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1.C Barrier-Layer Experiments and Initial Plasma Formation in Laser Plasma

The initial phases of plasma generation on the surface of transparent solid targets under high-intensity laser irradiation are not very well understood. The problem is exemplified by the anomalous burn-through speeds obtained from x-ray spectra of multilayered targets. Those data have shown that the outer plastic (CH) layers always burn through at rates much too high to be accounted for on the basis of hydrodynamics and/or beam nonuniformities.[1] Similarly, experiments where a high-intensity laser beam was focused on the surface of a transparent Lucite block showed evidence of self-focusing filaments in the bulk of the material,[2,3] which was identified as light leakage during the early part of the evolution of the laser pulse, before an absorbing plasma was formed on the surface. In all cases, a relatively thin metal layer the thickness of a few hundred angstroms reduces the x-ray burn-through rates to near nominal levels and eliminates the visible filaments protruding into the Lucite after irradiation. Qualitatively, this can be understood because the breakdown threshold of metal surfaces are known to lie well below those of dielectrics.[4] Thus, the irradiation of unprotected, dielectric laser-fusion targets may lead to significant light leakage into the interior of the target. It is not clear at this time if this light can change the bulk of the target shell in any appreciable manner prior to plasma formation on the surface, nor do we know if such a change may depend on the detailed target composition (e.g., layered targets, including cryogenic targets). If the target shell and any possible cryogenic layer could be perturbed by the leakage of low-intensity laser light, the subsequent hydrodynamics of the collapsing shell could be changed and would be expected to lead to reduced target performance.

Single-Beam Experiments

A number of experiments have been carried out recently at LLE to investigate the effects of light leakage through the surface of the target prior to plasma formation. These experiments were carried out on the glass development laser (GDL) under target and irradiation configurations indicated in Fig. 35.17. The primary diagnostic in these experiments consisted of microscopic inspection of the bulk plastic target material after laser irradiation.

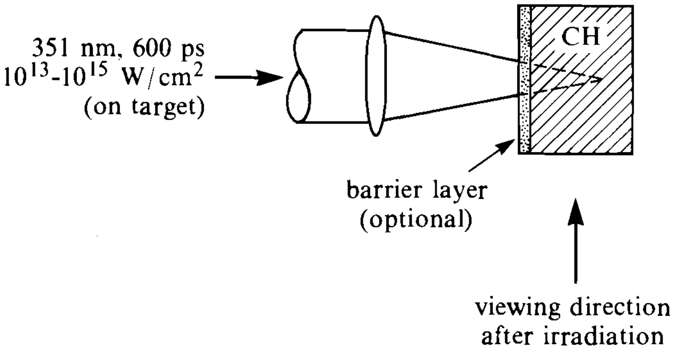

Fig. 35.17
Target and irradiation configurations of single-beam (GDL) experiments with barrier-layer targets.

The main results of the single-beam experiments are illustrated in Fig. 35.18, which shows microscope photographs taken of solid plastic (Plexiglas) targets after irradiation by a 351-nm, 600-ps laser beam at various intensities between 10^{13} and 10^{15} W/cm^2. The effects of conventional self-focusing or filamentation at low irradiation intensities are easily discernible in Fig. 35.18(a), while the effects of early light leakage at high irradiation intensities are shown in Fig. 35.18(b) and 35.18(c) for targets without and with thin barrier layers, respectively. The barrier layers consisted of up to 500 Å of Au or up to 1000 Å of Al evaporated on the surface of the target. In Fig. 35.18(b), one also observes what appears to be whole-beam self-focusing, as opposed to the small-scale filamentation visible in Fig. 35.18(a), the latter reflects the conical shape of the converging laser beam (nominal focus was approximately 700 μm inside the target), while the former collapses on axis well before the nominal focus. It is apparent from these photographs that the addition of a thin metal surface layer reduces the light leakage into the interior of the target [Fig. 35.18(c)], although nothing can be deduced from these images regarding any effects taking place within the first 200 μm of the target surface.

