X-ray Diffraction of Double-Shocked Diamond

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We are developing double-shock x-ray diffraction (XRD) to detect phase transitions (melting/diamond-bc8)

- The melting properties of carbon at high pressures are important for designing ICF implosions and for modeling planetary interiors
- Velocimetry and pyrometry measurements* on double shocked diamond reveal that the melting temperatures at pressures between 0.6 TPa and 2.5 TPa are relatively flat
- Double shock XRD measurements explored the diamond phase diagram for first shocks ranging from 300-800 GPa and final shock pressures up to ~1 TPa

* Hicks et al. (unpublished)
Collaborators


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The melting properties of diamond at high pressures are important for designing ICF implosions.
Phase transitions can be detected using x-ray diffraction on the secondary Hugoniot of diamond

- Double shock conditions access higher pressure states along the melt curve than states on the primary Hugoniot.
- At phase transitions, the Hugoniot is marked by plateaus caused by latent heat.
- The bc8 structure at high pressures has been proposed but has not been observed with XRD.
- The diamond phase is stable to 2 TPa under ramp compression (preliminary).

* L. Crandall
Double shock VISAR and SOP measurements use a step target design to determine the first shock pressures in diamond above the Hugoniot elastic limit.

VISAR: velocity interferometer for any reflector
SOP: streaked optical pyrometry

*Hicks (unpublished)*
Preliminary results* measured second shock pressures and temperatures to 2.5 TPa for first shock pressures between 300-400 GPa

Phase transitions can be detected using XRD

*Hicks (unpublished)
The powder x-ray diffraction image plate (PXRDIP*) platform is used to record diffraction patterns on OMEGA EP.

Impedance matching is used to determine the first shock pressures in the diamond (300-800 GPa)

LLNL AnalyzeVISAR code (Marius Millot) was used to process the VISAR / SOP data.
At the time of the x-ray exposure, the diamond is double-shocked, single-shocked, and unshocked.
Diffraction data was collected for first shocks between 350-850 GPa and final pressures up to ~1 TPa.
Summary/Conclusions

We are developing double-shock x-ray diffraction (XRD) to detect phase transitions (melting/diamond-bc8)

- The melting properties of carbon at high pressures are important for designing ICF implosions and for modeling planetary interiors

- Velocimetry and pyrometry measurements* on double shocked diamond reveal that the melting temperatures at pressures between 0.6 TPa and 2.5 TPa are relatively flat

- Double shock XRD measurements explored the diamond phase diagram for first shocks ranging from 300-800 GPa and final shock pressures up to ~1 TPa

* Hicks et al. (unpublished)
Summary/Conclusions

First reference

Second reference

Third reference

Fourth reference
The low-temperature, high-pressure phases of carbon are important for evolution models for solar (Uranus, Neptune) and extrasolar planets and white dwarfs.

Motivation

Ice giant

8 Mbar, ~8000 K

H, He gases
Superionic ice*, Methane, Hydrocarbons, Rocky core

\[ \text{Diamond} \]

\[ \text{Eggert et al.}^{**} \]

\[ \text{Neptune adiabat} \]

\[ \text{Wang}^{†} \]

\[ \text{Correa}^{‡} \]

\[ \text{Principal Hugoniot} \]

\[ \text{Metallic Fluid} \]

\[ \text{2nd Hugoniot (2 Mbar)} \]

\[ \text{BC8} \]

\[ * \text{Millot et al., Nat. Phys. 14, 297-302 (2018)} \]

\[ ** \text{Eggert et al., Nat. Phys. 6, 20-43 (2010)} \]

\[ † \text{Wang et al., Phys. Rev. Lett. 95, 185701 (2005)} \]

\[ ‡ \text{Correa et al., Proc. Natl Acad. Sci. USA 103, 1204-1208 (2006)} \]
Two-shock experiments* observed several temperature jumps at shock catch-up

**VISAR experiments**

**VISAR**: velocity interferometer for any reflector  
**SOP**: streaked optical pyrometry

*Hicks (unpublished)
Two-shock experiments* observed several temperature jumps at shock catch-up

VISAR experiments

VISAR: velocity interferometer for any reflector
SOP: streaked optical pyrometry

*Hicks (unpublished)
A first shock pressure of 2.2 Mbar in the diamond in measured from the adjacent quartz; the second shock pressure is less than 10 Mbar.

LLNL AnalyzeVISAR code (Marius Millot) was used to process the VISAR / SOP data.
At the time of the x-ray exposure, the diamond is double-shocked, single-shocked, and released.
A first shock pressure in the diamond is measured from the adjacent quartz.

LLNL AnalyzeVISAR code (Marius Millot) was used to process the VISAR / SOP data.
For first shocks ~4 Mbar, four distinct events are observed in the self-emission

VISAR experiments

VISAR: velocity interferometer for any reflector
SOP: streaked optical pyrometry

*Hicks (unpublished)
The wave-splitting can be explained by either strength or a phase transition.
For first shocks ~4 Mbar, four distinct events are observed in the self-emission.

VISAR experiments

Laser Drive

VISAR: velocity interferometer for any reflector
SOP: streaked optical pyrometry
Impedance matching

Imp match

- Quartz
- Us1 Quartz
- Diamond
- Reflect Quartz
- Copper
- Cu release

Pressure (GPa) vs. Particle Velocity (um/ns)