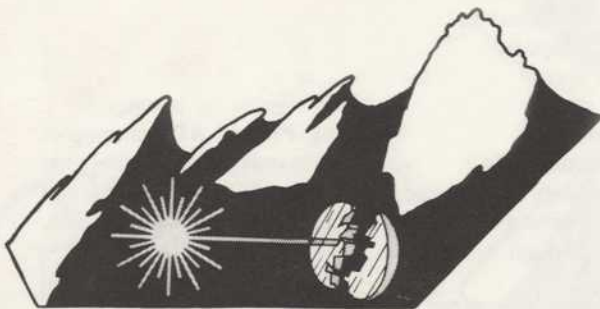




NBS SPECIAL PUBLICATION **620**

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Laser Induced Damage in Optical Materials: 1980



BOULDER DAMAGE SYMPOSIUM



STP 759

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Laser Induced Damage In Optical Materials: 1980

Proceedings of a Symposium Sponsored by:
National Bureau of Standards
American Society for Testing and Materials
Office of Naval Research
Department of Energy
Defense Advanced Research Project Agency
Air Force Office of Scientific Research

September 30–October 1, 1980
NBS, Boulder, Colorado 80303

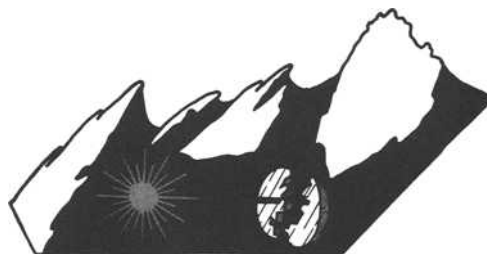
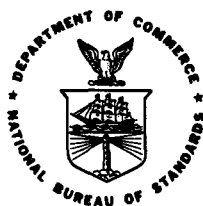
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BOULDER DAMAGE SYMPOSIUM

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Issued October 1981

Library of Congress Catalog Card Number: 81-600110

National Bureau of Standards Special Publication 620

Nat. Bur. Stand. (U.S.), Spec. Publ. 620, 483 pages (Oct. 1981)

CODEN: XNBSAV

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1981

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402
Price \$9.50

(Add 25 percent for other than U.S. mailing).

Foreword

The Proceedings contain the papers presented at the Twelfth Symposium on Optical Materials for High Power Lasers held at the National Bureau of Standards in Boulder, Colorado, on September 30 - October 1, 1980. The Symposium was jointly sponsored by the National Bureau of Standards, the American Society for Testing and Materials, the Office of Naval Research, the Defense Advanced Research Projects Agency, the Department of Energy, and the Air Force Office of Scientific Research. The Symposium was attended by over 150 scientists from the United States, the United Kingdom, Japan, France, and West 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 Dr. Harold E. Bennett of the Naval Weapons Center, Dr. Alexander J. Glass of the Lawrence Livermore Laboratories, Dr. Arthur H. Guenther of the Air Force Weapons Laboratory, and Dr. Brian E. Newnam of the Los Alamos Scientific Laboratory. They also served as editors of this report.

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 Thirteenth Annual Symposium on this topic will be held in Boulder, Colorado, November 17-18, 1981. A concerted effort will be made to ensure closer liaison between the practitioners of high peak power and the high average power community.

The principal topics to be considered as contributed papers in 1981 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.

The purpose of these symposia is to exchange information about optical materials for high power lasers. The editors will welcome comment and criticism from all interested readers relevant to this purpose, and particularly relative to our plans for the Thirteenth Annual Symposium.

H. E. Bennett, A. J. Glass
A. H. Guenther and B. E. Newnam
Co-Chairmen

DISCLAIMER

Certain papers contributed to this publication have been prepared by other than NBS authors. These papers have not been reviewed or edited by NBS; therefore, the National Bureau of Standards accepts no responsibility for comments or recommendations contained therein.

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 Bureau of Standards, nor does it imply that the equipment, instruments, or materials identified are necessarily the best available for the purpose.

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SYMPOSIUM WELCOME

Brian E. Newnam
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

On behalf of my fellow co-chairmen, Hal Bennett, Alex Glass, Art Guenther, and myself, Brian Newnam, I welcome you to the Twelfth Annual Symposium on Optical Materials for High Power Lasers. This ongoing series of meetings continues to be of importance to and attracts participants from the laser community around the world. To our foreign guests from the British Isles, Canada, England, France, Japan, Scotland, and West Germany, we extend our special greetings.

