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Title:

EXPERIMENTAL TECHNIQUES FOR SUBNANOSECOND RESOLUTION OF LASER-
LAUNCHED PLATES AND IMPACT STUDIES

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Experimental techniques for subnanosecond resolution of laser-launched plates and impact studies

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ABSTRACT

Miniature laser-launched plates have applications in shock wave physics, studying dynamic properties of materials and can be used to generate experimental data in a manner similar to a laboratory gas gun for one-dimensional impact experiments. Laser-launched plates have the advantage of small size, low kinetic energy, and can be launched with ubiquitous laboratory lasers. Because of the small size and high accelerations (10^7 - 10^{10} g's), improved temporal resolution and optical non-contact methods to collect data are required. Traditional mechanical in-situ gauges would significantly impair the data quality and do not have the required time response.

Keywords: VISAR, streak camera, laser-launched plates, shock, interferometry, subnanosecond, particle velocity

1. INTRODUCTION

Minature plates 3 - 50- μ m thick and 0.6 - 3 mm in diameter are launched off a transparent substrate to velocities from 0.3 to greater than 6 km/s. By properly controlling the laser's spatial and temporal parameters, nearly one-dimensional impacts of a flyer with a target can be obtained.^{1,2,3} The target materials and/or flyer plate properties can be studied to determine equation-of-state, dynamic strength properties, or chemical reaction of energetic materials.⁴

2. PLATE LAUNCH TECHNIQUE

A high-power Nd:YAG laser is pulsed through the transparent substrate and onto a thin aluminum film deposited on the opposite side of a substrate. The 1-5 GW/cm² laser beam is deposited in a few skin depths of metal; an intense plasma is formed, trapped between the substrate and the remaining metal. A thicker (5-50 μ m) rolled metal foil may be attached to the deposited metal. The deposited metal is intended as the plasma source to launch the thicker rolled metal foil, thus accelerating the foil away from the substrate surface, Fig. 1.

Fig. 1: Technique for launching thin (3 - 50- μ m) metal plates off transparent substrates.

3. OPTICAL DIAGNOSTIC TECHNIQUES

Diagnostic techniques to record performance parameters of thin (3-50 μm) laser-launched plates, ultra-short (<1 - 10 ns) shock and particle velocities require non-contact optical methods with high spatial and temporal resolution. Electronic streak cameras with gated-MCP and CCD-recorded images are used to record both spatial and temporal resolution concurrently for plate planarity. Plate acceleration and particle velocities of impacted surfaces can be recorded on the same streak camera by velocity interferometry (VISAR). Three-dimensional images of plates during acceleration and/or during impacting targets are recorded by pulsed-laser stereophotography

3.1 Optically-recorded velocity interferometry

A velocity interferometer (VISAR) is used to record the plate acceleration, terminal velocity, and the velocity of the interface between the PLATE and a transparent target material. Traditional VISARs use PMTs and digitizers to record the fringe information for data reduction with 1-5 ns temporal resolution. Laser-launched plates accelerate too rapidly for more traditional methods to record time and spatial resolution of the plate motion. To improve temporal resolution, VISAR fringe information is transmitted through optical fibers to an electronic streak camera with a CCD-readout. By recording the signals optically the bandwidth of the interferometer can be preserved. Temporal resolution of better than 0.1 ns/pt (10 GHz) is typical, with greater bandwidth possible. Two VISARs with different fringe constants are commonly used to resolve any possible ambiguity. Streak cameras are noted for high temporal resolution, but to get both high resolution and long time coverage, two or more streak cameras would be required. By trifurcating each optical fiber input and varying the optical length of each optical fiber, the signal exiting each fiber can be delayed relative to the others, Fig. 2. By placing the output fibers in the streak camera, the effective optical record length is tripled without loss of temporal resolution.⁶ Plate acceleration and impact onto a know transparent window with temporal resolution and record length is usually not possible with one streak camera record, Fig. 3.

Fig. 2: The streak-recording VISAR method increases record length over standard methods without compromising temporal resolution.

Fig. 3: VISAR plate acceleration profile with 0.1-ns/pt temporal resolution.

3.2 Plate impact planarity

The plate impact planarity can also be recorded on the same streak camera when part of the slit plane is used for imaging. As the plate approaches a transparent target, air between the plate and target is compressed and ionized; it emits broad band light that can be separated from the VISAR optical signals with a dichroic beamsplitter. The spatial and temporal features of this light signal give characteristics of the impact, such as planarity and tilt.³

3.3 Pulsed-laser Stereophotography

Pulsed laser or stereo photography can provide additional information on the plate planarity and launch characteristics, evaluate the experimental technique, and provide a more traditional image of the plate in flight. The critical experimental technique has been well documented.¹ The parameters used for our experiments are: 5-ns doubled Nd:YAG (532 nm) laser pulse and a 20X magnification stereo camera. The time between the plate launch and the exposure time is determined by placing both laser pulses on the electronic streak camera and measuring the difference to better than 1 ns. Figure 4 is a stereo pair of a laser-launched plate in flight.

4. EXPERIMENTAL RESULTS

Laser-launched plates are used to quantify dynamic material properties with techniques similar to ones developed for gas guns. By impacting an unknown material on a well-characterized optically transparent window of known shock and optical properties the equation of state of the unknown material can be deduced.⁷ The impact velocity and particle velocity of the interface is experimentally recorded. Because laser-launched plates are

significantly thinner than traditional gun-launched impact plates, improved time resolution is required. Verification of the laser-launched plate and streak-recording VISAR technique has been performed using known materials, i.e., OFHC copper, for impacting on characterized optical windows of lithium fluoride, PMMA, and sapphire. The impact velocity and particle velocity of the interface is recorded and the reduced data compared with data generated by gas gun experiments, Fig. 5 & 6.

Fig. 4: A stereopair of a 400- μm diameter Aluminum laser-launched plate is being accelerated away from the substrate. To view the stereo image, focus on the two dots above the images. When three dots are visible lower your view to the images. A third stereo image will appear between the pair.

5. CONCLUSIONS

By combining several optical diagnostic techniques a complete understanding of a physical event with subnanosecond time resolution is possible. These described techniques offer improved temporal resolution, small sample size, high pressures and strain rates for evaluating dynamic properties of metals and ceramics, determining bond strengths, the bonding of dissimilar and difficult materials, and the studying of optical properties of transparent materials under dynamic shock loading.

Fig. 5: A 50- μm OFHC copper plate acceleration and impact onto a window of known shock and optical parameters.

Fig. 6: The reduced pressure versus particle velocity data from two copper plate/window impacts. These data fit accepted data within 1 to 10 %. Improved precision and accuracy are anticipated with refined launch techniques.

6. ACKNOWLEDGMENTS

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