## Target fabrication-4: Cryo layering

**Schafer Corp**

<table>
<thead>
<tr>
<th>Overall Objective</th>
<th>Develop methods to mass produce cryo layers</th>
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| FY 01 Deliverables | 1. Evaluate application of present IFE layering for DD targets on a mass production basis.  
2. Draft plan for mass-layering of cryo targets |
| PI Experience     | Developed cryo layering techniques for NIF (ID) |
| Proposed Amount   | $100 k  
(POC: D. Bittner) |
| Relevance of Deliverables |  
[X] NIF......................... DD targets have more layering options than ID  
[ ] Laser RR Facility....  
[ ] Other DP/NNSA......  
[X] Energy............... Absolutely essential for IFE targets |
| Related OFES activities | None |
Progress on cryogenic layering

Goal of cryogenic layering program at LLNL:
Produce a 100 micron layer of solid DT in a 2mm capsule with surface roughness < 1µm RMS at T=18.3K.

Work is currently done in 2mm spheres with fill tubes.

Best DT layer produced in a sphere was a 125 µm layer in a 2mm diameter 40 µm thick plastic sphere.
RMS = 1.1µm @ 19.25K over modes 1 to 50

Best IR layer produced was a 100 µm layer of HD in a 1 mm diameter 40 µm thick plastic sphere.
RMS = 0.77 µm over modes 1 to 100 at ~16.6K

IR layers have been produced at 1.5 K below the triple point with minimal degradation from cooling.
A thermal gradient at the ice surface can be generated by heat absorbed in the vapor or the bulk ice.

For a heat flux $F$

$$T(x) = \frac{Fx}{k}$$

$$\left. \frac{dT}{dx} \right|_{x=h} = \frac{F}{k}$$

A heat flux $F$ of 0.5 mW/cm$^2$ gives the same thermal gradient as $DT$.

For wavelengths long compared to the ice thickness:

$$T(x) = \frac{qx^2}{2k}$$

- $k$ = thermal conductivity of ice
- $q$ = bulk heating rate

$$\left. \frac{dT}{dx} \right|_{x=h} = \frac{qh}{k} = 0.15 \text{ K/cm}$$ for $DT$ ($q=0.05 \text{ W/cm}^3$).
Experiments on flats show surface temperature gradients, $\delta T/\delta h$, reduces roughness.

(1) Heat flux across the gas/solid interface

\[ \delta T/\delta h = \frac{F}{K} \]

(2) Bulk heat generated with IR heating

\[ \delta T/\delta h = \frac{Qh}{\kappa \sqrt{1 + (2\pi h/\lambda)^2}} \]
Spherical geometry provides uniform thermal environment

50/50 DT is introduced as a gas into the sample cell.

Sample cell is 2mm x 40 micron plastic shell with a fused silica fill tube.

Joule heating studies are carried out at the resonant freq. of the layering sphere, ~ 10 GHz.
Layers in shells are characterized using the bright band in the shadowgraph image.

Apparent interface

Bright band is due to reflection off the gas/liquid interface.

- Apparent image for ~100\(\mu\)m layer is shifted ~ 50\(\mu\)m.
- Apparent image is more distorted for thin layers.
DT layers are smoothed by tritium decay heating of the solid

\[ \Delta T = \frac{Q h^2}{2\kappa} \]

\[ \delta T \text{ (bump)} = \Delta T + Qh\delta h/\kappa \]

Increased temperature on bump gives higher vapor pressure sublimating mass off the bump.

Smoothing is limited by increasing surface energy as higher energy crystal facets are exposed.
Native $\beta$ layers can not remain smooth to 18.3 K.

Layers plotted were formed by cooling at a constant rate from the triple point to 18.2K.

Layers degrade before reaching 19.1 K.

Other experiments were performed by cooling at 0.25 mK/min. through the triple point and then stepping up the rate until 18K. Results are similar to those shown.
Microwave heating of a spherical capsule

Temp. = 18.2 K  Cooling @ 2mK/min
with joule heating          just slow cooling

Problems with field imprinting upon the layer need to be solved.

Calculated field map for TM011 mode in 1" spherical cavity
fres=10.3 GHz
1.4% variation in power density between pole and equator of shell

Layering rates 6 x native β layering rates have been observed in a cylindrical geometry.

The only limiting factor is the amount of dissipated heat that can be tolerated in capsule.
Cryogenic fuel layers can be enhanced or formed by absorption of infra-red radiation.

Absorption of IR light generates volumetric heating, $Q_{IR}$, which adds to or replaces heating from beta layering.

$$\delta T(bump) \sim \Delta T + Qh\delta h/\kappa$$

$90 \mu m$ thick HD layer formed by uniform infra-red radiation.
The smoothest HD layers are formed by injecting IR into an integrating sphere using optical fiber.

**CD capsule:**
- 965 μm OD
- 37 μm wall
- 100 μm HD layer

**Graph:**
- 1.66% analysis
- modes: 1-100 = 0.77, 2-100 = 0.52, 3-100 = 0.36, 4-100 = 0.23, 5-100 = 0.21

**Diagram elements:**
- IR fiber
- cold tip
- IR fiber feedthru
- viewport
-viewport
- He exchange gas
- vacuum can
- integrating sphere

**Legend:**
- mode amplitude (μm²)
- mode number
- mode rms (μm)
We have succeeded in producing smooth layers 1.5 K below the triple point.

IR power absorbed \( \sim 30 Q_{DT} \)

\( \Delta T/\Delta t = 10\text{mK}/3\text{min} \)

Layer thickness \( \sim 80\mu\text{m} \)

<table>
<thead>
<tr>
<th>modes</th>
<th>rms (µm)</th>
<th>rms (µm)</th>
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</thead>
<tbody>
<tr>
<td>1-100</td>
<td>1.25</td>
<td>1.22</td>
</tr>
<tr>
<td>2-100</td>
<td>0.85</td>
<td>0.93</td>
</tr>
<tr>
<td>3-100</td>
<td>0.74</td>
<td>0.76</td>
</tr>
<tr>
<td>4-100</td>
<td>0.33</td>
<td>0.38</td>
</tr>
<tr>
<td>5-100</td>
<td>0.30</td>
<td>0.34</td>
</tr>
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</table>
Enhanced layering techniques produce smoother layers but also put added constraints on the system.

- Materials constraints
  - Capsule heating
  - Nonuniform energy deposition from external source
  - Capsule coatings
    - May inhibit enhancement technique

- Time constraints
  - Layer formation
    - Possibly longer time needed for enhanced layering
  - Layer degradation
    - Eventually must turn off enhancement technique

Hardware must provide functionality for enhanced layering.
The goal for FY01 is to determine which layering technologies are viable under IFE requirements.

- Integrate the current ICF layering technology database into IFE planning and identify information necessary to implement layering.
  - How compatible are the various layering techniques with current target designs and each of the target assembly, filling, and injection requirements?
  - What design changes are necessary to incorporate these layering techniques?

- Develop a plan for acquiring information necessary to implement cryogenic layering in an IFE environment.
  - What addition information is needed?
  - Of this additional information, what relevant data might we expect from cryogenic target development activities currently underway at LLNL (ID) and LLE (DD)?
  - How do we acquire the additional information? What experiments need to be performed?