CONF-810827--4

LA-UR-81-2367

TITLE: IMPEDANCE-MATCHING EXPERIMENTS USING HIGH-PRESSURE, LASER-DRIVEN SHOCK WAVES

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SUBMITTED TO: AIRAPT Conference on High Pressure in Research and Industry, Uppsala, Sweden, August 1981

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IMPEDANCE-MATCHING EXPERIMENTS USING HIGH-PRESSURE, LASER-DRIVEN SHOCK WAVES

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ABSTRACT

We have used a high-power laser to produce shock waves with pressures of 300 to 700 GPa. A series of impedance-matching experiments on aluminum-copper systems with 10% accuracy indicate several areas in which the experiment can be improved to reduce the errors. We are now making several such improvements, including upgrading both the laser and recording systems and modifying the target characterization techniques.

INTRODUCTION

Although preliminary experiments have shown that high-power lasers can produce higher shock pressures than other laboratory techniques (1-3), experimental difficulties have prevented us from obtaining useful equation-of-state (EOS) data (4). In this experiment we made a number of impedance-match measurements using aluminum-copper targets to assess the uncertainties and reproducibility of the results. We chose copper and aluminum because both have been well studied at lower pressures, have good theoretical EOS models, and are relatively easy to fabricate into targets. It seemed that we could make the best assessments of our technique by minimizing problems associated with theoretical interpretation and target fabrication. Using the results of our measurements as a guide, we have begun to make several improvements which we expect will greatly improve future results.

EXPERIMENT

The measurements were performed on the Janus Nd-glass laser facility at Livermore. Incident laser intensities on the targets varied from 5×10^{13} to 4×10^{14} W/cm^2 with a pulse length of 300 ps and a wavelength of 1.06 μm. The size of the laser focal spot was between 150 and 400 μm.

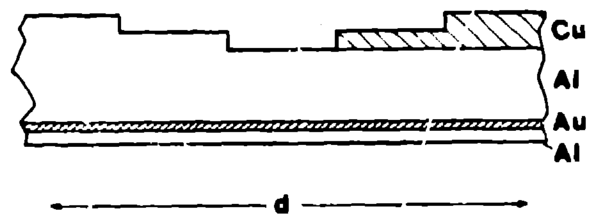

Fig. 1. Schematic diagram of a target foil. A laser pulse, focused to diameter *d*, heats the bottom side of the foil and drives a shock wave into it. Typical steps are 5μm high and 50μm wide.

The targets were metallic foils which were vapor deposited at Los Alamos (see Fig. 1). A GEAR Pico-V streak camera (5) recorded shock wave transit times through various thicknesses of copper and aluminum. The resulting shock velocities are shown in Fig. 2. The points cluster around the extrapolation from lower pressure measurements (6), but there are fluctuations of about ±10% about the mean.

