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Proceedings

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Christopher Wren Carr, Vitaly E. Gruzdev, Detlev Ristau, Carmen S. Menoni

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Symposium Welcome

on the occasion of the Annual Laser Damage Symposium – Fifty Third Annual Symposium on Optical Materials for High Power Lasers

Vitaly Gruzdev
Department of Physics and Astronomy, University of New Mexico (USA)

On behalf of co-chairs of this conference, Cristopher Wren Carr, Carmen S. Menoni, Detlev Ristau, our Emeritus co-chair, M. J. Soileau, and me, Vitaly Gruzdev, I am delighted to welcome all presenters and participants to the 53^{d} Laser Damage Symposium also known as Boulder Damage Symposium or Annual Symposium on Optical Materials for High-Power Lasers! The name of this conference is associated with the location of more than 45 meetings of the Symposium held in Boulder – a beautiful city right at the foothills of the Rocky Mountains in Colorado, USA. Traditionally held at the NIST facility in Boulder, Colorado over last decades, the conference relocated to Millennium Harvest House Hotel in the central part Boulder in 2015. At that Hotel, the 50th anniversary of the conference was celebrated in 2018. In 2019, the conference was hosted by Omni Interlocken Hotel in Broomfield, which is not located directly in Boulder, but still in the Boulder area. The plans of the conference co-chairs to further promote the travel of the conference across the USA and hold the meeting of 2020 in Rochester, New York were altered by the COVID-19 pandemics. In 2020, the conference was successfully held in the format of digital forum thanks to the brilliant technical assistance of SPIE. To address still existing safety concerns related to COVID-19 and the travel limitations that continue affecting many our colleagues worldwide, co-chairs have decided to run this year's Symposium in the digital format one more time. It was not an easy decision since this format does not fit some important traditions of the conference as well as reduces opportunities for networking. For example, it is already the second year when we cannot take a traditional group photo of conference participants and network during a Wine & Cheese testing. However, the digital format of the conference helps to keep the laser-damage community connected and vibrant, provides a good platform for exchange of new results and ideas, and assists with keeping our research network live and prepared for switching back to the usual in-person format in 2022.

This Symposium was founded by Arthur Guenther and Alexander Glass in 1969 to bring together scientists and engineers of a newly evolving laser community to both understand and subsequently mediate a specific problem: why and how high energy laser radiation damages transparent optical elements, e. g., glass lenses that are assumed to have negligible absorption at laser wavelength. Detailed analysis of this "small issue" rapidly drove researchers to recognizing the need for a multidisciplinary approach and the need to engage scientists from diverse technical and scientific areas including laser science and optics, solid-state physics, materials science, and chemistry. As the damage issue began to be investigated, subtler aspects of the problem were uncovered and brought to the attention of both fundamental and applied laser researchers as well as laser engineers. Within a few years following the first meeting, this conference became one of the major international venues for lively discussions of high-intensity laser-material interactions and communications among researchers and engineers from academics, industry, national laboratory staff, and the military.

What looked as a "small issue" at the early years of this conference is now recognized as a highly non-trivial research and technical challenge that affects key developments in many areas of strategic importance worldwide, e. g., development of laser ignition facilities and petawatt laser facilities. The vitality of the problem of laser-induced damage is evidenced by new participants joining a core of laser damage specialists each year as well as a stable number of conference presentations and papers published annually in the Proceedings of Laser Damage Symposium. Research in this area is continuously motivated by a quest to understand the process of laser interaction with transparent and multi-layer materials as well as polished surfaces as laser parameters tend toward shorter pulses, shorter wavelengths, and higher powers. The need of both applied and basic research in this field is driven by the design and development of novel lasers; novel optical materials; and, operation of traditional lasers in challenging ambient environments. Availability of large-scale and table-top ultrafast laser systems has made a significant push on this research area by enabling 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 continuously delivers new optical materials with potential for use in high-power and high-energy laser systems. The field of laser damage continues to attract the attention of researchers, engineers, scholars, industry, and funding agencies based upon innovative developments in optics, materials properties modification, and beam-solid interactions.

To support the continuing progress in understanding the laser damage process and advancing damage thresholds, it is important to have access to the massive data on laser damage accumulated since 1969 in this area. The Boulder Damage Symposium (BDS) Proceedings first published by the National Institute of Standards and Technology (NIST) and then by SPIE have become the most complete and heavily subscribed resource focused on all aspects of laser damage and physics of laser-material interactions that has ever been compiled in this area. A collection of the Proceedings (from 1969 to 2008 inclusive) published by SPIE in a single DVD was later supplemented by another DVD with Proceedings papers published from 2009 through 2014 inclusive. Now, the Proceedings of Laser Damage Symposium of all years are available via SPIE's Digital Library service. The organizers are grateful to the authors of Proceedings papers for their contributions to this publication. In addition to the conference Proceedings, selected papers have been published in several Special Sections on Laser Damage of *Optical Engineering* – the flagship journal of SPIE:

Laser Damage section in December 2012 (v. 51, No. 12),

Laser Damage II section in December 2014 (v. 53, N. 12),

Laser Damage III section in January 2017 (v. 56, N.1),

Laser Damage IV section in December 2018 (v. 57, N.12),

Laser Damage V section in March 2021 (v. **60**, No. 3),

Laser Damage VI section in July 2022 (v. **61**, No. 7 – to appear).

The work of Guest Editors of those Special Sections – Vitaly Gruzdev and Michelle Shin (sections from I to III), and Vitaly Gruzdv and Jonathan Arenberg (sections from IV through VI) – is greatly appreciated.

Significant contribution to the success of this conference is made by the International Program Committee (IPC) comprised of eminent researchers from the key international research centres and groups involved into laser-damage research worldwide. This committee has significantly contributed to developing the content of the symposium program through identification of leading experts and inviting them to speak on the topics of high interest for the laser-damage community. Presently, the IPC consists of representatives from the United States of America, Germany, France, Japan, China, Lithuania, and the UK. 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 research activities discussed at this symposium. As a good example, I would refer to the development and recent revision of the International Standard on measurement of laser-damage threshold. Tremendous efforts of the IPC Chair – Dr. Detlev Ristau of Laser Zentrum Hannover (Germany) – to keep IPC actively engaged are greatly acknowledged.

