NBS SPECIAL PUBLICATION 688

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

Laser Induced Damage in Optical Materials: 1983

BOULDER DAMAGE SYMPOSIUM

STP 911

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[2]Some divisions within the center are located at Boulder, CO 80303.
[3]Located at Boulder, CO, with some elements at Gaithersburg, MD.

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DEPARTMENT OF COMMERCE * NATIONAL BUREAU OF STANDARDS *

BOULDER DAMAGE SYMPOSIUM

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FOREWORD

The Proceedings contain the papers presented at the Fifteenth Symposium on Optical Materials for High Power Lasers held at the National Bureau of Standards (NBS) in Boulder, Colorado, on November 14-16, 1983. 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 approximately 200 scientists from the United States, the United Kingdom, Israel, 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. Arthur H. Guenther of the Air Force Weapons Laboratory, Dr. David Milam of the Lawrence Livermore National Laboratory, and Dr. Brian E. Newnam of the Los Alamos National Laboratory. They also served as editors of this report. Dr. Alexander J. Glass of KMS Fusion acts as Conference Treasurer with Aaron A. Sanders of the National Bureau of Standards as the Conference Coordinator.

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 Sixteenth Annual Symposium on this topic will be held in Boulder, Colorado, from October 15-17, 1984. 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 1984 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. Comprehensive modeling studies are, as well, anticipated.

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 Sixteenth Annual Symposium.

H. E. Bennett, A. H. Guenther,
D. Milam, and B. E. Newnam
Co-Chairmen

DISCLAIMER

In Memoriam

Ann T. Glassman
1947 - 1983

How many of us will miss the smiling face, interactive personality, and professional commitment of Ann Glassman. Her untimely departure has left a void in the lives of the individuals with whom she came in contact. Nowhere will she be missed more than by those of us in the ASTM and related laser damage community.

Ann had graduated magna cum laude in physics from the University of Massachusetts, was elected Phi Beta Kappa, and received a M.S. degree in optics from the University of Rochester, to name but a few of her achievements. She had worked at the University of Dayton Research Institute and Lawrence Livermore National Laboratory before going to the Electro-optic branch of the U.S. Air Force Avionics Laboratory, Wright Patterson AFB, in 1980. But to those who read these proceedings, she will best be remembered for her tireless and often thankless efforts in developing laser standards and advancing our understanding of laser induced damage in optical materials.

We all will miss you, Ann

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WELCOME TO THE 15TH ANNUAL SYMPOSIUM
ON OPTICAL MATERIALS FOR HIGH POWER LASERS

Dr Arthur H. Guenther
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On behalf of my Co-Chairmen, Hal Bennett, Naval Weapons Center; Dave Milam, Lawrence Livermore National Laboratory; and Brian Newnam, Los Alamos National Laboratory, I would like to welcome you to the 15th Symposium on Optical Materials for High Power Lasers, our formal title. At our first meeting in 1969 it was called the Symposium on Damage in Laser Glass, the following year in 1970 it became Damage in Laser Materials and in 1972 Laser Induced Damage in Optical Materials. We had suggestions from Martin Stickley in 1974 to project a more positive image by introducing the concepts of optics reliability. In 1978 we had two suggestions, one by Harry Winsor to refer to the meeting as one on power optics while Alex Glass proposed damage avoidance. All suggestions reflect to some degree our interests, but as Hal Bennett said a few years ago, I suspect we will forever be known simply as the Boulder Damage Symposium, certainly as long as we continue to meet in Boulder, which I hope will be for a long time.

