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PLASMA DEVELOPMENT IN LOW Z LASER FUSION TARGETS

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ABSTRACT

The details of the initial plasma formation, the propagation of the plasma front through the target material, and the development of the initial low temperature plasma to the final state of ionization in a laser fusion target is not well understood. In transparent dielectric targets, the initial plasma breakdown begins by electron avalanche ionization at energy densities of about 5-10 J/cm^2 (λ = 1.06 μ and pulse duration $\leq$ 1 nsec). Since typical focal areas for glass lasers are less than 10^{-4} cm^2, 5×10^{-4} J causes breakdown in these targets. These numbers lead to stringent restrictions on the temporal character of laser pulses which are designed for laser fusion research. We present measurements showing the temporal character of a dye-mode-locking laser oscillator over an intensity range greater than 50 db. Once breakdown occurs, the deposition of laser light in the target is severely altered as the electron density approaches $n_e \approx 10^{21}\text{cm}^{-3}$. We show time resolved steak data on the spatial development of plasmas in thin dielectric targets.

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1. Introduction

In this paper, we discuss two problems associated with the initial stages of target heating by laser radiation. The first problem is the energy delivered to the target prematurely because of imperfect mode-locking in the laser oscillator and amplified spontaneous emission through the amplifier chain. The second problem is the initiation and the growth of the breakdown of the dielectric material.

To achieve the short pulses required for laser fusion experiments we use a dye-mode-locked oscillator to generate 100 psec, gaussian pulses. The mode-locking process starts from bandwidth limited, spontaneous fluorescence noise generated by the active oscillator materials.(1) The more intense noise pulses begin to bleach the mode-locking dye as they are amplified during sequential round trips in the optical resonator. The more intense pulse generally wins out and is observed as the mode-locked oscillator output signal. In an actively mode-locked oscillator in the cw limit, only one pulse developes to the steady state limit.(2) In our oscillator, the passive mode-locking procedure and operation in the transient regiem may allow lower level noise pulses to appear in the mode-locked pulse train. Parasitic feedback loops often exist in a complicated optical resonator because of dust particles, damage spots, etc. The additional feedback mechanisms can also give rise to additional pulses in a mode-locked pulse train. These low level pulses can be amplified to levels which are sufficient to destroy laser fusion targets before the arrival of the main heating pulse.

An additional source of target damage is amplified spontaneous emission (ASE). Target damage occurs when the amplifier gain is sufficient to amplify spontaneous noise generated in the initial stages of the amplifier train to damaging levels. The experiments described here were done on two laser systems at LLL: the JANUS system shown in Figure 1 and the Long Path Laser. Both of these systems have a master oscillator and an amplifier chain. A calculation of the expected ASE noise level has been done by Leppelmeier (3). For the JANUS system, where the amplifier gain at 1.06 μ may be greater then 10^4, 1-20 mJ of energy may be intercepted by the target. This level of irradiation can cause premature target damage.

Understanding premature target damage and the early development of laser plasmas relies on a detailed knowledge of the initial stages of plasma formation. For uniform compression of fusion targets, it is important that the critical density surface developes from the initial breakdown point at a rate that is fast compared to the fluid dynamic rate for the implosion. Present theories of optical damage in solid dielectrics (4) stress the statistical nature of the beginning of an electron avalanche process. Our primary interest is to determine the reproducibility of the breakdown process and the rate of growth of the critical density surface in a direction transverse to the optical axis.

II. Target Damage

The energy required to exceed typical dielectric breakdown thresholds in laser fusion targets is very small because of their small dimensions. A typical laser fusion target, as shown in Figure 2, may subtend an area of 4×10^{-4} cm^2. Milli-joules of laser energy distributed uniformly over the target produces an energy flux of several J/cm^2; levels which exceed glass dielectric breakdown thresholds.(4) If the target material is not completely clean or if there are glue spots or dust particles attached to the surface, damage may occur at levels lower than those associated with the intrinsic breakdown limit.