Once again we are indebted to our gracious hosts here at the National Bureau of Standards in Boulder. In particular, we acknowledge the overall support of Robert A. Kamper, Chief, of the Electromagnetic Technology Division, the coordination activity of Aaron A. Sanders, Group Leader of the Optical Electronic Metrology Group, and the helpful assistance of his secretary, Pat Rice. In addition, this year Art and Alex brought their secretarial staff from Kirtland and Livermore, namely Pat Whited and Mary Ann George, to conduct the registration. The services of Giovanni Fiorenza and Allan Stewart of the Air Force Weapons Laboratory are also appreciated. I should also mention that David Milam of Lawrence Livermore Laboratory, a well-known veteran of these meetings, served us well in the pre-conference organization.

As many of you have experienced, the printed proceedings of these Laser Damage Symposia in our personal libraries are frequently borrowed by interested colleagues. These valuable volumes have become hard-to-replace collector's items. So, I am pleased to report that the ASTM has recently republished, and offers for sale, the proceedings for the years 1977, 1978, and 1979 under their publication numbers STP 655, STP 689, and STP 726, respectively.

Further good news comes from Art Guenther who told me that the library staff at the Air Force Weapons Lab is preparing a bound compilation of the first 10 year's proceedings from 1969 to 1978. It will include listings by author, co-author, title, subject, and materials. The published abstracts will also be included. Art expects it to be ready in 1981, and it will be distributed to registrants at this year's symposium as well as the past contributors not presently in attendance.

Since the first Laser Damage Symposium in 1969, interest in this area of research has shown a large increase. As indicated by both the number of papers presented and the number of registered participants, shown in the bar graph (Fig. 1), the level of activity peaked in 1977. Since that time, participation in these symposia has been consistent at the level of approximately 45 contributed papers and 150 registrants. Although one might consider that this is a maturing field, it is apparent to most of us that there is a substantial amount of work yet to be done.

Each year's damage symposium has a different character - either some new understanding, or a concentration of papers on a particular aspect by a number of researchers, or even a controversial paper. In the early seventies, self-focusing and plasma formation at window surfaces received great attention. In 1978, we celebrated our Tenth Annual Symposium by devoting a portion of the proceedings to invited review papers summarizing the state-of-the-art in the primary topics. Last year, the characterization of thin films and their impurities received special emphasis.

I will not hazard suggesting which subjects at this year's symposium will, in retrospect, appear as having received the most significant advances in our knowledge and understanding. One can observe, however, that the papers are fairly well divided among the four major headings of bulk materials and measurements, mirrors and surfaces, thin films, and breakdown theory.