While these single-beam experiments illustrate—as have earlier experiments using 1-μm light—that there is some light leakage into the interior of the target prior to surface plasma formation, even for 351-nm irradiation, we have not yet succeeded in determining the amount of light leakage nor its effect on targets that are only several microns thick. However, we may speculate that in the presence of

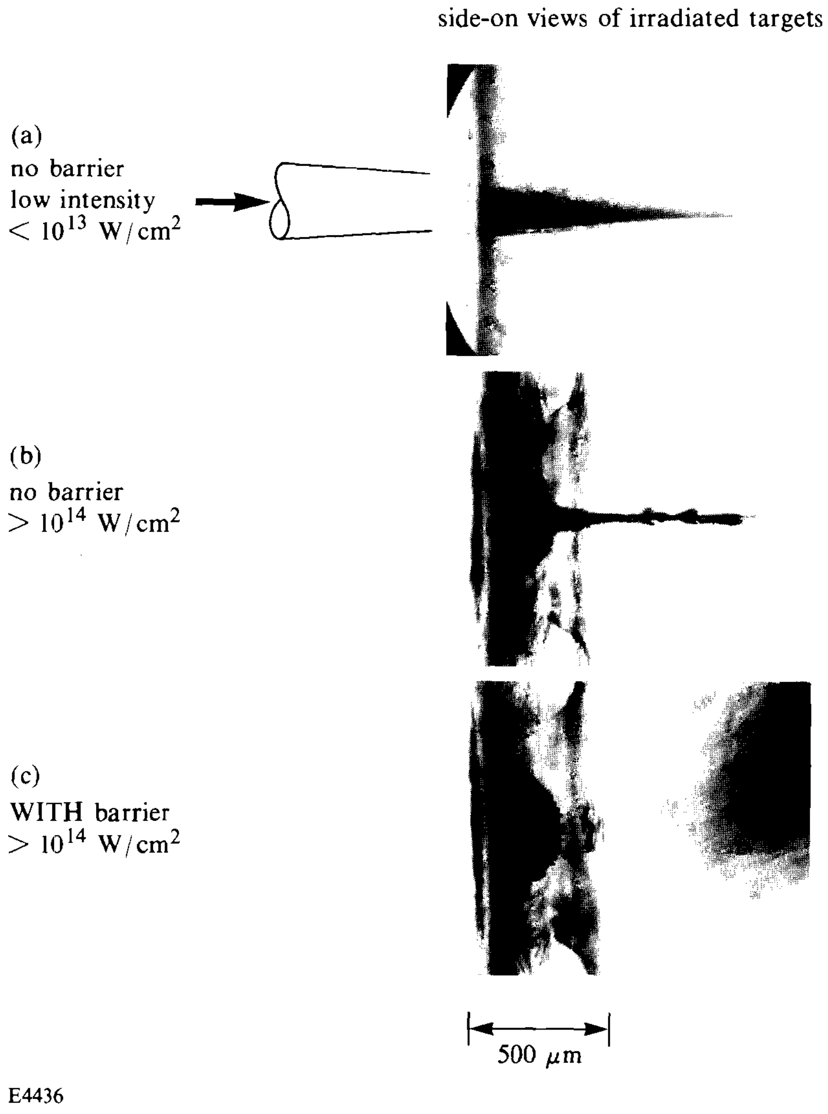

Fig. 35.18
Microscope photographs of Plexiglas targets after irradiation by 600-ps, 351-nm laser pulses of varying intensity: (a) $\leq 10^{13}$ W/cm^2 without barrier layer; (b) $\geq 10^{14}$ W/cm^2 without barrier layer; and (c) $\geq 10^{14}$ W/cm^2 with 500-Å Al barrier layer. The nominal focus was ~700 μm inside the target. Small-scale filamentation is apparent in (a), while whole-beam self-focusing appears to have occurred in (b). The hemispherical crater created by the surface plasma ablation and the subsequent shock waves are apparent in (b) and (c).

impurities or target imperfections, such leakage may cause breakdown inside the target[5] with concomitant problems expected for high-performance, laser-fusion compression experiments. Follow-up experiments on this subject are in progress.

24-Beam OMEGA Experiments

The OMEGA experiments on barrier-layer targets fall into two categories—one using special multilayer signature targets to determine x-ray burn-through times, and the other using high-performance, DT-filled glass microballoons with and without plastic overcoating.

The burn-through times for various layer thicknesses of CH are typically determined from multilayer targets such as are shown in Fig.

