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of the

Society of Photo-optical Instrumentation Engineers

17th Annual Technical Meeting

SEMINAR-IN-DEPTH

DEVELOPMENTS IN LASER TECHNOLOGY-II

AUGUST 27-29, 1973
SAN DIEGO, CALIFORNIA

Editor:
RALPH F. WUERKER

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Introduction

Welcome to the SPIE's DEVELOPMENTS IN LASER TECHNOLOGY II seminar! Before us is a seminar of 32 papers which beautifully demonstrate the wide applicability of the laser. This conference is uniquely inter-disciplinary, and will include physicists, electrical engineers, biologists, oceanographers, mechanical and civil engineers, artists, sculptors, medical doctors, dentists, etc.

Cumulatively, the speakers represent a quarter of a millenium of laser experience, even though the laser is only twelve years old. Several of the participants have been active with lasers for more than a decade. Ray Hoskins was a member of Ted Maiman's team which brought the first (ruby) laser to life in 1960. Carroll Alley is another pioneer. His lunar ranging work represents ongoing aspects of the Apollo Program. The Apollo Program and lasers began at about the same time. One is over, having as one of its major accomplishments the placement of laser reflectors on the moon's surface. John Emmett started with a laser under Professor Schawlow who worked with C. Townes on the original concept of the laser. Bill Krupkie, Keith Brueckner, and O. Barr will separately describe the application of the laser to controlled nuclear fusion. These are both governmental and private efforts aimed at solving, over the long term, the world energy crisis.

It is worth noting that the lasers that range on the moon and the lasers that are used to try to ignite deuterium in controlled thermonuclear research are generically related; both are Q-switched solid state lasers. Bill Eppers is a pioneer at Wright Field who has probably heard more laser promises than anyone. It is fair to say that up until the last three years the military services funded most of the American laser development. Q-switched solid state lasers were first developed under military contracts.

Leon Goldman is one of the pioneers of the laser in medicine. He has contributed greatly, mitigating the imagined dangers of non-ionizing laser radiation. His work has led to realistic safety standards. At a general talk on lasers, any mention of Leon's tattoo-erasing with a ruby laser is good for a laugh. It just so happens that the dyed cells of tattooed skin are selective (absorptive) of ruby laser light; similar discoveries with cancerous cells could lead to an important mode of treatment. The tunable dye lasers and parametric lasers now offer a greater choice in wavelength so that advances in this area should be forthcoming? The laser has found a permanent home in the medical field. This was illustrated to me when a nurse expressed surprise at hearing that the laser was only twelve years old.

Joe Goodman (Stanford) and Nicholas George (CalTech) have been active in coherent aspects of the laser, a product of the laser's extreme monochromaticity. Holography has made the first stored 3-D images, has opened a technique in nondestructive testing, and is being developed as a computer memory. The 3-D aspects of coherent imagery are being used by oceanographers to study food chains in the ocean depths. This will be described by Gene Stewart.

Victor Evtuhov is another old soldier who will be represented by Michael Barnoski. Both have been working on communications through glass threads, an area which will revolutionize short range communications, as well as help alleviate the copper supply problem. Bob Presley and J. Steele represent the laser in the fields of commerce: Presley for the solid state laser--welding, drilling, and cutting; and J. Steele, for the oldest laser company, will describe uses in civil engineering--laying out tunnels, skyscrapers, putting together 747 jet aircrafts, and setting the drain of a sewer.

Ten years ago one wag called the laser "a solution looking for a problem." Another called it a sophisticated scientific development. I believe that this conference will show both to be wrong.

It is my contention that lasers are actually simple devices, which I claim accounts in part for their vitality in these days of dwindling research and development budgets.

The laser has been a major invention, as testified by this conference. What it has done has brought in some new options and new approaches to many standing problems and tasks. In many ways, it has fostered new ways of approaching old problems. It is this aspect (namely, the options) that makes the laser a truly great invention. It is my contention that the laser has not as yet reached its final plateau in development or application. I believe that the next twelve years will be even more wonderful than the last.

