LLNL-CONF-424004

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

# Optimization of azimuthal uniformity of thermal conductance between Al TMP and Si cooling arms

S. D. Bhandarkar, E. A. Mapoles, J. J. Kroll, J. S. Taylor, B. Haid, J. D. Sater, J. Klingmann, C. Castro, A. Nikroo

February 18, 2010

19th Target Fabrication Meeting
Orlando, FL, United States
February 21, 2010 through February 26, 2010

# Optimization of azimuthal uniformity of thermal conductance between Al TMP and Si cooling arms

Presentation at the

19th Target Fabrication Meeting

Feb 23rd, 2010

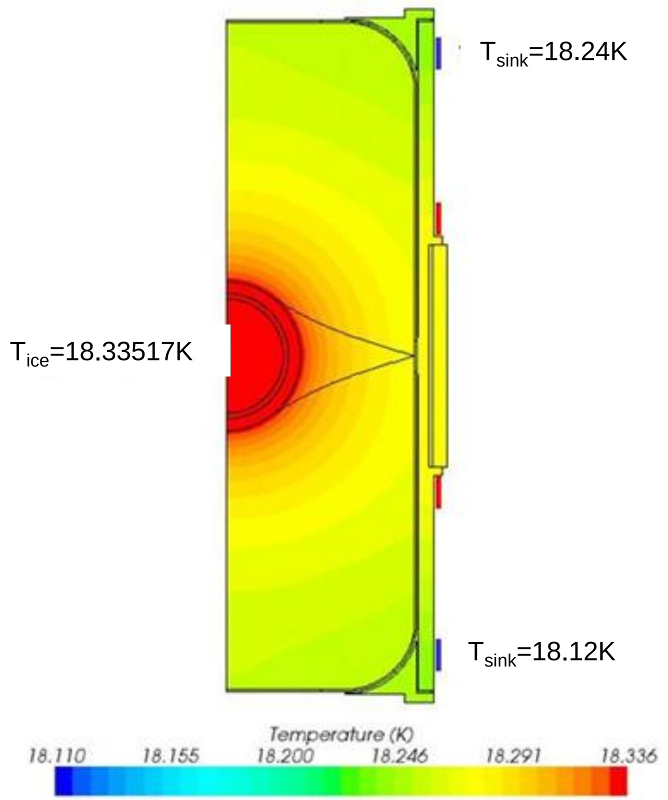
**Suhas Bhandarkar,**
**Evan Mapoles, Jeremy Kroll, John Taylor, Ben Haid, Jim Sater, Jeff Klingmann, Carlos Castro, LLNL**
**Abbas Nikroo, GA**



