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# Laser Induced Damage in Optical Materials: 1989

BOULDER DAMAGE SYMPOSIUM

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NIST SPECIAL PUBLICATION 801

# Laser Induced Damage in Optical Materials: 1989

## Proceedings of the Boulder Damage Symposium, November 1-3. 1989

Sponsored by

National Institute of Standards and Technology
American Society for Testing and Materials
International Society for Optical Engineering
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Department of Energy

BOULDER DAMAGE SYMPOSIUM

October 1990

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## FOREWORD

The Proceedings contain the papers presented at the Twenty-First Symposium on Optical Materials for High-Power Lasers held at the National Institute of Standards and Technology in Boulder, Colorado, on November 1-3, 1989. The Symposium was sponsored jointly by the National Institute of Standards and Technology, the American Society for Testing Materials, the International Society for Optical Engineering, the Defense Advanced Research Project Agency, and the Department of Energy. The Symposium was attended by approximately 200 scientists from the United States, Canada, the United Kingdom, Japan, France, and the Federal Republic of Germany. It was divided into sessions devoted to the following topics: Materials and Measurements, Mirrors and Surfaces, Thin Films, and, finally, Fundamental Mechanisms. The Symposium Co-Chairmen were Harold E. Bennett of the Naval Weapons Center, Arthur H. Guenther of the Los Alamos National Laboratory, Lloyd L. Chase of the Lawrence Livermore National Laboratory, Brian E. Newnam of the Los Alamos National Laboratory, and M. J. Soileau of the University of Central Florida. They also served as editors of the proceedings.

The editors assume full responsibility for the summary, conclusions, and recommendations contained in the report, and for the summaries of discussion found at the end of each paper. The manuscripts of the papers presented at the Symposium have been prepared by the designated authors, and questions pertaining to their content should be addressed to those authors. The interested reader is referred to the bibliography at the end of the summary article for general references to the literature of laser damage studies. The Twenty-Second Annual Symposium on this topic will be held in Boulder, Colorado, October 24-26, 1990. A concerted effort will be made to ensure closer liaison between the practitioners of high-peak power and high-average power.

The principal topics to be considered as contributed papers in 1990 do not differ drastically from those enumerated above. We expect to hear more about improved scaling relations as a function of pulse duration, area, and wavelength, and to see a continuing transfer of information from research activities to industrial practice. New sources at shorter wavelengths continue to be developed, and a corresponding shift in emphasis to short wavelength and repetitively pulsed damage problems is anticipated. Fabrication and test procedures will continue to be developed, particularly in the diamond-turned optics and thin-film areas. It has been our intention to pause and reflect on progress over the past twenty years to the Symposium on Optical Materials for High Power Lasers. It will be our pleasure to present the last (Thin Film, the Second Decade) in a comprehensive array of tutorial lectures by distinguished workers in the field of laser induced damage in optical materials.

The purpose of these symposia is to exchange information about optical materials for high-power lasers. The editors will welcome comments and criticism from all interested readers relevant to this purpose.

H. E. Bennett, A. H. Guenther, L. L. Chase,
B. E. Newnam, and M. J. Soileau,
Co-Chairmen

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Certain papers contributed to this publication have been prepared by non-NIST authors. These papers have not been reviewed or edited by NIST; therefore, the National Institute of Standards and Technology accepts no responsibility for their accuracy, nor for their comments or recommendations.

Certain commercial equipment, instruments, and materials are identified in this publication in order to explain the experimental procedure adequately. Such identification in no way implies approval, recommendation, or endorsement by the National Institute of Standards and Technology, nor does it imply that the equipment, instruments, or materials identified are necessarily the best available for the purpose.

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## Thin Films

## FUNDAMENTAL MECHANISMS

WELCOME FOR 21st BOULDER DAMAGE SYMPOSIUM

**M. J. Soileau**
**Professor of Electrical Engineering and Physics**
**Director, Center for Research in Electro-Optics and Lasers**
**University of Central Florida**
**Orlando, Florida**

It is my pleasure and duty to call this year's meeting to order. I was abroad when the final program was put together by my co-chairs and did not learn of this honor until a couple of weeks ago. I had no time to prepare until this weekend, so this will be a bit rough and without the benefit of elegantly prepared slides.

I don't mean to take a stab at my co-chairs, but I must admit that as I began my preparation I couldn't remember a single thing about previous opening remarks by my esteemed colleagues! Did I miss something? Surely these distinguished leaders of national laboratories must have said something profound and prophetic! So I spent part of the day Saturday reviewing the past utterances which have launched this meeting.

It is true that the memory is the second thing to go, because as I read the opening remarks for the past 20 meetings, I found many, profound statements--a few of which are listed below:

This is a quote from the next speaker from 1972:

"It is a pleasure to be here this afternoon."
Martin Stickley, 1972.