Figure 3a shows a typical damage site on a hollow glass ball which was purposely irradiated with 100 psec, milli-joule energy pulses. Figure 3b shows that more complete damage can occur when the focusing conditions differ. In this case a 100-300 μJ pulse was focused onto the glue joint. This damage, if it developed before the laser compression pulse arrived, would prevent meanful compression of the target.

We are not yet able to determine the absolute short-pulse damage threshold of these glass shell targets. The optical aberrations of our lenses, as well as the static and dynamic aberrations of the laser systems have prevented us from accurately measuring the absolute energy density of the interference structure in the focal region. Our philosophy has been to eliminate any chance of target malfunction caused by pre-pulse processes. To this end, we are developing fast pockel's cell switches. saturable absorbers, and precise monitoring techniques.

Target damage from amplified spontaneous emission is difficult to quantify. The usual result is shown in Figure 4. We have found that when a target intercepts more than 10 mJ of 1.06 radiation, damage to the glue joints may occur. The damage threshold is very sensitive to the type of glue used and to the orientation of the glue joint with respect to the optical axis. We have not yet determined when the ASE damage occurs in time. Since the laser pulse usually occurs about half way through the fluorescence pump pulse (about 500 μsec into an 800 μsec flashlamp pulse) it is possible that the target is still intact when the laser compression pulse arrives. Until we obtain more data on this point we plan to reduce the amplified spontaneous emission level below the target damage threshold observed upon inspecting the target after the pump pulse.

III. Pre-Pulse Measurements

We have measured the prepulse history of the mode-locked laser oscillator on the JANUS system over an intensity range of 50 db, with time resolution of 1 nsec. The experimental arrangement is shown in Figure 5. A fiducial pulse is generated by the glass wedges and follows path 1 to allow identification of the single switched-out oscillator pulse, of the residuals from rejected pulses in the train, and of spurious noise pulses. Appropriately placed beam attenuators and the high photodiode sensitivity allow us to observe temporal structure which is up to 50 db down in intensity from the main pulse.

Figure 6 shows some typical results from our oscillator. Eighteen pulse trains were examined, of these 4 trains had pre-pulse energies less than 30 db down from the main pulse, 8 trains had structure between 40 and 50 db down in energy, and 5 showed no pre-pulse structure at all. The residual intensity in the pulse preceeding the switched-out pulse is down at least 50 db.

For the JANUS laser system which is designed to produce 20-40 J pulses, a 40 db reduction in intensity still leaves 2-4 mJ of energy which can damage the target. As a result, we feel that it is very important to carefully tune the oscillator and to monitor each target pulse. We are also considering employing saturable absorbers to further reduce pre-pulse effects.

IV. Initial Plasma Formation

To study the transverse development of the critical density in a dielectric target, we have observed transmitted laser light as a function of time. Figure 7 shows the experimental set-up. The purpose of this experiment is to set limits on the rate of formation of the critical surface.

Figure 8 shows a streak photograph of the time development of the breakdown. The image of the laser focal regions is seen to increase in intensity until breakdown occurs at the center of the beam. At this point, 1.06 μm radiation is either absorbed at the critical surface or refracted out of the field of view. The transverse rate of plasma formation is given by the growth rate of the absorbing region. The rate of growth is very dependent on the power delivered to the critical region.

At present, we are unable to provide an accurate number for the growth rate. An accurate value will be available shortly.

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2. D. J. Kuizenga and A. E. Siegman, "FM and AM Mode-Locking of the Homogeneous Laser - Part I and Part II," IEEE J. of Quant. Electron. QE-6, 694-715 (Nov. 1970).

   D. J. Kuizenga, D. W. Phillion, T. Lund, and A. E. Siegman, "Simultaneous Q-Switching and Mode-Locking in the cw Nd:YAG Laser," Optics Comm. 9, 221 (Nov. 1973).

