	Article	6/30/16	011001	1,190	8
56	1	Jan-17	160321SSPR	Field	Article	7/8/16	011002	1,658	5
56	1	Jan-17	160429SSPRR	Zhu	Article	7/11/16	011003	277	0
56	1	Jan-17	160551SSPR	Papernov	Article	7/15/16	011004	303	2
56	1	Jan-17	160320SSPR	Field	Article	7/15/16	011005	1,445	4
56	1	Jan-17	160594SSPR	Muehlig	Article	7/18/16	011006	137	0
56	1	Jan-17	160631SSR	Scharring	Article	8/1/16	011007	5,198	15
56	1	Jan-17	160697SSPR	Negres	Article	8/1/16	011008	2,346	15
56	1	Jan-17	160565SSRR	Shen (Jiang)	Article	8/3/16	011009	233	1
56	1	Jan-17	160739SSR	Lorbeer	Article	8/15/16	011010	1,517	4
56	1	Jan-17	160549SSR	Han (Feng)	Article	9/8/16	011011	219	1
56	1	Jan-17	160635SSPRR	Bellum	Article	8/25/16	011012	1,750	6
56	1	Jan-17	160694SSR	Phillips (Perram)	Article	8/26/16	011013	154	5
56	1	Jan-17	160835SSR	Bardy	Article	8/29/16	011014	354	30
56	1	Jan-17	160848SSR	Raemer	Article	9/8/16	011015	245	4
56	1	Jan-17	160617SSPR	Demos	Article	9/8/16	011016	1,233	5
56	1	Jan-17	160914SSR	Bauer (Perram)	Article	9/20/16	011017	142	5
56	1	Jan-17	160686SSPR	Field	Article	9/21/16	011018	1,967	5
56	1	Jan-17	160810SSRR	Xu (Emmert)	Article	10/12/16	011019	214	3
56	1	Jan-17	160636SSPRR	Bellum	Article	10/12/16	011020	1,197	5
56	1	Jan-17	161045SSPR	Jiao	Article	10/13/16	011021	131	9
56	1	Jan-17	160864SSR	Doualle (Gallais)	Article	10/17/16	011022	212	9
56	1	Jan-17	160796SSR	Gehring	Article	10/25/16	011023	118	2
56	1	Jan-17	160863SSPR	Durak (Velpula)	Article	11/4/16	011024	210	3
56	1	Jan-17	161048SSR	Saripalli	Article	11/7/16	011025	125	1
56	1	Jan-17	160970SSRR	Sun	Article	11/30/16	011026	336	9
56	1	Jan-17	160821SSRR	Ma (Cheng)	Article	12/8/16	011027	165	4
56	1	Jan-17	160855SSPR	Qiu	Article	10/24/16	011108	1,183	5
							TOTAL	**25276**	**165**
57	12	Dec-18	2018-1218-LaserDam	Gruzdev and Arenberg	Guest Editorial	1/3/19	121901	1,259	0
57	12	Dec-18	180121SSPRR	Zhu	Article	9/11/18	121902	183	2
57	12	Dec-18	180229SSRR	Gebrayel	Article	9/11/18	121903	228	3
57	12	Dec-18	180630SSR	Wagner	Article	9/13/18	121904	1,006	1
57	12	Dec-18	180519SSRR	Liu	Article	9/24/18	121905	143	1
57	12	Dec-18	180628SSRR	Wilson	Article	11/8/18	121906	242	1
57	12	Dec-18	180603SSRR	Muehlig	Article	10/30/18	121907	97	0
57	12	Dec-18	181020SSR	Li (Zhao)	Article	12/18/18	121908	117	3
57	12	Dec-18	180631SSRR	Zhang (Cheng)	Article	12/12/18	121909	201	5
57	12	Dec-18	181015SSR	Stolz	Article	12/18/18	121910	229	5
57	12	Dec-18	180742SSR	Shi	Article	1/3/19	121911	117	0
							TOTAL	**2676**	**21**
							GRAND TOTAL	**48562**	**495**

Figure 5. Download and citation data for the Special Sections on Laser Damage according to the data as of January 10, 2020.

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