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Please use the following format to cite material from this book:


ISSN 0277-786X
ISBN 9780819478825

Published by
SPIE
P.O. Box 10, Bellingham, Washington 98227-0010 USA
Telephone +1 360 676 3290 (Pacific Time)· Fax +1 360 647 1445
SPIE.org

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Printed in the United States of America.

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International Program Committee

The cochairs of this series of symposia rely heavily on an International Program Committee to ensure their awareness of significant research in the broad field of laser-induced damage throughout the world. Its members are also frequently the source of suggestions for invited speakers and mini-symposium topics and leaders. The committee performs a vital service as an outreach for the conference on a global scale. Individuals with suggestions for the meeting are requested to contact any committee member (next page) who is either an acquaintance or in close proximity. The committee is ably led by Detlev Ristau, International Program Committee Chair.

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Symposium Welcome

On the occasion of the SPIE Laser Damage (41st Boulder Damage) Symposium

Vitaly Gruzdev
University of Missouri (United States)

On behalf of my fellow co-chairs, M. J. Soileau, Gregory Exarhos, Detlev Ristau, and Christopher Stolz, I extend a hearty welcome to all participants of the 41st Annual Symposium on Optical Materials for High Power Lasers held at the NIST facility in Boulder, Colorado. The conference starts its fifth decade under the new official name – SPIE Laser Damage Symposium. This change was motivated by the strong need to adjust the name with the real content of the symposium, to maintain its status and to provide better referencing to it for online search via internet search engines. In this connection it is important to note that the previous names – both official (Annual Symposium on Optical Materials for High-Power Lasers) and unofficial (Boulder Damage Symposium) – do not include the proper combination of the two key words – laser damage. This does not hurt the very high status of the conference among the laser-damage community because since the first meeting organized by its co-founders – Art Guenther and Alex Glass – in 1969 it has been performing the role of major international platform for lively discussions and communications between researchers and engineers from academics, industry, and military related to all aspects of laser-induced damage. Fluctuating from year to year, the number of presentations has the strong trend to increase (Fig. 1) indicating the enormous vitality of this field and the continuously growing interest to the related topics. Proceedings of the Boulder Damage Symposium (BDS) have become the most complete and major resource of information on laser damage and multiple related areas compiled since the early stages of that field. The 40-year collection of the proceedings (from 1969 to 2008 inclusive) has been published in a single DVD distributed among participants of the last year's symposium. The tremendous efforts of the authors to prepare the manuscripts for this series of proceedings of SPIE help to maintain the unique status of the proceedings and are gratefully acknowledged here.

Significant contribution to the success of the BDS has been done by the international program committee representing leading research centres and groups of the laser-damage community worldwide. Presently, the committee consists of representatives from the UK, Germany, France, Japan, China, and the United States of America. Besides providing contributions to the conference program, the international program committee is also active in promoting the conference and in attracting researchers from around the world. The engagement of the committee has initiated participation from more than 30 countries including America, Europe, Asia, Africa, and including Australia during the last decade is acknowledged here as being very important.

Following the 40-year tradition, the conference addresses four core topics including materials and measurements, fundamental mechanisms, thin films as well as surfaces, mirrors, and contamination. One invited presentation is delivered for each of the topics to provide an overview of particular research directions and educate the younger generation of conference participants. In order to track the current trends in research and further intensify the scientific dialogue at the BDS, a mini-symposium dedicated to a hot current topic in laser material interaction has been organized every year since 1992. This year’s mini-symposium on “Femtosecond laser damage” is chaired by Dr. Wolfgang Rudolf from the University of New Mexico and has attracted a large number of interesting contributions from industrial companies and research institutes from France, the United States, and Germany.

Continuing the success of the damage competition held the first time in 2008, Chris Stolz kindly organized another competition with the target to review the present state of the art in multilayer coatings for femtosecond-laser optics. This initiative found a broad resonance within the community and resulted in 28 samples submitted by companies and research institutes from China, Japan, Germany, and the United States of America. Sample testing was performed by
the group with Detlev Ristau at Laser Zentrum Hannover e.V. (Germany), who accomplished an enormous amount of work by evaluating femtosecond laser-induced damage threshold of all the samples. This outstanding effort is appreciated by the community, and the organizers acknowledge this special contribution by Chris Stolz and Detlev Ristau. Chris Stolz delivered a talk about the competition at the mini-symposium and has prepared a summary paper on the competition which can be found in the present volume of the conference proceedings.