It might be of interest to pause at this 15th symposium to briefly note where we have been and speculate to some degree about where we are going. It would be impossible to do that and not recall some of the earlier stalwarts and luminaries of the meeting like Martin Stickley, already mentioned, as one of the early organizers, Johnny Myers and Haynes Lee, predecessors to John Detrio of the ASTM. And can we ever forget our frequent "words of wisdom from Winsor" (I, like more of you, feel comfortable with his already mentioned power optics to describe the general scope of this symposium). There are other individuals who have gone on to other endeavors after making their initial contributions here--Hellwarth, Marburger, Bolling, DeShazer, Guiliano, Kerr, Parks, Austin, McMahon, Bliss, Braustein, Fradin, to name but a few. There are those who are still with us from the early days--Milam, Bennett, Sparks, Bass, Edwards, and Feldman. We, of course, shouldn't overlook our frequent foreign participants who have added much in stimulating our discussions--Woods and Manenkov, to mention just two. These names and their principal interests also reflect the thrusts of our meeting over the years, e.g., let's just look at the index from the first meeting in Table I. It's refreshing to note that in the summary of that first meeting in 1969 the review started out with the following, "in a comprehensive survey of the bulk damage problem in laser glass Earlan Bliss of the Air Force Cambridge Research Laboratory stressed the importance of studying the dependence of damage thresholds on several critical parameters such as pulse duration, temperature, wavelength, and focusing configuration as a means of identifying which of several competing processes were responsible for the observed damage." There was much discussion on self-focusing with presentations from CGE (John Davit), a leader in glass laser technology at that time. While Swain talked of surface treatment by etching or repolishing, Young of American Optical talked of microinhomogenieties such as platinum and dielectric inclusions, as well as entrapped *bubbles, and their relation to the intrinsic damage level for homogeneous glasses. Some of their comments and concerns are as applicable today while in another regard we have laid to rest and passed on to other issues. In our conclusions that year we stated, "it was the goal of the symposium to review the present status of damage in laser glass. Those people most knowledgeable in the field representing government laboratories, the glass industry, laser manufacturers, and university research scientists stated their individual points of view regarding this complex and multi-faceted problem" (how many times have we used that adjective--multi-faceted). I would be remiss if I did not read the last comment by Alex Glass and myself. "In view of the number of problems remaining to be solved it is suggested that another symposium on laser damage be held in 1970. Hopefully, at that time a better understanding of the nature of damage in laser glass will be obtained. Higher threshold values will have been reproducibly achieved and some agreement can be arrived at using useful and realistic standards." Some of those desires we have achieved in an admirable manner, on others we have failed to succeed, such as in damage standards, but we are making progress as you will hear later during this meeting. The next two tables show the index from 1973, our 5th meeting. Glance at the topics and authors. As we move on to the 10th symposium shown in Tables III and IIIa you will see a continuation of the changing trends of the conference's interest as well as in its size (that was the year Jerry Bettis won our logo contest). Alex Glass, in that symposium welcome said that "it is still his annual hope that each year's symposium will be the last, not because he disliked the subject or because he found Boulder inhospitable, but that he would like to think that we could solve the problem of laser damage and move on to new challenges.*

At this our 15th meeting, I appreciate Alex's earlier comments, but perhaps because of the flexibility of this meeting in moving to new problem areas as old ones are solved, I believe this meeting will die only when there is no longer a need or artereosclerosis sets in. Initially, the push was supplied by inertial confinement fusion and generally commercial applications while today we appreciate an added impetus from the defense community as evidence by President Reagan's speech calling for revolutionary defensive systems earlier this year.

It was said five years ago that the failure of optical materials either transient or permanent remains the major limit to the performance of high power laser systems. "Although there have been great advances it remains as one of the highest leverage areas for improvement" and it still is.

We must not forget that one of the purposes of these symposia and proceedings comes under the heading of consciousness raising. There is no question that this symposium series has always been willing to address new challenges and take advantage of new opportunities and certainly the proceedings have made it easy to advance the field. De Vignaud once said, "nothing holds up the progress of science so much as the right idea at the wrong time." But, I may add to that, if the work is documented properly one can go back and in many cases use those ideas when the right time does come along. After all, much of what we have recorded has been the result of a hueristic process, that is, rule of thumb which is used to guide a problem's solution, like getting the dirt out, use wide band gap materials with high melting points that are physically strong. These empirical rules are now being placed on firm quantitative footing. Furthermore, based on our improved physical understanding, sometimes we can use design tricks to get around problems. It is interesting to note that in the early days we were talking mostly about the problems associated *with easily observable catastrophic laser damage, then we concentrated on threshold conditions requiring a microscope to note the first observable pinhole and now we search for precatastrophic indicators using more sensitive approaches such as particle emission.*

Over this period we have seen the growth of research groups, well regarded in the damage field such as the Naval Weapons Center, University of Southern California, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, the Air Force Weapons Laboratory, and now North Texas State, together with groups outside the United States, such as G.E. Hirst, the Lebedev and the University of Hanover to name but a few. To these we could add industrial organizations, government laboratories and universities in the applied materials area as well.