"Whatever turns you off." (Alex's definition of damage)
Alex Glass, 1974

"A name which invokes images of people cracking rocks."
Alex Glass, 1976. (In response to Martin Stickley's call for a more positive sounding name for the conference.)

"Our onion unfortunately, exists in Hilbert Space." (Alex borrowing from an ancient philosopher's description that learning is like peeling an onion--each layer exposes another.)

"Who cares?" (Alex on why study damage?)
Alex Glass, 1976.

"It is my annual hope that each year's symposium will be the last." (Alex the failed prophet.)
Alex Glass, 1978.

"The key...is terawatts per megabuck.
Alex Glass, 1978.

"Power Optics." (A supplier of megabucks at the time in comparing laser optics to electronics.)
Harry Winsor, 1978.

"Aside from a gain medium, lasers require mirrors." (Insightful words from the great visionary.)
Harry Winsor, 1978.

"Progress has been made, but I am confident that in 10 years we will celebrate the 20th and Art and Alex will still be running it!" "...we owe a debt to these 2 young men." (Note the term young.)
Martin Stickley, 1978.

To this point I've spared you the profound utterance of my current co-chairs such as:

"Welcome to the Tenth Anniversary Damage Symposium." (Art Guenther gave this greeting at the 11th meeting.)
Art Guenther, 1979.

Then there were profound things said regarding the international participation.

"...countries represented include the British Isles, Canada, England, France, Japan, Scotland, and West Germany."
Brian Newnam, 1980.

"International contributors...have come a long way..."
Hal Bennett, 1985.

It should be clear to all how difficult it is for me since these guys have used up all the good stuff! Further review of these openings presented me with a good outline for my remarks. I will follow the trail blazed by my predecessors:

Outline

1. Welcome participants.

2. Acknowledge sponsorship of NIST, ASTM, and others.

3. Count the papers for this year's meeting and comment on the statistical distribution.

4. Observe that thin films are a major problem.

5. Profound and prophetic statement about the future of the meeting.

I do welcome you to the 20th Anniversary Boulder Damage Symposium. Those of you who are still asleep or partially hung over, may be confused by the fact that last year was our 20th Anniversary celebration. The resolution of this dilemma is the fact that last year was the 20th meeting and this is the 20th Anniversary (but the 21st meeting). One might say that this meeting is old enough to drink - but you will also note that there is no wine and cheese this year. This situation has resulted from rulings by NIST accountants. In fact, the accountants have made it difficult for us to conduct business as usual, so you can expect further changes next year.

We do want to thank NIST and the ASTM for their continued sponsorship and all the helpful folks at Boulder who make the meeting run smoothly.

There are about 70 papers this year with contributions from 6 countries in addition to the U.S. The talks from abroad constitute 27% of the papers, about the same percentage as from Livermore and Los Alamos. About an equal number of papers come from U.S. aerospace companies (15%) and U.S. universities (16%). About 9% are from DoD labs and the remaining 8% from various other sources.

Our next speaker (Martin Stickley) has suggested on a number of occasions that the name of the conference be changed to something more positive. I want to finish this presentation by noting that there are many positive things being done with phenomena studied by participants in these meetings. Here is a list of a few:

"Spin Offs" of LID Phenomena

1. Laser marking, cutting and drilling of materials.

2. Laser medicine
   a. laser scalpel
   b. laser-induced breakdown for eye treatments and plaque removal.

3. Laser disc storage - the first application of LID to consumer products.

4. Photorefractive information storage, processing, and phase conjugation interconnects.

5. Nonlinear refraction and nonlinear absorption for limiters, switches, and optoelectronic computing.

6. Electro-absorptive switches using UHV manufactured quantum well devices (SEED's).

So I issue a challenge to us all to keep the name Damage Symposium, but continue to seek positive applications of the phenomena we study. A wise professor once told me that phenomena are neither good or bad--they exist and it's up to us to find ways to make good things using phenomena given by nature.

Before I left Orlando, I looked into by crystal ball for a glimpse of future laser damage or optical materials problems--here is my short list:

Future Topics for Optical Materials Research

1. Thin films for all applications. Two talks viewing 20 years of thin film work.

2. New laser host and nonlinear optical materials for compact, efficient, tunable and solid state lasers for many old and many new applications.

3. X-ray optics for lasers (remember Harry Winsor said that lasers have mirrors...), and optics for x-ray microscopy and x-ray lithography.

4. Materials for x-ray lithography.

I'm sure that these and other topics will keep optical materials people busy for some time--the only question is where will the funding come from? DoD funding will surely decline as peace is breaking out all over. DOE funding usually finds its way to the national labs--but not much finds its way out. DARPA, under Martin Stickley's leadership, provided much of the spark that lead to modern day materials and much of the research reported at this conference. Materials research tends to be too long-term for present day funding. We need to all do our part in ensuring continued research support for the foundation of the technology food chain--materials research.