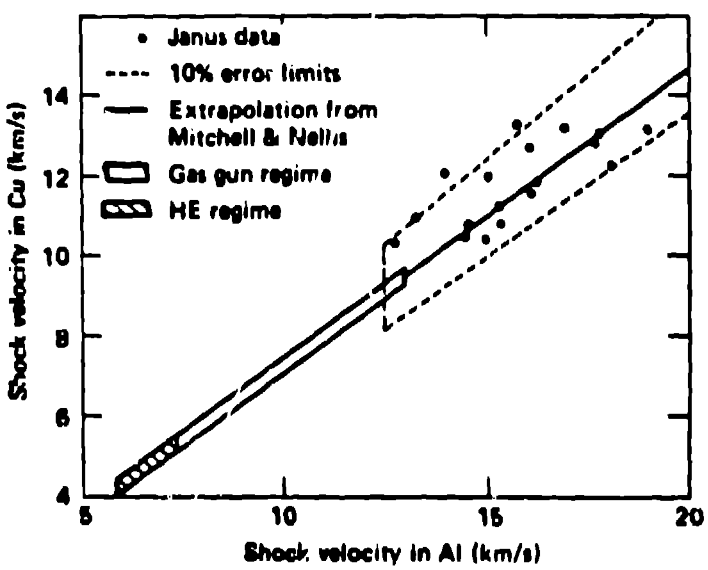

Fig. 2. Aluminum-copper impedance matching results. Measurements made at low pressures using high explosives and at intermediate pressures using the Livermore gas gun facilities (6) are compared with the laser data points at higher pressures. (Shock velocities of 13 km/s in copper and 18 km/s in aluminum imply pressures of about 7 Mbar and 5 Mbar, respectively.)

DATA INTERPRETATION AND UNCERTAINTIES

Although the points can be averaged to give results consistent with our best knowledge of the EOS data, we feel that it would be much better to reduce the uncertainties further, if possible, in case there are systematic errors which are being hidden by the fluctuations. Our goal for now is to try to decrease the fluctuations to about >2% to 3%. Consequently, we have tried to make an objective assessment of our experiment to determine the major sources of errors and the best ways to reduce them.

1) Timing Uncertainties. Presently our timing resolution is about 10 to 15 ps and shock transit times are 200 to 300 ps per step; thus the timing uncertainty is around ±5%. We are working on a streak camera triggering system, similar to that used at the University of Rochester (7), which should increase our writing speed (and improve the timing resolution) by as much as a factor of five. We are also considering buying a new, higher-resolution camera. In either case we expect sufficient resolution to do accurate measurements, but we do not yet have the necessary technology in hand.

2) Target Characterization. We measured the step thicknesses mechanically with an accuracy of about 0.2 μm (4% of a 5-μm-thick step), and we assumed nominal densities for the foils. Recently we acquired the use of a Zeiss Interferometric Microscope to measure the step heights optically with an accuracy of better than 0.05 μm. We have also begun an experiment to measure the areal densities in target steps by detecting backscattered 3 MeV protons from each step using a focal spot <20 μm in diameter (8). Preliminary results yield densities around 98% of nominal. We feel that we have made considerable progress in characterizing our targets, thus effectively eliminating this as a major problem.

3. Shock Wave Planarity and Uniformity. Some of the streak camera records in this series of shots show evidence of non-planarity of the shock fronts. The large convergence angle of the f/1 laser focusing optics can lead to local intensity variations when the target is tilted or not perfectly flat. We are redesigning the focusing optics using an f/5 lens to reduce the sensitivity to target position and to minimize spatial nonuniformities in the focal spot. We are also redesigning the optics that collect the target light and focus it onto the streak camera slit to improve the spatial resolution of the recording system.

4. Target Preheat. The layer of high-density material in the target substrate (Fig. 1) reduces the preheat from laser-generated hot electrons to a negligible level at the pressures we have obtained here. For experiments at higher pressures, however, we will need to reduce the

preheat further, probably by converting the laser to a shorter wavelength, thereby mitigating hot electron production.

5. Shock Decay. By measuring the average shock velocity in two sequential steps in each material, we have seen evidence for shock decay. This decay, caused by an overtaking rarefaction wave following laser-pulse termination, will be easier to study using a larger number of thinner steps and the expected improvement in timing and spatial resolution of the recording system. It should be possible to reduce shock decay by proper shaping of the laser pulse in time. We are now installing on the Janus system a new oscillator which has the potential capability of stacking several short pulses in series, and by varying the intensity of these pulses we can produce a quasi-continuous pulse of more or less arbitrary time history. We will study the effects of such pulses to try to minimize shock decay.

SUMMARY

We obtained a number of impedance-matching points for aluminium-copper systems in the pressure regime from 3 to 7 Mbar and used the results to assess the magnitude and sources of the major uncertainties. We have now begun to make a series of improvements in the experiment with the goal of reducing the errors to about 2% to 3%. With care and perhaps a little luck we should be able to make another series of shots with much better results within about a year.

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