Ralph F. Wuerker
General Chairman

Seminar Committee

GENERAL CHAIRMAN

RALPH F. WUERKER
TRW Systems Group
Redondo Beach, California

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Session I

SESSION CHAIRMAN

CARROLL ALLEY
Department of Physics
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College Park, Maryland

ACTIVE ASTRONOMY — TRACKING THE MOON BY LASER

Carroll Alley
Department of Physics, University of Maryland

ABSTRACT*

Over the last five years NASA has supported ranging on the lunar surface with a ruby laser.[1,2] The laser was constructed by the KORAD Corporation and is installed at the McDonald Observatory in Texas.

The laser emits a 20 joule — 30 nanosecond pulse. Of the returning signal, collected by the McDonald telescope, approximately on: photoelectron is produced. The photomultiplier on the telescope is range gated to reduce the background. Signal averaging techniques are used. With this whole system one can measure distance from McDonald Observatory to the moon to an accuracy of ~10 centimeters.

Experiments are aimed at determining more precisely the orbit of the moon. Better knowledge of the orbit of the moon can be used to determine more accurately the shape of the earth. Future experiments were described in which laser ranging would be done simultaneously from different points on the earth, i.e., different stations. These measurements would afford a means of predicting continental drifts and early prediction of earthquakes. Ideally, it would be better to have a more intense laser and a laser which emitted in the green where photomultipliers are more sensitive. Funding for these necessary improvements have not been forthcoming.

*Note: This summary was prepared by R. F. Wuerker, Chairman of the Laser Seminar, since an abstract or paper was not received by date of publication.

1. C. Alley, APOLLO II LASER RANGING RETRO-REFLECTOR (LR^3) EXPERIMENT . . published in Bogden Maglich editor.

ADVENTURES IN EXPERIMENTAL PHYSICS Vol. Alpha Published World Science Communication. P. O. Box 683, Princeton, N. J. 08540, (1972), pages 127 to finish.

2. P. L. Bender, et. al., THE LUNAR LASER RANGING EXPERIMENT, Science Vol. 182, 19th of October 1973, pages 228 to 238.

THEORY AND EXPERIMENT IN LASER DRIVEN FUSION

Keith A. Brueckner
KMS Fusion, Inc.

The production of fusion energy from a pellet of thermonuclear fuel can be achieved on a level useful for power production only if the pellet is highly compressed with efficient energy transfer from the external energy source into the pellet. The simple model of a uniformly compressed DT sphere can be used to determine the fusion energy production. Figure (1) gives the ratio of fusion energy output to initial thermal energy for a uniform initial temperature of 5 kev. The energy multiplication, for an initial thermal energy of one kilojoule, is 5 at a density of 300 gm/cm^3, 16 at 600, 40 at 1000, and 80 at 2000. For high energy input on high compression, the energy multiplication levels off at about 200 corresponding to about 35% burnup of the DT. The energy multiplication can be increased if the fuel is only centrally heated to the ignition point of 5 kev, with the rest of the fuel ignited by an expanding supersonic burning front propagating outward from the fuel center. Figure (2) shows a typical example of the propagation of a supersonic burning front. Figure (3) shows the energy multiplication with the fuel center heated to 5 kev over a few micron radius and the rest of the fuel at 500 ev. With an initial thermal energy of one kilojoule, the energy multiplication is 130 at $\rho = 600$ gm/cm^3, 400 at $\rho = 1000$ gm/cm^3, and 700 at $\rho = 2000$ gm/cm^3. The energy multiplication reaches a maximum of about 1200 for initial thermal energy of 5-10 kilojoules, independent of initial density, corresponding to about 35% fuel burnup. The effect of the cen-

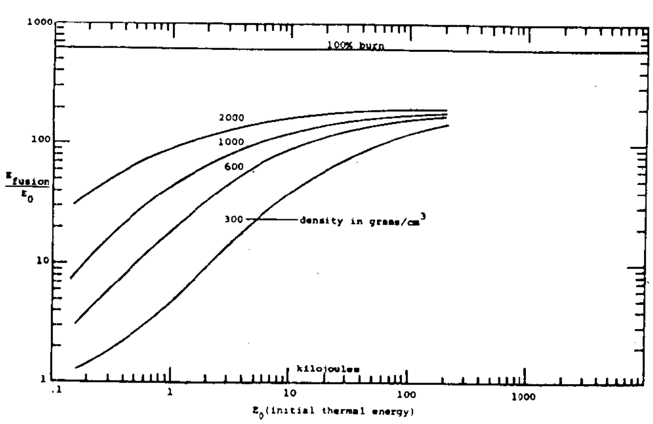

FIGURE 1 - Ratio of fusion energy to initial thermal energy for a uniformly compressed DT sphere initially heated to 5 kev.

