IFE Chambers:
Modeling and Experiments at UCSD

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5th US-Japan Workshop on Laser IFE

March 21-23, 2005
General Atomics, San Diego

Electronic copy:  http://aries.ucsd.edu/najmabadi/TALKS
UCSD IFE Web Site: http://aries.ucsd.edu/IFE
UCSD Research under the High-Average-Power Laser Program

- Final optics
- Target engineering
- Chamber dynamics
- Chamber armor
- Blanket
- System integration
I. Simulation of IFE Chamber Dynamics

The focus of our research effort is to model and study the chamber dynamic behavior on the long time scale, including Hydrodynamics and Energy & particle transfer mechanisms.
Spartan Chamber Simulation Code

**SPARTAN features:**
- Physics: Navier-Stokes equations with state dependent transport properties; Coronal model for radiation.
- Numerics: Godunov solver; Embedded boundary; and Adaptive Mesh Refinement
- Two-Dimensional: Cartesian and cylindrical symmetry
- Use results from rad-hydro codes (BUCKY) as initial condition.

All results presented are for a chamber filled with 50 mTorr of Xe
Without Radiation, a high temperature zone would be developed in the chamber.

- **$T_{\text{max}} = 5.3 \times 10^4 \text{ K}$**
  - *t = 0.5 ms*
  - Convergence of shocks leads to a hot zone.

- **$T_{\text{max}} = 3.1 \times 10^5 \text{ K}$**
  - *t = 3 ms*
  - (After one bounce)

- **$T_{\text{max}} = 2.2 \times 10^5 \text{ K}$**
  - *t = 8 ms*
  - Hot zone does not disappear

- **$T_{\text{max}} = 1.3 \times 10^5 \text{ K}$**
  - *t = 20 ms*

- **$T_{\text{max}} = 5.1 \times 10^4 \text{ K}$**
  - *t = 65 ms*

- **$T_{\text{max}} = 3.2 \times 10^4 \text{ K}$**
  - *t = 100 ms*
Radiation is the Dominant Energy Transfer Mechanism

**Case I: No Radiation**

- After the first “bounce” kinetic energy of gas is converted into internal energy (hot zone). Conduction to the wall is too slow.

**Case II: With Radiation**

- The energy is dissipated by radiation. The gas temperature is effectively pinned by radiation (~5,000K for Xe)
A variety of chamber geometries has been considered

- Infinite cylinder (Cartesian symmetry)
- Finite cylinder (Cylindrical symmetry)
- Sphere (Cylindrical symmetry)
- Octagon (Cylindrical symmetry)
Impact of Chamber Geometry on Chamber Temperature at 100 ms

A large number of cases with different geometries were simulated:

- 3-D effects can be observed and sufficiently described by using a combination of Cartesian and axisymmetric cylindrical 2-D models.
- Shape of the chamber makes little difference in peaks and averages of the temperature (< 10%).
- Peak Xe temperature is set by radiation at about 5,000K.
II. Armor Simulation Experiments At Dragonfire Facility
Thermo-Mechanical Response of Chamber Wall Can Be Explored in Simulation Facilities

Requirements:
- Capability to simulate a variety of wall temperature profiles
- Laser pulse simulates temperature evolution
- Vacuum Chamber provides a controlled environment

A suite of diagnostics:
- Real-time temperature ([High-speed Optical Thermometer])
- Per-shot ejecta mass and constituents ([QMS & RGA])
- Rep-rated experiments to simulate fatigue and material response
  - Relevant equilibrium temperature ([High-temperature sample holder])
- Capability to isolate ejecta and simulate a variety of chamber environments & constituents
Experimental Setup

- High-Temperature Sample holder
- Thermometer head
- Laser entrance
- QCM
- RGA
Real-time Temperature Measurements Can Be Made With Fast Optical Thermometry

- Spectral radiance is given by Planck’s Law (Wien’s approximation):
  \[ L(\lambda, T) = C_1 \varepsilon(\lambda, T) \lambda^{-5} \exp(-C_2/\lambda T) \]
- Since emittance is a strong function of \( \lambda, T, \) surface roughness, etc., deduction of temperature from total radiated power has large errors.