3. Calculation by G. W. Leppelmeier:

   $$Q = \sqrt{\pi}\ \frac{E\,a^2\,A\,e^{\alpha L}}{16\,f^2\,\alpha^2 L} = \text{Joules stopped by target}$$

   E = effective stored energy density in J/M^3, $e^{\alpha L}$ = gain

   a = target diameter in M, f = focal length of lens in M

   A = lens area - M^2, L = length of gain media M.), α = effective gain M^{-1}.

4. N. Bloembergen, "Laser Induced Electronic Breakdown in Solids," IEEE J. Quant. Electron. QE-10, 375-386 (March 1974).

   See articles by G. W. Leppelmeier and B. Newnam in "Laser Induced Damage in Optical Materials 1974," A. J. Glass and A. H. Guenther eds., NBS Special Publication, U. S. Gov. Print Office, Washington, D.C., 1974, to be published.

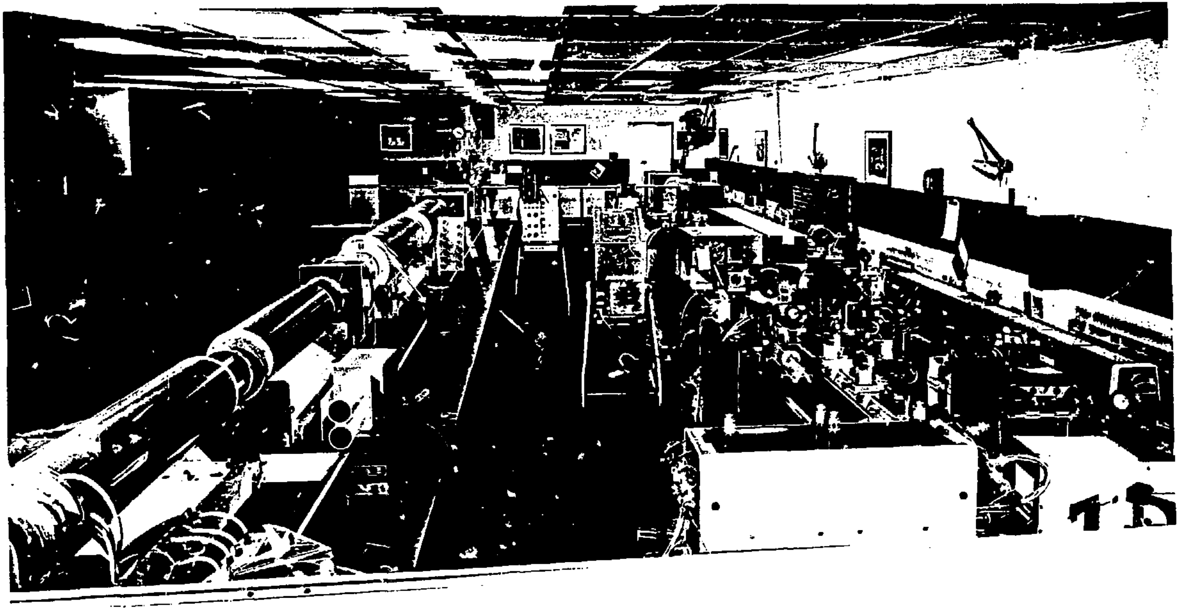
FIGURES

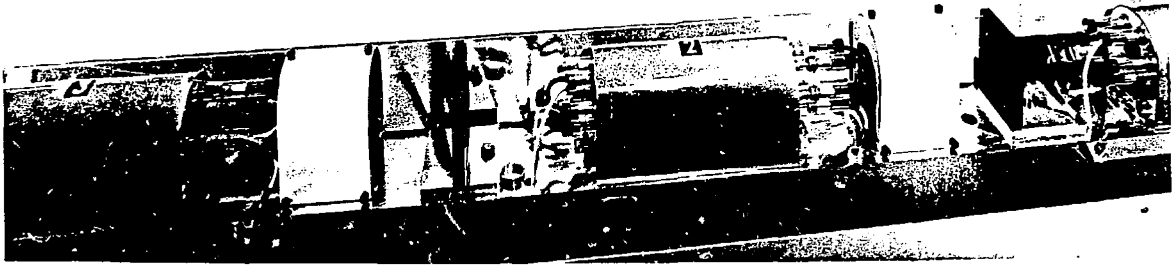
1. Janus Laser System