The next figure attempts to show how the focus of the meeting has changed from the early emphasis on glass and the original "cry for help" which gave us the impetus to start this series of meetings. Most old issues were bulk related with self-focusing drawing the attention of experimentalists and theoreticians alike for 5 or 6 years. These interests stemmed from systems experience and much work was done in analyzing high power and high energy systems from a diffraction standpoint to avoid the failure problems. These early years were more descriptive of the interaction process addressing, among other subjects, probability and statistical issues. Then careful experimental data arrived, together with new materials, figures of merit and scaling relationships, problems principally relating to windows, and once their limits were sufficiently defined; onto surfaces and mirrors with new processing techniques such as single point diamond micromachining developed to advance their utility. The explosion of surface characterization instrumentation brought reams of revealing information to bear on our problems, too much perhaps. Finally, we could not escape thin films and recognition of them as a rat's nest of problems that must be, somehow, unwoven. Fundamental mechanisms continued at a relatively steady pace but with changes in emphasis from self-focusing to avalanches, statistics, scaling, accumulation of damage, nonlinear processes and now precatastrophic indicators and detailed thermomechanical failure analysis.

Let me now dwell a moment on thin films, the major remaining problem area when it comes to the various classes of optical materials. As many of you know, I have been concentrating my work in the thin film area for the last several years. As a result I will limit my remarks about the future to that field. I believe we are now on the verge of major improvements in the damage resistance of optical thin films. I say this for several reasons. First, I have already alluded to the improved characterization instrumentation that is available, a similar situation certainly preceded improvements in bulk and surface damage levels. Secondly, an improved and perhaps, more importantly, a great acceptance of our understanding of key issues relating to impurity initiated damage through the absorption of CW or pulsed laser radiation as a function of spot size and other parameters has evolved. And finally, through several most interesting advances in the areas of thin film deposition technology. We have as well made major improvements from a design standpoint and these tricks, if you will allow me, have worked well. The magnitude of under and over barrier layers and of nonquarterwave stacks, to name the more obvious. But we do not anticipate further major advances along those lines. The most important area, of course, is the area of deposition for its through this process that we produce useful coated optical elements. We see synergistic *relationships developing between the subjects of laser induced desorption and ion assisted deposition and what they mean in cleaning, activating, or otherwise preparing the surface for deposition. The use of the Kaufman type ion gun, a development of the National Aeronautics and Space Adminstration program in ion assisted deposition, leading to films or better microstructure, i.e., film with a structure which is on the order of 40 nanometers, random in nature, and noncolumnar and thus, less susceptible to water infiltration. Ion deposition techniques are leading to films of greater packing density, closer to bulk values with less volume for voids or impurities. Both features we feel will lead to high damage resistant films. Another emerging technique is atomic layer epitaxy (ALE) which offers films of still higher packing density and of more uniform structure. Normally the growth of films starts at random sites which then coalesces. Under these conditions it is very difficult to escape entrapped voids. ALE on the other hand deposits an atomic layer at a time, with some annealing and recrystalization of the material which apparently forms films closer to the parent materials bulk density and noncolumnar in nature. The extent to which deposition techniques such as these together with MBE, etc., will advance our ability to handle high energy and high power levels remains to be seen, but I anticipate them to be great. There is of course work underway on the laser annealing of thin films in the hopes of realizing some of the improvement noted in fused silica using a similar approach by workers at the Naval Weapons Center and Lawrence Livermore National Laboratory. Hopefully we will hear more of this work in the next few years. These impending improvements in thin film properties should also make them more stable over longer periods and more environmentally durable.*

We are in good position to make use of our knowledge of the interrelationship between chemical and physical properties (structural, optical, and thermal) as regards selection of materials and predicting their performance. Laser activity in the damage area will certainly concentrate at shorter wavelengths and emphasize rep rate testing, damage accumulation, lifetime, etc., as a function of our operating parameter experience. This will come as a result of the interest in systems such as excimer and free electron lasers, etc., and will be based upon quality experimental data and computer modeling.

