Preprint
UCRL-JC-144185

Experimental Design for Laser Produced Shocks in Diamond Anvil Cells

S.J. Moon, R. Cauble, G.W. Collins, P.M. Celliers, D. Hicks, L.B. Da Silva, A. Mackinnon, R. Wallace, B. Hammel, W. Hsing, R. Jeanloz, K.M. Lee, L.R. Benedetti, M. Koenig, A. Benuzzi, G. Huser, E. Henry, D. Batani, O. Willi, J. Pasley, G. Henning, P. Loubeyre, D. Neely, M. Notley, and C. Danson

This article was submitted to
12th Biennial International Conference of the American Physical Society Topical Group on Shock Compression of Condensed Matter
Atlanta, GA June 24 – 29, 2001

U.S. Department of Energy

Lawrence Livermore National Laboratory

June 22, 2001

Experimental Design for Laser Produced Shocks in Diamond Anvil Cells

S. J. Moon[1], R. Cauble[1], G. W. Collins[1], P. M. Celliers[1], D. Hicks[1], L. B. Da Silva[1], A. Mackinnon[1], R. Wallace[1], B. Hammel[1], W. Hsing[1], R. Jeanloz[2], K. M. Lee[2], L.R. Benedetti[2], M. Koenig[3], A. Benuzzi[3], G. Huser[3], E. Henry[4], D. Batani[4] O. Willi[5], J. Pasley[5], G. Henning[5], P. Loubeyre[6], D. Neely[7], M. Notley[7], and C. Danson[7]

[1]*Lawrence Livermore National Laboratory*
P.O. Box 808, L-041, Livermore, CA 94550
[2]*University of California, Berkeley*
[3]*L.U.L.I., C.N.R.S. Ecole Polytechnique, France*
[4]*University Milan-Bicocca and I.N.F.M., Italy*
[5] *Imperial Collage, London, UK*
[6]*C.E.A. Bruyeres-le-Chatel, France*
[7]*Rutherford Appleton Laboratory, UK*

Abstract. Laser driven shock measurements have been performed on pre-compressed samples. A diamond anvil cell (DAC) has been used to statically compress water to 1 GPa and then strong shocked with an energetic laser. The use of intense laser irradiation can drive shocks in targets making it possible to study the equation of state (EOS) of samples well into the hundreds of GPa regime. Generally, such experiments employ a sample initially at normal density and standard pressure, therefore providing data on the principal Hugoniot. In this experiment the initial state of the sample was varied to provide data off the principal Hugoniot. We report the work that was done on the Vulcan laser and describe a method to achieve off principal Hugoniot data.

INTRODUCTION

Diamond anvil cells (DAC) are used to generate ultra-high pressures in static samples and can generate high-quality isothermal equation of state (EOS) data up to several hundred GPa. This technique incorporates the use of two large diamonds statically compressed in an anvil vice. To yield data at temperatures greater than room temperature a laser can be focused in the sample region heating the sample to several hundred degrees. There are limits to the amount of energy that can be deposited and the heating of the diamond can result in thermal stress and lower achievable pressures.

A novel idea is to use the diamond anvil cell to statically compress a sample and then use a high-powered laser to strong shock the pre-compressed sample. The measurement is a traditional shock Hugoniot EOS measurement that can yield data off the principal Hugoniot. In this paper we present a design for a thin-flat diamond anvil cell which can pre-compress a sample to ~1 GPa and then strong shocked to ~100 GPa. We discuss an experiment performed at the Vulcan laser facility and present the data and simulations.

DIAMOND ANVIL CELL DESIGN

In laser-generated shock experiments a high intensity laser can generate a strong shock. This intensity and resulting pressure must be maintained for a suitable length of time to traverse the diamond and enter the sample region. The laser spot size must also be sufficiently large such that a planar region remains after side refraction takes place. A typical high intensity laser of ~10^{14} W/cm^2 generally has a pulse length of several nanoseconds and spot size of several hundred microns. Assuming an intensity of 5×10^{13} W/cm^2, the resulting pressure of ~800 GPa generates a shock with velocity ~23 μm/ns in diamond. Given a 4 ns pulse the shock travels ~90 μm before the laser pulse is over. Assuming a refraction velocity of ~33 μm/ns the shock will have thickness of ~40 μm after 9 ns from the start of the pulse and travel a distance of ~200 μm. A thin diamond is needed for ns pulse duration. In addition a fast diamond sound speed leads to a fast side refraction of the planar shock. If we assume a decay angle of ~30 degrees a spot size of >400 μm diameter is needed to retain a planer shock of >100 μm at breakout after traveling through 200 μm of diamond. A modified DAC is needed since the thick diamonds and small sample areas in a standard DAC are not sufficient for a laser generated shock measurement.

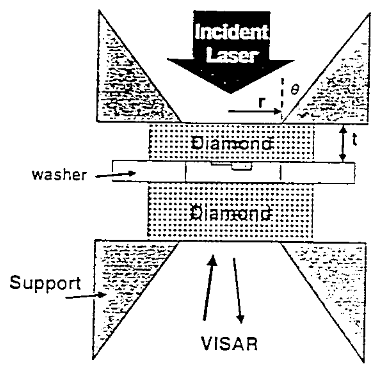

FIGURE 1 Cut away section of the Diamond Anvil Cell design shows the compression of two diamond flats between WC supports with a conical light port with angle θ and diameter 2r. The high intensity laser is incident on a thin diamond of thickness t.