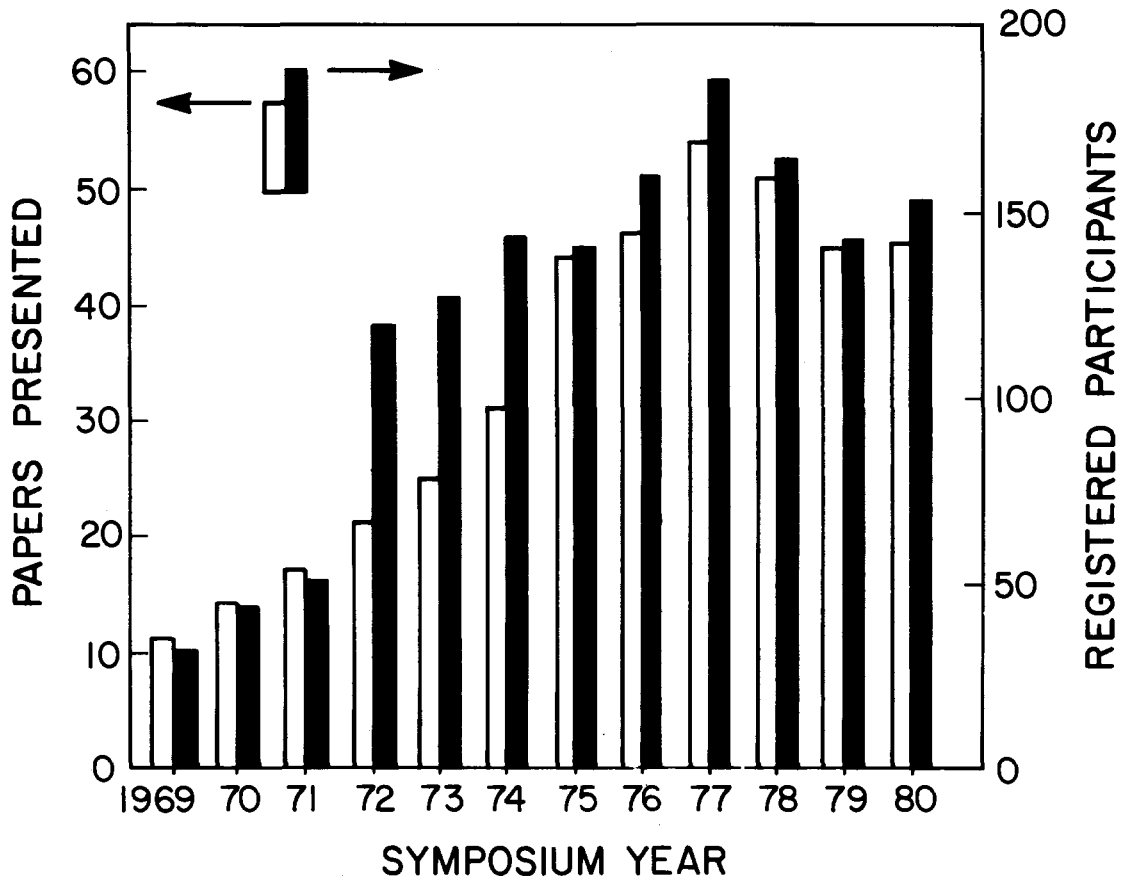
What have we learned over the past decade or so? We have made certain progress in a number of areas. Let me cite some examples. First, we came to understand the phenomena of self-focusing. Second, we learned how standing-wave electric fields are responsible for the once mysterious asymmetry of front- and rear-surface thresholds of windows. Third, we developed experimental methods to separate the surface- and bulk-absorption components of laser windows. Fourth, we determined, but yet do not understand, that a half-wave thick SiO_2 barrier layer, deposited between an AR coating and substrate, increases, on the average, the laser damage resistance. Likewise, for half-wave SiO_2 overcoats on multilayer reflectors. Fifth, we found that testing of a statistically significant number of samples is necessary to determine a dependence reliably, especially with thin-film optics which have so many materials parameters in the mix. As a last example, we learned that for the most damage-resistant materials there is generally no correlation of the average linear absorption properties and the damage threshold. It is apparent that localized impurities of even sub-micron dimensions are the limitation.

What areas now deserve our special attention or continued emphasis? For particular laser systems operating at high-repetition rates, we need to know if and how our experiments with 1-on-1 irradiation can be related to multi-shot survival. Perhaps, single-shot-per-site tests can be used for identifying superior materials and designs, but supplemental N-on-1 tests may be necessary. Next, we need to further examine how large a test laser beam must be to provide threshold data applicable to large laser systems. In the past year, damage tests with large-diameter (~1 cm) beams produced some disappointing surprises when contrasted to tests with very small beams (0.1-mm diameter). Still yet another need is for development of rugged optical components for the ultraviolet wavelengths from 190 to 350 nm. Research in this spectral region is still in its infancy, and large projects such as laser fusion, laser isotope separation, as well as military applications, have needs here.

To solve the existing damage problems, we need to bring to bear the well-developed talents from outside as well as within the laser community. For timely progress in

understanding surface- and thin-film damage resistance, for example, there is need for close collaboration of 1) the producers of optical components, 2) researchers who have perfected diagnostic techniques for measuring spatially-resolved optical properties, e.g., absorption, 3) surface physicists, and 4) experts in the measurement of damage thresholds. Recognizing that such diverse talents focused on particular problems might well identify solutions, the Department of Energy, the Air Force and Navy laboratories, within the past year, did convene special groups of materials and laser experts to consider difficult optics problems in the ultraviolet and infrared.

In conclusion, I wish to acknowledge the sponsorship and financial support of this meeting by six organizations. These include the American Society for Testing and Materials, the National Bureau of Standards, the Department of Energy (in particular, Lawrence Livermore Laboratory), the Office of Naval Research, the Defense Advanced Research Projects Agency, and a new sponsor, the Air Force Office of Scientific Research. Sponsorship by so many prominent organizations underlines the need for continued progress in developing and testing optical materials for high-power lasers.



