Precision Equation-of-State (EOS) Measurements on NIF Ablator Materials Using Laser-Driven Shock Waves

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Summary

Precision equation-of-state (EOS) measurements are obtained on GDP and Ge-GDP from \(~1\) to \(10\) Mbar

- Design of NIF ignition targets requires precise knowledge of the ablator EOS
  - initial NIF target designs use Ge-doped GDP ablators
- Precision EOS measurements are obtained using the impedance-matching (IM) technique with quartz standard
- GDP results are in agreement with available LEOS 5310 model
- Ge-GDP data are consistent with LEOS models with 0.5\% and 0.2\% Ge doping
- Results show that shocked GDP and Ge-GDP reach similar compressibilities

Collaborators

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To support NIF experiments, the effect of ablador stoichiometry on equation of state was investigated

- Recent studies identified the effect of H:C ratio using CH and CH$_2$*

- GDP has a H:C ratio of 1.4 and added 0 atoms; Ge-doping adds considerable complexity

- Knowing the EOS of CH is not sufficient due to differences in material properties (initial density, index of refraction, compositional stoichiometry)

- These can be characterized separately with experiments on GDP and Ge-doped GDP

<table>
<thead>
<tr>
<th>Material</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>CH</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>CH$_2$</td>
</tr>
<tr>
<td>GDP</td>
<td>CH$<em>{1.4}$O$</em>{0.01}$</td>
</tr>
<tr>
<td>Ge-GDP</td>
<td>CH$<em>{1.4}$O$</em>{0.05}$ + Ge$_{at 0.6%}$</td>
</tr>
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</table>

Impedance Matching $U_S = F(U_p)$

EOS measurements are obtained from the impedance-matching technique.

Rankine–Hugoniot Equations

$\rho_0 U_s = \rho_1 (U_s - U_p)$

$P_1 - P_0 = \rho_0 U_s U_p$

Initial state
(from $U_s$ in standard)

Known standard Hugoniot

Release isentrope (known std.)

Random errors

Systematic errors

E17323d
**Random Errors**

Higher precision is obtained with a transparent standard compared to an opaque standard.

- Only information is transit time
- Can use only integrated shock
- No knowledge of shock stability
- EOS observables are obtained at the contact interface

$U_s$ is inferred from transit times
Systematic errors are assessed by using $\alpha$-quartz’s experimental Hugoniot and approximating release isentropes via the Mie-Grüneisen EOS.

- $\Gamma$ describes pressure differences between equal volume states on the Principal Hugoniot:
  \[ \Gamma = V \left( \frac{dT}{dE} \right)_V \]

- Combining $dE = TdS - PdV$, with $dS = 0$, leads to a recursion relation in the $P-V$ plane.

- $\Gamma$ is assumed to be constant in the high-pressure fluid regime, with value $\Gamma = 0.64 \pm 0.11$.

The measured GDP EOS is in agreement with available models over the ~1- to 10-Mbar pressure range.
The Ge-GDP data are consistent with available LEOS models in the $P-\rho$ plane
Structure in Ge-GDP $P-\rho$ EOS data is due to initial density variations.
Precision equation-of-state (EOS) measurements are obtained on GDP and Ge-GDP from ~1 to 10 Mbar.

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*M. A. Barrios et al., Phys. Plasmas 17, 056037 (2010).*
Comparison of GDP and Ge-GDP results indicates that both materials reach similar compression states.
EOS differences between laser and Z-machine results peak at ~6% in density and ~4% in pressure.
Percent differences in resulting CHx pressure and density using laser and Z-machine quartz fit.
Percent differences in resulting CHx pressure and density using laser and Z-machine quartz fit

![Graph showing differences in CHx pressure and density using laser and Z-machine quartz fit.](image-url)