This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

# Cryogenic considerations dominate many aspects of the target design & materials

**Simulation of thermal symmetry required at 18K**




**Requirement for low mode roundness: ±0.5 mK**

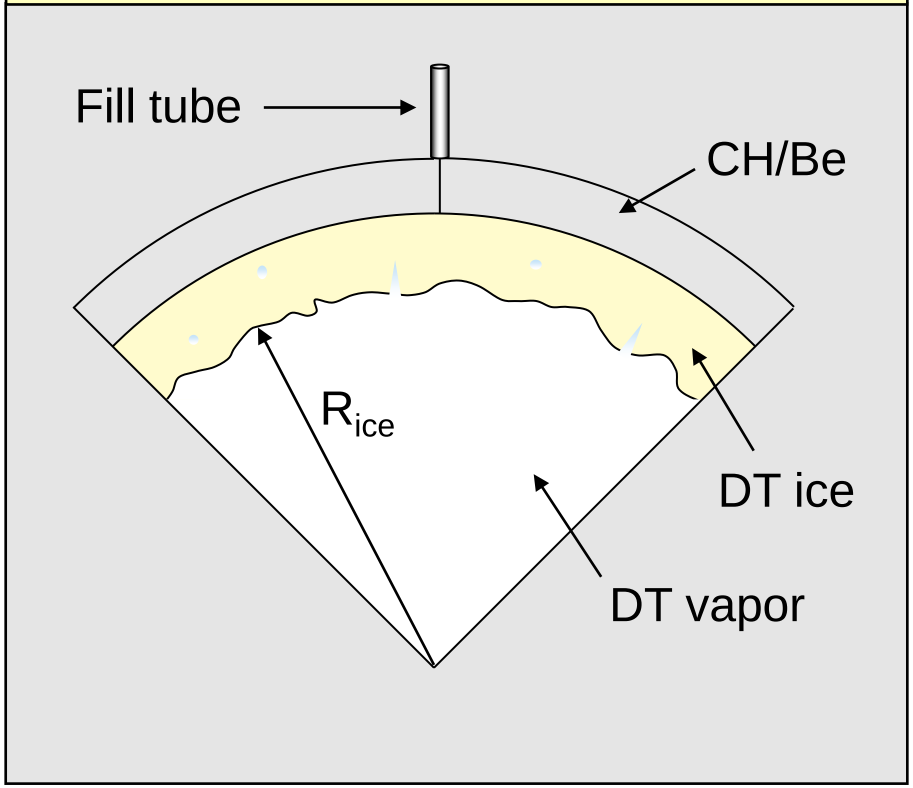
**Cryogenic issues at 18K**

- ***Thermal impedance between the hohlraum (TMP) and cooling arms***
- $He/H_2$ flow through capillary fill-tubes (Thurs AM)
- Visco-elastic thin films: windows and tents (Thurs and Fri AM)
- High degree of density control of tamping gas (He or $H_2$) in the TMP
  - Leak tight