Following the 52-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 specific topic in laser material interaction has been organised every year since 1992. This year, a mini-symposium "Mid-infrared materials, lasers, and laser-induced effects" is chaired by Dr. Vitaly Gruzdev, University of New Mexico, USA and Dr. Konstantin Vodoyanov, CREOL, University of Central Florida, USA.

Continuing the success of the damage competition held for the first time in 2008, Chris Stolz and Raluca Negres (both of Lawrence Livermore National Laboratory, USA) have successfully organized another competition that pursues the topic of the previous year. This year's competition considers multilayer laser mirrors for femtosecond pulse operation at 515 nm. This competition is a continuation from last year's one done on similar mirrors with nanosecond pulses at 532 nm in order to check the performance contrast in two different pulse-length regimes. Companies and research institutes from China, Japan, Germany, and the United States of America have submitted multiple samples for analysis. Damage tests with 200-fs pulses were done at the LIDARIS test facility in Lithuania. The effort of the facility team lead by Andrius Melninkaitis is greatly appreciated. Raluca presents the competition results and has prepared a summary paper that can be found in the present volume of the conference proceedings.

One of the early traditions of the Symposium is a tutorial that is usually held as a pre-conference Sunday event. The change of the conference format from in-person to digital has forced us to run the tutorial as a final conference event on Friday,

October 15. The tutorial is focused on use of machine learning for managing Laser Damage and will be delivered by Laura Mascio-Kegelmeyer, Lawrence Livermore National Lab, USA. Laura's effort and contribution to the Symposium is gratefully acknowledged.

The Digital format of the Symposium has affected the regular structure of the conference. Presentations of the Symposium are scheduled within 4 days with two live sessions in the morning and two live sessions in the evening. Each live session consists of a keynote talk on one of the four major topic areas of the symposium and a question-answer session for oral presentations of specific topic. Presentations of the Mini-Symposium including the invited talk by Konstantin Vodopuyanov are scheduled for the morning session of Thursday, October 14. Pre-recorded presentations are available for registered conference participants 2 days prior to the official beginning of the conference. The live sessions are organized and timed so as to address the specific time-zone difference between European and Asian participants of the conference. Presenters of posters have the opportunity to deliver 5-minute overviews of their posters within two live sessions. Also, an all-conference virtual networking event is scheduled on Thursday morning.

Another tradition of the symposium is to acknowledge the best presentations that described significant results at the previous year's meeting. 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. Winners of each of the awards receive a honorarium 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. In 2020, no presentations were awarded since it was the first year of our experience with digital format of the conference, and the switch of the conference format significantly affected all presenters. This year, we resumed this tradition, and three presentations will be awarded in the following categories:

- THE ALEXANDER GLASS BEST ORAL PRESENTATION AWARD for the best regular talk;
- THE ARTHUR GUENTHER BEST POSTER AWARD for the best poster presentation;
- THE MJ SOILEAU BEST STUDENT PAPER AWARD for the best oral or poster presentation delivered by a registered student participant.

The bestowal ceremony for the winners of this year's conference will takes place at the beginning of the next Symposium in 2022.

Much of the success of this meeting is attributed to the untiring efforts of the conference SPIE staff: Diane Cline (SPIE, Symposium Secretary), Dawn Jackson (SPIE), Shari Nephew (SPIE), Scott Calhoun (SPIE), and Rob Whitner (SPIE). We especially appreciate the multi-year effort of Diane Cline (SPIE) who retired from SPIE at the end of 2021. Rob Whitner becomes a Symposium Secretary staring from 2022. We gratefully appreciate our annual co-sponsor, Lawrence Livermore National Laboratory. The contribution of LIDARIS and Andrius Melninkaitis for performing the laser damage tests for the annual laser-damage thin-film competition is greatly appreciated. We acknowledge the cooperating organizations: Lawrence Livermore National Laboratory; School of Optics – CREOL and FPCE, College of Optics and Photonics, University of Central Florida; Laser Zentrum Hannover; and University of New Mexico. We especially acknowledge support of our sponsors this year: Lawrence Livermore National Laboratory; LIDARIS LIDT Service;NEXTCORPS LUMINATE; Optimax; Plymouth Grating Laboratory; Spica Technologies Inc.; Ultrafast Innovations; Laboratory for Laser Energetics, University of Rochester; Arrow Thin Films; Laser Components; and Kaufman & Robinson The Ion Beam Authority.

Finally, we acknowledge the tremendous work of the conference co-chairs who have done their best to keep the conference running and make it successful during the highly challenging period of COVID-19 pandemics. We note that Vitaly Gruzdev departs from the brilliant team of Laser Damage symposium co-chairs in 2022 to support rotation and renewal of the team. Finally, we thank all participants of the conference for their contributions and participation in this Symposium.

Summary of Meeting

Laser Damage Symposium:
53d Annual Symposium on Optical Materials for High Power Laser
(aka Boulder Damage Symposium)
12-15 October 2021

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ABSTRACT

These proceedings contain the papers delivered as oral and poster presentations at the 53d annual Laser Damage Symposium (aka Annual Symposium on Optical Materials for High-Power Lasers, also Boulder Damage Symposium). As in 2020, because of the COVID-19 pandemics, the conference was held in the format of digital forum on 12-15 October 2021. The symposium was divided into 11 live Zoom sessions 1.5 hours each. The traditional days of the symposium (Sunday evening through Wednesday) were changed, and the online sessions of the Symposium began on Tuesday and finished on Friday morning. Scope of the conference followed the traditional four major topics: Thin Films; Surfaces, Mirrors and Contamination; Fundamental Mechanisms; Materials and Measurements. A Mini-Symposium was devoted to overview of mid-infrared optical materials, lasers, and laser effects including laser-induced damage. A Tutorial on applications of machine learning for managing laser damage was held by Laura Mascio-Kegelmeyer, Lawrence Livermore National Lab (USA) as a final symposium event on Friday morning. The conference was opened by Vitaly Gruzdev 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.