**Temperature deduction by measuring radiance at fixed \( \lambda \)**

- One-color: Use tables/estimates for \( \varepsilon(\lambda_1, T) \)
- Two colors: Assume \( \varepsilon(\lambda_1, T) = \varepsilon(\lambda_2, T) \)
- Three colors: Assume \( \frac{d^2\varepsilon}{d\lambda^2} = 0 \) [usually a linear interpolation of \( \ln(\varepsilon) \) is used]

**Our observations**

- Two-color method achieves sufficient accuracy (~1%). Three-color method is too difficult.
Status of High-Speed Thermometer

The diagram shows the components of the high-speed thermometer, including:

- Band-pass filter/focuser
- Expander/neural filter
- 50-50 splitter
- Single fiber from head to splitter/detector
- PMT

The images depict the physical setup of the thermometer, including the experimental setup and the oscilloscope monitoring the signal.
A Variety of Measure has reduced the noise in thermometer signal considerably.

- Little difference in thermometer signal when averaged over 4, 8, 16, and 32 shots.
- Thermometer is calibrated based on the melting point of tungsten.
## Armor Irradiation Test Matrix

<table>
<thead>
<tr>
<th>Test matrix:</th>
<th>Initial Temp.</th>
<th>ΔT</th>
<th>No. of Shots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1A:</td>
<td>RT</td>
<td>2,000°C</td>
<td>$10^3$ (100s)</td>
</tr>
<tr>
<td>Sample 2A:</td>
<td>RT</td>
<td>2,000°C</td>
<td>$10^4$ (~16 mins)</td>
</tr>
<tr>
<td>Sample 1B:</td>
<td>RT</td>
<td>~2,000°C</td>
<td>$10^5$ (~2.8 hr)</td>
</tr>
<tr>
<td>Sample 3A:</td>
<td>RT</td>
<td>~2,500°C</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Sample 2B:</td>
<td>RT</td>
<td>2,500°C</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Sample 3B:</td>
<td>~RT</td>
<td>2,500°C</td>
<td>$10^5$</td>
</tr>
<tr>
<td>Sample 4A:</td>
<td>500°C</td>
<td>2,000°C</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Sample 5A:</td>
<td>500°C</td>
<td>2,000°C</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Sample 4B:</td>
<td>500°C</td>
<td>2,000°C</td>
<td>$10^5$</td>
</tr>
<tr>
<td>Sample 6A:</td>
<td>500°C</td>
<td>2,500°C</td>
<td>$10^3$</td>
</tr>
<tr>
<td>Sample 5B:</td>
<td>500°C</td>
<td>2,500°C</td>
<td>$10^4$</td>
</tr>
<tr>
<td>Sample 6B:</td>
<td>500°C</td>
<td>2,500°C</td>
<td>$10^5$</td>
</tr>
</tbody>
</table>

**Samples:** Powder metallurgy tungsten samples from Lance Snead.
Powder Metallurgy Tungsten Samples After Laser Irradiation

- Samples are polished to a “mirror-like” finish.
- The “damaged” area has a “dull” finish.
- A brown background is placed in the photograph to enhance contrast.

- Optical microscope at low resolution
- “Black” areas appear black because of the “dull finish” (they appear as whitish to the naked eye)
Effects of Shot Rate and Temperature Rise

370mJ (~2000°C ΔT), RT

530mJ (~2500°C ΔT), RT

10^3 shots 10^4 shots 10^5 shots
Effects of Shot Rate and Temperature Rise

370mJ (~2000°C ∆T), 500°C

High Magnification

530mJ (~2500°C ∆T), 500°C

10^3 shots  10^4 shots  10^5 shots
Effects of Shot Rate and Temperature Rise

530mJ (~2500°C ΔT), RT

530mJ (~2500°C ΔT), 500°C

10^3 shots 10^4 shots 10^5 shots
Material Response: At First Glance

- It appears that samples evolves at two different time scales:
  - Low shot count: Defect planes appear,
  - High shot count: Individual “nuggets” form (are we seeing the powder constituents breaking apart?)

- Higher equilibrium temperature leads to less damage
  - Highly visible in low shot counts, For example, 1,000 shots at $\Delta T \sim 2,500^\circ C$ with 500$^\circ C$ sample is “almost” damage free while the corresponding RT sample shows damage.
  - At high shot count, samples with higher equilibrium temperature also show “slightly” less damage.