Comparison of Proposed First Wall Experiments

Jake Blanchard
HAPL MWG
Fusion Technology Institute
University of Wisconsin

Albuquerque – April 2003
Goal

- Assess the ability of various proposed experiments to mimic HAPL conditions
Comparing Experiments

• Which available experiments can be used to test materials for HAPL?
  – XAPPER
  – Z
  – RHEPP
  – UCSD Laser
  – Infrared

• Match surface peak temperature and then compare spatial distributions
## Parameters

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Type</th>
<th>Energy (keV)</th>
<th>Max Fluence (J/cm²)</th>
<th>Approx. Depth (microns)</th>
<th>Pulse Width (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RHEPP</td>
<td>Ions</td>
<td>750</td>
<td>7</td>
<td>1-10</td>
<td>100</td>
</tr>
<tr>
<td>Z</td>
<td>X-Rays</td>
<td>0.8-1.2</td>
<td>3000</td>
<td>1-2</td>
<td>6</td>
</tr>
<tr>
<td>XAPPER</td>
<td>X-Rays</td>
<td>0.1-0.4</td>
<td>7</td>
<td>1-2</td>
<td>10-30</td>
</tr>
<tr>
<td>UCSD</td>
<td>Laser</td>
<td></td>
<td>0.7</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Electra</td>
<td>electrons</td>
<td>500</td>
<td>2</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Infrared</td>
<td>Infrared</td>
<td></td>
<td>q=10 MW/m²</td>
<td>0</td>
<td>&gt;10 ms</td>
</tr>
</tbody>
</table>
Initial Approach

• Consider three cases using analytical results
  – Surface heating
  – Volumetric heating which decays exponentially
  – Uniform volumetric heating over a fixed depth
  – Initial results are for semi-infinite solids, so the results are only valid for short pulses
Constant Fluence

surface

\[ T_s = \frac{2F}{k} \sqrt{\frac{\kappa}{\pi t_p}} \]

exponential

\[ T_s = \frac{2F\sqrt{\kappa}}{k\sqrt{\pi t_p}} - \frac{F}{\beta k t_p} \left[ 1 - \exp\left(\beta^2 \kappa t_p\right) \text{erfc}\left(\beta \sqrt{\kappa t_p}\right) \right] \]

uniform

\[ T_s = \frac{F\kappa}{lk} \left\{ 1 - 4 i^2 \text{erfc}\left(\frac{l}{2\sqrt{\kappa t_p}}\right) \right\} \]
Scaling of Temperatures
Surface Temperature vs. Pulse Width for Fixed Fluence

Fluence=1 J/cm²

- blue: surface
- green: l=1 microns
- red: l=2 microns
- cyan: e-folding=2 microns

Surface Temperature (°C) vs. Pulse Width (µs)
Scaling of Temperatures
Fix Surface Temperature at 80 ns Pulse Width

![Diagram showing temperature scaling with different pulse widths and fluences.](image)
RHEPP

2.2 J/cm², 100 ns for 1 micron depth
5.25 J/cm², 100 ns for 4 micron depth
Infrared Tests

- Time scales are long for infrared tests, so analytical models are not appropriate
- Cases were re-rerun for 50 microns of tungsten on 3 mm of ferritic steel
- Metric is now surface temperature, temperature distribution, and stresses in steel
Temperature Distributions in Steel after last pulse – 150 MJ target

100 Microns of Tungsten

HAPL Low Yield
6.5 meter, no gas

IR Experiment – 0.7 MW/m²
80 ms on, 160 ms off
Stress Distributions
after last pulse for 150 MJ Target

100 Microns of Tungsten

HAPL Low Yield
6.5 meter, no gas

IR Experiment – 0.7 MW/m²
80 ms on, 160 ms off
Ideal Experiment

• Preserve peak power and pulse width
• Preserve time-averaged power
• Preserve initial temperature
• Preserve gradients through steel (cool back of sample)
Conclusions

• Peak temperatures do not scale directly with inverse square root of pulse width
• RHEPP, Z, UCSD laser, and Xapper can simulate peak temperatures in HAPL walls, but with shorter times to peak and with sharper temperature distributions (Electra cannot)
• These effects are likely relatively unimportant
• IR can easily duplicate the important stress distributions throughout a duplex sample (this requires active cooling)
• It isn’t clear that other options can mimic stress distributions in duplex samples (Electra might)
Future Work

• Monitor and model experiments
• Create design criteria from modeling
• Model cracking of tungsten (growth through tungsten and at steel interface)
• Model high cycle fatigue in steel
• Model castellation
• Put yield model into BUCKY