70 abstracts were submitted to the symposium and included into the conference program, of which 39 were delivered as pre-recorded or live oral presentations, and 10 were presented at virtual poster sessions. 21 accepted presentations were not delivered. Each poster presenter did have an opportunity to pre-record a 2-minute overview that was demonstrated during live poster sessions and was followed by questions and answers. All pre-recorded talks and posters were published online and made available to registered conference participants via SPIE Digital Library two days prior to the conference to allow advance preparation of questions for live Question-and-Answer sessions. With 136 registered on-line participants, 18 of which were students, the meeting attendance was above the average level over the last decade, although it was almost 2.5-time reduction of online registrations compared to the meeting of 2020 with 426 registered participants. However, the number of presented talks and posters significantly advanced this year compared to 2020.

The program was split between 11 virtual sessions with two morning (Tuesday through Thursday) and two afternoon (Tuesday and Wednesday) sessions to provide better opportunities for participants from diverse time zones. The online sessions accommodated live keynote talks followed by questions and answers, live Question-and-Answer sessions for oral presentations, and overview and discussion of posters. Of two Thursday morning sessions, one contained live (not pre-recorded) presentations from the Mini-Symposium, and the other was completely devoted to all-conference networking. The Friday morning session accommodated the Tutorial and conference closing. Maximum online attendance was at the first Tuesday morning session (73 participants) that accommodated the Welcome talk, conference opening, and two keynote talks. Attendance of other online sessions varied from 25 to 65 people, with average about 50 attendees per session. Spanning of the conference participants over multiple time zones was one of major challenges for scheduling the online sessions. To address it, all live presentations were

recorded by SPIE and made available via SPIE Digital Library within 24 hours after each conference day. In spite of the challenges, the conference offered attendees a good opportunity to network and make many new acquaintances. Although held annually in the US, Laser Damage Symposium continues to be a true international conference with 73 registered attendees and 32 presentations from North America, 49 attendees and 30 presentations from Europe, and 11 attendees with 8 presentations from Asia this year. For comparison, the virtual meeting of the Symposium in 2020 was attended by 255 registered participants from North America, 153 from Europe, and 28 from Asia.

The 54th Annual Symposium of this series will be held in the traditional in-person format in Hilton Garden Inn Rochester / University and Medical Center in Rochester, New York, 18-21 September 2022. In response to feedback of conference participants, the 54th and following meetings are planned to travel between East-Coast and West-Coast US cities with a plan to return to Boulder (Colorado) each third year. 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. The mini-symposium of the 2022 meeting will be on Application of Metasurface Optics for use with High-Power Lasers.

The principal topics to be considered in 2022 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. 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. Two significant novel trends include the growing number of presentations on few-cycle laser pulses and PW-class laser facilities with discussion of various LID-related aspects of development and operation of those huge lasers. We also expect to hear more about new measurement techniques including time-resolved pump-probe methods 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 nanostructured surfaces and meta-optic materials, and related laser-damage issues attract growing attention due to their intensive development and potential use in high-power lasers to replace thin films. 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 delivered keynote presentations of a tutorial and review nature during the live online sessions in 2021. Invited contributors covered recent breaking developments in the four key areas of the research on laser-induced damage and optical materials for high-power lasers. A keynote talk of the Mini-Symposium was delivered by Konstantin Vodopyanov (CREOL, University of Central Florida, USA) and was devoted to nonlinear optical response of semiconductors to ultrashort mid-infrared laser pulses. Continuing the recent conference tradition, a tutorial on applications of machine learning for managing laser damage was held by Laura Mascio-Kegelmeyer (Lawrence Livermore National Lab, USA).

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 – 53[d] 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 12-15 October 2021 online in the format of digital forum. This choice of the conference format was a difficult decision of co-chairs done to address the existing safety concerns related to the COVID-19 pandemics and the travel limitations that affected many our colleagues worldwide. 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 136 registered representatives of academia, industry, national research laboratories and centers from 11 countries including USA, Germany, China, Japan, France, Lithuania, Czech Republic, Hungary, Russia, United Kingdom, and Switzerland. Compared to the anomalously high number of 426 registered participants for the Laser Damage Symposium held as a digital forum in 2020, this year the number of participants was close to the average level (Fig. 1). Countries of North America, Europe, and Asia were represented at the conference in 2021 with no participants from other continents (Fig. 2).

The total of 70 abstracts were submitted to the Symposium, they were all included into the final program. Of them, 50 were delivered within the traditional 3-day format of the meeting including 40 oral and 10 poster presentations. Both the number of submissions and number of delivered presentations were appreciably higher than last year. This fact correlates with reduction of the COVID-19 pandemics and slow returning to the usual style of life. The reduced number of presentations was favorable for splitting them into 11 virtual sessions with 4 sessions on Tuesday and Wednesday, 2 sessions of Thursday morning, and 1 session on Friday morning.

Although, held annually in the US, this is a truly International conference with 45.4% of the attendees and 54.3% of the presentations coming from Europe and Asia 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 use of artificial intelligence and machine learning to predict laser-damage events on large-scale pieces of optics and was brilliantly delivered by Dr. Laura Mascio-Kegelmeyer (Lawrence Livermore National Lab, USA) in the morning virtual session of Friday as the final conference event. The conference began on Tuesday, 12 October 2021 with a welcome talk delivered by Dr. Vitaly Gruzdev (University of New Mexico, USA) in live format. The Welcome talk was followed by two keynote talks.

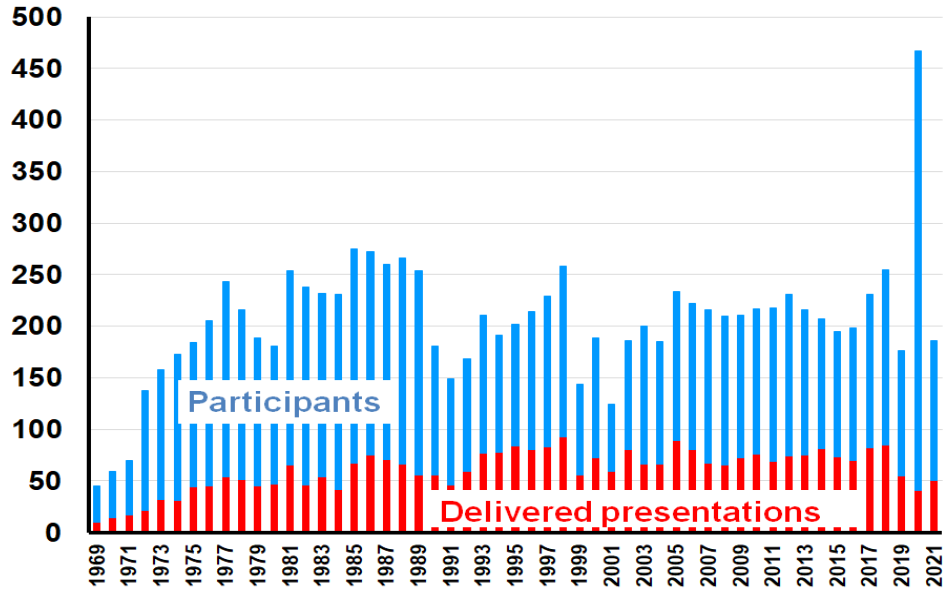

Fig. 1. Registered participants (blue) and number of presented papers (red) vs year from 1969 through 2021 inclusive.

2. Symposium Co-Chairs

The Boulder Damage Symposium was founded by Dr. A. H. Guenther and Dr. Alexander Glass. Over the last 53 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.
2022	V. E. Gruzdev departs, no new co-chairs added.

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
Eyal Feigenbaum	Lawrence Livermore National Laboratory	USA
Ella S. Field	Sandia National Laboratory	USA
Lars O. Jensen	Laser Zentrum Hannover e. V.	Germany
Takahisa Jitsuno	Osaka University	Japan
Laurent Lamaignere	CEA	France
Klaus Mann	Laser-Laboratory Gottingen e. V.	Germany
Andrius Melninkaitis	Vilnius University	Lithuania
Jean-Yves Natoli	Institut Fresnel	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
Christopher Stolz	Lawrence Livermore National Laboratory	USA
Meiping Zhu	Shanghai Institute of Optics and Fine Mechanics	China

4. Pre-symposium event: Tutorial

Symposium Tutorial is the newest Symposium event introduced for the first time in 2014. That first 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 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. It 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 2019 meeting. In 2020, pandemics of COVID-19 substantially changed our plans, and the tutorial was cancelled.

This year, the Tutorial featured applications of artificial intelligence and machine learning to predict laser-damage events on large-scale pieces of optics and was entitled "Practical guide to machine learning for managing Laser Damage". The tutorial was brilliantly delivered by Dr. Laura Mascio-Kegelmeyer (Lawrence Livermore National Lab, USA) in the morning virtual session of Friday as the final conference event. It attracted 34 registered conference participants and received brilliant feedback.

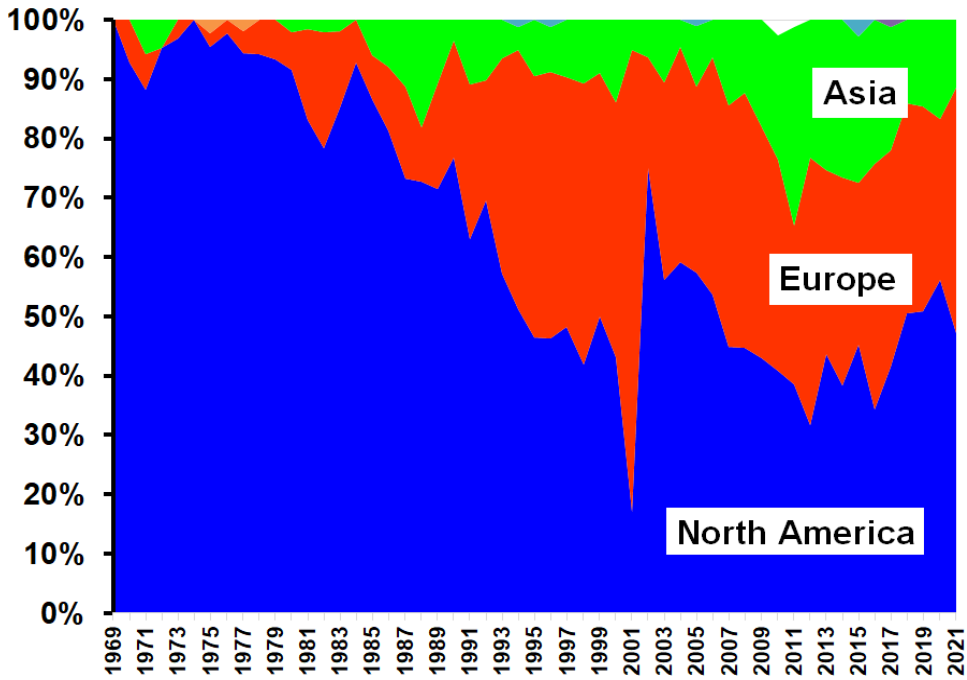

Fig. 2. Continent-distribution chart of the presentations delivered at the conference vs year from 1969 through 2021 inclusive. Tiny areas at the top part of the chart depict minor representations from Africa and Australia.

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. The specific topics of 2021 include: beam-size influence on thresholds of LID by sub-picosecond laser pulses; use of xenon to densify hafnia films; design optimization of multilayer dielectric (MLD) mirrors and diffraction gratings to suppress LID by sub-picosecond pulses; hybrid MLD mirrors for deep-UV wavelengths produced by free-electron lasers; evaluation of material properties of hafnia and silica utilized in MLD final mirrors of the National Ignition Facility (NIF); characterization of LID thresholds of silicon oxynitride films deposited by ion beam sputtering; influence of oxygen partial pressure on properties of alumina films; characterization of high-reflecting and anti-reflecting coatings for high-average-power picosecond pulses; thermal effects in LID of MLD mirrors and gratings; approaches to control LID of multilayer coatings by modification of spatio-temporal structure of femtosecond pulses; and use of spatial plasma-enhanced atomic layer deposition to produce high-LID-threshold coatings. From posters, we did learn about dynamic modeling of femtosecond LID in MLD gratings; influence of relative humidity during coating deposition of LID threshold of hafnia-silica coatings at 532 and 1064 nm; novel approaches to treatment of surfaces prior to coating deposition for space applications; design of dispersion mirrors for high-power ultrafast lasers; degradation of coatings subjected to action of burst-mode femtosecond laser pulses at 515 nm; development of durable coatings for pico-second laser at 266 nm; pulse-width scaling of LID threshold deposited on LBO crystals at IR and UV wavelengths; and improvement of environmental stability of sol-gel coatings.

Oxide films including hafnia and silica continued to attract major attention in the field of thin-film materials. Major attention is traditionally paid to coatings at 1064 nm, 1030 nm, 800nm, 780 nm, 532 nm, and 355 nm, but also novel results are reported at 515 nm, 266 nm, and sub-140 nm. Damage of multilayer coatings by sub-picosecond pulses is another significant focus this section with strong trend towards studies of coatings for few-cycle pulses. Significant attention is paid to the laser-damage issues in multilayer coatings of large-scale optics of high-power laser facilities and to influence of ambient conditions on coating properties during deposition process. 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.

This year, invited talk of Dr. Vladimir Pervak (Ludwig-Maximilians-Univ. München, Germany) overviewed ultrafast nonlinear effects induced in dispersive multilayer mirrors at peak intensity slightly below damage threshold. The overview also considered approaches to employ or mitigate those effects. The dispersive high-reflecting coatings frequently play a key role in generation of few-cycle laser pulses since dispersion can substantially affect their structure. This year, 23 submissions including 14 talks and 9 posters were accepted for presentation within this topic making this section the second largest one among the four major topics of the conference. The steady high level of submissions to this section of the conference confirms a strong non-decaying interest of the optical-coating community to various laser-damage issues (Figs. 3 and 4).

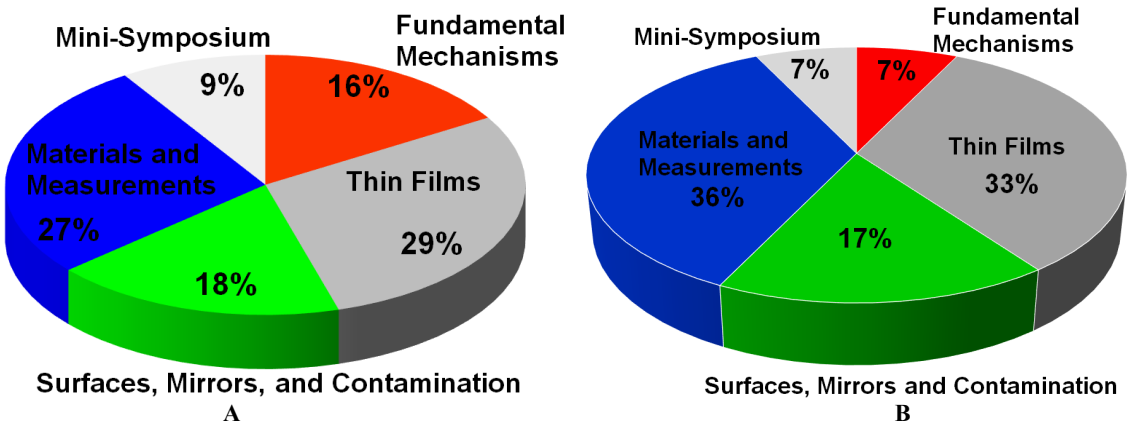

Fig. 3. Distribution of presentations of the 51st Laser Damage Symposium in 2019 (A) and 53d Symposium in 2021 (B) by key topics. Numbers show percentage of presentations of specific topics.

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. In 2020, the competition was focused on the mirrors for nanosecond laser pulses at 532 nm at normal incidence. This year's competition continued last year's damage competition theme which surveyed state-of-the-art VIS high reflectors in the nanosecond regime to fill in the trends in damage resistance vs. wavelength vs. pulse duration. Mirrors submitted to damage tests were required to meet a minimum reflection of 99.5% at normal incidence for 515-nm light. The participants of this effort did have freedom to select the coating materials, coating design, and deposition method. A selection of samples received in 2020 and new sample submissions in 2021 were damage tested using the raster scan method with a 200-fs pulse length laser system operating at 5 kHz. Experiments were performed at the laser-damage testing facility of LIDARIS (Lithuania) to enable not only direct comparison among the participants, but also the performance contrast in two different pulse length regimes. The effort of the facility team lead by Dr. Andrius Melninkaitis is especially acknowledged for their substantial contribution to the success of this year's competition.

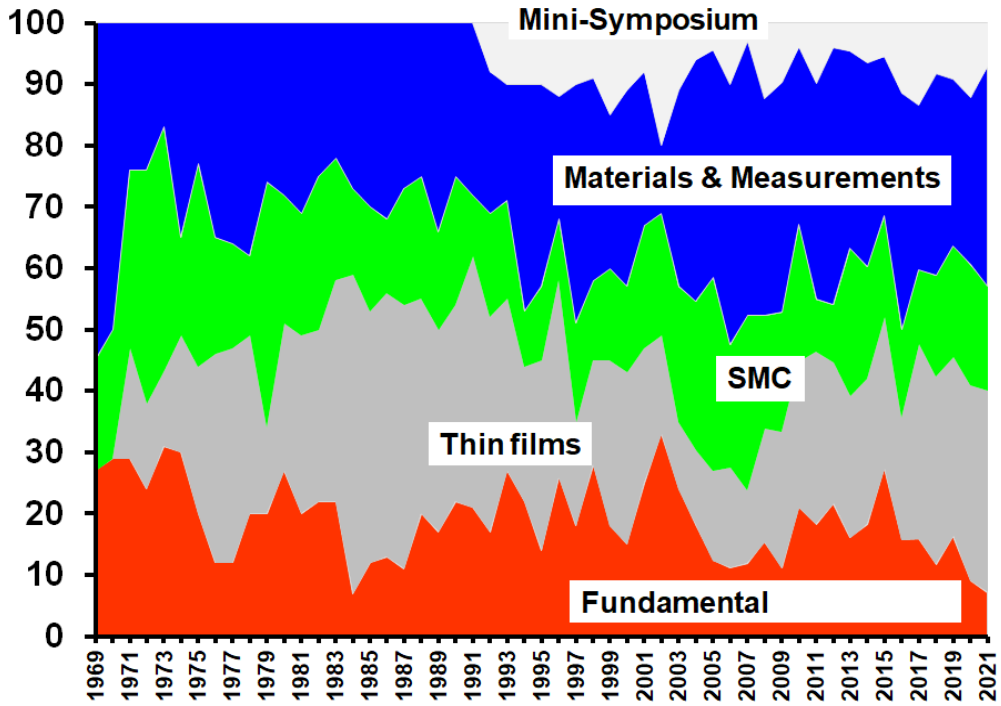

Fig. 4. Distribution of presentations over four major topics and mini-symposium vs year from 1969 through 2021 inclusive. The vertical axis shows percentage of presentations of the major conference section.

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 Wednesday (October 13) in the talk entitled "515-nm, femtosecond laser mirror thin film damage competition".

The Table 3 below summarizes the 11 damage-test competitions performed from 2008 to 2021 inclusive.

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, all submissions of this topical area were devoted to ultrafast / sub-picosecond laser-material interactions and ultrashort-pulse laser effect. We learned about use of particle-in-cell method to model LID of multilayer coating by few-cycle pulses; pulse-width scaling of LID threshold of metal coatings characterized within 15 orders of magnitude; interactions of tightly-focused mid-infrared laser pulses with bulk optical materials; and time-resolved studies of LID of single-crystal YAG by femtosecond pulses. The presentations considered nonlinear absorption, free-carrier generation, and initiation of LID in multilayer stacks as well as typical dielectrics and semiconductors. Continuous efforts were made to characterize the fundamental mechanisms of laser damage in fused silica, hafnia, and titania as the most popular optical materials. Major attention was paid to modeling of laser-material interactions including nonlinear absorption, free-carrier generation, and dynamics of material removal. The invited talk was delivered by Dr. Leonid V. Zhigilei (Univ. of Virginia, USA). It provided a detailed overviewed of molecular-dynamics simulations focused on dynamics of formation of different phases of matter during ablation of solid surfaces in liquids by sub-picosecond laser pulses. With one poster and 4 oral presentations delivered at the meeting, this area was the smallest among the 4 major topics of the Symposium (Figs. 3, 4). This fact signals about substantial reduction of interest to the fundamental effects and mechanisms of the laser-matter interactions related to laser damage.

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
2020	532-nm nanosecond laser mirror thin films at normal incidence
2021	515-nm, femtosecond laser mirror thin films at normal incidence

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, oral presentations of this topical area addressed embedded chemical contamination of MLD diffraction gratings manufactured by e-beam deposited silica and its role as possible precursor of LID; use of line scan camera to detect contamination of protective windows in laser powder bed fusion; the factors that control durability of dielectric-enhanced aluminum mirrors; sculpturing of the surface of thin films of all-silica mirrors for high-power

applications; and the physical mechanisms that background applications of low-pressure plasma to remove organic contamination from silica sol-gel antireflection films. From posters of this section, we learned about influence of polishing conditions of threshold of surface LID of SrB_4O_7 crystals; analysis of LID morphology of fused-silica surface with enhanced LID resistance after magnetic-field assisted polishing; formation of laser-induced contamination on dielectric coatings by sub-picosecond laser pulses at 515 nm at MHz repetition rate; characterization of particle density of ultrasonically cleaned substrates by LID testing methods; fabrication of shadowers with optimized topography by pulsed CO_2 laser; and ultra-sensitive laser-based detection of surface contamination for space applications.

A very remarkable amount of papers dealt with fused-silica surfaces subjected to action of multiple (from 2 to billion) laser pulses. Also, a significant amount of papers was focused on influence of surface contamination of various types on threshold and morphology of surface laser-induced damage. The keynote talk was delivered by Dr. Joseph J. Talghader (Univ. of Minnesota, Twin Cities, USA) and featured the interaction of continuous-wave radiation with contamination particles on optical surfaces as next to them (in air). It was demonstrated that the tiny dust particles can be accelerated towards the surfaces by inhomogeneous heating followed by dominating plasma emission from the side that first meets a laser beam. With 6 accepted oral and 6 accepted poster presentations, this key area shows substantially increased this year as compared to 2018, 2019, and 2020 (Fig. 3) with a steady trend to growth over last 8 years (Fig. 4).

