Target fabrication-4: Cryo layering---- *Schafer Corp*

Overall Objective………….	**Develop methods to mass produce cryo layers**
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………….. ***(POC: D. Bittner)***	**$ 100 k**
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

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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

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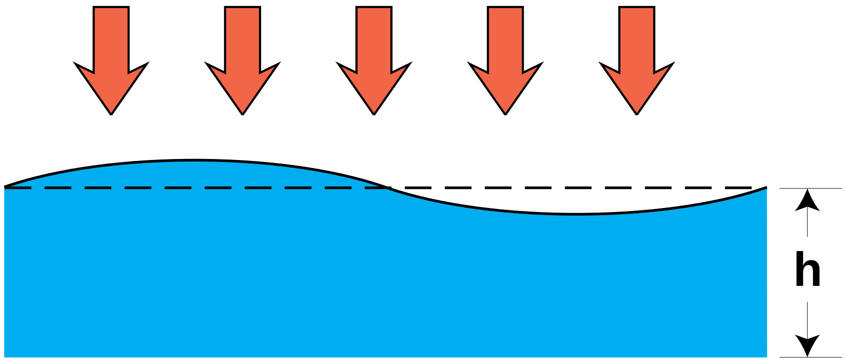
Heat Flux



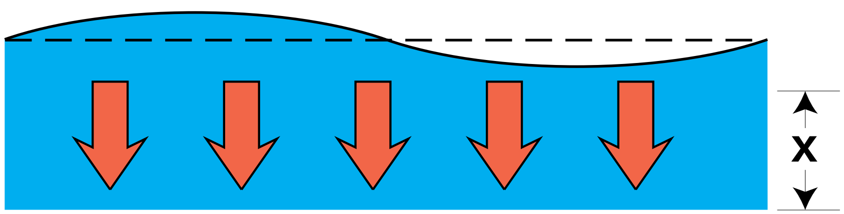
For a heat flux F

$$T(x)=Fx/k$$

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

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

Bulk Heating



For wavelengths long compared to the ice thickness:

$$T(x)=qx^2/2k$$

k = thermal conductivity of ice

q = bulk heating rate

$$\left.\frac{dT}{dx}\right|_{x=h}=qh/k = .15\,\frac{K}{cm}\ \text{for DT}\ (q=0.05\,\frac{W}{cm^3})$$

Experiments on flats show surface temperature gradients, $\delta T/\delta h$, reduces roughness.

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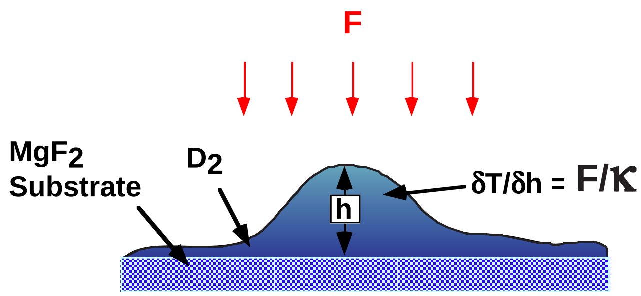
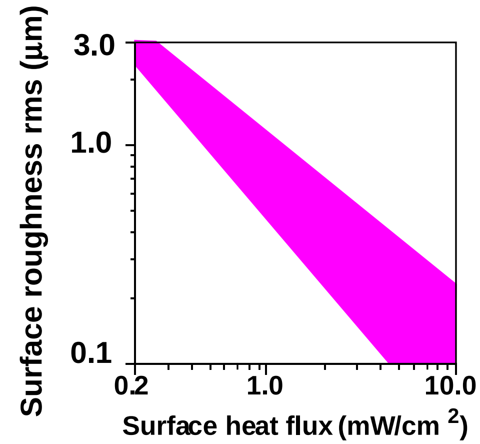
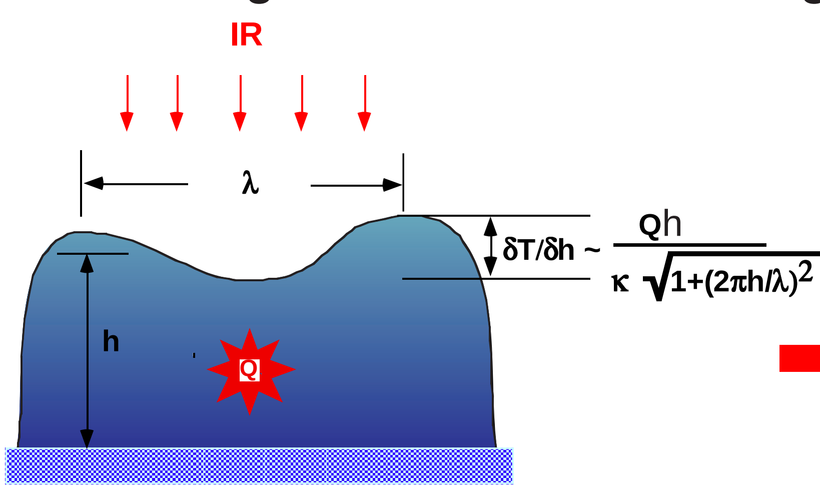
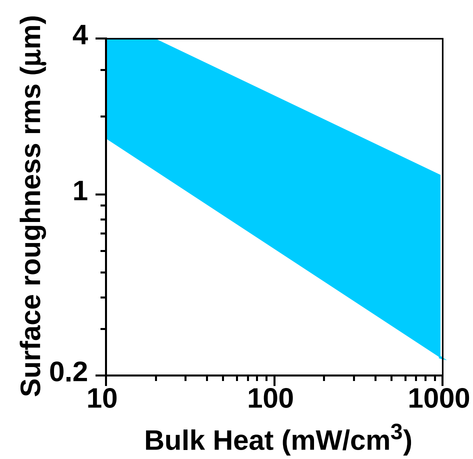
(1) Heat flux across the gas/solid interface