REMARKS TO THE 12TH ANNUAL SYMPOSIUM ON
OPTICAL MATERIALS FOR HIGH-POWER LASERS
Boulder Damage Symposium
30 September 1980

Major Harry Winsor
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Bolling AFB, D. C. 20332

I am pleased to once again address my remarks to this symposium. As many of you have noted, I have transferred to a new job. Effective 26 September 80, I left the Defense Advanced Research Projects Agency (DARPA) and assumed my new duties as a Program Manager in the Electronic and Material Sciences Directorate (NE) of the Air Force Office of Scientific Research (AFOSR).

This change has raised two topics which I wish to address: First, what is the status at DARPA/MSD and who has taken responsibility for the programs I managed at DARPA and second, what are my new responsibilities at AFOSR?

Both organizational and managerial changes have occurred at DARPA since I last addressed this gathering. The old Materials Science Office (MSO) has become the Materials Sciences Division (MSD) of the new office called the Defense Sciences Office (DSO). The director designate of DSO is Dr. Elliot Leventhal, who is coming to DARPA from Stanford University. The deputy director of DSO is Dr. Richard Reynolds formerly of MSD. Dr. Edward Van Reuth has assumed the position of acting director of MSO, which now has "three and a half" program managers: Dr. Michael Buckley, Dr. Sven Roosild, Lt. Col. Lauren Jacobson (USAF), and Dr. Joseph Friebele (half-time). The programs I managed have been distributed to three of these program managers, Drs. Buckley, Jacobson, and Friebele's. Those attending this symposium are primarily interested in Dr. Friebele programs, since he has assumed responsibility for all the electro-optical and optical materials efforts I formerly managed. Dr. Buckley has assumed the Laser Aided Machining effort into his Advanced High Speed Machining program, and the Autoreplication program. He has also taken responsibility for two new programs I may be contributing to from AFOSR: Ultimate Ablator and Propellant Science.

The status of the major programs Dr. Friebele has assumed is as follows: the Laser Windows, Coatings and Mirrors program has been narrowed down and concentrated on the development of thin films suitable for HF laser mirrors and windows in a space environment. This program has demonstrated almost complete success, as you will hear later. The UV-Visible Laser Components program has taken a turn toward the basic research direction with the expansion of a thrust to understand the growth habits of high quality thin films in intense ultra-violet and visible pulses, and the beginning of a university

effort to understand the growth habits of high quality thin films. The Large Optics Materials Program is funding a 60 cm diameter carbon-carbon composite mirror substrate, and has expanded into the area of particulate composites in its search for zero coefficient of thermal expansion (CTE). We are currently demonstrating a first order zero in the CTE of a composite consisting of niobia spheres in a nickel matrix. The amounts of nickel and niobia can be adjusted to position the zero in the CTE anywhere in the region 0K-300K.

Other programs of interest to the people attending this conference are proceeding normally. A new program to study highly efficient laser host materials has just started. New ideas in this area should be referred to Dr. Friebele, as should new directions for research on Fiber Optic Sensor Systems (FOSS). FOSS is discussed extensively elsewhere, so all I will say here is that the program has a very successful record to date and has attracted a high degree of attention in Navy and Defense circles.

The Forged Flir Optics program is nearing a major decision point. The program has produced forged potassium bromide lenses which have at times nearly met the required specifications for the Army's MOD FLIR system. If a moisture protection coating can successfully protect the KBr in the military environment, forged lenses will be able to successfully fill a number of potential roles in military systems, as well as scientific applications. Forged lens technology looks very promising at this point.

I will also discuss one program Dr. Buckley has taken over: The Laser Aided Machining Program has been renewed for a 3 year period to complete the definition of the technology of combining machining with laser irradiation. Materials successfully machined to date include superalloys, hardened tool steel, silicon carbide, silicon nitride, lithium aluminum silicate, alumina, mild steel, and many others.

At this time, I would like to thank all of you who have worked with me while I have been at DARPA, especially those of you who have been responding to my requests for completion report preparation so that my programs can be properly documented as I leave, and those of you who have helped me manage the 15 program areas in which I have worked. I could not have done anything without you.

Let me now say a few words about some potential new research area on the horizon. The area of laser damage is a good place to start. I notice a striking fact that I hope only seems to be little appreciated: Laser damage prevention is very closely related to research the electronics industry is performing on laser processing of semiconductors. In fact, semiconductor processing research may provide the best diagnostics possible on impurity migration, phase changes, and micro-yield under laser loading. I hope laser damage people make full use of the rapidly growing body of these "controlled laser damage" results to understand the materials mechanisms responsible for the laser damage they are trying to avoid. This interaction appears strikingly fertile from my perspective.