**Hydrogen ice layers are critically dependent on cryogenic performance of the target**

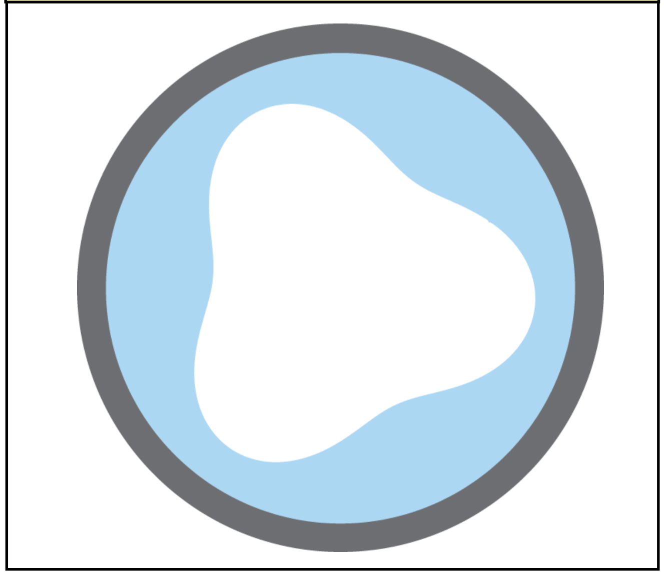
# Ice layer specs

**Cross-section of a NIF shell**

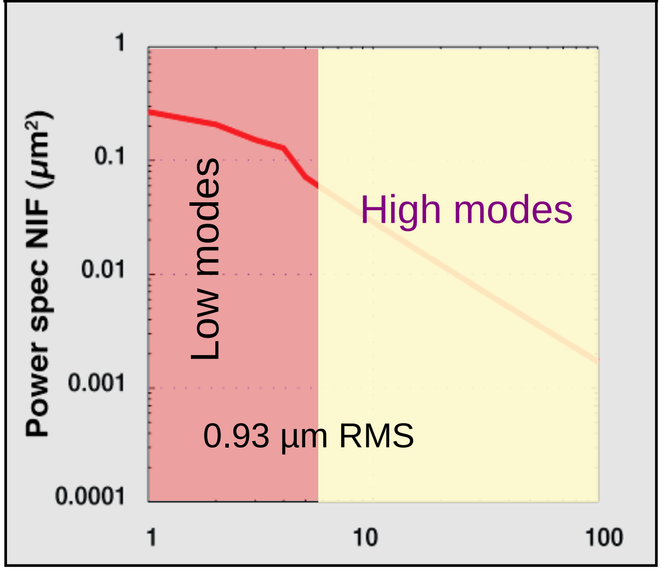



**Requirements and tolerances for the ice layer are specified as a power spectral density**

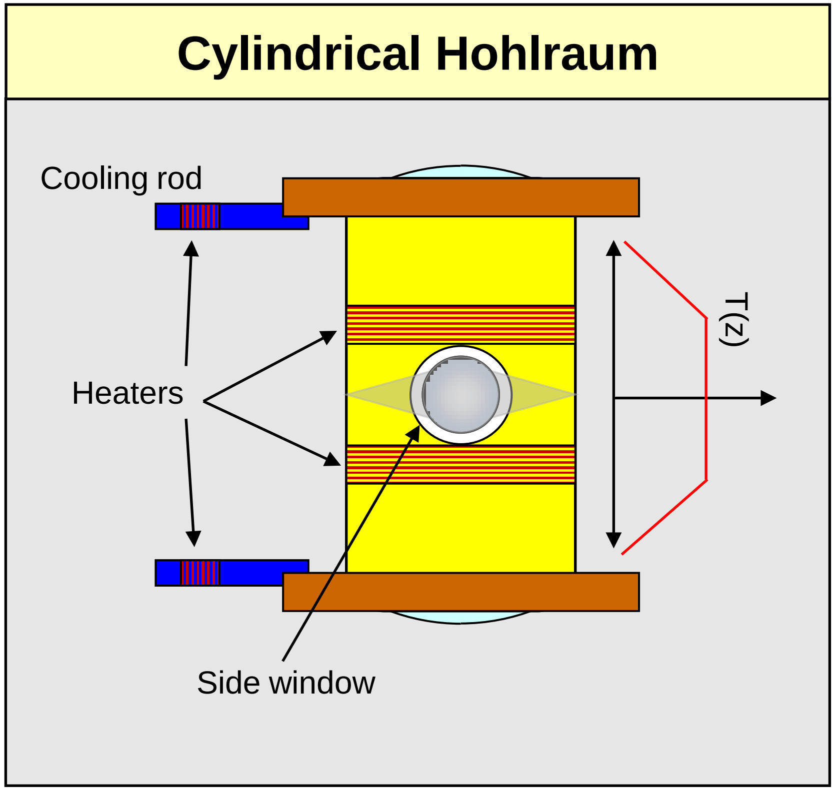
**Low Modes**



**NIF DT Power Reqmt (1D)**



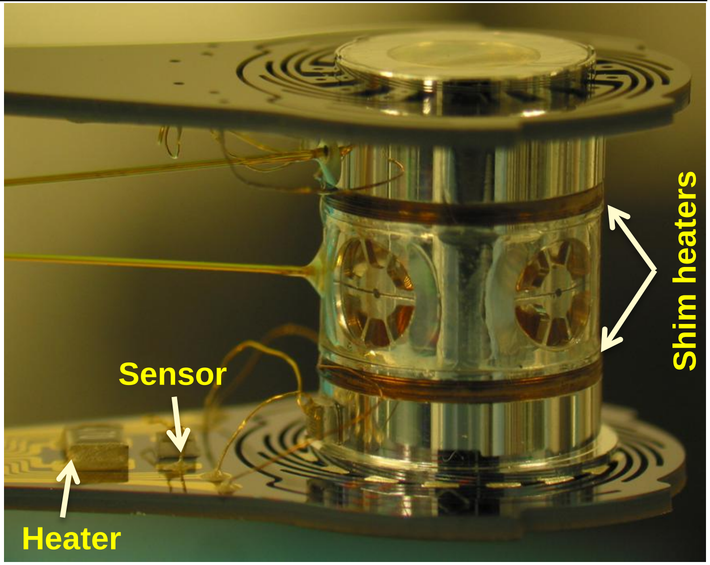
# 'Shimming' heaters are used to create a thermally spherical hohlraum




- **Cylindrical configuration leads to capsule being cooler in the mid-plane relative to the ends**
  - —This makes a layer that is thicker on the equator that the poles.
- **Heat the center using heaters: "shimming" to generate spherical thermal profile**
- **This depends**
  - — on conductivity of the adhesive
  - — on conductivity of the TMP
  - — conductivity of the bond between the Si cooling arm and the TMP

