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TITLE: PLANAR STREAK CAMERA LASER-DRIVEN SHOCKWAVE STUDIES

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PLANAR STREAK CAMERA LASER-DRIVEN SHOCKWAVE STUDIES

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Abstract

High pressure equation-of-state parameter determination is now possible using a high-energy laser to drive shock waves into a multiple foil target. Recent progress in the design of streak cameras and targets has reduced the errors and uncertainties in impedance-match measurements to about 5-10%, and further improvements are expected in the near future. Initial measurements are reported for pressures in the few-megabar region for gold and aluminum.

Introduction

For nearly three years we have been developing techniques to use high-energy pulsed lasers and fast streak cameras to measure equation-of-state (EOS) parameters at high pressures with enough accuracy to be useful in improving theory. Although our early results[1] were met with a number of difficulties that prevented precision measurements, we now see hope of doing impedance-match shock velocity measurements to about ± 5% in the near future and somewhat better results eventually.

Ragan et al.[2] recently measured EOS parameters at pressures considerably gre extremely expensive, and because gas guns are presently unable to generate the high pressures needed, we have been trying to use lasers to generate shock waves in small samples. We have seen that we can measure shock velocities from samples of two materials in contact.[3] However, the pressures were less than 1 TPa, the shock wave was not very uniform, we were unable to make sufficiently uniform targets, and hot electron preheat made the preshocked condition of the sample uncertain. Recently, Trainor et al.[4] were able to generate shocks of 2 TPa using a well-characterized laser, and we have solved some of our target problems. Consequently, it appears that high-quality, laser-driven EOS measurements will soon become possible. This paper will outline the present status of our experiment.

Experiment

To generate pressures of 1 TPa with a laser, power densities of approximately 10^{14} W/cm^2 are required. Thus a laser that produces a pulse of 10^{11} W (for example, 30 J in 300 ps) must be focused to a spot size of approximately 300 μm, and the entire experiment must be scaled to this size. In particular, if the shock is to remain reasonably planar, the target thickness must be much less than the spot diameter. Much of the energy from high-power lasers is deposited in a distribution of high-energy electrons, presenting a difficulty not encountered in generating explosive-driven shocks: the high-energy tail of the hot electrons can preheat the foil before the shock arrives. The thicker the foil, the less preheating produced at the rear, but increasing the foil thickness increases the likelihood of having a rarefaction overtake the shock wave before it breaks through the rear surface. The actual choice of a target thickness is a compromise between the two problems and depends on the laser power available.

To infer an EOS point for the simple case of a shock wave in an initially cold material, it is necessary to measure at least two shock parameters. One of these is usually the shock velocity, as it is readily measured, but no reliable way of directly determining the particle velocity, pressure, density, or internal energy has yet been developed for laser experiments. Instead we avoid measuring a second parameter by using an impedance-matching technique in which the shock velocity is measured simultaneously in two materials in contact with each other. If the EOS of one material is known, an EOS point for the unknown can be determined because the particle velocity and pressure are continuous across the interface.

Figure 1 shows a layout of the experiment. The laser pulse, 20-30J in a 300-ps-long pulse from a 1.06 μm Nd glass laser, is focused to a spot about 200 μm in diameter on the target foil. The laser energy heats the surface and drives a shock wave into the foil; when the shock emerges at the rear, the foil is heated to over 1 eV. A lens behind the target collects the emitted light and focuses it onto the streak camera slit. To measure the shock velocities in the sample, we use the streak camera to time the delays between shock arrival at the rear of the substrate and at the various layers attached to the substrate.

The heart of our recording apparatus is the visible-light streak camera. This camera, manufactured by General Engineering and Applied Research, Inc.[5] (GEAR), utilizes a proximity-focused, or planar, streak tube based upon a design developed at the Los Alamos Scientific Laboratory.[6] The camera's ability to maintain temporal resolution over a large range of light levels (In Ref. 7 the dynamic range is reported to be in excess of 1000X) is important to this type of experiment because target luminosity depends strongly on foil thickness and material, giving streaks with components of different brightnesses. The large dynamic range of the streak camera is due to the planar streak tube. Parallel electron optics are used to eliminate problems encountered with space-charge buildup in conventional tubes. The photoelectron beam passes through an optically flat, passive microchennel plate which limits transverse photoelectron velocities to maintain tube resolution at all current levels. The microchannel plate also permits higher photoelectron extraction fields than in an extraction grid type tube, increasing the number of photoelectrons available per picture element before photocathode spacecharge effects begin to dominate. A secondary benefit of this design is increased sensitivity and improved statistical streak quality compared to our earlier work, much of which employed streak tubes with extraction grids.