Since we don't have an official wine and cheese gathering, I hereby propose that we forgo small gatherings of old friends for dinner, etc. and meet instead at the Dark Horse for an informal, pay as you go, social hour.

Manuscript received
2-14-90

# SEARCH FOR TECHNOLOGY TRANSFER IN HIGH POWER OPTICS

C. Martin Stickley

BDM International, Inc.
1300 N. 17th St., Suite 950
Arlington, VA 22209

In the late 60's and through the 70's, DARPA supported a broad program to develop optics for use with high power cw $CO_2$ lasers and new laser and nonlinear optical materials. This paper summarizes those efforts and asks anyone who knows in what defense systems these have been used to contact the author.

In the late 1960's and through the 1970's, the Materials Sciences Office (now the Defense Sciences Office) of the Defense Advanced Research Projects Agency (DARPA) funded a broad program to develop optics for high power continuous development of approaches to fabricate large area windows with high transparency (absorption of $10^{-5}$ per cm), optical surface preparation techniques which leave very little residual absorption, and techniques for depositing antireflection as well as reflecting coatings for transparent windows and mirrors. Some development of new laser and nonlinear optical materials was also funded. Approximately $22.9 M dollars were spent between 1967 and 1978.

The Defense Sciences Office is now searching for examples of where optical parts fabricated using these techniques and the laser and NLO materials have been used in defense systems. While defense uses are of primary importance, NASA and industrial uses are also of interest.

Technologies which may have had the best chance of being utilized include, for windows: casting of fluorides, reactive atmosphere processing of halides, forging of halides, and CdTe growth, distortion and damage studies; for surfaces and coatings: polymers and surface preparation of halides, fluorides, and selenides; for lasers: erbuim glass, and holmium and erbium in YLF; for mirrors: beryllium optics; and for laser damage: platinum removal and surface preparation of Owens-Illinois glass, and bulk and surface damage of ruby.

The tables which follow summarize the activities which were supported in each major area. Included are the specific technology developed (e.g. fluoride fusion casting), the contractor, the amount of funding provided, and at the time period where the work was done.

If the reader knows of areas where any of these technologies may have been used in defense systems (as well as for NASA and the commercial sector), please contact the author.

# LASER WINDOW MATERIALS

## Fluorides

| | | | |
|---|---|---|---|
| ● Fluoride Fusion Casting | Raytheon | 166K | 76-77 |
| ● Scaling of Fluoride Casting | Raytheon | 790K | 74-76 |

## Halides

| | | | |
|---|---|---|---|
| ● Halide Superalloys for High Power Windows | Raytheon | 191K | 72-73 |
| ● Halide OH Removal | Hughes Res. Labs | 174K | 72 |
| ● Reactive Atmosphere Processing | Hughes Res. Labs | 215K | 76-78 |
| ● RAP of KBR | Hughes Res. Labs | 244K | 74-76 |
| ● Extrusion and Cross-Rolling | Honeywell | 1 95K | 72-73 |
| ● Forging of Alkali Halides | Honeywell | 1483K | 73-78 |
| ● Radiation Hardening | Oklahoma | 113K | 72-74 |
| ● Press Forging Halides | NRL | 521K | 72-75 |
| ● RAP of KBR - Characterization | NRL | 80K | 76 |

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# LASER WINDOW MATERIALS

## II-VI Materials

| | | | |
|---|---|---|---|
| ● II-VI Distortion and Damage | USC | 1336K | 72-77 |
| ● CVD of Cadmium Telluride | Raytheon | 192K | 73-75 |
| ● CVD of CdTe and GaP | Raytheon | 196K | 75-77 |
| ● Characterization of II-VI Materials | MIT | 308K | 73-76 |

## Chalcogenides

| | | | |
|---|---|---|---|
| ● Oxygen-Free Chalcogenides | Catholic University | 283K | 72-74 |
| ● Structure-Dependent Absorption | Texas Instruments | 72K | 73-74 |

## Other

| | | | |
|---|---|---|---|
| ● Covalent Carbon Window Materials | UCLA | 114K | 75-76 |
| ● Copper-Leaded CERVIT | Owens Illinois | 27K | 76 |

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# LASER WINDOW MATERIALS

## Measurement Techniques

| | | | |
|---|---|---|---|
| ● Spectroscopy of Halides | Cornell | 209K | 75-76 |
| ● Emissivity Facility | Block Eng. | 250K | 73-75 |
| ● Multiple Wavelength Calorimetry | Alabama | 58K | 74-76 |
| ● Chemical Laser Window Absorption | Raytheon | 60K | 74-75 |
| ● $CO_2$ Laser Window Evaluation | AVCO | 279K | 75-76 |
| ● Proof Testing | MIT | 168K | 75-76 |
| ● Mechanical Properties | MIT | 320K | 72-75 |