For several reasons we had a greater influx of papers than we expected this year, as seen in the last figure. It may be due in part to the lack of a components meeting normally held in conjunction with this symposium. We have had to do two things. Extend the meeting to 2 1/2 days. Second, we had to increase the number of poster papers from 10 to 12 each day. We are going to try something new and ask each author to give a 1 1/2 minute summary of the key aspect of his presentation. Through this we hope to accomplish many things, highlight the feature of the research, which might go unnoticed if recourse is given only to reading an abstract, written months ago, (2) let one see who the authors are (i.e., give them exposure) and (3) help them to know what some of the other poster presentations are about, which they themselves may wish to see. As usual the posters will be available in both the morning and afternoon of the first two days.

We are glad that you all have finally received your copy of the 1981 proceedings which, as you note, contained 63 papers. You will be glad to know that the 82 proceedings have gone to the printers as well and they should be in your hands shortly. The delay in the 81 proceedings in part came from accepting papers, primarily from the Soviet Union, even though they were not presented at *the meeting. They added considerably to our book's size. I guess people just want their damage related work published in these volumes. We will be looking more closely at that policy since it does add measurably to the work of the co-chairmen. The lateness of the 82 proceedings is primarily from late manuscript arrival. In this case you can help us by getting your manuscripts in on time. It has been suggested we date the manuscripts as they are received so you will all know who the good and bad guys are.*

Finally, we would like to thank Bob Kamper, Aaron Sanders, Susie Rivera, Shelley Etzel, Kathy Sherlock, and Pattie Mannos. I would like to add a personal thank you to Pat Whited, my secretary, for her most welcome and professional help. We couldn't run this meeting in the style, particularly this year, without the support of our sponsors. We are thankful to the National Bureau of Standards, DARPA, ONR, DOE, AFOSR, and of course the ASTM. To all of you and especially our foreign visitors, a warm welcome to this, our 15th Boulder Damage Symposium.

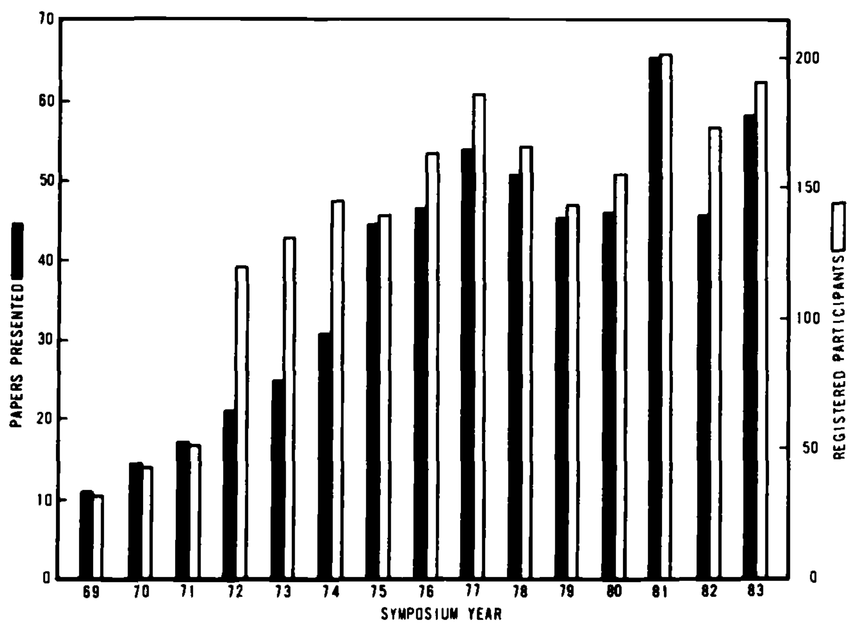
PAPERS PRESENTED
REGISTERED PARTICIPANTS
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FIGURE 1