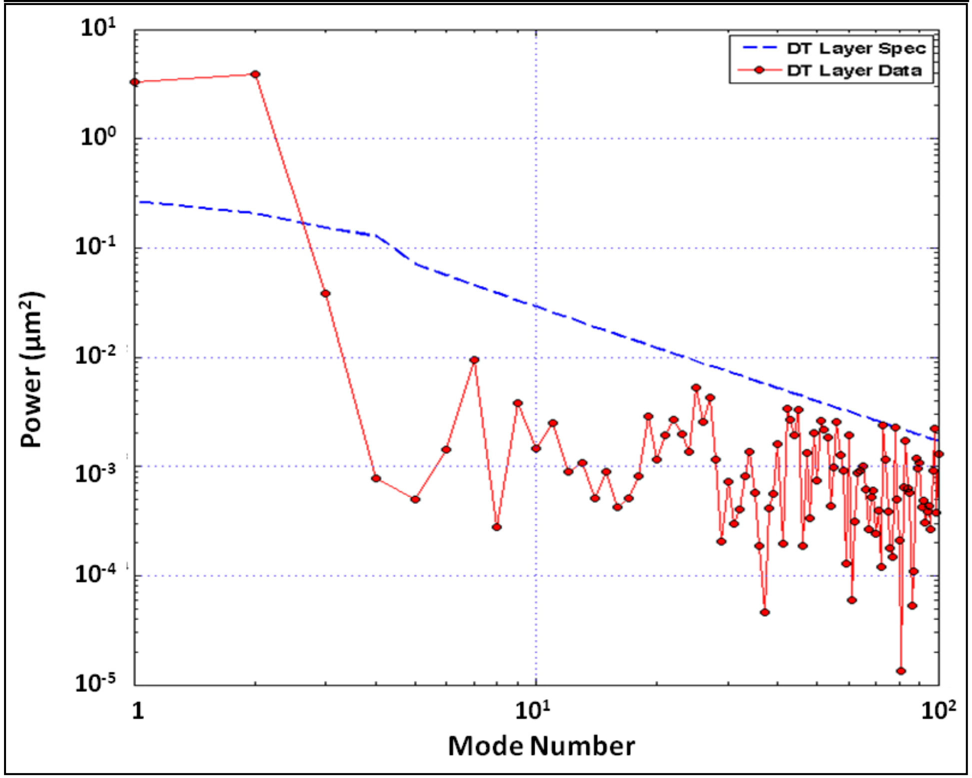
# Layers met the high mode spec in target R5

## NIF Cryogenic Target




- Si used for its high conductivity (4000 W/mK) and brittleness at shot time
  - Deep RIE fabrication
- Flexures accommodate difference in thermal contraction (0.4% vs 0.02%)