35.19, which also illustrates the multilayer targets used in these experiments. The temporal emission from a metal signature layer buried below a CH layer is related to the laser pulse using an x-ray streak camera with an absolute laser fiducial imprinted on the record. Typical streak records of an Au signature layer buried below a 6-μm CH layer show an abnormally early rise of the Au signal in the absence of any barrier layer, while a 500-Å Al barrier layer significantly delays the onset of the Au emission. In fact, when these data are compared with one-dimensional hydrodynamic simulations,[3] one finds that the temporal behavior of the signals from the signature layer obtained with the barrier layer is in fairly good agreement with the simulations, while those without the barrier layer cannot be explained on the basis of these or similar two-dimensional simulations. Our present experiments do not, however, permit us to determine the processes involved in causing the enhanced apparent burn-through rates in the absence of barrier layers. We suspect that the origin of these effects is the same as that causing the self-focusing channels in the single-beam, solid-plastic-target experiments. It may also be argued that with the absence of signature layers (buried metal or other high-Z layers), no damage may occur to targets of dimensions (<20 μm) typical for present-day laser-fusion experiments. However, Bloembergen[5] has shown that bulk and surface imperfections or impurities, or simple dielectric interfaces with microstructure, may significantly lower the breakdown threshold. Thus, it would be natural to assume that all or most present-day laser-fusion targets may suffer decreased interface breakdown thresholds, which could either destroy

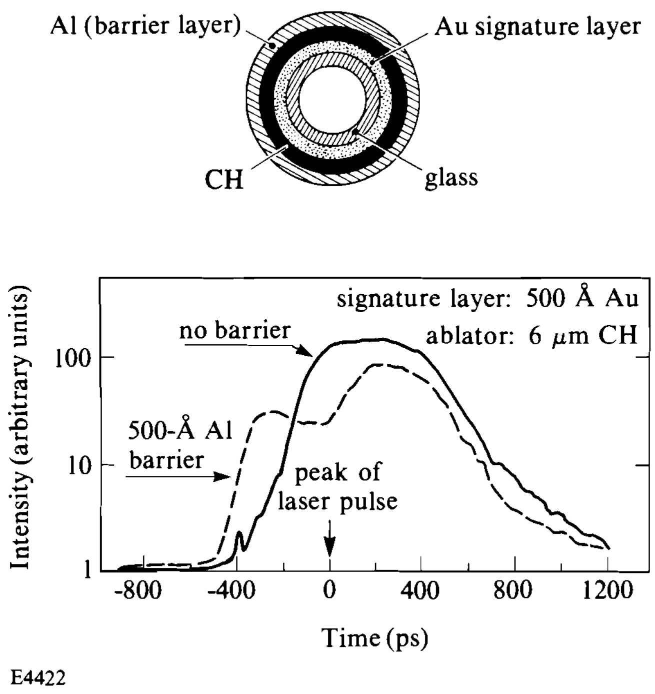

Fig. 35.19
Multilayer target configurations and temporal evolution of x-ray signals from signature layers buried below 6 μm of CH under spherical irradiation conditions. Note the delayed onset of the Au emission with targets overcoated with 500 Å of Al.

the integrity of the target shell or contaminate the fuel with shell debris. (Note that the inside surface of typical laser-fusion targets are generally less well characterized than are the outside surfaces.)

At present, our knowledge is insufficient to determine all the implications of early light leakage in direct-drive laser-fusion experiments. For the near term, it appears that thin metal barrier layers (surface coatings of a few hundred angstroms) are sufficient to prevent the most damaging problems of light leakage during the low-intensity rising part of the incident laser pulse.

OMEGA experiments using glass microballoons (GMB's) with or without CH ablator layers of up to 10 μm have shown for some time that plastic-overcoated targets perform much worse (i.e., have much lower than expected neutron yield) than bare GMB's when compared with one- or two-dimensional hydrocode simulations. Overcoating these targets with <500 Å of Al has generally raised the neutron yields (such thin layers have negligible influence on the hydrodynamics or the predicted neutron yields). However, they have typically failed to raise the fuel $<\rho R>$ correspondingly. At this point, we are not able to explain the details of these observations, but we suspect that problems relating to irradiation uniformity mask part of the present data. Further investigations of these subjects are in progress.

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