(2) Bulk heat generated with IR heating



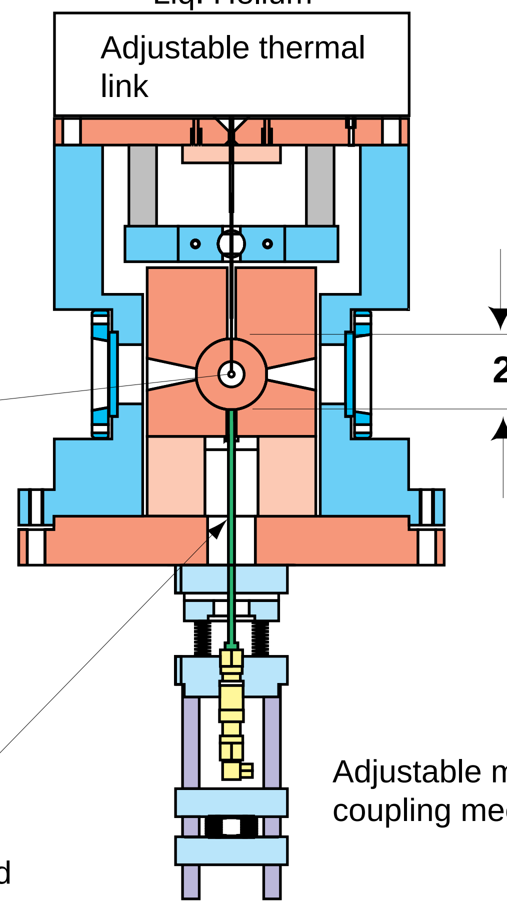


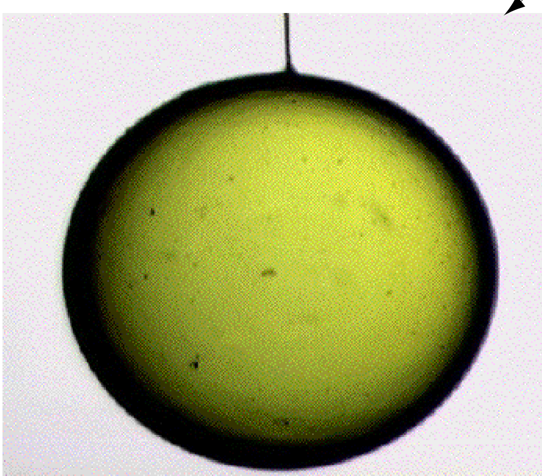
Spherical geometry provides uniform thermal environment

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.

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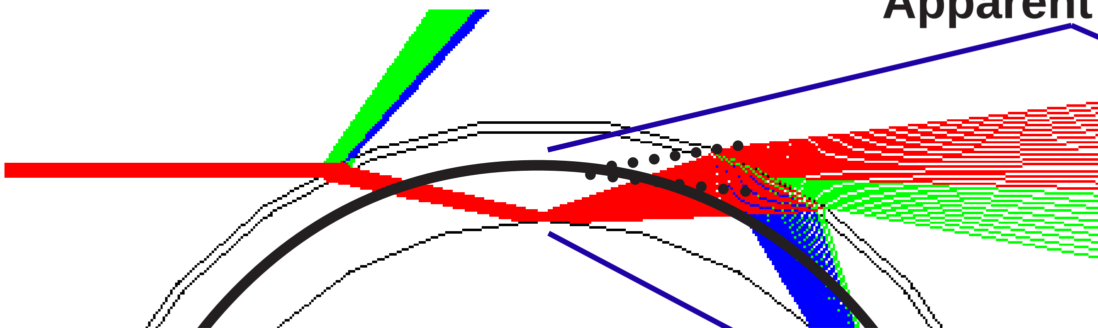
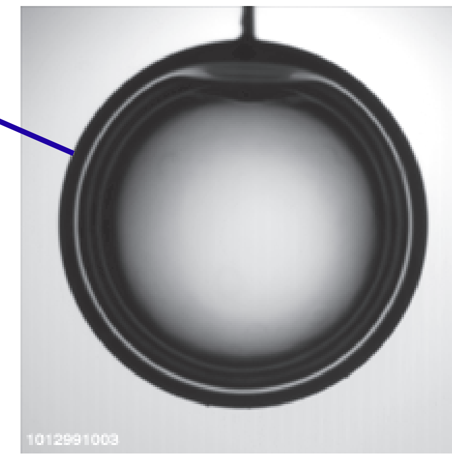
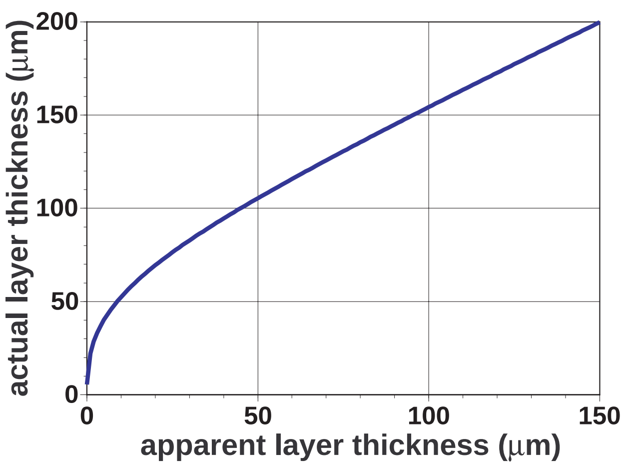
Apparent interface