2. A Typical Laser Fusion Target which Consists of a Hollow Glass Shell 74 μm in outside diameter is shown.

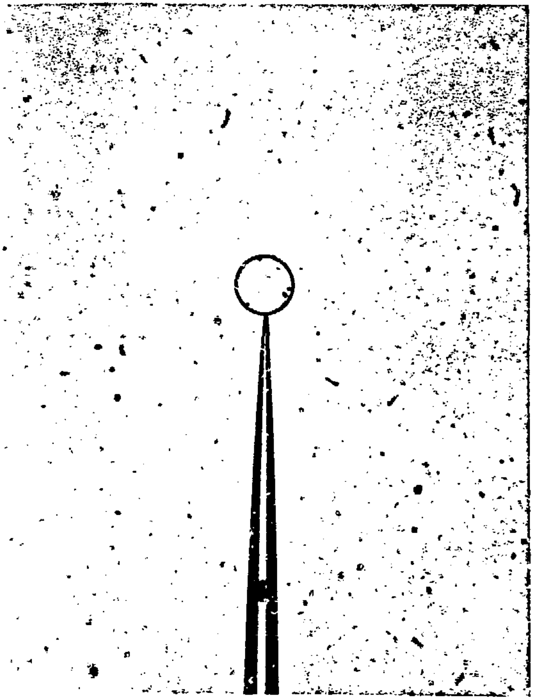
3a Damage Caused in a Hollow Glass Ball by a Focused mJ Laser Pulse

b Shattered Shell Caused by Focusing 100 to 300 μ J of Laser Energy on the Glue Joint Attaching the Hollow Shell to the Glass Stalk.

4. Photograph Shows the Hollow Ball Blown From the Stalk by Approximately 20 mJ of Amplified Spontaneous Emission From the Long Path Laser.
5. Diagram of the Experimental Set-up Used to Study the Prepulse Characteristics of the JANUS Oscillator.
6. Typical Experimental Records From the Prepulse Experiments Shown in Figure 5.
7. Experimental Set-up to Study the Time Development of the Initial Target Breakdown
8. Streak Camera Record of the Target Breakdown, 70 μ Glass Ball







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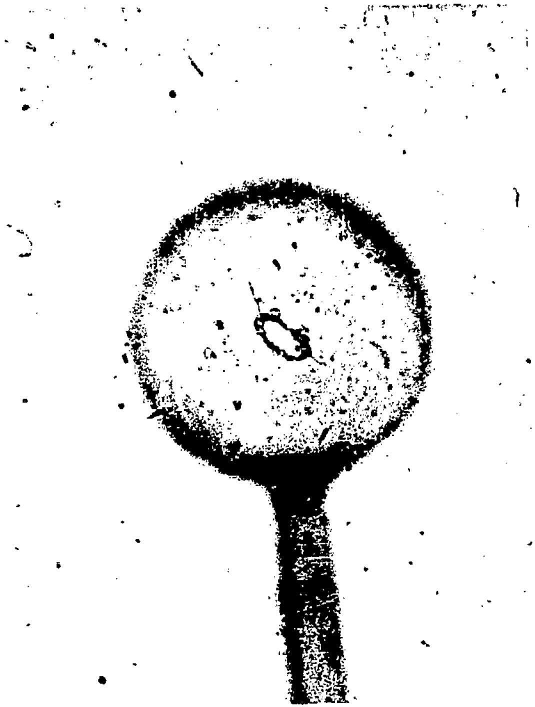