## Theory

| | | | |
|---|---|---|---|
| ● Theory of Coatings and UV Materials | Xonics | 1342K | 72-78 |

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# LASER COATINGS AND SURFACES

| | | | |
|---|---|---|---|
| ● Polymer Protective Coatings | UC Berkeley | 169K | 75-77 |
| ● Polymer Protective Coatings | Rockwell | 149K | 73-74 |
| ● Surface and Coating Technology | Hughes Res. Lab | 1076K | 73-76 |
| ● Window Polishing and Characterization | NWC | 1696K | 72-77 |
| ● Passive Characterization/HF Coatings | NWC | 1042K | 76-77 |
| ● Coating Stress Measurements | Perkin Elmer | 200K | 76-77 |
| ● Coating Growth and Stress | AFCRL | 255K | 73-75 |
| ● Transparent Abrasives | Raytheon | 207K | 73-75 |

# LASER MATERIALS

| | | | |
|---|---|---|---|
| ● Erbium Glass | American Optical | 191K | 69–71 |
| ● Holmium in YLF | Sanders Associates | 203K | 71–73 |
| ● Near Visible Laser Materials | Sanders Associates | 270K | 72–75 |
| ● Ceramics for Lasers | Union Carbide | 193K | 1977 |
| ● Wide Linewidth Materials | Texas Instruments | 225K | 72–73 |

# MIRRORS AND SURFACES

| | | | |
|---|---|---|---|
| ● Beryllium for Optics | Perkin Elmer | 1434K | Prior to 69 |
| ● Ion Beam Optical Figuring | Kollsman | 146K | Prior to 69 |

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# NONLINEAR OPTICAL MATERIALS

| | | | |
|---|---|---|---|
| ● Cinnabar | Tyco | 190K | 70–71 |
| ● Chalcopyrite | Stanford | 279K | 70–74 |
| ● High Damage Threshold Materials | Isomet | 98K | 1973 |
| ● Chalcogenides | Westinghouse | 230K | 72–75 |
| ● IR Laser Components | Westinghouse | 201K | Before 1969 |
| ● IR Quantum Counter | Purdue | | |

# DAMAGE TO LASER MATERIALS

## Glass

| | | | |
|---|---|---|---|
| ● Laser Glass Damage | Owens Illinois | 616K | 69–71 |
| ● Glass Surface Treatment | Owens Illinois | 291K | 72–73 |

## Ruby

| | | | |
|---|---|---|---|
| ● Bulk and Surface Damage | Hughes Res. Labs | 400K | 69–71 |

## Measurement Techniques

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| ● Laser Measurements | NBS | 2369K | Prior to 69 |
| ● Laser Damage Measurements | NBS | 161K | 72–73 |

## Mirrors

| | | | |
|---|---|---|---|
| ● RF Sputtered Metal Mirrors | Battelle NW | 450K | 72–73 |

## Research

| | | | |
|---|---|---|---|
| ● Miscellaneous Topics | Harvard, NWC, USC, AFCRL, Raytheon, Bendix | 749K | 71–76 |

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11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

The Twenty-First Annual Symposium on Optical Materials for High-Power Lasers (Boulder Damage Symposium) was held at the National Institute of Standards and Technology in Boulder, Colorado, November 1-3, 1989. The Symposium was sponsored jointly by the National Institute of Standands and Technology, the American Society for Optical Engineering, the Defense Advanced Research Project Agency, and the Department of Energy. Approximately 200 scientists including representatives of the United Kingdom, France, Japan, Canada, and the Federal Republic of Germany, attended the Symposium. The Symposium was divided into sessions concerning Materials and Measurements, Mirrors and Surfaces, Thin Films, and, finally, Fundamental Mechanisms. As in previous years, the emphasis of the papers presented at the Symposium was directed toward new fromtiers and new developments. Particular emphasis was given to materials for high power apparatus. The wavelength range of the prime interest was from 10.6 μm to the uv region. Highlights included surface characterization, thin film substrate boundaries, and advances in fundamental laser-matter threshold interactions and mechanisms. The scalling of damage thresholds with pulse duration, focal area, and wavelength was discussed in detail. Harold E. Bennett of the Naval Weapons Center, Arthur H. Guenther of the Los Alamos National laboratory, Lloyd L. Chase of the Lawrence Livermore National Laboratory, Brian E. Newnam of the Los Alamos National Laboratory, and M. J. Soileau of the University of Central Florida were co-chairmen of the Symposium. The Twenty-Second Annual Symposium is scheduled for October 24-26, 1990, at the National Institute of Standards and Technology, Boulder, Colorado.

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