## Power Spectral Density plot

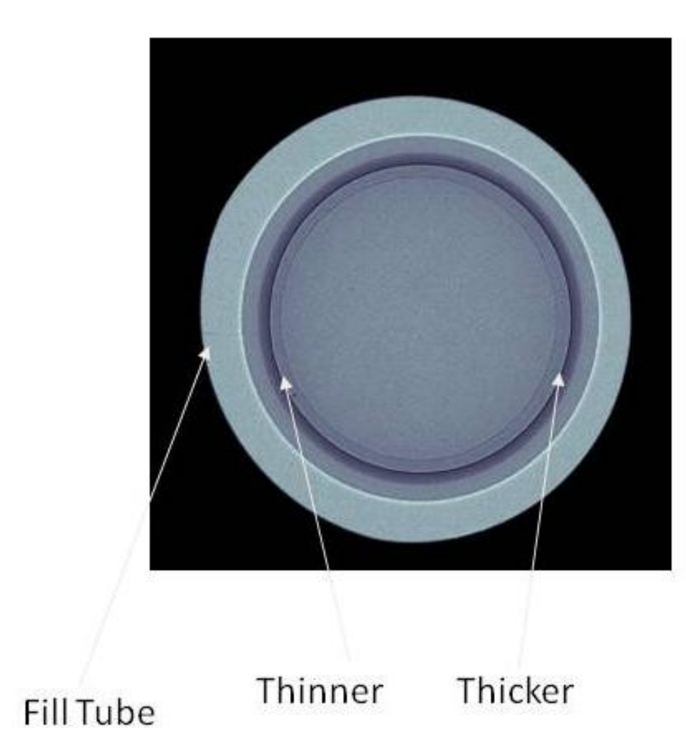



**Layers were smooth enough to meet the high mode spec**

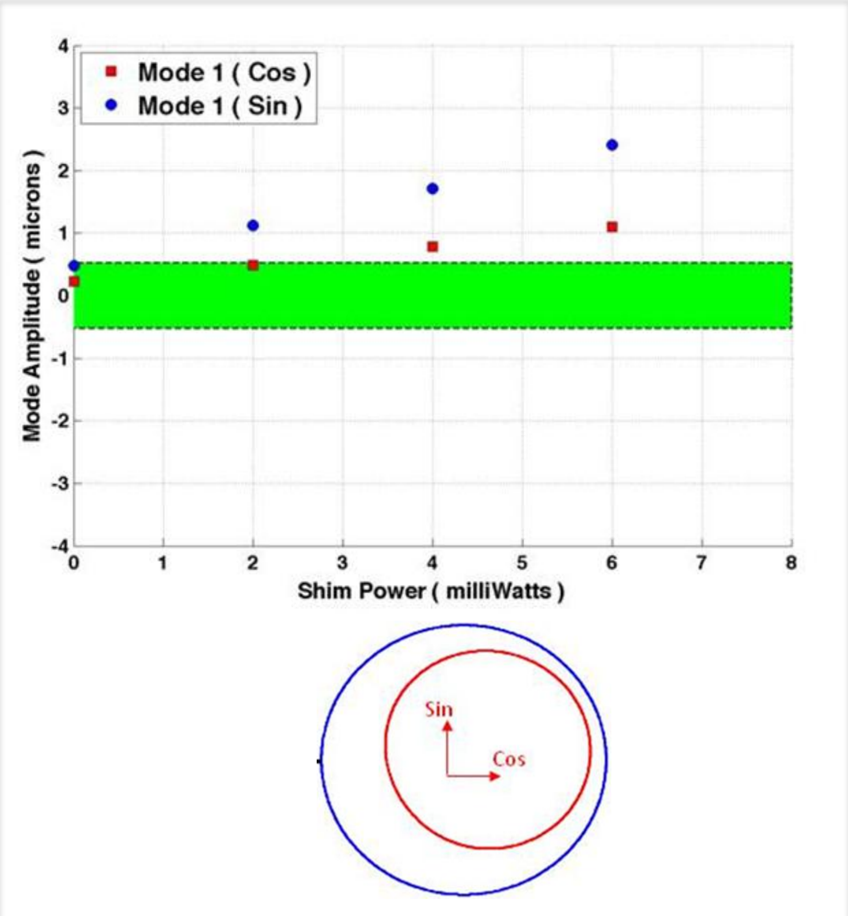
# Early prototype targets showed de-centering of the ice layer with shimming power

De-centering of the ice layer occurs as the power required to shim mode P2 is supplied to the shimming heaters