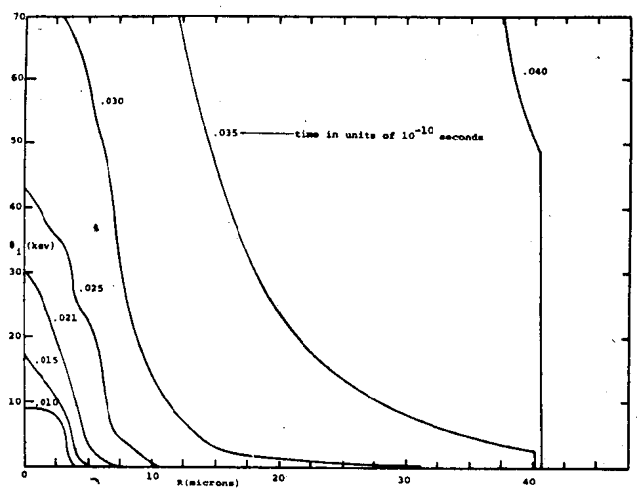

FIGURE 2 - Thermonuclear burning front in DT at an initial density of 2000 gm/cm^3.

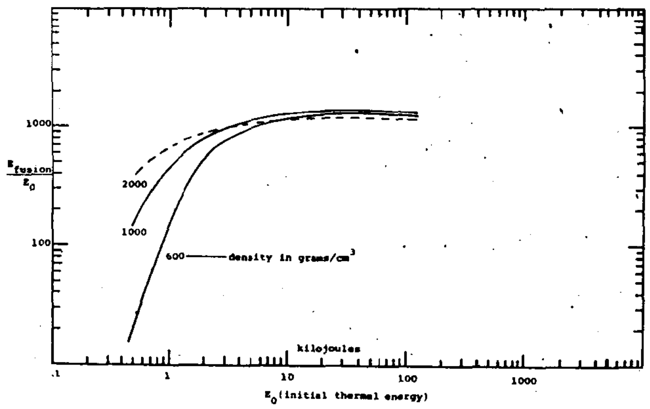

FIGURE 3 - Ratio of fusion energy to initial thermal energy for a uniformly compressed DT sphere initially heated to 5 kev over a few micron radius, with the rest of the DT at 500 ev temperature.

trally-initiated burning wave increases the energy multiplication by about a factor of ten over the uniformly heated case.

Calculations of the implosion of a DT sphere in spherical symmetry show that high compression can be produced by a laser pulse with proper time variation. The pressure driving the implosion is produced by the penetration of energy from the underdense laser deposition region into the dense plasma which results in ablation of the dense pellet surface. The efficiency of this process depends on the efficiency of energy absorption from the laser beam into the underdense plasma and on the subsequent energy partition between the compression of the dense pellet core and the energy removed in the high temperature expanding plasma produced by the ablation process. The latter partition can be estimated from a hydrodynamic model or determined by computer simulation of the energy deposition, energy transfer, and hydrodynamic processes. The result is that 6 to 10% of the absorbed energy is transferred into compression and heating of the dense pellet core.

Detailed computer simulations of the full process of laser coupling for 1.06 micron wavelength, thermal energy flow, hydrodynamics, nuclear reactions, and of the energy transport in the nuclear reaction products and radiation, give results in approximate agreement with the numbers just given.

Of particular interest for the experiments now being undertaken by several groups in the USA and other countries is the prediction that the "breakeven" condition, with fusion energy equal to laser energy, can be reached with laser energy of about one kilojoule. This prediction holds, however, only if several conditions are satisfied. These are:

A. Configuration requirements
   1) laser pulse time variation properly matched to pellet configuration
   2) spherical symmetry of pellet illumination
   3) spherical symmetry of pellet configuration

B. Physics requirements
   1) stable hydrodynamic motion
   2) adequate laser-plasma coupling
   3) absence of appreciable pellet preheat.