SYMPOSIUM TRENDS

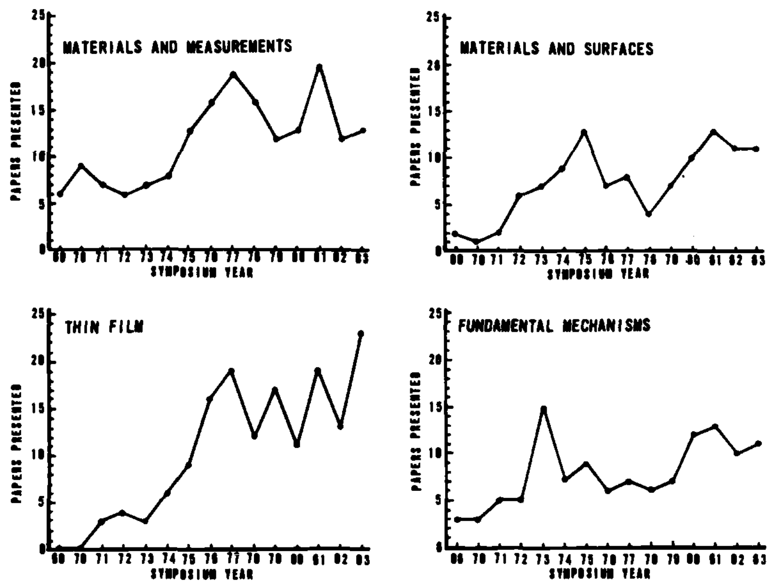

FIGURE 2

TABLE I

BOULDER DAMAGE SYMPOSIUM 1969

TABLE IIA

BOULDER DAMAGE SYMPOSIUM 1973

SELF-FOCUSING

SURFACE DAMAGE

OPTICAL COATING DAMAGE

TABLE IIB

DAMAGE TO INFRARED COMPONENTS

THEORY AND FUNDAMENTAL PROPERTIES

TABLE III

BOULDER DAMAGE SYMPOSIUM
1978

INTRODUCTORY REMARKS

MEASUREMENT OF ABSORPTION CHARACTERISTICS

BULK MATERIAL PROPERTIES

TABLE IIIA

MIRRORS AND SURFACES

THIN FILM DAMAGE

COATING MATERIALS AND DESIGN

BREAKDOWN PHENOMENA

ASTM WELCOME

John A. Detrio
University of Dayton Research Institute
Chairman, ASTM Subcommittee F1.02 on Lasers

It is my pleasure to welcome you to the 1983 Boulder Damage Symposium. It is difficult to think of this as the 15th annual meeting; the field of laser damage seems as lively as ever. However, there has been a trend toward shedding more light than heat on the subject during this symposium. The early days were filled with pointed comments and controversies. Lately we have been a little more civil. Possibly another sign of maturity with the laser damage field is the convergence of experiment and theory in certain areas and greater attention to details in studying components for use in "technological" applications of laser science. Coating damage may represent the last real challenge to the systematic understanding of materials damage issues for practical components. The bulk of this year's papers concern coating damage.

I would like to share a few comments about the participation and role of the American Society for Testing and Materials. ASTM committees attempt to fulfill two purposes:

The development of standards
The dissemination of knowledge

The Boulder Damage Symposium has always been considered as addressing the secondary mission. We have hoped that at an appropriate time in the development of laser science and technology the need for standards would arise and we would be in a position to respond to the needs of the laser community.

The most significant paper with respect to justifying ASTM participation in the damage conference is the reporting of an interlaboratory comparison of 1.06 µm damage to thin films. The impetus for this round robin comes from Europe. Don't be surprised to find DIN coating damage specifications required on optics sold abroad. America's voluntary consensus standards system rarely rises to the challenge of standards development unless a clear economic threat is perceived. We in the U.S. have been invited to participate in the ISO deliberations on coating specifications but it is impractical to respond without a working organization of volunteers to support that participation. Expertise is needed to draft standards documents and to provide technical commentary on proposed standards.

If you sense the need for representing the interests of American organizations in the development of international standards, several things must be done. First, a consensus U.S. position (set of standards documents) must be developed and the U.S. must have formal representation at the Technical Group Meetings to work toward an international consensus on standards. This process can ensure that all countries receive equitable treatment but only if they invest in that participation.

I would like to thank those who provide the financial support for the Symposium including AFOSR, DARPA, DOD, ONR, and our hosts, NBS, especially Aaron Sandars and his assistants.

Once more, welcome to the Boulder Damage Symposium. Enjoy an interesting and stimulating program and an equally interesting and stimulating group of attendees.

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