**LEH View**




**Mode Amplitude vs Shim Power**

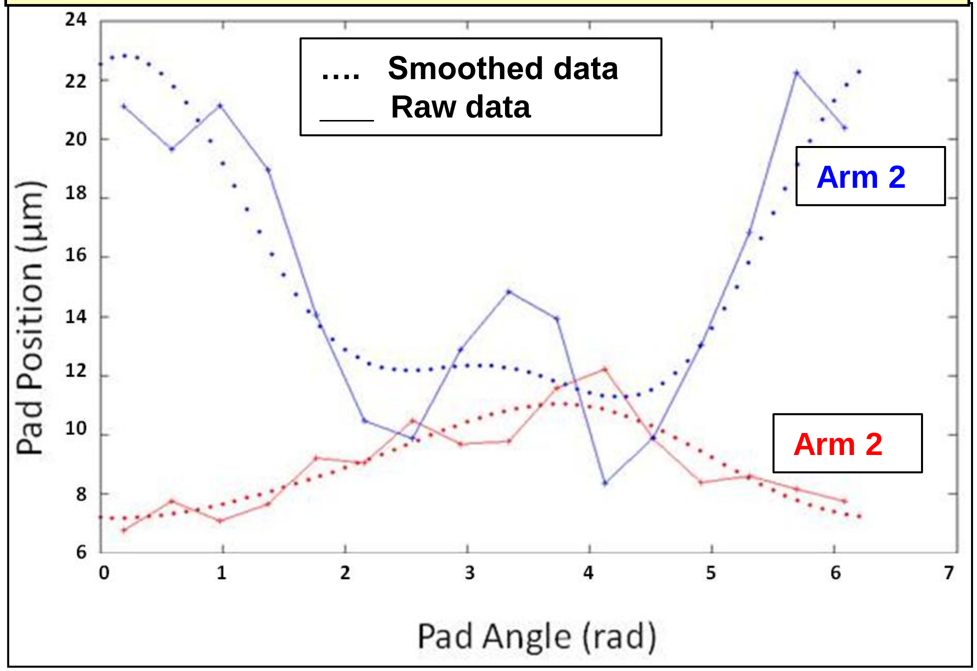



**De-centering is a result of azimuthal thermal *a*symmetry**

# Prototype layering target bond line thickness data

**Prototype layering target**

**Degree of azimuthal bond asymmetry**

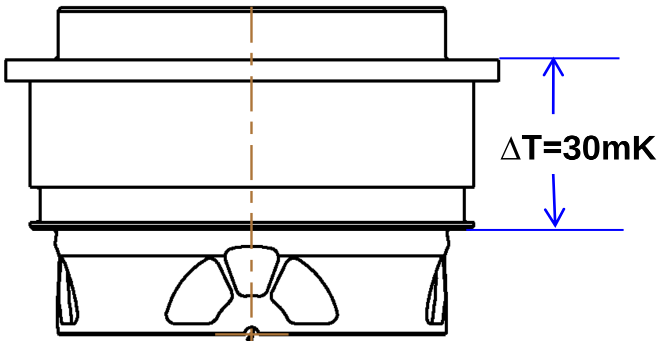



**Wedge analysis predicted a de-centering drift towards the fill tube with 34 degree off axis component**

**Actual drift was towards the fill tube with 16 degree off axis component**

# FEA thermal model of the TMP

• Requirement: 0.5 mK axisymmetry for low mode roundness

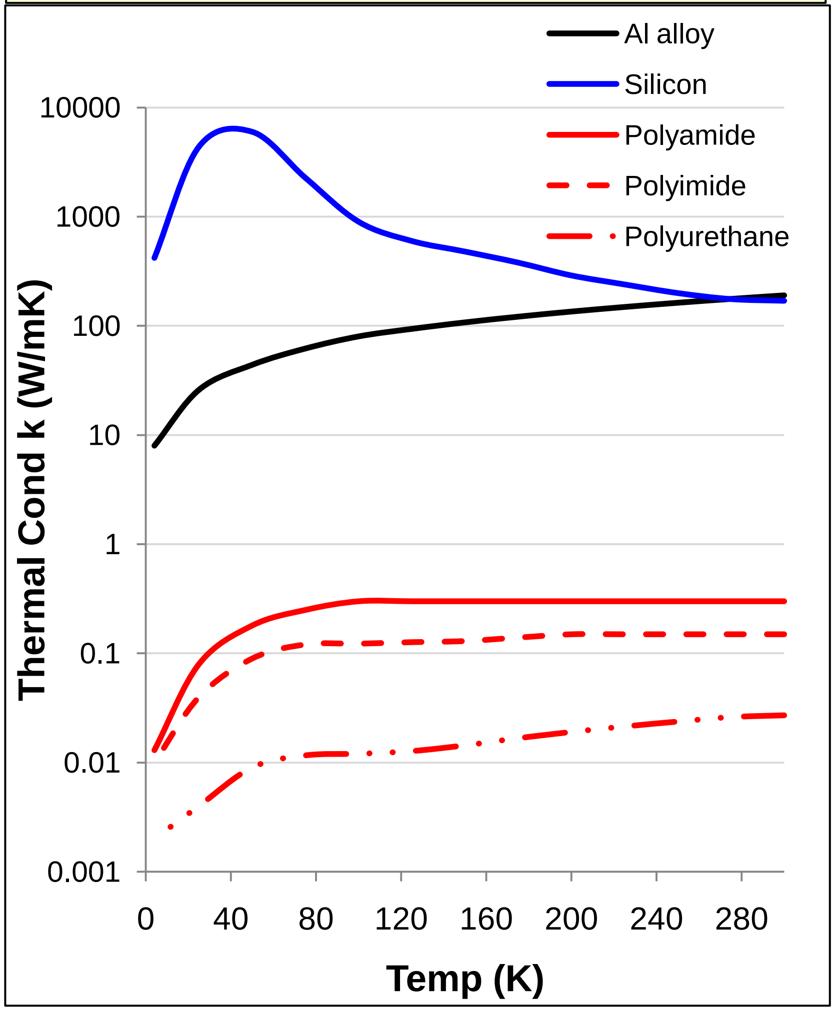



Using $k_{glue}$= 0.1 W/mK &

$k_{Al5052}$ = 20 W/mK

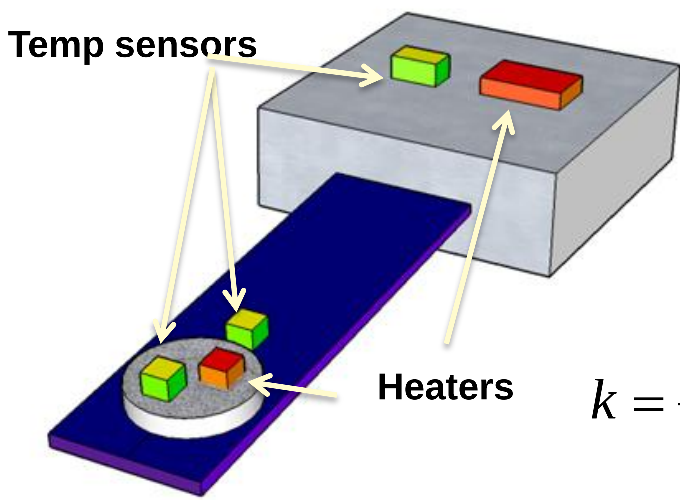
- ΔT=1.8 mK for PV Δt=0.2μm
- *ΔT=0.5 mK for PV Δt=0.1μm*
- ΔT=0.25mK for PV Δt=0μm
- Centering : ±5μm

