Hot-Spot Mix and Compressed Ablator $\rho R$ Measurements in Ignition-Scale Implosions

Ch. 3: 7.2 to 12.7 keV

1-D spectral image

100 $\mu$m

Phonon energy

Space

Ge $K_\alpha$, Cu $K_\alpha$, Ge $He_\alpha$ + satellite

Tri-doped CH ablator (N120219)

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Summary

Hot-spot mix and compressed ablator $\rho R$ are diagnosed with x-ray spectroscopy

- Cu and Ge dopants placed at different radial locations in the plastic ablator are used to study the origin of hot-spot mix\(^1\) via He\(_{\alpha}\) + satellite emission spectroscopy\(^2\)
- Low neutron yields and hot-spot mix mass around the 75 ng limit\(^3\) are observed
- A compressed ablator $\rho R$ of 0.35 to 0.5 g/cm\(^2\) is inferred from Cu and Ge K-edge absorption

Shell material near the ablation surface comprises most of the hot-spot mix mass.

\(^1\)B. A. Hammel et al., High Energy Density Phys. 6, 171 (2010).
\(^3\)S. W. Haan et al., Phys Plasmas 18, 051001 (2011).
Collaborators

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Cu and Ge dopants are placed at different radial locations in the plastic ablator to study the origin of hot-spot mix.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Dopant (atm. %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Cu (0.14%)</td>
</tr>
<tr>
<td>2</td>
<td>Ge (0.20%) Si (0.87%)</td>
</tr>
<tr>
<td>3</td>
<td>Ge (0.20%) Si (1.64%)</td>
</tr>
<tr>
<td>Outer</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Si (1.15%)</td>
</tr>
<tr>
<td>5</td>
<td>None</td>
</tr>
</tbody>
</table>

The x-ray ablation front reaches the Ge-doped layer, but not the Cu-doped layer.
The measured spectrum has features from the shell (Cu, Ge K edge; Cu, Ge Kα) and the hot spot (Ge Heα + satellite emission)*

- The compressed ablator ρR is inferred from the K-edge absorption and the hot-spot mix mass is inferred from Cu, Ge Heα + satellite emission
- Cu, Ge Kα emission is from a compressed ablator photopumped by x-ray continuum from the hot spot

*Regan et al., Phys. Plasmas 19 056307 (2012); R. Epstein, PO4.00008, this conference
Shell material near the ablation surface—CH(Ge)—comprises most of the hot-spot mix mass.

A 15-ng upper limit of mix mass from the inner ablator is estimated from the Cu He$_\alpha$ + satellite emission.
Low neutron yields and hot-spot mix mass around the 75-ng limit are observed

The NIF requirement (driven by radiative cooling) is that CH(Ge) hot-spot mix mass < 75 ng*

- Hot-spot mix-mass analysis assumes 125-ps x-ray burnwidth

The ablator $\rho R$ is estimated from Cu, Ge K edges for the tri-doped ablator.

Cold opacities of Cu and Ge are used for estimate (i.e., for Cu the shell transmission is proportional to $\exp[-\rho R(Cu) \mu_{\text{cold Cu}}]$).
\( \rho R \) of compressed tri-doped ablator is 0.35 to 0.5 g/cm\(^2\) for N120219 (C:H = 1:1.35)

- \( \rho R(\text{Cu}) \) and \( \rho R(\text{Ge}) \) are inferred from the measured drop of intensity at the K-edge
- Atomic fractions of elements in the ablator measured at General Atomics are used to infer \( \rho R(\text{CH}) \) and \( \rho R(\text{Si}) \)
- \( \rho R(\text{CH, Cu}) = 0.035 \) to 0.139 g/cm\(^2\)
- \( \rho R(\text{CH, Ge, Si}) = 0.306 \) to 0.374 g/cm\(^2\)
- Total ablator \( \rho R = 0.35 \) to 0.5 g/cm\(^2\)
- Simulated ablator \( \rho R = 0.68 \) g/cm\(^2\) is comparable to experimental result
Summary/Conclusions

Hot-spot mix and compressed ablator $\rho R$ are diagnosed with x-ray spectroscopy

- Cu and Ge dopants placed at different radial locations in the plastic ablator are used to study the origin of hot-spot mix via $\text{He}_\alpha +$ satellite emission spectroscopy.
- Low neutron yields and hot-spot mix mass around the 75 ng limit are observed.
- A compressed ablator $\rho R$ of 0.35 to 0.5 g/cm$^2$ is inferred from Cu and Ge K-edge absorption.

Shell material near the ablation surface comprises most of the hot-spot mix mass.

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The x-ray continuum is fitted with a model including the hot-spot x-ray emission and the compressed-shell attenuation

- X-ray continuum from hot spot transmitted through the shell
  \[ I(\nu) = I_0(\nu) \exp[-\tau] \]

- Hot-spot x-ray continuum emission
  \[ I_0(\nu) = I_c \exp[-h\nu/kT] \]

- Optical thickness of the compressed shell
  \[ \tau(h\nu < \text{Cu K edge}) = M_1/(h\nu)^3 \]
  \[ \tau(\text{Cu K edge} < h\nu < \text{Ge K edge}) = (M_1 + M_2)/(h\nu)^3 \]
  \[ \tau(h\nu > \text{Ge K edge}) = (M_1 + M_2 + M_3)/(h\nu)^3 \]
Hot-spot mix and compressed ablator $\rho R$ are diagnosed with x-ray spectroscopy around peak compression.

High-Z–doped ablator material emits K-shell emission when mixed into the hot spot.

X-ray continuum from the hot spot is attenuated by the K edge of a high-Z dopant in the compressed ablator.