One of the young traditions of the symposium is to acknowledge authors of who presented notable results at the previous year's meeting. The authors receive best-paper awards consisting of a cut-glass piece of art with symposium emblem and date and names of the authors embedded into the glass by controlled laser-induced damage made with focused beam from a Q-switched laser. Bearing in mind the experience of the previous years, a new rule has been introduced starting from this year: for the awarded authors it is mandatory to prepare and publish manuscripts of their presentations in the conference proceedings.

Much of the success of the meeting can be attributed to the untiring efforts of the SPIE staff as well as Jenessa Huffman from Lawrence Livermore National Lab (Symposium Assistant). The organizers also acknowledge the support of the NIST staff and especially Kent Rochford (NIST Coordinator) for coordinating activities and arranging for the audio-video facilities in the meeting room. We gratefully appreciate the annual co-sponsoring from the Lawrence Livermore Laboratory's significant support of this meeting. The contribution of Laser Zentrum Hannover e.V. (Germany) in performing the laser damage tests for the competition is greatly appreciated. We appreciate support from Pacific Northwest National Laboratory and Office of Naval Research. We also acknowledge the other cooperating organizations: School of Optics – CREOL and FPCE, College of Optics and Photonics, University of Central Florida, and the University of Missouri.
Summary of Meeting

Laser-Induced Damage in Optical Materials
41st Annual Symposium
21-23 September 2009

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1. Abstract

These proceedings contain the papers presented as oral and poster presentations at the 41st Annual Symposium on Optical Materials for High-Power Lasers. The conference was held at the National Institute of Standards and Technology facility in Boulder Colorado on 21-23 September 2009. The symposium was divided into the traditional sessions devoted to the following topics: thin films; surfaces, mirrors and contamination; fundamental mechanisms; materials and measurements; and finally, a mini-symposium on “Femtosecond laser-induced damage” which included a thin film femtosecond laser damage competition. A roundtable discussion was introduced this year on the topic of “Experimental identification of fundamental LIDT mechanisms: techniques, challenges, and new approaches”. The conference was opened by Dr. Vitaly Gruzdev with a symposium welcome. Dr. Gregory J. Exarhos of Pacific Northwest National Laboratory (USA), Dr. Vitaly Gruzdev of the University of Missouri, Columbia (USA), Dr. Detlev Ristau of the Laser Zentrum Hannover e.V. (Germany), Dr. M. J. Soileau, of the University of Central Florida (USA), and Mr. Christopher J. Stolz of the Lawrence Livermore National Laboratory (USA), co-chaired the symposium. The founding organizers are Dr. Arthur H. Guenther and Dr. Alexander J. Glass.

All told, 72 papers were presented, including oral and poster presentations plus a mini-symposium. No parallel sessions were held, allowing the opportunity to discuss common research interests with all the presenters. With 139 registered participants, the meeting offered an opportunity to make many new acquaintances. Although held annually in the US, this is a truly International conference with 33 percent of the attendees and 57 percent of the presentations coming from abroad. As usual, the National Institute of Standards and Technology in Boulder, Colorado, offered a setting conducive to interchanges between individuals working in closely related and complementary fields. We look forward to future opportunities to come together again in this setting.

The 42nd Annual Symposium of this series will be held in Boulder, Colorado, 27-29 September 2010. A concerted effort will be made to ensure a close liaison between the high-peak-power and high-average-power communities, as well as to include damage issues related to various research efforts and commercial laser applications. A mini-symposium on laser ablation and applications will occur. Invited talks are also anticipated to open the four major topical areas.

The principal topics to be considered as contributed papers in 2010 do not differ drastically from those enumerated above. We expect to hear more about the impacts of contamination on the laser resistance of optical components and the impacts of surface and material defects since both of these topics continue to generate significant interest. High-energy laser windows, crystals, and transparent ceramics continue to place limitations on laser systems so remain active areas of research and spirited debate. Refinement of the mitigation strategy consisting of damage initiation followed by arresting damage growth through post-processing techniques while not creating downstream damage is also expected to be a continued focus as a large number of laser-resistant UV optics are manufactured for various international large-aperture fusion lasers. Short pulse laser optics and damage phenomena remain an active area of research. We also expect to hear more about new measurement techniques to improve our understanding of the different damage mechanisms or to improve the manufacturing of optical materials and thin films for optical components of greater laser damage resistance.
As was initially established in 1992, several distinguished invited speakers will make presentations of a tutorial or review nature, in addition, other contributors will cover late-breaking developments of interest to the attendees. The purpose of this series of symposia is to exchange information about optical materials for high-power / high-energy lasers. The editors welcome comments and criticism from all interested readers relevant to this purpose.

Key words: laser damage, laser interaction, optical components, optical fabrication, optical materials and properties, thin film coatings, contamination, metrology, fundamental mechanisms.