9. Materials and Measurements

Among the four main sections of the conference, this one continuously stays 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 topics of oral presentations were online monitoring of damage growth on optics of the National Ignition Facility (NIF) due to CCD blooming; impact of intensity fluctuations on initiation and growth of LID; development of large-area input shadowers with intricate geometry to suppress growth of exit-surface damage on fused silica; experiments required to support the proposed US National Damage Standard; analysis of distribution of lifetime for dielectric and metallic mirrors; theoretical analysis of accumulated probability of LID-site growth at NIF; use of Optical Science Laser for damage testing at NIF; methods and apparatus for characterization of LID and functional performance of ultrafast laser optics; comparative study of generation of UV defects in UV-grade fibers induced by different lasers and broad-band sources; fatigue testing of optics at UV wavelengths; influence of grain-boundary density of ZnSe polycrystalline samples on LID by few-cycle laser pulses; analysis of bulk LID threshold variations in fused silica from the view-point of material developers; influence of temporal pulse modulations on LID of silica optics at 351 nm in nanosecond regime; and influence of polarization handedness and ellipticity of nanosecond laser pulses on LID of oriented liquid crystals. The posters were devoted to applications of post-processing and beam blockers to improve final optics of the LaserMegaJoule (LMJ) facility; study of LID threshold of thin nematic liquid crystals damaged by femtosecond pulses; high-speed imaging of photoresist stripping produced by laser radiation without damaging the substrate surface; degradation phenomena and photo-luminescence of silica glass irradiated by lasers at 266 nm; LID metrology with small and large beams on a unique testbed; MELBA setup to characterize impact of laser-pulse parameters on LID at UV wavelengths in nanosecond regime; development of a new laser bench to study optical materials under high fluence; lifetime of large-area purified nematic liquid crystals irradiated by multiple infrared laser pulses; and use of multi-pass lock-in thermography to measure absorption of optical coatings. As usually, multiple presentations were focused on measurements of laser-damage threshold in various materials including fused silica, liquid crystals, and multilayer high reflectors. A fair amount of talks was devoted to new or improved test facilities / setups to measure laser-induced damage threshold and characterize optical properties of materials. 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. Substantial attention was again paid to UV lasers. The invited talk delivered by Dr. Tanya Z. Kosc (Laboratory for Laser Energetics, University of Rochester, USA) featured approaches to minimize risk of LID of large-aperture KDP/DKDP crystals by transverse stimulated Raman scattering. With 15 accepted oral and 10 accepted poster presentations (25 total), this topical section was the largest in the conference program of 2021 (Fig. 3).

10. Mini-Symposium

This year, the Mini-Symposium was focused on materials, laser effects, and high-intensity laser-matter interactions at mid-infrared (MIR) wavelengths. The topic was motivated by rather low representation of recent developments in the field of MIR lasers and optical materials at Laser Damage Symposium. Meanwhile, specialized conferences, e. g., OSA's Advanced Solid State Lasers pay very significant attention to the progress in that wavelength range. On the other hand, the MIR laser community has met many LID-related issues that are familiar to the laser-damage community from other wavelength ranges. Therefore, there was a need to engage the laser-damage and MIR laser communities. Vitaly Gruzdev (University of New Mexico, USA) and Konstantin Vodopyanov (CREOL, University of Central Florida, USA) volunteered to organize this Mini-Symposium, and contributed a lot of energy and enthusiasm to this event. The Mini-Symposium hosted 5 talks delivered in live format on Thursday morning including the invited talk by Dr. Konstantin Vodopyanov (CREOL- The College of Optics and Photonics, University of Central Florida, USA). It overviewed nonlinear absorption and free-carrier generation in typical semiconductors (e. g., ZnSe and GaP) by femtosecond MIR laser pulses. Reported experimental data did not receive reasonable fit by the traditional models, e. g., the Drude model for free electrons. This fact gave a reason to discuss possible special regimes of MIR ultrafast laser-material interactions.

A brief summary of the past mini-symposium topics starting from 1992 and the organizing chairs is listed below in Table 4. In 2020, the Mini-Symposium was devoted to ceramics and glasses and was organized and chaired by by Dr. Shanmugavelayutham K. Sundaram (New York State College of Ceramics, Alfred University, USA). It hosted 6 oral presentations on the topics related to structure, properties, and laser interactions of glasses and ceramics with emphasis on potential use of those materials in high-power and high-energy lasers. A Mini-Symposium of the 2022 Laser Damage meeting on applications of metasurface optics in high-power lasers will be organized by Dr. Eyal Fengenbaum (Lawrence Livermore National Laboratory, USA).

11. Keynote and Invited Presentations

As usually, the 53^{d} Laser Damage Symposium was highlighted by four keynote presentations in the four major topical areas of the conference:

1. "Limitation of dispersive optics for ultrafast physics", **Vladimir Pervak**, Ludwig-Maximilians-Universitat München (Germany) – area of Thin Films.
2. "The impact of surface particulates and laser-accelerated particles on continuous-wave laser damage", **Joseph J. Talghader**, University of Minnesota, Twin Cities (USA) – the area of Surfaces, Mirrors, and Contamination.
3. "Atomistic simulations of nanoparticle generation and surface modification by short pulse laser ablation in liquid environment", **Leonid V. Zhigilei**, University of Virginia (USA) – the area of Fundamental Mechanisms.
4. "Minimizing risk for laser damage due to transverse stimulated Raman scattering in large-aperture KDP/DKDP plates for polarization control at 3w", **Tanya Z. Kosc**, Laboratory for Laser Energetics, University of Rochester (United States) – the area of Materials and Measurements.

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

"Mid-IR high-order multiphoton absorption and nonlinear refraction in GaP, ZnSe, GaSe, and ZGP crystals", **Konstantin Vodopyanov**, CREOL- The College of Optics and Photonics, University of Central Florida (USA).

In 2020, plenary talks were introduced into conference program for the first time. Two plenary talks were delivered at the first morning sessions:

"A vision of the future for high power laser research and applications: motivation and strategies", **Michael E. Campbell**, Laboratory for Laser Energetics, University of Rochester (USA);

"Progress on the 10PW laser facility at Shanghai", **Ruxin Li**, Shanghai Institute of Optics and Fine Mechanics (China).

