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Diamonds aren't forever – Sandia researchers use strong shock waves to melt diamond

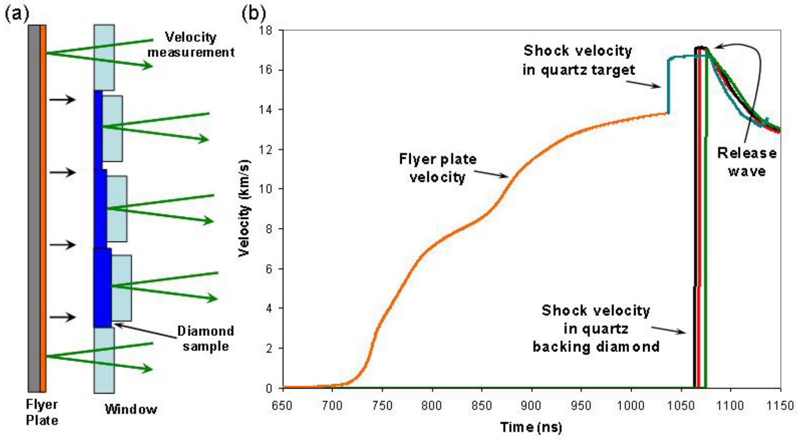
Hyper-velocity plate impact experiments have been performed at Sandia National Laboratories to measure the melt properties of diamond using a sound speed technique; use of this technique to infer melt at these pressures (6 to 10 million times atmospheric pressure) is unprecedented.

PHILADELPHIA, Pennsylvania, Oct. 30, 2006 – Diamond is one of the materials being considered as an ablator material in the design of fuel capsules for inertial confinement fusion (ICF) experiments at the National Ignition Facility. ICF uses high-powered lasers to vaporize a target capsule containing fusion fuel, creating an implosion that compresses the fuel in the capsule to the temperatures and pressures necessary for fusion. Understanding diamond's shock melting properties is critical to designing capsules and radiation drive pulse-shapes that minimize microstructure effects from mixed solid and liquid phases during this implosion phase. Variations in density and other properties have the potential to create instabilities that could, if large enough, prevent the ICF capsule from imploding with the necessary degree of symmetry.

A strong shock wave imparts significant energy to the material through which it travels. Along with the increase in pressure, this internal energy results in a large increase in temperature. At a sufficient shock pressure the temperature rise will be large enough to cause the material to melt, resulting in a high pressure, high temperature molten liquid. In most materials this shock melting pressure is a few million times atmospheric pressure (a few Mbar).

In diamond the shock melting pressure was found to be remarkably high; a shock wave strength of 6-7 Mbar was required to reach the onset of melting in diamond. Furthermore, for shock strengths between ~6 and 10 Mbar the resulting material was a mixture of molten carbon and solid diamond. Shock strengths of greater than 10 million times atmospheric pressure were required to fully melt the diamond upon shock compression. This 3-4 Mbar coexistence region observed for diamond, the pressure regime where the shocked state lies on the melt line, is extraordinarily large. In comparison, the coexistence region for beryllium, another candidate capsule ablator material, was found to be approximately 0.5 Mbar, with the onset and completion of melt at ~2.1 and 2.6 Mbar, respectively.

Shock wave experiments were performed on micro-crystalline samples of diamond over the pressure range of 5 to 14 Mbar. To reach these pressures states, Sandia researchers used the hyper-velocity flyer plate technique developed at the Sandia Z Accelerator to launch solid state, composite aluminum/copper flyer plates to velocities between 14 and 24 km/s.



(a) Schematic diagram of the experiment. A composite aluminum/copper flyer plate impacts a series of quartz and diamond/quartz targets with varying diamond thickness. Velocity of the plate and the shock front in quartz is measured using a velocity interferometer. (b) Typical data. The flyer plate velocity is measured above and below the diamond samples during launch of the plate; the measurement transitions to the shock front in quartz upon impact. A steady shock is produced, followed by a rapid release in pressure. Similar data are obtained in the quartz backing the diamond samples; these measurements allow the thickness of diamond at which the release wave overtakes the leading shock to be determined, thereby enabling the release wave velocity to be inferred.

Melting was observed by measuring the speed of sound in the shocked material. By using a composite aluminum/copper plate a steady shock wave followed by a well defined pressure release is imparted to the diamond sample. The release wave following the shock wave travels at the sound speed of the diamond in the shocked state; the magnitude of the sound speed is highly dependent on whether this shocked state is a solid or liquid. A significant drop in the sound speed was observed for shock compression between 6 and 7 Mbar, indicating the onset of melting in the diamond sample. This study represents the highest pressure study of melting ever performed using the sound speed technique.

These experimental results are in good agreement with Sandia's quantum molecular dynamics calculations which indicate the onset of melting at 6.9 Mbar and the completion of melting at 10.4 Mbar. Similarly good agreement between experiment and the quantum calculations is found for the sound speeds and shock speeds in the solid and liquid phases.

The high pressures required to achieve complete melting in diamond and the very large coexistence region place significant constraints on the design of ICF capsules with diamond ablators. One option being considered would be designs that put the first shock below the coexistence region and the second shock above it, thereby jumping over the mixed phase region.

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Multi-Mbar Measurements of Shock Hugoniots and Melt in Beryllium and Diamond for ICF Capsule Physics

Invited Session ZI2: Z Pinches, HED Science, Target Fabrication and Invited Postdeadline
12:00 AM–12:30 PM, Friday, November 3, 2006
Philadelphia Marriott Downtown - Grand Salon CDE

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