2. Introduction

The 41st Annual Symposium on Optical Materials for High-Power Lasers (a.k.a. the Boulder Damage Symposium, because of its Boulder, Colorado, venue, and this year now named the SPIE Laser Damage Symposium) was held 21-23 September 2009. This symposium continues to be the principal U.S. and International forum for the exchange of information relative to the interaction of intense laser light with optical media and components. Historically, the meeting has been divided into four broad categories: thin films; fundamental mechanisms; materials and measurements; and surfaces, mirrors, and contamination as illustrated in figure 1.

3. Cochairs

The Boulder Damage Symposium was founded by Dr. Arthur H. Guenther and Alexander Glass. Over the last 41 years many prominent leaders within the high power laser community have contributed significantly as cochairs to this conference. A historical timeline of their contributions are listed below:

1969 A. J. Glass, A. H. Guenther (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 L. L. Chase departs; add M. R. Kozlowski
1997 add G. J. Exarhos, 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
Fig. 1  Historical statistics of conference attendance and paper submission (top) and distribution of submissions by topical area (bottom).
4. Thin Films

Because of the tremendous range of applications of optical multilayers for modifying the optical performance of elements (e.g., reflectivity, wavelength sensitivities, polarization, or simply protection, etc.), this receives attention. Besides damage thresholds or sensitivity, topics include advanced thin deposition technology, film structure, film design, film response to environmental attack and aging, and numerous reports on important film properties such as adhesion, thermal conductivity, absorption, stability, defect identification, aging – drift and moisture infusion, and conditioning processes to improve performance.

UV and shot pulse coatings dominated this session reflecting work currently being done in UV lithography, laser fusion, and ultrafast lasers. The thin film damage competition started in 2008 was continued to increase understanding and as a means to solicit more participation from the private sector and rejuvenate interest in this topic. 786 nm high reflectors were tested at 180 fs with damage thresholds ranging from 0.2 to 1.1 J/cm² to complement the theme of the minisymposium. A multitude of deposition processes, coating materials, and manufacturing techniques submitted to this competition provided some interesting results and contrast to last year’s nanosecond damage results.

5. Fundamental Mechanisms

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

The emphasis this year was on understanding the role and behavior of defects within optical materials and surfaces with an emphasis on either short wavelengths (UV) or short pulses (fs). The fundamental nature of the minisymposium topic reduced the size of this session.

6. Surfaces and Mirrors

Here one will find presentations on surface preparation (including single-point diamond micro-machining and ductile grinding), subsurface damage characterization, roughness and scattering, environmental degradation and aging, as well as substrate material properties, including cooling techniques, and, of course, damage measurements and the cleaning of surfaces. The crux of the contamination problem is fundamentally that damage experiments done in controlled clean laboratory settings do not necessarily yield the same results as laser operations in less pristine operating environments. There is a significant amount of work needed in understanding what contamination is acceptable, what contamination is threatening to optic survivability, and how fluence-limiting or lifetime-limiting contamination can be eliminated or mitigated from operating laser systems.

Damage of fused silica optical surfaces at 351 nm remains a very active area of research within the international laser fusion community. Studies emphasize understanding precursors and potential mitigation techniques to arrest growth of initiated damage without causing downstream modulation which could damage downstream optics.

7. Materials and Measurements

This section deals with laser damage to the bulk of transparent optical media – whether amorphous, polymeric, polycrystalline, or crystalline – and its preparation, as well as reports of material properties of import to their optical function and / or the damage process, e.g., linear and nonlinear refractive indices, absorption, thermal conductivity,
stress-optic coefficients, moduli, and defects. Also included are new techniques for measuring these quantities, which present a continuing challenge as materials are improved in quality and diversity.

There is always interest in improved measurement systems or new instruments particularly in the area of photothermal or photoluminescence non-destructive defect characterization. A number of different optical materials such as CaF₂, fused silica, KDP, MgF₂ sapphire, and ceramics are also being studied and reported. Finally a new instrument for measuring nonlinear absorption in optical materials over a wide spectral range was introduced.

8. **Mini-Symposium on Femtosecond Laser-Induced Damage**

This year the meeting was concluded with a small mini-symposium dealing with the topic of femtosecond laser-induced damage. This material is critical in high power laser systems as a laser resistant transparent material used for beam focusing and environmental barrier. The talks covered a multitude of topics covering both bulk and surface properties, defects, damage mechanisms over a wide range of pulse lengths, and finally the challenges associated with characterization of this unique material. The mini-symposium was organized this year by Wolfgang Rudolph from the University of New Mexico (USA). A brief summary of the past mini-symposium topics starting in 1992 and the organizing chairs are listed below.