Results

Figure 2 shows a streak from an earlier experiment[3] in which the target was a 13 μm-thick aluminum substrate with a gold step on one half and an aluminum step on the other. (We chose gold and aluminum because they were easy to fabricate, their EOS parameters are relatively well known, and they emit more light than most other materials.) The figure illustrates some of the difficulties which can arise in these experiments. The notch along the left side of the streak between the aluminum channel and the gold layer resulted from a burr on the gold step. This burr, which extended the entire length of the channel, resulted from the technique used in fabricating the targets. The roundness of the bottom part of the streak of light emerging from the channel was apparently caused by material left in the channel during fabrication. Both of these problems should be resolvable with improved target evaporating techniques, but more serious is the lack of planarity of the shock emerging from the aluminum step since this is caused by nonuniformity of the laser focal spot. The hottest part of the spot was to the left in this streak. As a result the shock pressure and velocity were smaller at the right side, and the shock emerged from the aluminum step later at the right edge of the streak than near the channel. To obtain timing information from a streak such as this one, where the shock emerges in a nonplanar fashion, we measured from the point of streak emergence in the channel to the point nearest the channel on either step. Of course the accuracy of such a measurement will not be adequate to provide meaningful results unless a much more planar shock breakout can be obtained.

By measuring several such targets, some of them with the aluminum step to the hotter side of the laser pulse, we found that the gold shock velocity was systematically higher than calculated from the aluminum shock velocities and the EOS of the two materials. A likely explanation is that some hot electrons from the target surface penetrate the substrate; those on the gold side deposit their energy much nearer the interface than those on the aluminum side because of the greater stopping power of gold. Consequently, extra energy in the gold layer enhances the shock velocity there.

To reduce the number of hot electrons reaching the rear of the substrate we changed the target design to include a thin layer of gold in the substrate itself. The gold layer was put near the surface because it was thought that the shock pressure would be relatively constant for this configuration.[8] Another improvement in the target fabrication technique involved the use of a mask which could be positioned and tightened against the target without letting air into the evaporation vacuum chamber.[9] The ability to loosen and tighten the mask avoided the necessity of using a photoresistive or similar removable layer of material in the channel to achieve sharp step edges. Construction of the targets without removing them from the vacuum between steps greatly increased the adherence of the various layers, although we used a small amount of oxygen in the substrate aluminum evaporation to decrease surface roughness. A final change in the targets involved the use of two steps of material on each side of the center channel to allow us to measure any shock velocity decay with increasing foil thickness.

Figure 3 shows a streak made using one of the new targets. Shock velocities and pressures are roughly similar to those of Fig. 2, but the discrepancy between the measured and calculated gold shock velocities in this and other similar shots has been reduced to 5 to 10%, indicating that the thin gold layer in the substrate is of some help.

Uncertainties in the timing and the target characterizations (density, step thicknesses, and surface smoothness) are each a few percent, and we are hopeful that they can be reduced further in the near future. However variations in the laser focal spot uniformity remain larger than the 10% uniformity which should be attainable with this type of laser. Although the actual effect of such nonuniformities on the spatial uniformity of the shock pressure are not known, it appears likely that we will need to either upgrade our laser in a major way or do measurements at another laser if we are to increase our overall experimental accuracy very much.

Acknowledgments

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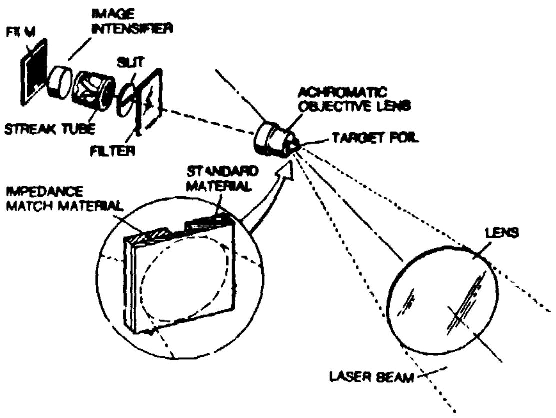
FIGURE CAPTIONS

1. Layout of the optical system. Light from the laser is focused onto a target foil in a vacuum chamber. Rapid heating drives a shock wave into the foil, and when the shock reaches the back surfaces, it heats them to approximately 1 eV. The streak camera records the luminosity of the foil and measures the time delays between shock arrival at the back of the substrate and the backs of the steps to determine the shock velocities in the steps.
2. An early impedance-match target and the resulting streak. Time increases from bottom to top in the streak.
3. An improved impedance-match target and the resulting streak. The dark regions of the target are gold and the light regions are aluminum. Time increases from botton to top in the streak. The addition of the 1-μm-thick gold layer to the substrate appears to have reduced the discrepancy between measured and calculated gold shock velocities.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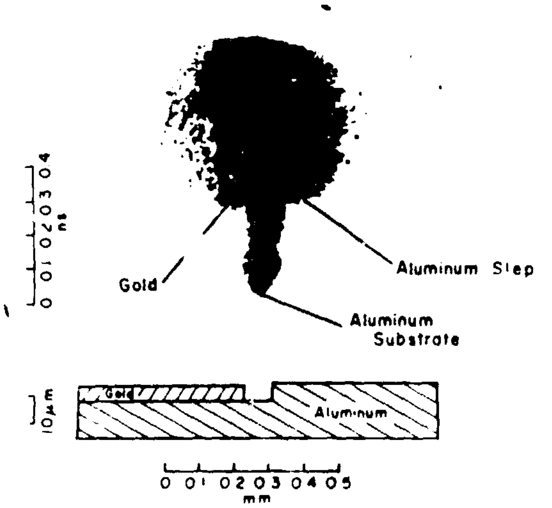
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