If these requirements are not met, the breakeven energy can be very markedly affected. Particularly striking is the effect of a poorly matched laser pulse. The breakeven energy for a square laser pulse and a DT sphere is several hundred megajoules. A drop in compression of a factor of ten as a result of imperfect convergence can increase the breakeven energy by a factor of ten to one hundred.

The configuration requirements on the laser energy variation in space and time, although difficult to meet, can be satisfied with properly designed illumination systems and laser oscillators giving controllable sequences of stacked pulses. The pellet symmetry can also be provided by careful pellet fabrication and selection methods. We have studied the effect of variation in the laser and pellet parameters, using 2-dimensional computer simulation, and determined the allowable departures from complete symmetry. These conditions are imposed on our laser system and pellets.

The problems of the physics of the laser-driven process are too difficult to resolve without experimental results, although very important analyses and calculations have been made.

The stability of the pellet implosion has been studied analytically and by computer simulation, using a 2-dimensional code. The results show stable motion, with initial disturbances not being amplified during the implosion. The laser-plasma coupling presents difficult problems which are of a complexity very familiar for the past two decades in the controlled-fusion programs. Closely associated with the coupling problem is the effect of anomalous laser-coupling on the energy flow into the pellet. Present theories estimate that a wide range of anomalous phenomena can occur which may seriously alter the predictions of the laser-driven process. Experiments are intended to resolve these uncertainties.

We have carried out a number of experiments using a neodymium-glass laser brought to full operation during July of this year. The laser configuration is shown in Figure (4). The laser driving the main amplifier train is a VK800 laser built by CGE, with some modifications and with Owen-Illinois ED-2 glass replacing the original French laser glass. This laser operates reliably on a six-minute cycle with an energy output from the 80 millimeter output amplifier of 250 to 350 joules. A considerably higher output is possible, but has not been used because of possible glass damage from self-focusing. The output from the 80 millimeter amplifier is expanded to 100 millimeter diameter and further amplified in seven amplifier modules built by GE. Each module contains three disks of glass at

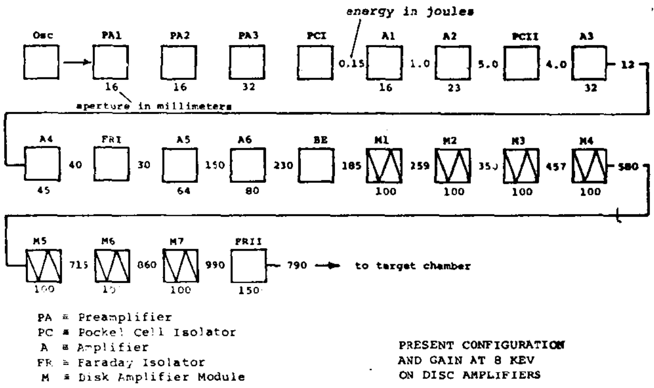

FIGURE 4 - Configuration of KMSF laser.

Brewster's angle. The path length of the laser beam in each disk is 3 centimeters and the effective aperture is 122 cm^2. The glass stores 0.32 joules/cm^3 with 8 kev pumplamp voltage and 0.36 joules/cm^3 with 9 kev pumplamp voltage. With 200 joules input with 3 nsec pulse width (FWHM) to the GE system, the measured output from the first six modules is approximately 840 joules at 8 kev flashlamp voltage. The predicted output of seven modules at 8 kev is 990 joules and at 9 kev approximately 1400 joules. The measured gain is in good agreement with the design predictions.

The laser is protected against damage from reflected laser energy by Pockel cell isolators at the entrance to the 16 mm rod of the main amplifier chain, between the 23 and 32 mm rods, by a Faraday rotator between the 45 and 64 mm rods, and by a Faraday rotator at the exit of the GE amplifiers. The protection is adequate against the full output energy re-entering the exit end of the GE rotator.

The laser pulse beam from the CGE oscillator is approximately Gaussian with a pulse width (FWHM) of 1.3 or 3 nanoseconds. The pulse is strongly distorted through the CGE and GE amplifiers due to partial saturation of the amplifiers. A pulse-stacking oscillator has been built to replace the CGE oscillator to give