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



- **Apparent image for ~100μm layer is shifted ~ 50μm.**
- **Apparent image is more distorted for thin layers.**

DT layers are smoothed by tritium decay heating of the solid

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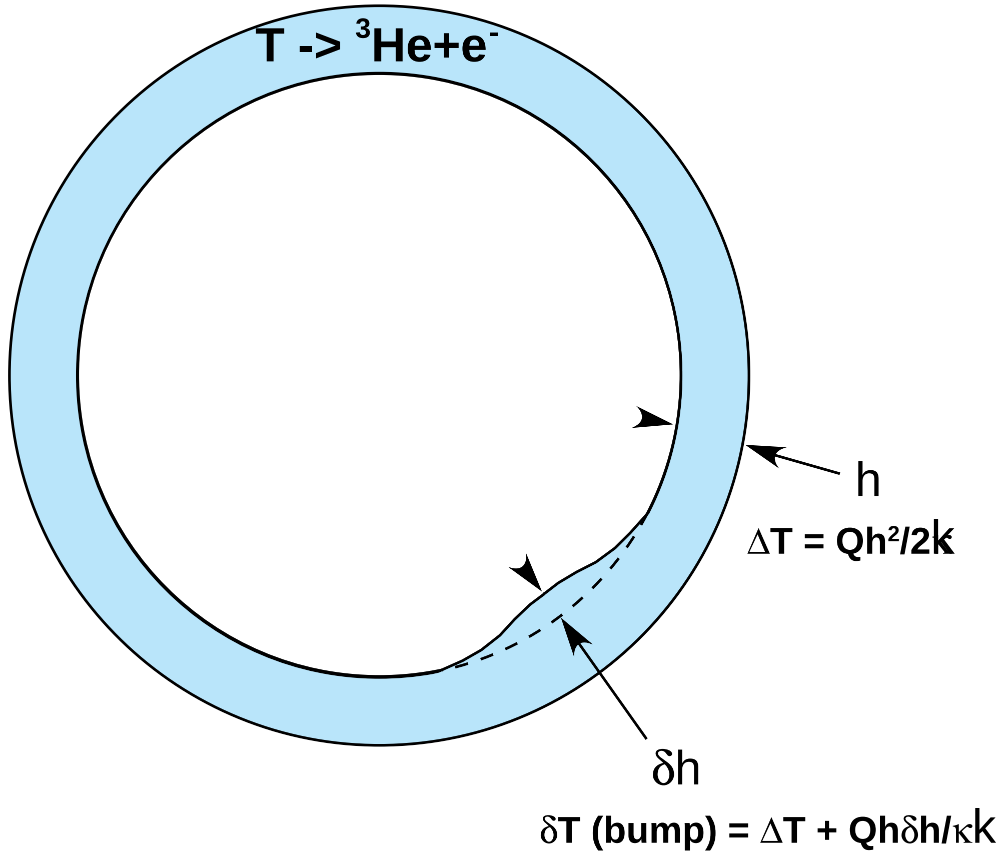

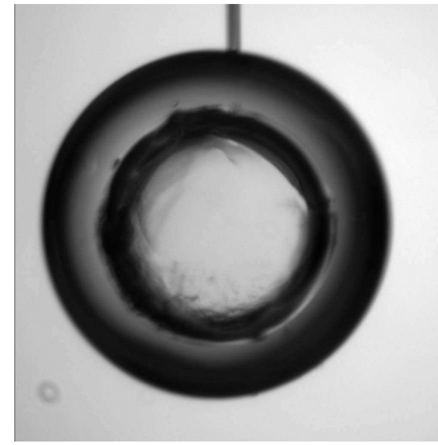

Rough layer formed from quick frozen solid

Smooth layer formed while slowly cooling through triple point

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 ß layers can not remain smooth to 18.3 K.

