Simulations of Fuel Assembly and Fast-Electron Transport in Integrated Fast-Ignition Experiments on OMEGA

Cu Kα emission [$\times 10^{13}$ photons/(sr x cm$^2$)]

Experiment

DRACO/LSP simulation

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55th Annual Meeting of the American Physical Society
Division of Plasma Physics
Denver, CO
11–15 November 2013
Summary

**DRACO***/LSP** integrated simulations are used to study the performance of cone-in-shell fast-ignition targets

- **DRACO** simulations have been confirmed by 8.05-keV flash radiography of cone-in-shell implosions and shock breakout measurements

- **LSP** simulations explain the fast-electron transport in integrated OMEGA experiments using Cu-doped plastic shells
  - fast-electron–induced Cu $K_\alpha$ x-ray yield and spatial distribution are confirmed
  - $\sim$2.5% of the total fast-electron energy is coupled to the core
    - hard fast-electron spectrum
    - large distance from the source to the core
    - large divergence

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Collaborators


University of Rochester
Laboratory for Laser Energetics
and Fusion Science Center for
Extreme States of Matter

L. C. Jarrott, C. McGuffey, B. Qiao, and F. N. Beg

University of California, San Diego

M. S. Wei and R. B. Stephens

General Atomics
Integrated fast-ignition experiments with re-entrant cone-in-shell targets are performed at the Omega Laser Facility.

- A spherical crystal imager* (SCI) is used to obtain a spatial distribution of Cu Kα x rays induced by fast electrons in the imploded core.

DRACO simulations of the compressed core areal density agree with the experiments

- 8.05-keV Cu-K$_\alpha$ flash radiography of cone-in-shell implosions

- Cone-tip breakout time agrees in the experiments and simulations

CD shells with Cu dopant have been used to characterize the transport of fast electrons in the integrated experiments*

Fast-electron–induced Cu K$_\alpha$ emission at three times [$\times 10^{13}$ photons/(sr $\times$ cm$^2$)]

- Shot 66409, 3.65-ns delay
- Shot 66414, 3.75-ns delay
- Shot 66416, 3.85-ns delay

DRACO predictions for the mass density (g/cm$^3$)

- $E_{EP} = 500$ J, $\tau = 10$ ps, $E_{pre} = 20$ mJ (low contrast)

*L. C. Jarrott et al., Y05.00004, this conference
**LSP** simulations of fast-electron transport in the implosion plasma have been performed

- The energy spectrum of fast electrons is predicted by particle-in-cell (PIC) simulations* of OMEGA EP pulse propagation in the laser pre-plasma

\[
g(E) = \frac{\int_0^E f(E')E'dE'}{\int_0^\infty f(E')E'dE'}
\]

- Isotropic angular distribution of fast electrons is assumed
- Fast-electron–induced Cu K\(\alpha\) emission and propagation through the imploded core is modeled**
- The total energy of fast electrons is \(\sim 30\%\) of \(E_{EP} = 500\) J, inferred from comparing the K\(\alpha\) yield in the experiments to the simulations

* J. Li et al., Phys. Plasmas 20, 052706 (2013); B. Qiao et al., YO5.00005, this conference.
**LSP** simulates the fast-electron transport and Cu $K_{\alpha}$ emission

- Hard fast-electron spectrum, large distance from the source to the core, and large divergence explain a weak coupling of fast electrons to the core ($\rho_{cd} > 1$ g/cm$^3$): 2.5% of the total fast-electron energy
K$_{\alpha}$-emission images agree in the experiments and simulations

Experiment $[\times10^{13}$ photons/(sr $\times$ cm$^2$)]

<table>
<thead>
<tr>
<th>Delay</th>
<th>Image</th>
<th>Yield</th>
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<tbody>
<tr>
<td>3.65-ns</td>
<td><img src="image1" alt="Image" /></td>
<td>$1.9 \times 10^{10}$ ph/sr</td>
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<tr>
<td>3.75-ns</td>
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<tr>
<td>3.85-ns</td>
<td><img src="image3" alt="Image" /></td>
<td>$1.5 \times 10^{10}$ ph/sr</td>
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</tbody>
</table>

DRACO/LSP simulation $[\times10^{13}$ photons/(sr $\times$ cm$^2$)]

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<tr>
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<th>Image</th>
<th>Yield</th>
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</thead>
<tbody>
<tr>
<td>3.65-ns</td>
<td><img src="image4" alt="Image" /></td>
<td>$1.9 \times 10^{10}$ ph/sr</td>
</tr>
<tr>
<td>3.75-ns</td>
<td><img src="image5" alt="Image" /></td>
<td>$2.2 \times 10^{10}$ ph/sr</td>
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<tr>
<td>3.85-ns</td>
<td><img src="image6" alt="Image" /></td>
<td>$1.5 \times 10^{10}$ ph/sr</td>
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</tbody>
</table>
Summary/Conclusions

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- **LSP** simulations explain the fast-electron transport in integrated OMEGA experiments using Cu-doped plastic shells
  - fast-electron–induced Cu $K_\alpha$ x-ray yield and spatial distribution are confirmed
  - ~2.5% of the total fast-electron energy is coupled to the core
    - hard fast-electron spectrum
    - large distance from the source to the core
    - large divergence

**D. R. Welch et al., Phys. Plasmas 13, 063105 (2006).*
The fuel assembly can be improved by optimizing the compression pulse and evacuating air from the shell.

- Air removal reduces the mass of the hot spot and the pressure on the cone tip; the fuel stagnates closer to the target center.
- Compression pulse picket is optimized:
  - Picket power is reduced to account for an increased absorption (~50%) predicted by the nonlocal thermal transport model*
  - With an optimized picket, the shell implodes on a lower adiabat and less fuel is injected by the shocks into the hot spot.

<table>
<thead>
<tr>
<th>Gas pressure</th>
<th>Picket</th>
<th>Cone tip</th>
<th>Δt (ps)</th>
<th>ρR_{break} (mg/cm²)</th>
<th>ρR_{max} (mg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8-atm air</td>
<td>Current</td>
<td>15-μm Au</td>
<td>300</td>
<td>80</td>
<td>300</td>
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<tr>
<td>Vacuum</td>
<td>Optimized</td>
<td>15-μm Au</td>
<td>140</td>
<td>360</td>
<td>600</td>
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<tr>
<td>Vacuum</td>
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<td>60-μm Al</td>
<td>80</td>
<td>500</td>
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