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LASER-GENERATED SHOCKWAVE EXPERIMENTS AT EXTREME HIGH PRESSURES

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ABSTRACT
The results of experiments on the generation of shockwaves by laser light are presented. The experiments were performed at the Lawrence Livermore Laboratory. The results show that the shockwaves generated by the laser light are of a high pressure and are of a high velocity. The results also show that the shockwaves generated by the laser light are of a high temperature and are of a high density. The results are presented in a series of plots showing the pressure, velocity, temperature, and density of the shockwaves as a function of time.

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LASER-GENERATED SHOCKWAVE EXPERIMENTS AT EXTREME HIGH PRESSURES

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ABSTRACT

We discuss the application of high-power lasers to production of extreme high pressures. Shock velocities consistent with pressures up to 2 TPa in aluminum have already been measured, and experiments in the 4 TPa range are now planned. We describe the status of our programs to develop new diagnostic techniques and perform experiments to characterize perturbing influences on the shock.

INTRODUCTION

It has become clear that the high-power lasers developed for inertial-confinement-fusion research can produce shock pressures far exceeding those possible by any previously employed laboratory technique. A number of preliminary experiments have been performed (1-4), and the potential for making accurate materials properties measurements at pressures above 1 TPa (≈ 10 Mb) now seems encouraging. We have recently used the Janus laser at Livermore to generate and measure shock pressures near 2 TPa in aluminum (4), and our calculations indicate that on the very large systems now being built, well characterized experiments in the 10 TPa range may be possible. This would permit exploration of an interesting physical regime where materials properties are poorly understood theoretically.

In this paper we outline our efforts to develop diagnostic techniques for studying laser-generated shocks. We also present preliminary results of experiments to understand important phenomena related to such shocks.

DIAGNOSTICS FOR LASER-GENERATED SHOCK EXPERIMENTS

Diagnostic requirements for laser experiments are extremely severe, due to the small sample sizes and short time scales that are necessarily employed in these studies. Samples used in the present work are typically disk-shaped, with diameters no greater than a few mm and thicknesses of 10-50 μm . Laser pulse lengths are typically < 1 ns. Thus measurements require spatial resolution near 1 μm and time resolution < 10 ps. Our present shock experiments consist of measuring shock velocities u_s . The laser irradiates one side of a disk target, generating the shock wave. The other side of the target is imaged onto the slit of an ultrafast streak camera, which records the spatial

and temporal dependence (to within 10 ps) of the luminosity emitted from this surface. When the shock arrives to within a few skin depths δ of the rear surface, the camera records a rapidly increasing signal with rise time $\delta/u_s \sim 10$ ps. Thus, the shock arrival time is determined to within ~ 10 ps. By placing steps of known separation on the rear target surface we measure u_s by measuring the transit time across the steps. This technique has been successfully used in (3) and (4).

We are presently attempting to develop a second diagnostic for measuring Hugoniot parameters. The most promising approach appears to be measurement of the mass velocity, in which the interface of a composite target, composed of two adjoining slabs (one a low density, the other a higher density material), is backlighted by an intense x-ray source (5). An ultrafast x-ray streak camera records the x-ray transmission as a function of time. As the shock crosses the interface between the slabs, the interface is carried along with the material, and the transmitted x-ray flux changes due to the differing opacities of the two slabs to the source. The time dependence of the transmission yields the velocity of the target interface, which equals the mass velocity on either side of the interface. The x-rays may be produced by a laser-generated source (5) or an external pulsed source. We have designed a feasibility experiment which will use a Cu-Al target and a Blumlein x-ray generator. We are aiming for 5-10% accuracy in our initial experiments. Once the Hugoniot of one selected material has been obtained, this "standard" may be subsequently used in impedance matching experiments.

Another diagnostic of interest to us is a shock temperature measurement, in which a dispersing element would direct the thermal radiation emitted from the target onto the slit of a streak camera, whose output would be compared to a gray-body spectrum to get the temperature. Since shocks in the 1-2 TPa range usually produce temperatures of ≥ 10 eV, the newly developed soft x-ray streak cameras would be of great use here.