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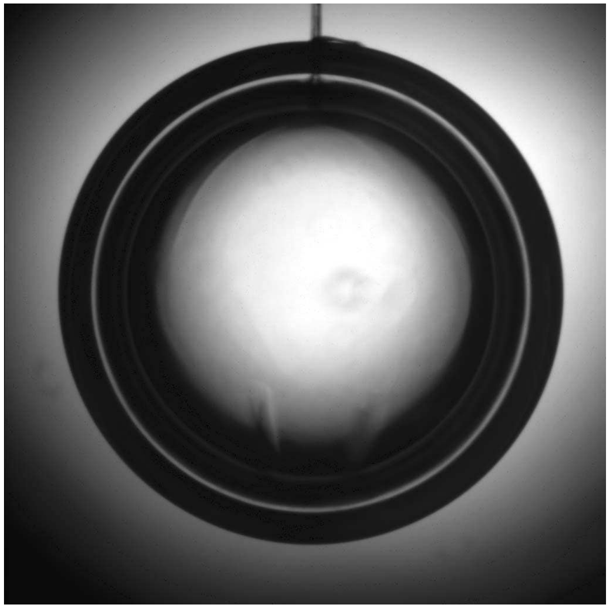
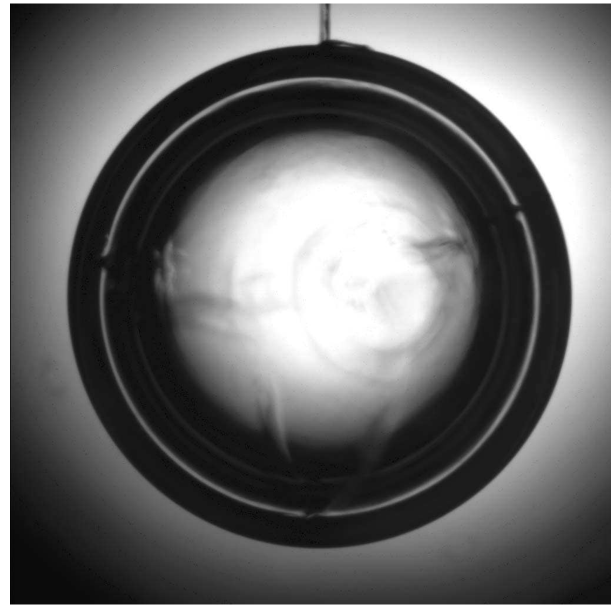


Temp =19.05K



Temp =18.63K

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

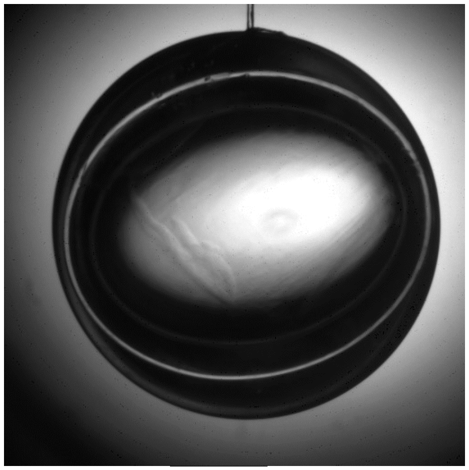
Layers degrade before reaching 19.1 K.

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.

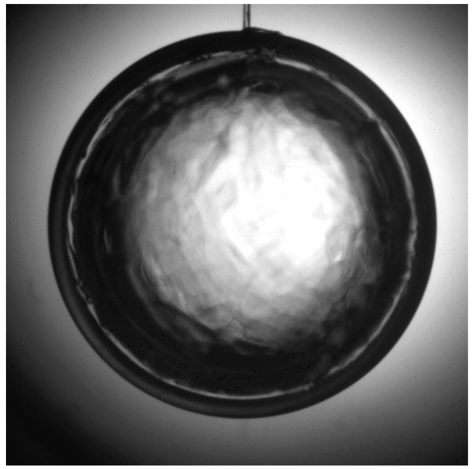
Microwave heating of a spherical capsule

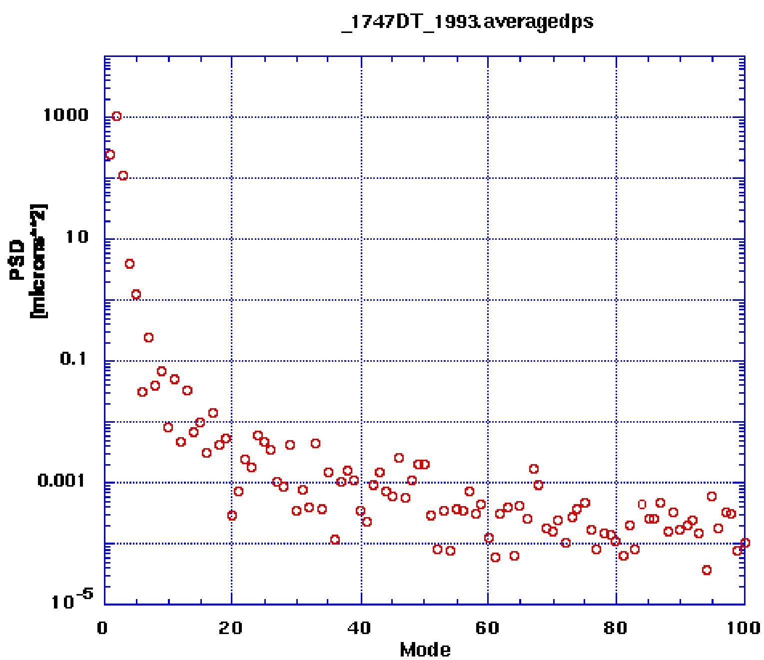
Temp. = 18.2 K Cooling @ 2mK/min

with joule heating

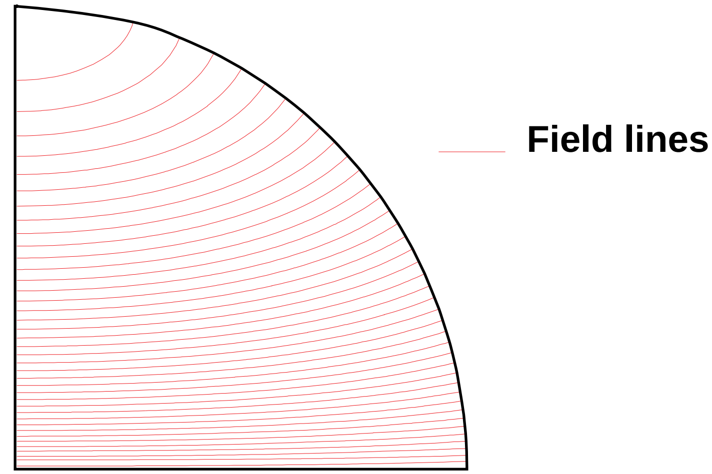


just slow cooling





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



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

Layering rates 6 x native ß layering rates have been observed in a cylindrical geometery.

The only limiting factor is the amount of dissipated heat that can be tolerated in capsule.

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Cryogenic fuel layers can be enhanced or formed by absorption of infra-red radiation.

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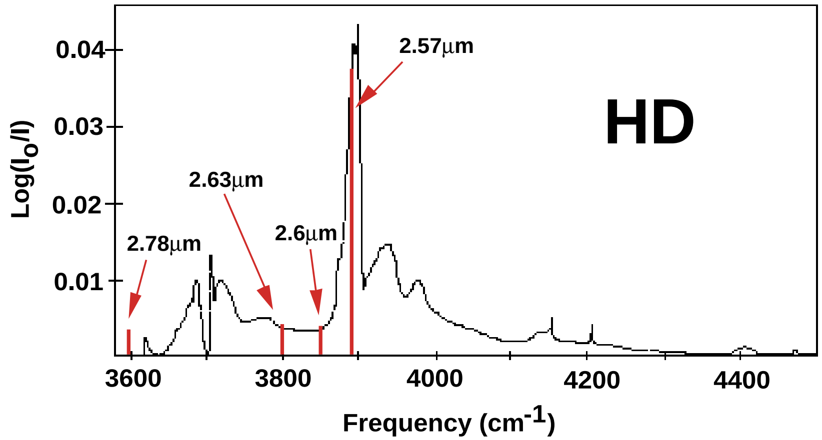
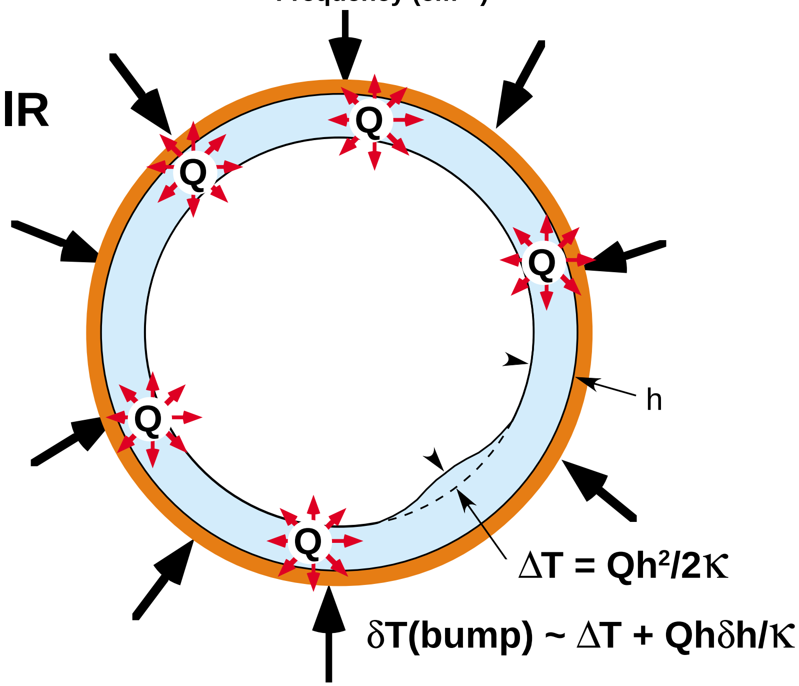
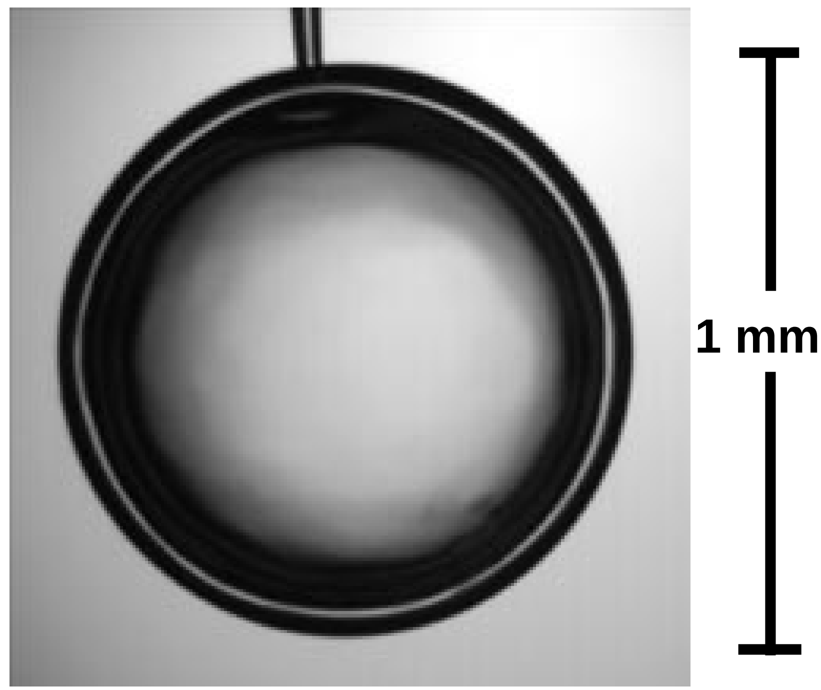


Absorption of IR light generates volumetric heating, Q_{IR} , which adds to or replaces heating from beta layering





90μm 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.

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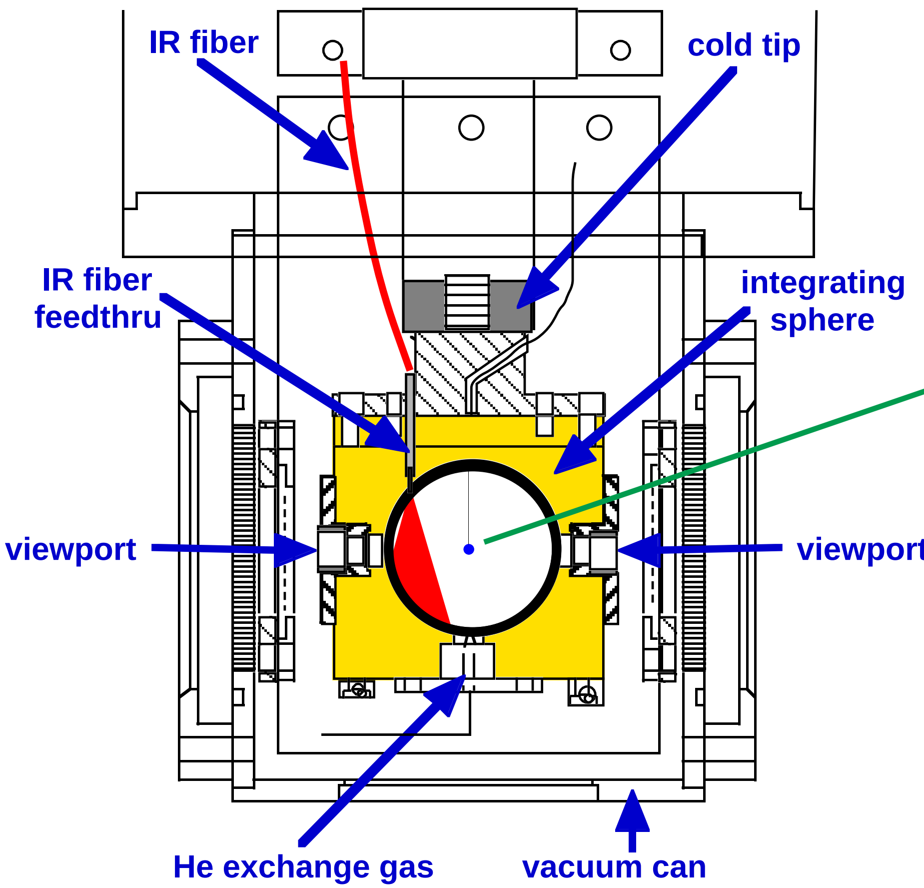
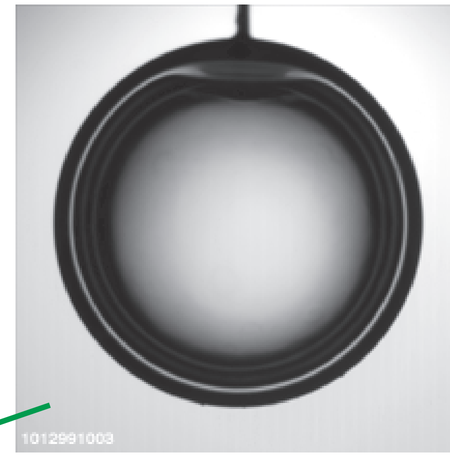
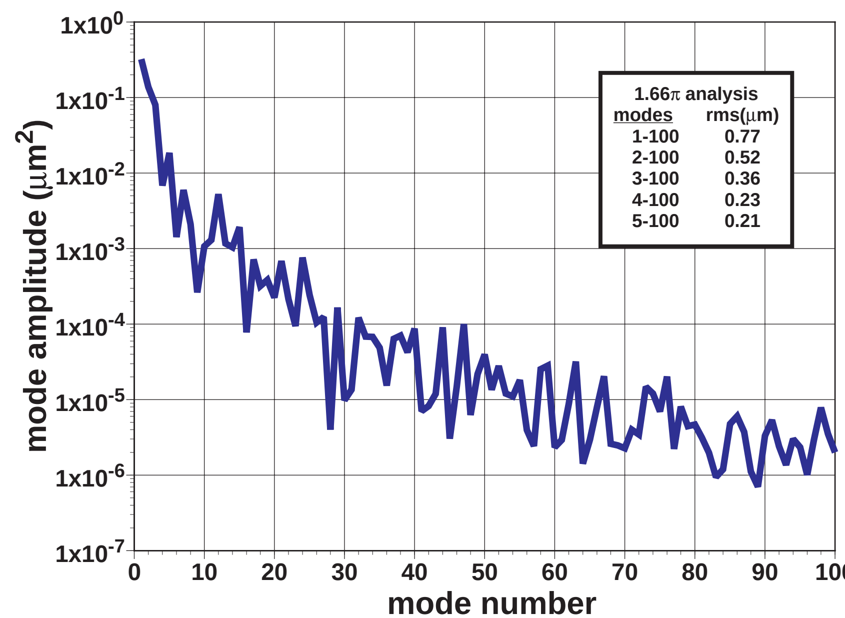




CD capsule:
965 μm OD
37 μm wall
100 μm HD layer



We have succeeded in producing smooth layers 1.5 K below the triple point.

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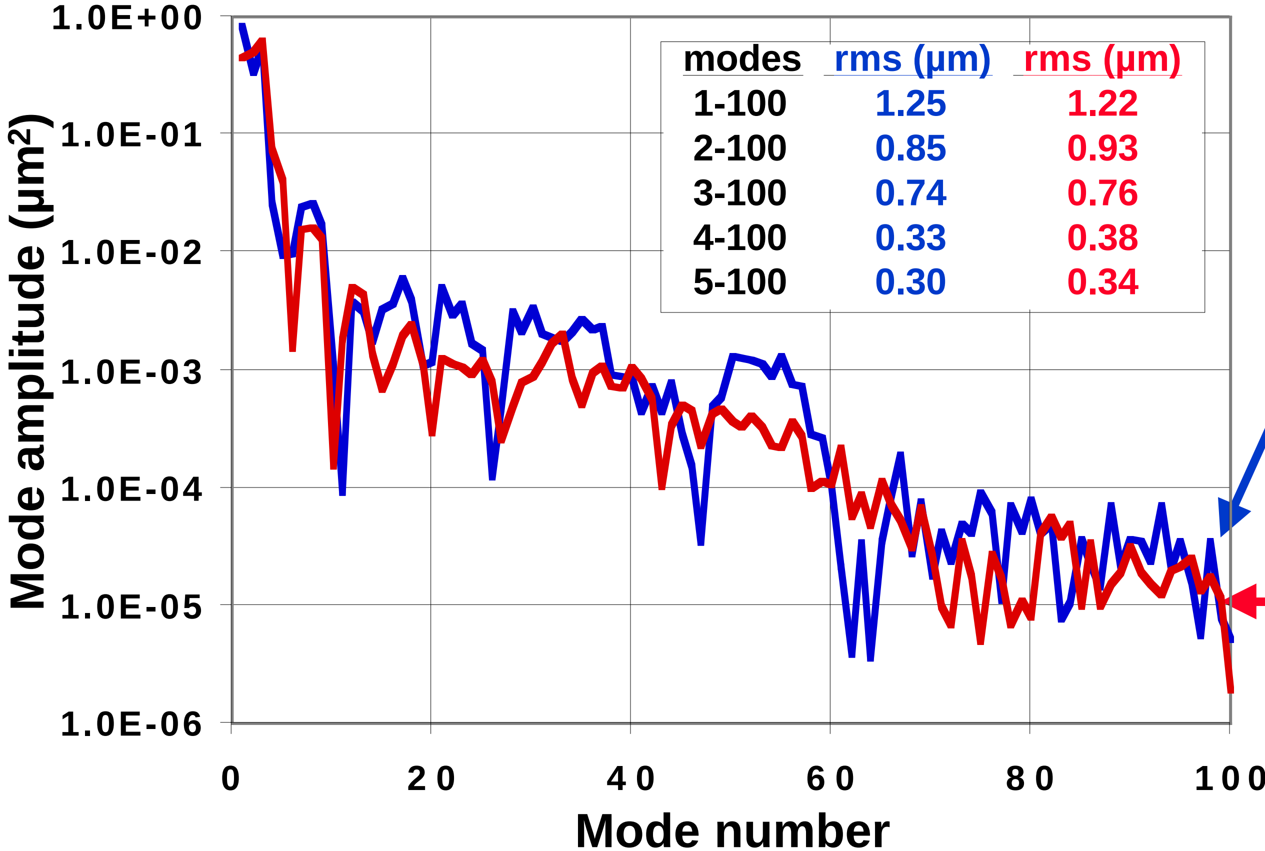
IR power absorbed ~ 30 Q_{DT}

$\Delta T/\Delta t$ = 10mK/3min

Layer thickness ~ 80µm



modes	rms (µm)	rms (µm)
1-100	1.25	1.22
2-100	0.85	0.93
3-100	0.74	0.76
4-100	0.33	0.38
5-100	0.30	0.34

T_{melt} - 0.13K

T_{melt} - 1.66 K

Enhanced layering techniques produce smoother layers but also put added constraints on the system.

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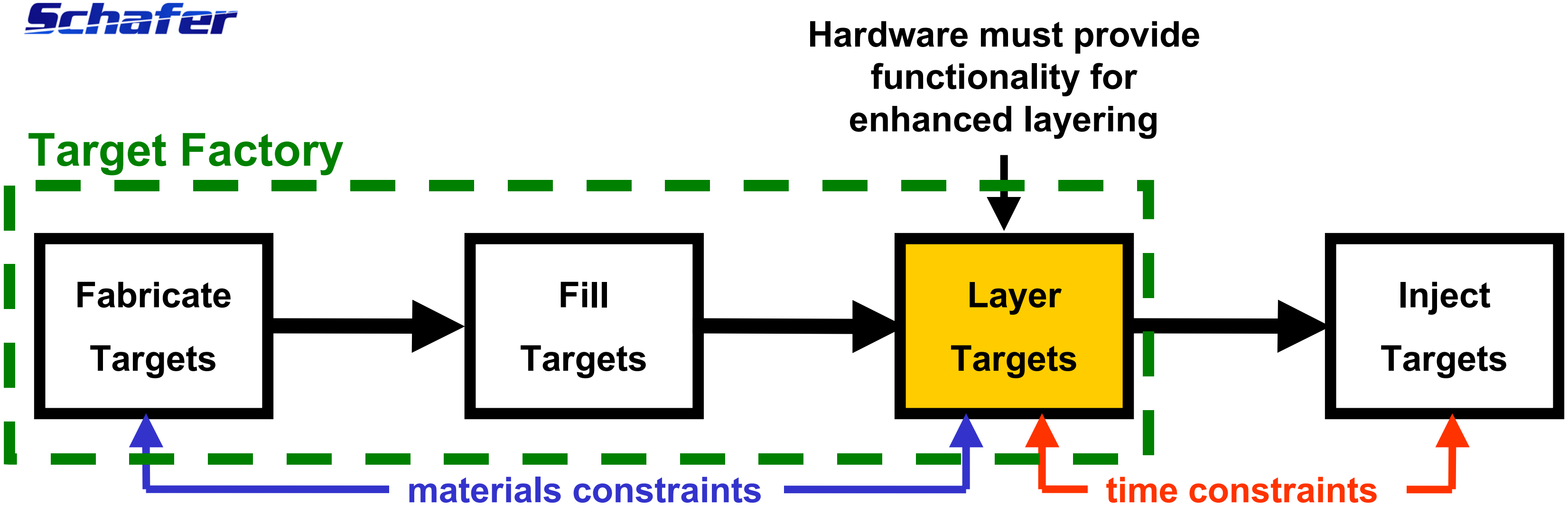

- materials constraints
  - capsule heating
    - nonuniform energy deposition from external source
  - capsule coatings
    - may inhibit enhancement technique

- time constraints
  - layer formation
    - possibly longer time needed for enhanced layering
  - layer degradation
    - eventually must turn off enhancement technique

The goal for FY01 is to determine which layering technologies are viable under IFE requirements.

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- **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?**