The area of "controlled damage" to materials needs to be studied from the materials side for another purpose: the development of materials which can handle very high laser fluxes without prohibitive damage, for use as beam dumps for example. Beam dumps for a

space based laser will require good ablation resistance and very high mass efficiency, requirements not particularly important for ground based systems.

I could mention other programs at this point, but the above examples will serve very well. DARPA and AFOSR need more good ideas and welcome them from any source.

Speaking of AFOSR, let me now say a few words about my new job. My duties at AFOSR may include some of the new programs I was investigating while at DARPA, notably the Gun Propellant Science program and the Ultimate Ablator program. My new AFOSR responsibilities include microlithography, surface acoustic wave spectroscopy of semiconductors, dielectrics, and metals.

The new DARPA programs are envisioned to start during FY 81(Oct 80-Sep 81) and increase to approximately \$1.2M/yr and \$800K/yr expenditure rates, respectively. The AFOSR program has some room for new starts in either the sub-micron lithography area, the definition of electronic and physical properties at very small sizes, and improved microwave and millimeter wave signals processing materials. The program's expenditure rate is currently about \$1.2M/yr.

Should you have any ideas for new programs in these areas, or know a colleague who does, I may be phoned at (202) 767-4931 (Autovon 297-4931), telecopied at (202) 767-4977 (6 minute automatic telecopy machine), or contacted at the following address:

AFOSR/NE
ATTN: Major H. Winsor
Bolling AFB, DC 20332

Should you have any further questions, or ideas which do not fall under my listed program responsibilities, I will try to direct you to the responsible person or agency. I look forward to our continued relationship.

Finally, let me thank the organizers of this Symposium. They have done a superlative job for 11 years and are still going strong and getting better. I have especially enjoyed working with them and hope my new job allows me to continue attending this annual gathering. It has a very special place in my heart, largely due to the solid repeat performers the organizers have assembled. I also wish to thank them for the opportunity to present these remarks, and all of you for listening.

Boulder Damage Symposium 1980

ASTM Welcome

John A. Detrio
University of Dayton
Dayton, Ohio 45469

On behalf of the American Society for Testing and Materials I welcome you to the 12th Annual Symposium on Optical Materials for High Power Lasers - The Boulder Damage Symposium.

The conference organizers, Hal Bennett, Alex Glass, Art Guenther, and Brian Newnam, have put together a fine program with 25 presented papers and 20 poster papers. The next two days should be filled with stimulating papers and opportunities for discussions.

I would like to depart from the usual platitudes that you might expect from the very first welcome speaker and extend a challenge to you. I extend the challenge because the ASTM is charged with developing consensus standards; standard definitions, standard test methods, standard practices, and even standard materials. This is a voluntary effort requiring the cooperation of users and producers in the development of standards and specifications.

In the 12 years that this conference has been held, starting with the ASTM sponsorship of the very first meeting, we in the subcommittee "on Lasers" have yet to develop and adopt a single standard document. We have one in draft form but nothing published.

I challenge you to participate in the development of damage standards for these reasons:

1. Better agreement on definitions and test methods would improve communication and eliminate many of the disagreements over measured values of damage threshold.
2. The availability of standard test methods would simplify the procurement of laser components. Producers and users would be talking the same language.
3. To develop good standard test methods you would have to perform interlaboratory exchange of specimens. These Round Robins would permit the precision and accuracy of test methods to be specified. Round Robin participation can also be a humbling experience--maybe you're not as good as you think you are.
4. This hard close look at the test methods will improve the understanding of the measuring processes. You would have to consider factors such as
Scaling with pulse duration,
Scaling with area,
Scaling with wavelength,
Sampling practices, and
Statistical analysis.

Plus all of the measurement practices already required (power, beam profile, and pulse shape).

These remarks only briefly summarize the challenges and rewards of working on standards. It's hard work with limited, apparent short-term reward. In the long run, better quality optics and better quality measurements will repay the costs.

I will end with another invitation. We will meet tonight in an informal rump session to assess the needs for standards and to solicit your ideas on that subject. Producers, coaters, polishers, and materials suppliers should attend. If you are concerned with quality assurance - or just interested in better science - if you think you're up to it, join me.

Enjoy the conference!

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National Bureau of Standards
Washington, D.C. 20234

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