Precision Equation-of-State (EOS) Measurements Using Laser-Driven Shock Waves On the OMEGA Laser

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Summary

Precision equation-of-state (EOS) measurements are obtained using quartz as a standard

- The impedance-matching (IM) technique has been used for decades to obtain EOS measurements, mainly using opaque standards.

- Both random and systematic errors, inherent in IM, must be addressed.

- Transparent standards (quartz) allow one to measure the shock velocity ($U_s$) within the standard, reducing random errors.

- This high-precision technique was applied to CH and CH$_2$. 
Collaborators

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Rankine–Hugoniot equations

\[ \rho_0 U_s = \rho_1 (U_s - U_p) \]
\[ P_1 - P_0 = \rho_0 U_s U_p \]

The measurement of two variables is needed to close these equations; e.g., \( U_s = F(U_p) \).
Impedance Match $U_s = F(U_p)$

The particle velocity and pressure are conserved across a contact interface.
Need to minimize experimental error and address systematic errors for precision EOS measurements

- Measurement accuracy depends on knowledge of standard.
- Most IM studies quote only random errors.
- Cannot propagate systematic errors using theoretical EOS.

- Random errors

\[
\frac{\delta \rho}{\rho} \approx (\eta - 1), \quad \eta = \frac{\rho}{\rho_0}; \quad \eta \approx 4 - 6 \rightarrow \frac{\delta \rho}{\rho} \propto (3 - 5) \times \delta u_s
\]
Systematic Errors

At high pressures inconsistencies exist between EOS models and data for aluminum.
Random Errors

Higher precision is achieved using a transparent standard

- $U_s$ is inferred from transit times
- Laser
  - Sample
  - $U_s$ $\Delta x$

VISAR-1 shot 29425

IM velocity

VISAR-1 shot 52118

Instantaneous velocities

SiO$_2$ pusher

$U_s$ is inferred from transit times
Quartz validity as a standard is established through ample study of its EOS and agreement with previous results.

\[ \alpha\text{-quartz EOS (Al as reference)} \]

\[ \begin{align*}
\text{GPa} & \quad 140 & 450 & 945 & 1594 \\
\text{Laser} & \quad \sim 0.3 \text{ ns} \\
\text{Nuclear} & \quad \sim 10 \mu\text{s} \\
\text{Gas gun explosive} & \quad \sim 100\text{s of ns}
\end{align*} \]

\[ \begin{align*}
\text{Release isentrope (±)} \\
\text{Direct impact}
\end{align*} \]

\[ \begin{align*}
\text{Direct measurement}^1 & \quad \text{IM with Al standard}^1 \\
\text{IM with SiO}_2 \text{ standard}^2
\end{align*} \]

\[ \begin{align*}
\text{Particle speed (µm/ns)} & \quad 0 & 5 & 10 & 15 & 20 \\
\text{Shock speed (µm/ns)} & \quad 5 & 10 & 15 & 20 & 25 & 30 & 35 \\
\text{Pressure (GPa)} & \quad 0 & 20 & 40 & 60 & 80 & 100 & 120
\end{align*} \]

\[ \begin{align*}
\text{Particle speed (km/s)} & \quad 5 & 10 & 15 & 20 & 25 \\
\text{Particle speed (µm/ns)} & \quad 0 & 5 & 10 & 15 & 20 & 25 & 30 & 35 \\
\end{align*} \]

\[ \begin{align*}
\text{D. G. Hicks et al., Phys. Plasmas} & \quad 12, 082702 (2005). \\
\text{M. D. Knudson et al., J. Appl. Phys.} & \quad 97, 073514 (2005). \\
\end{align*} \]
Precision EOS data more tightly constrain polystyrene (CH) EOS

![Graph showing pressure vs. density with EOS data points and various EOS models.](image)
Precision EOS data more tightly constrain polystyrene (CH) EOS and polypropylene (CH$_2$) EOS.
Summary/Conclusions

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