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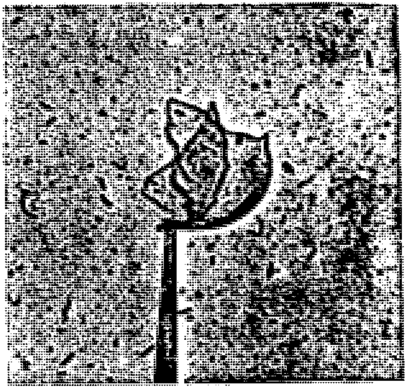

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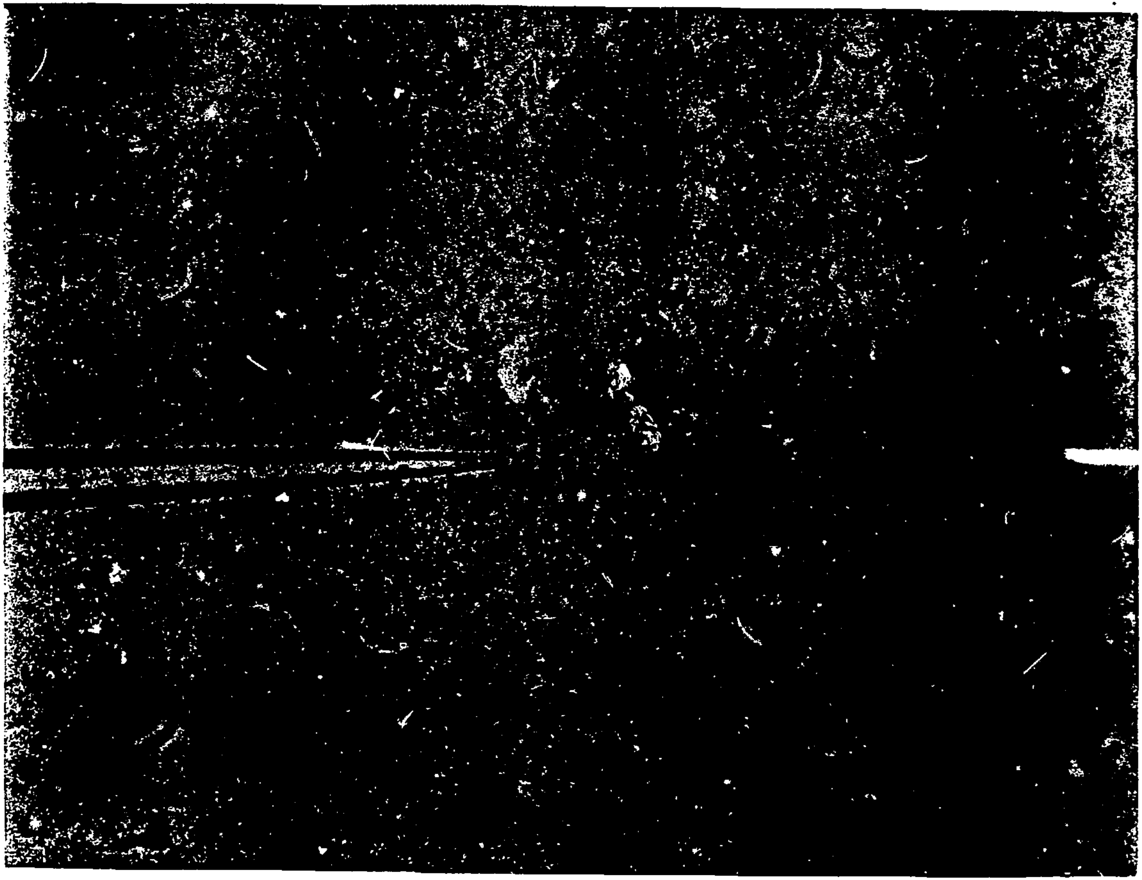