They were focused on general topics of common interest for the laser-damage community. An industry talk:

"Harnessing the power of light", **Thomas Battley** (New York Photonics Industry Association, USA)

overviewed the history and current status of photonics and optics industry in the State of New York that was planned as a location of the 2020 meeting. Those talks received good feedback.

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
2020	S. K. Sundaram	Optical ceramics and glasses
2021	Vitaly Gruzdev, Konstantin Vodopyanov	Mid-infrared optical materials, lasers, and laser-material interactions

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 of 500 US dollars 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, quality of presentation, and responses to questions during presentation. It receives one of the following awards:

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

Submission of a manuscript to the conference proceedings is a mandatory condition of receiving an award.

In 2020, no presentation were awarded because the conference was run in the digital-forum format, and it was not easy to figure out novel criteria to evaluate the presentations delivered as pre-recorded videos. However, in 2021 all delivered presentations were evaluated, and the following papers were selected by Co-Chairs for the awards:

Alexander Glass Best Oral Presentation Award:
"515-nm, femtosecond laser mirror thin film damage competition", Rauca A. Negres, C. J. Stolz, Lawrence Livermore National Laboratory (USA); G. Bataviciute, A. Melninkaitis, LIDARIS Ltd (Lithuania); SPIE paper No. 11910-28.

M. J. Soileau Best Student Paper Award:
"Sculptured thin film based all-silica mirrors for high power lasers", **Lukas. Ramalis**, U. Norkute, R. Buzelis, L. Grineviciute, T. Tolenis, Ctr. for Physical Sciences and Technology (Lithuania); SPIE paper No. 11910-43.

Arthur Guenther Best Poster Award:
"Simulation of femtosecond laser induced electron excitation in a Multi-Layer Dielectric (MLD) grating", **S. Zhang**, J. R. Smith, The Ohio State Univ. (USA); E. Dalton, A. Davenport, C. S. Menoni, Colorado State Univ. (USA); V. E. Gruzdev, The Univ. of New Mexico (USA); E. A. Chowdhury, The Ohio State Univ. (USA); SPIE paper No. 11910-45.

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. 5). 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

In March 2021, another special section on Laser Damage was published in vol. 60, No. 3 of *Optical Engineering*:
https://www.spiedigitallibrary.org/journals/optical-engineering/volume-60/issue-03#SpecialSectiononLaserDamageV
V. Vitaly Gruzdev and Jonathan Arenberg again serve as Guest Editors for this special section that contains 9 papers.

In response to intensive requests of Laser Damage-2021 presenters, it was made a decision to arrange a rapid publication of one more special section – Laser Damage VI – with the minimum possible duration between submission and publication. Vitaly Gruzdev and Jon Arenberg have again volunteered to do this tremendous service for the laser-damage community. As a result, this special section will appear in vol. 61, No. 7 (2022) of *Optical Engineering*. Of 6 submissions, 5 were reviewed and accepted for publication, one was rejected.

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

Table 5. Submission overview of the 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
Laser Damage V (v. 60, no. 3, 2021)	9	9	0
Laser Damage VI (v. 63, No. 7, 2022)	6	5	1

14. In Conclusion

The plans to hold the 52nd (2020) and 53d (2021) meeting of the Laser Damage Symposium in Rochester, New York were changed by the COVID-19 pandemics. The pandemics forced organizers to run the meetings of 2020 and 2021 in the format of digital forums with only online options for presentation of talks and posters. We have survived difficult challenging time, but we have demonstrated real dedication to research and the conference that cannot be affected by any pandemics. We especially acknowledge the tremendous support from SPIE during those challenging times. We are optimistic and hope to run the 54th meeting in Rochester, New York in the usual in-person format.

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 venues on the East and West coasts will be highly supportive for addressing the concerns from conference attendees received previous years.

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.

We must also note tireless assistance of SPIE who handle the administrative and technical functions of the symposium. Their presence, experience, resources, and professionalism clearly were made manifest with on-line reservations, payment by credit cards, preparation of the conference program, 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.” We especially acknowledge the technical staff of SPIE and their significant role in providing the opportunities for the on-line conferencing and virtual networking of Symposium participants.

15. Acknowledgments

A number of volunteers help tirelessly with some of the administrate duties necessary to put on a conference of this magnitude. Diane Cline of SPIE took care of all the administrative planning, co-chair teleconferences, and other organizational tasks including registration. SPIE Publishing Department staff Joel Shields and Jenny Woods made a great work on preparation of this volume of the conference proceedings and the publication of the manuscripts into it. Much of the success of this meeting is attributed to the efforts of the conference SPIE staff: Dawn Jackson (SPIE), Shari Nephew (SPIE), Scott Calhoun (SPIE), and Rob Whitner (SPIE). We especially appreciate the multi-year effort of Diane Cline (SPIE) who retired from SPIE at the end of 2021. Rob Whitner becomes a Symposium Secretary staring from 2022. Their tireless assistance and enthusiastic support are greatly appreciated by organizers, presenters, and all attendees of this Laser Damage meeting.

We gratefully appreciate our annual co-sponsor, Lawrence Livermore National Laboratory. The contribution of LIDARIS and Andrius Melninkaitis for performing the laser damage tests for the annual laser-damage thin-film competition is greatly appreciated. We acknowledge support of our sponsors this year: Lawrence Livermore National Laboratory; LIDARIS LIDT Service;NEXTCORPS LUMINATE; Optimax; Plymouth Grating Laboratory; Spica Technologies Inc.; Ultrafast Innovations; Laboratory for Laser Energetics, University of Rochester; Arrow Thin Films; Laser Components; and Kaufman & Robinson The Ion Beam Authority. All conference sponsors are acknowledged in this volume of conference proceedings.

We acknowledge the cooperating organizations for their support of activity of conference Co-Chairs during preparation of this meeting and their conference trips: Lawrence Livermore National Laboratory (USA), School of Optics – CREOL and FPCE, College of Optics and Photonics, University of Central Florida (USA); Laser Zentrum Hannover eV (Germany); Colorado State University (USA); and The University of New Mexico (USA).

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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