The design is shown in figure 1. The cut away shows two thin plates of diamond with a tungsten carbide (WC) anvil as a support to compress the sample. An angle of ~30 degrees for the conical light port is used due to a minimum in tension and tungsten carbide is used since its elastic module is closest to diamond[5].

The laser is normal to the front of the thinnest diamond generating a strong shock. This shock propagates through the diamond into the sample. A thin Al step was placed in the cell to measure the shock velocity in the Al and use this measurement to determine the shock pressure. A VISAR is incident on the other end and reflected off the Al where breakout times can be seen.

The diamond flat with a pressure, P on the sample side. This thin-flat diamond is loaded. For a circular plate uniformly loaded a simple relation exists for the maximum stress[6], S_m, in the plate,

$$S_m = k\, w\, r^2/t^2$$

Where r is the radius, t is the thickness, w is the load, and k is a constant dependant on the how the sample is constrained, either k=1.24 for simply supported or k = 0.75 for fixed edges. Since our sample can be compressed to a value above the elastic limit of the stainless steel washer k is somewhere between fixed and simply supported. For a given value of r = 300μm and t = 200 μm and using the value of tensile strength of diamond, 2.8 GPa, for the maximum stress we arrive at a maximum load of between 1.0 and 1.6 GPa. This pressure can be increased to ~7 GPa by going to a 500 μm thick diamond.

HUGONIOT MEASUREMENT FOR PRE-COMPRESSED WATER

An accurate equation of state of H_2O is an important constituent of models of the cores Uranus and Neptune[1]. The principal Hugoniot avoids the Superionic region, while the pre-compressed Hugoniot travels through it.

The high intensity laser VULCAN at Rutherford Appleton Laboratory was used to induce a plane shock wave. The laser was incident on a 200 μm thick diamond flat with an intensity of a few times 10^{14} W/cm^2 and 4 1ns stacked pulses to give a total pulse length of 4ns. This intensity produces a strong shock in the diamond that unloads in an Al step target used to measure the shock velocity. The shock then enters the water sample. Strong shocks in water (> 200 GPa) are expected to ionize water so that the shock front will reflect light. We can measure the shock front velocity with a velocity interferometer (optical Doppler shift measurement).

Hugoniot measurements are limited to a single track through phase space. The shaded region in figure 2 shows this track can be expanded by changing the initial state of the material. However, this initial state needs to be accurately determined in order that the measurement is accurate. Through pre-compression the initial temperature is know and the initial density can be determined by measurement of the pressure in a region where the density-pressure relation is know. This results in an accurate determination of the initial state.

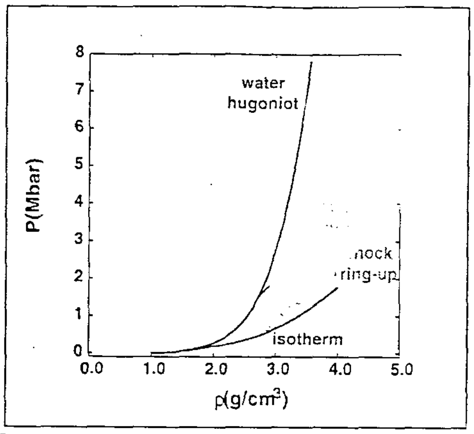

FIGURE 2. The water hugoniot is shown along with the isotherm. The shaded region shows the acessable area through the use of pre-compressed samples.

Data

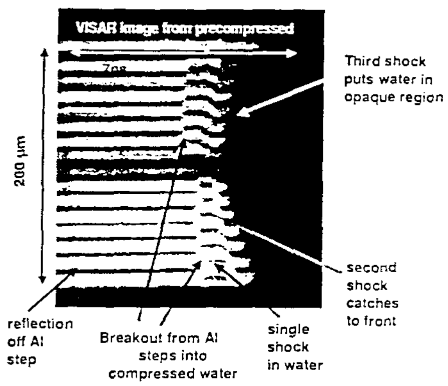

FIGURE 3 Visar image from a 0.735 GPa pre-compressed sample.

The VISAR measurement is taken and the know pressure and a fit for the index of refraction. See figure 3 where a The laser pulse launched three succesive shocks

CONCLUSION

We have designed and tested a new technique to generate off principal Hugoniot equation of state data through the novel use of a diamond anvil cell. The cell was pre-compressed to 1 GPa and then shock compressed to several hundred GPa and shock pressures were generated from ~50 to 300 GPa. These were inferred through breakout time measurements from a stepped Al target and assuming modified QEOS water EOS.

The shocked material was transparent around 50 GPa and opaque in the region between 190 to 300 GPa. This technique is a powerful method to measure EOS data in a region not before addressed.

References

1. Cavazzoni, C; Chiarotti, GL; Scandolo, S; Tosatti, E; Bernasconi, M; Parrinello, M. "Superionic and metallic states of water and ammonia at giant planet conditions," SCIENCE, JAN 1, 1999, V283(N5398):44-46.
2. Hemley, R. J. (2000). EFFECTS OF HIGH PRESSURE ON MOLECULES. Annu. Rev. Phys. Chem. 51: 763-800
3. W. B. Hubbard, Science 275, 1279 (1997)
4. W. B. Hubbard et al., in Neptune and Triton, D. P. Cruikshank, Ed. (Univ. of Arizona Press, Tucson, 1995), pp. 109-138.
5. Adams, D.M.; Christy, A.G.; Norman, A.J. "Optimization of diamond anvil cell performance by finite element analysis," Meas. Sci. Technol. 4 (1993), PP 422-430.
6. S. Timoshenko, Strength of Materials

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

University of California
Lawrence Livermore National Laboratory
Technical Information Department
Livermore, CA 94551