RELATED PHYSICS EXPERIMENTS

A number of fundamental questions must be addressed before accurate EDS experiments can be performed. What are the preheating effects of the hot (2-100 keV) electrons produced in the laser-light absorption process? Can a shock generated by a relatively short pulse (< 1 ns) be made uniform, or will it always more closely resemble an impulsive blast wave? Can hydrodynamic efficiency (shock energy/laser energy) be improved, and is it degraded by such processes as lateral plasma flow out of the laser-generated plasma plume?

We are presently conducting a series of experiments to directly measure preheat temperatures due to laser-generated hot electrons. The technique uses the same laser/target/camera configuration used to find u_s , except in this work the targets are simple foils of Al, varying between 12.5 and 25 μm thickness. The idea is to record the temporal dependence of the luminosity at the rear surface of the foil. This signal will contain an early-time component due to hot-electron preheat and a more intense component due to shock heating. Also measured in the experiment is the shock transit time through the foil, from which the shock pressure and temperature at the rear surface may be inferred. Given the shock temperature and the ratio of the measured luminosities, we can calculate the preheat temperature.

In a preliminary series of experiments on 25 μm thick disks, no preheat signals could be detected (our detection threshold is ~ 1 eV) for laser intensities between 10^{14} and 10^{15} W/cm^2 . This was a surprising result, since calculations predict preheat temperatures up to ~ 12 eV for these intensities.

When two thinner targets ($12.5 \mu\text{m}$) were irradiated preheat signals were clearly detected. In two shots, preheat temperatures of 2 and 6 eV were measured for incident intensities of 4 and $7.5 \times 10^{14} \text{ W/cm}^2$, respectively. Further experiments are presently underway to corroborate these early results.

Another area of interest concerns a surprising plasma expansion which we observed in our earliest experiments on small disks (7). In those experiments intense heating was observed at the edges of the disks within 100 ps after arrival of the laser pulse at the target surface. It was suggested (7) that this phenomenon might be due to fast electrons leaving the laser focal-spot area and travelling along the target surface, where a preferential path would exist due to return-current heating (3) in a skin-depth thickness of the surface. Could this phenomenon remove enough energy from the focal spot area to greatly reduce the magnitude of the laser-generated shock? There is some evidence that it could. Shock velocity experiments at Los Alamos Scientific Laboratory (LASL) (3), in which all conditions apparently were similar to those used in our shock velocity experiments, except target geometry, produced pressures which were an order of magnitude lower (0.2 TPa) than those we observed. The difference in targets was simply that the LASL group used Al disks with diameters ($\sim 1 \text{ cm}$) much greater than the laser spot diameter ($\sim 200 \mu\text{m}$), whereas our disk diameters (1 mm) were comparable to the spot diameters (300-400 μm). If a surface is required to support this lateral energy flow, then we expect the phenomenon to be more important in experiments where target diameter is large, perhaps important enough to lead to a much weaker shock.

To better understand this phenomenon, we have begun two experiments. In the first, we have irradiated the end of a small (100 μm diam) wire and used the streak camera to measure the velocity of the energy flow along the wire's surface. A velocity of $3 \times 10^8 \text{ cm/s}$ is measured, close to that indicated in our shots on small disks. In the second experiment, we have measured the shock transit times through large diameter (1 cm) Al disks as a function of laser intensity. From these measurements, average shock pressures within the disks can be inferred. In our first series of shots we were able to generate pressures ranging from 0.6 to 2.8 TPa, which are much greater than those obtained in the LASL experiments. Thus lateral energy flow cannot explain the lower pressures measured. However, these pressures are somewhat lower than our code predicts, so lateral energy flow (not treated in the code) may be having some effect. A systematic study of shock transit time vs. disk diameter is now underway to clarify this situation.

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