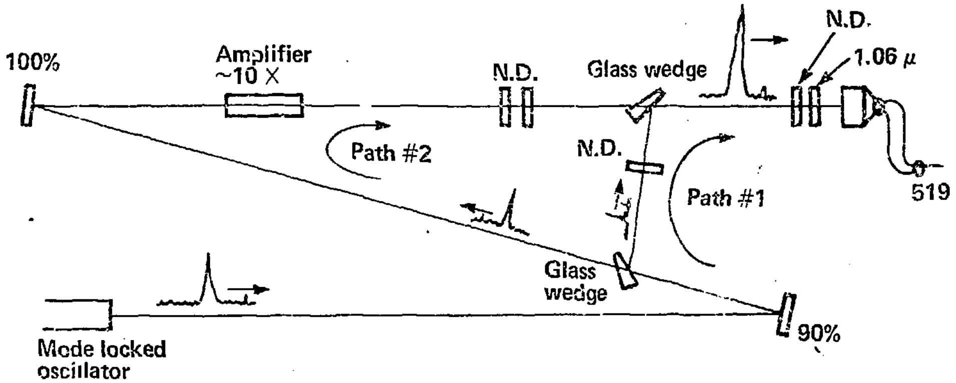
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Amplifier
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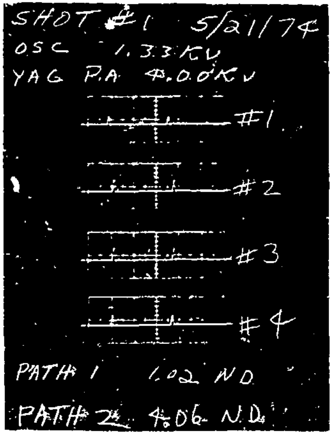

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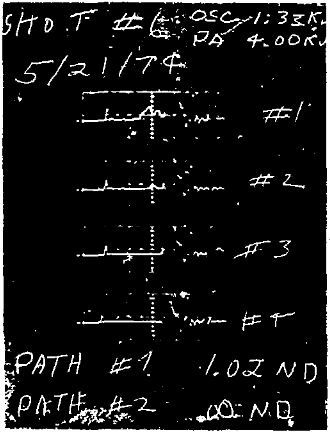
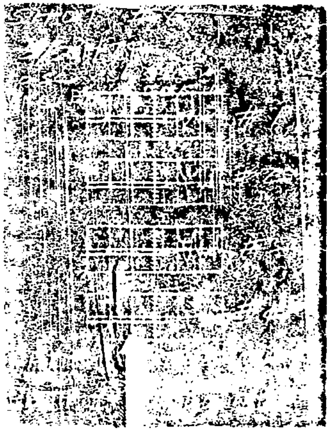
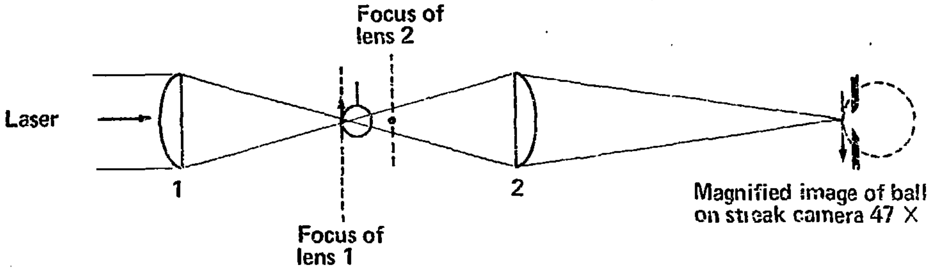


Noise pulse



Rejected pulse



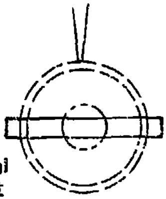


Image of ball & laser focal spot on streak camera slit

TARGET BREAKDOWN