<table>
<thead>
<tr>
<th>Year</th>
<th>Chair</th>
<th>Topic</th>
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</thead>
<tbody>
<tr>
<td>1992</td>
<td>Brian Newnam</td>
<td>Damage Issues for Lithographic Optics</td>
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<tr>
<td>1993</td>
<td>Karl Guenther</td>
<td>Quest for the Invincible Laser Coating -- Critical Review of Pulse</td>
</tr>
<tr>
<td>1994</td>
<td>Claude Klein</td>
<td>Laser Induced Damage to Optical Coatings: Causes and Cures</td>
</tr>
<tr>
<td>1995</td>
<td>Floyd Hovis</td>
<td>Contamination and the Laser Damage Process</td>
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<tr>
<td>1996</td>
<td>Robert Setchell</td>
<td>Laser-Induced Damage in Optical Fibers</td>
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<tr>
<td>1997</td>
<td>David Welch</td>
<td>Damage and Lifetime Issues for Laser Diodes</td>
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<td>1998</td>
<td>Norbert Kaiser</td>
<td>Optics for the Deep UV</td>
</tr>
<tr>
<td>1999</td>
<td>David Sliney</td>
<td>Laser Damage Processes in the Eye and Other Biological Tissue</td>
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<tr>
<td>2000</td>
<td>Mark Kozlowski</td>
<td>Defects in Glass</td>
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<td></td>
<td>Hideo Hosono</td>
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<tr>
<td>2001</td>
<td>Mark Kozlowski</td>
<td>Optical Materials for Telecommunications</td>
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<tr>
<td>2002</td>
<td>Detlev Ristau</td>
<td>Optics Characterization -joint with 7th International Workshop of</td>
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<td></td>
<td></td>
<td>Laser Beam and Optics Characterization.</td>
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<tr>
<td>2003</td>
<td>William Latham</td>
<td>Understanding Optical Damage with Ultra-short Laser Pulses</td>
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<tr>
<td>2004</td>
<td>Keith Lewis</td>
<td>Damage Issues in Fiber Laser Systems</td>
</tr>
<tr>
<td>2005</td>
<td>Leon Glebov</td>
<td>Perwatt Lasers</td>
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<tr>
<td>2006</td>
<td>Alan Stewart</td>
<td>Optics in a Hostile Environment</td>
</tr>
<tr>
<td>2007</td>
<td>Stan Peplinski</td>
<td>Lifetime Issues for CW and Quasi CW Lasers</td>
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<tr>
<td>2008</td>
<td>Christopher Stolz</td>
<td>Fused Silica</td>
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<td></td>
<td>Hervé Bercego</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>Wolfgang Rudolph</td>
<td>Femtosecond Laser-Induced Damage</td>
</tr>
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9. **Invited Talks**

As usual, the 2009 meeting was highlighted by several invited presentations. They included:

1. “Mirror characterization in the LIGO 4km interferometers,” Rana Adhikari, California Institute of Technology (USA).

2. “Ultrafast laser-induced modifications of energy bands of non-metal crystals,” Vitaly Gruzdev, University of Missouri, Colombia (USA), paper 7504-27 / 75040G.
3. “Aspects of laser optics qualification for space applications,” Wolfgang Riede, Deutsches Zentrum für Luft-und Raumfahrt e.V. (Germany), paper 7504-55 / 75040T.

4. “Nonlinear optical spectroscopy: absorption and refraction,” Eric W. Van Stryland, College of Optics and Photonics, University of Central Florida (USA), paper 7504-64 / 750415.

10. Conference Awards

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

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

Best oral paper:
“Nonlinear spectroscopy: absorption and refraction,” Eric Van Stryland, David Hagan, Scott Webster, Lazaro Padilha, College of Optics and Photonics, University of Central Florida (USA), paper 7504-65 / 750415.

Best poster paper:

11. In Conclusion

The location in Boulder, Colorado, during autumn at the venue of the National Institute of Standards and Technology and its outstanding facilities and support staff were appreciated by all. The 139 attendees were easily accommodated with ample opportunity to mingle and socialize.

The organizers of the Boulder Damage Symposium look for opportunities to join with other related groups for joint meetings in the future. For example, in 2002 we had a joint meeting with the 7th International Workshop on Laser Beam and Optics Characterization, again with no parallel sessions.

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

12. Acknowledgments

A number of volunteers help tirelessly with some of the administrative duties necessary to put on a conference of this magnitude. SPIE staff took care of all the administrative planning and on-site tasks including registration, setup, and general questions as well as the publication of all of the manuscripts into these proceedings.

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

Books:


Proceedings:


Compact Discs:


Journal articles:


