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High Throughput Cryogenic Layering for IFE

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High Throughput Cryogenic Layering Concept

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- IFE requires high throughput for all target production processes:
  - NIF: 3 targets per day
  - IFE: multiple targets per second
  - The IFE target processing rate is 5 orders of magnitude higher.
- An IFE specific layering approach is needed.
  - A method to rapidly layer each target is needed.
  - Current controlled layer growth methods are slow.
  - Parallel processing of many targets at once is essential.
    - Fluidized bed
    - In sabot layering
- Both approaches (rapid layering AND parallel processing) will be essential to meet the demanding IFE requirements.

Layering Processes for IFE

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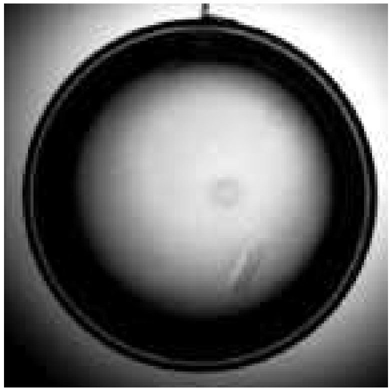
- **Controlled nucleation with <u>slow</u> initial layer growth is the more mature layering technology.**
  - **Requires temperature gradient across the shell. The cold spot is the nucleation point.**
  - **Demonstrated in NIF research. Layers have been made with sub-micron smoothness.**
  - **Current layering procedures would be difficult to scale to IFE requirements.**



Layering Processes for IFE

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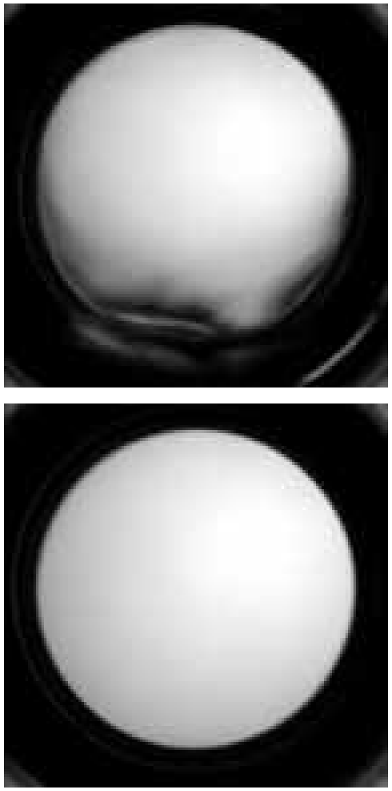
- **Uncontrolled nucleation and subsequent highly enhanced layering would be ideal. Experiments on cylinders have been promising.**
  - **Requires uniform thermal environment around the shells.**
  - **Compatible with fluidized bed layering technique.**
  - **Much faster than the controlled nucleation method.**
  - **Only demonstrated in cylinders at present.**



Layering has been carried out at 5x the native beta layering rate with joule heating

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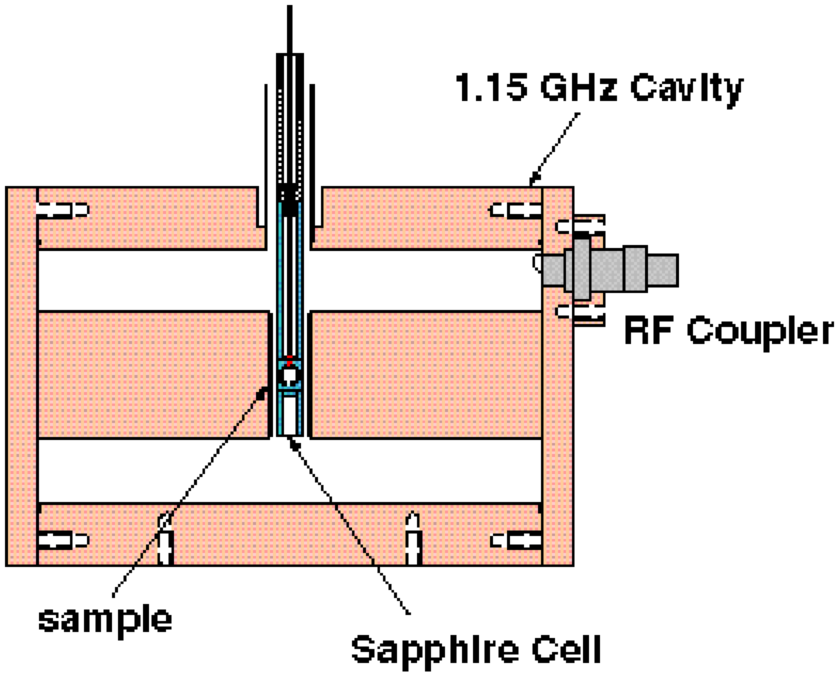
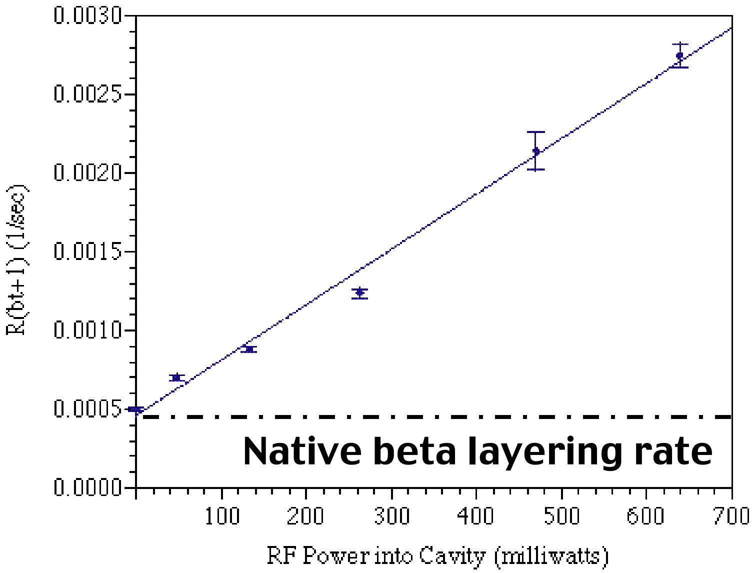
Cylindrical samples are placed at the center of a 1GHz resonant cavity.





The layering rate was measured for samples in an E field ranging from 0 to 800 V/cm.

Joule heating is a likely candidate to perform quick layering on IFE capsules

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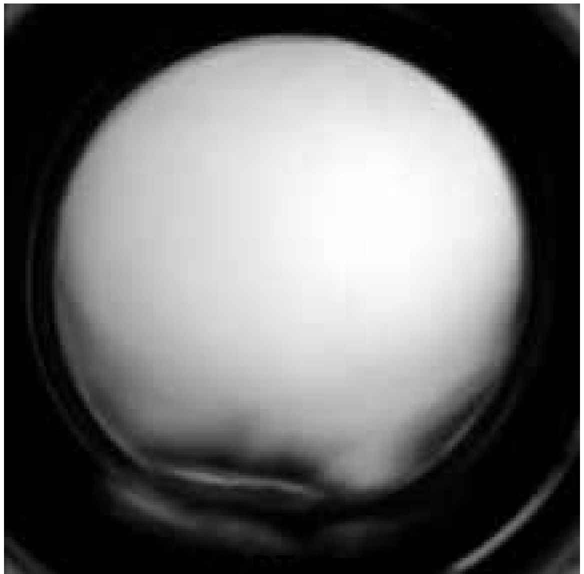
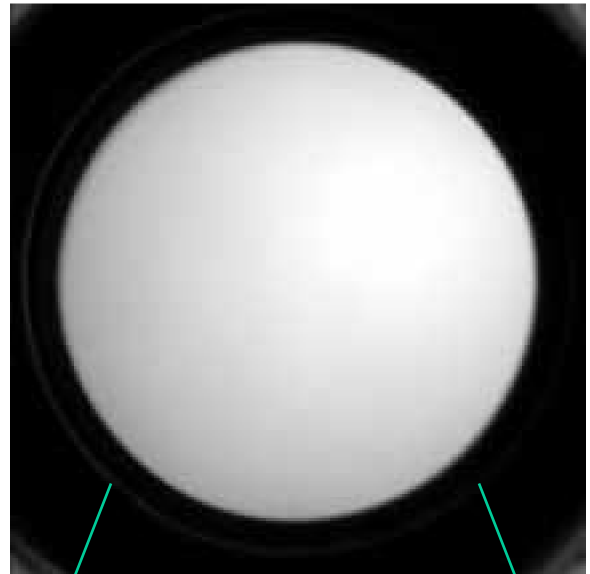
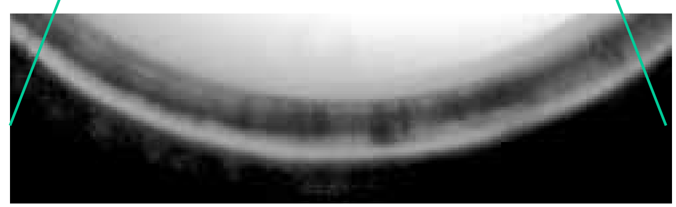


Initial DT layer



Final layer 40 minutes later



What is this structure in the layer?

These layers were generated at 19.4 K with an applied E field of ~ 800 V/cm.

Excellent results in cylinders don't necessarily mean joule heating can rapidly produce excellent spherical layers.

This experiment must be repeated in a spherical capsule to determine whether this technique is acceptable for rapid layering.

Joule heating can smooth large defects in the layer.

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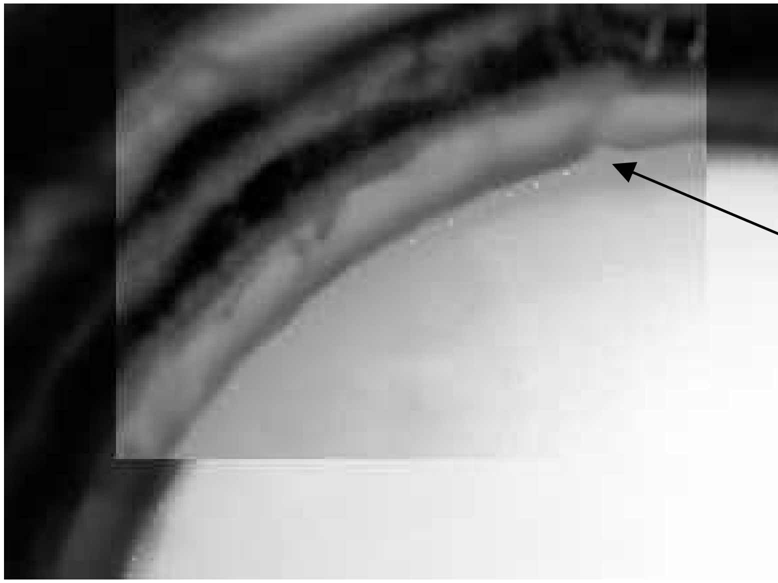
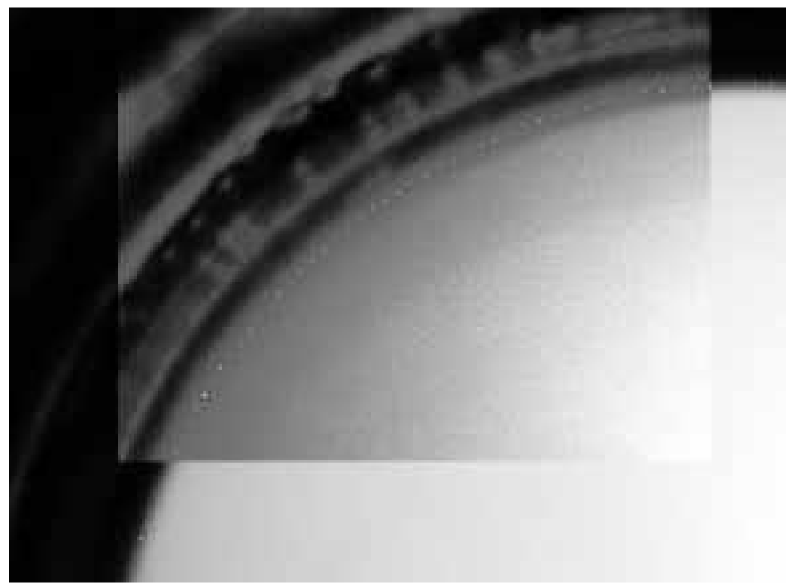


ß smoothed layer
Initial RMS is 2.9 µm at 19.4K

Large crack in DT layer



After joule heating with 560 V/cm for 280sec RMS is 0.8 µm. The crack is gone. Other structure in the ice layer is more regular.

Rapid layering basic proof of concept experiments need to be done on spherical capsules.

- **Apparatus:**
  - Requires DT.
    - RF needs a slightly ionized gas.
  - Spherical shell with fill tube.
    - Cylindrical and planar geometry studies are non-optimal.
    - Fill tube avoids the expense and complexity of permeation fills.
  - RF excitation (joule heating).
    - Low cost and good scalability.
    - Frequencies < 1 GHz may be preferable.
  - Metrology using shadowgraphy.
- **Experimental goals:**
  - Determine if rapid layering really works?
  - Shorten layering times (10 minutes? 5 minutes?)
  - Find optimal RF field and temperature profile for rapid layering.

Joule heating conceptually fits in well with fluidized bed layering.

- **Fluidized bed advantages:**
  - Reduce joule heating requirements for uniform RF fields. Rapid and random target movements average inhomogeneities.
  - Suitable for large batches.
  - Very shallow bed concepts may be compatible with controlled layer growth methods.
- **Experimental data is needed to design the layering module for the Integrated Layering Experiment.**
  - What are the tolerances for temperature and RF field uniformity?
  - How is the RF intensity ramped as the targets leave the bed?

Successful layering require capsule materials properties to be known and controlled.

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What is the dielectric loss tangent for capsule wall materials?

The power loss in a dielectric is described by: $P = \frac{1}{2}\omega\varepsilon''\varepsilon_0 E^2$

Bulk polystyrene has a favorable loss tangent of tan δ = 0.0001 at 1 GHz.

A 650 V/cm field would give an additional heat load of 5 μW in a shell with a10 μm wall and 3 mm diameter.

This compares favorably with the 350 μW of power that would be deposited in the DT vapor.

Tan δ should be measured in real target materials to insure the heat load doesn't become unreasonable.

Tan δ deserves extra attention for the in-sabot layering method since the capsule may be surrounded by dielectric materials.

Metal coatings might have negative effects for joule heating .

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Gold coatings

Room temp σ=4.5 * 10^7 mho/mete

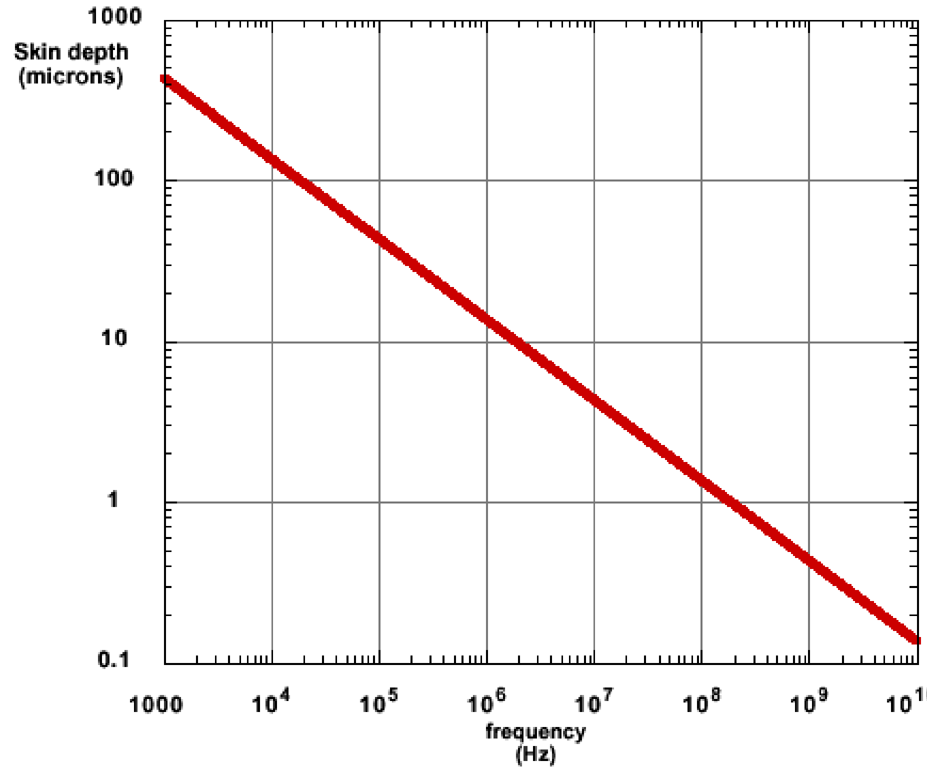
Assumed RRR of 30.

Skin depth is $\delta = (2/\omega\sigma\mu)^{0.5}$

(0.4 microns at 1 GHz)

Skin depth is not an issue for a 300 Å coating of reasonable conductivity.

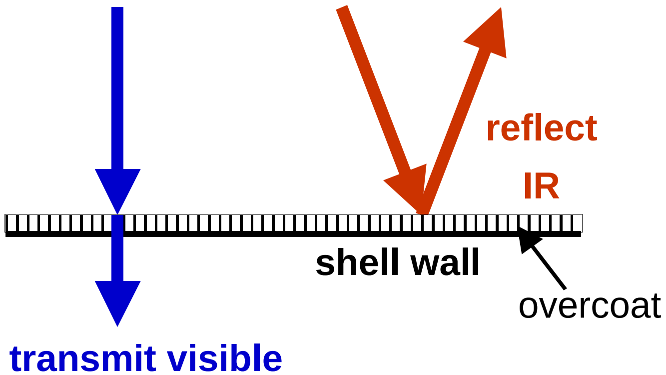
An estimate of eddy current heating indicates that power deposited in the capsule can be substantial.

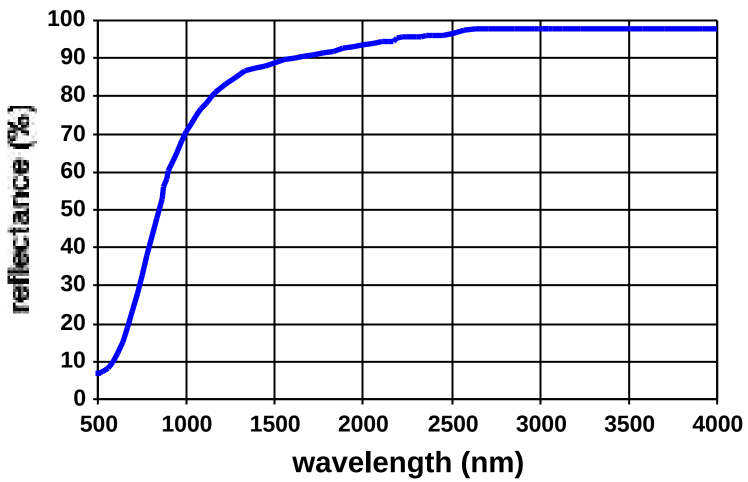


For a 3mm capsule in a typical field that a joule heated capsule Q is on the order of a watt at 1GHz.

Heating scales with the gold conductivity and with freq.^{2} so eddy current heating is manageable.

There may be alternatives to overcoating capsules with gold.





- **A metal coating on a capsule can be an impediment to our ability to implement Joule heating and to characterize layers.**
- **Multilayer dielectric coatings potentially provide several advantages for layering**
  - **reflect unwanted IR**
  - **transmit in visible to provide a window for characterization**
  - **better compatibility with Joule heating**
- **Currently investigating choices for coating material.**

Metrology for layering.

- **The advent of rapid digital cameras make the testing of every target feasible.**
  - 5 Hz camera speeds are well within the state of the art.
  - Limited metrology can allow defective targets to be removed from the reactor feed in real time.
  - Shadowgraphy data can be used to control the layering process in real time.
- **To adapt shadowgraphy to IFE, work would need to be done:**
  - to establish the ideal wavelength range for imaging the ice through the coating and encapsulated foam shell. (Far UV?)
  - to develop rapid analysis algorithms and hardware.
  - to develop control algorithms to use the resulting data for layering process control.

Conclusions

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- Joule heating shows promise.
- Need to determine soon if the rapid layering technique works in spheres.
- As materials are developed for capsule construction, key properties need to be measured.
- Limited real time analysis of each IFE capsule may be possible, even with metal coatings.