**Thermal conductivity vs T**

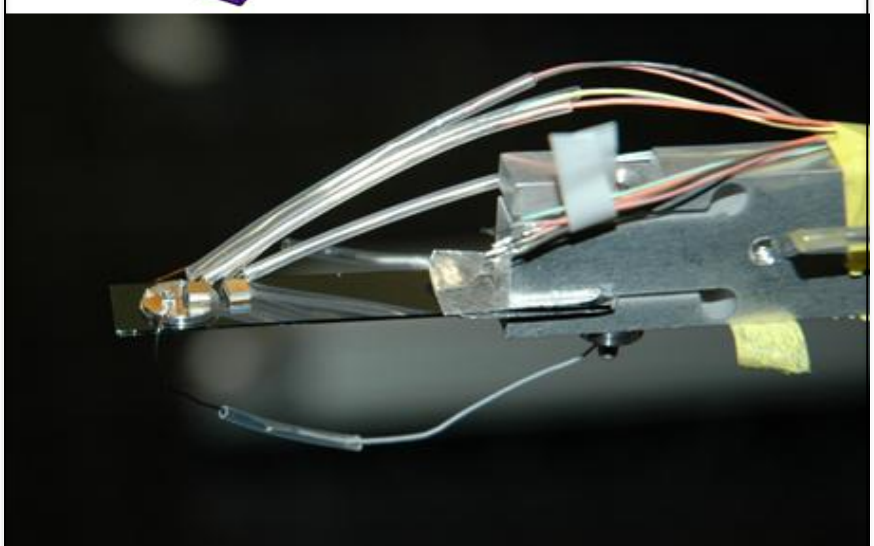


# Thermal conductivity measurements @18K

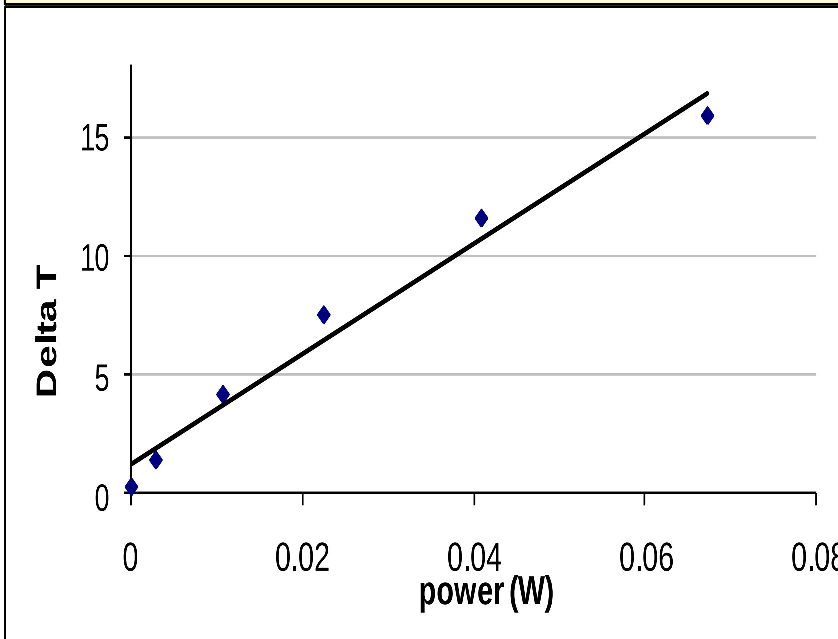
## Experimental set-up




$$k = \frac{Qt}{A\Delta T}$$



## Delta T vs Heater Power

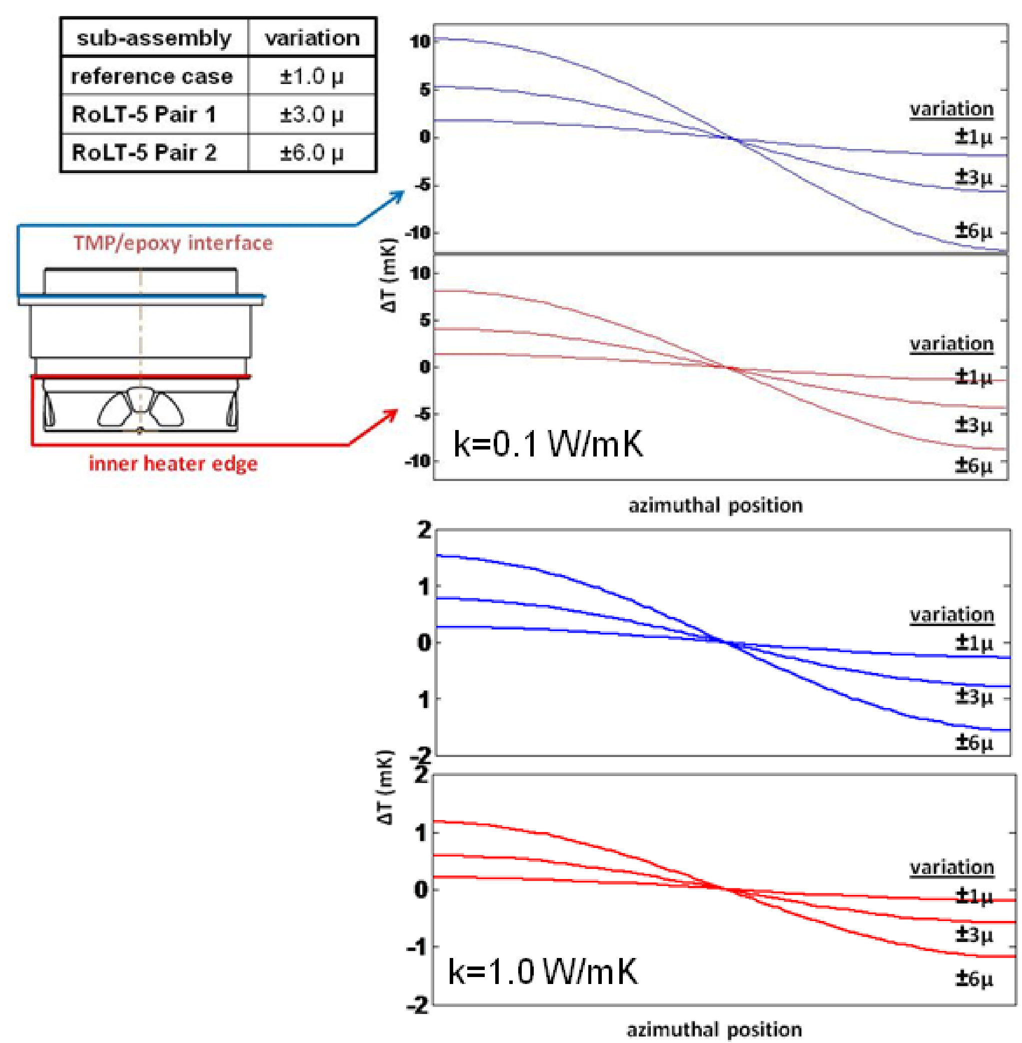



**$k_{18K}$=0.006 W/mK**

**k was an order of magnitude smaller than expected**

# Role of the thermal conductivity of the adhesive

## Simulation of TMP thermal asymmetry




| sub-assembly | variation |
|---|---|
| reference case | ±1.0 μ |
| RoLT-5 Pair 1 | ±3.0 μ |
| RoLT-5 Pair 2 | ±6.0 μ |

**Glue thermal conductivity, $k_{glue}$, needs to be increased → composite adhesive**

# Interplay between thermal conductivity and thickness requirements

Need to improve thickness control and conductivity

### Single phase adhesive

- k~0.006 W/mK
- Thickness control has to be submicron

### Composite adhesive

- Expect higher k
- Expect higher viscosity
- Particle size - submicron

### Squeeze flow

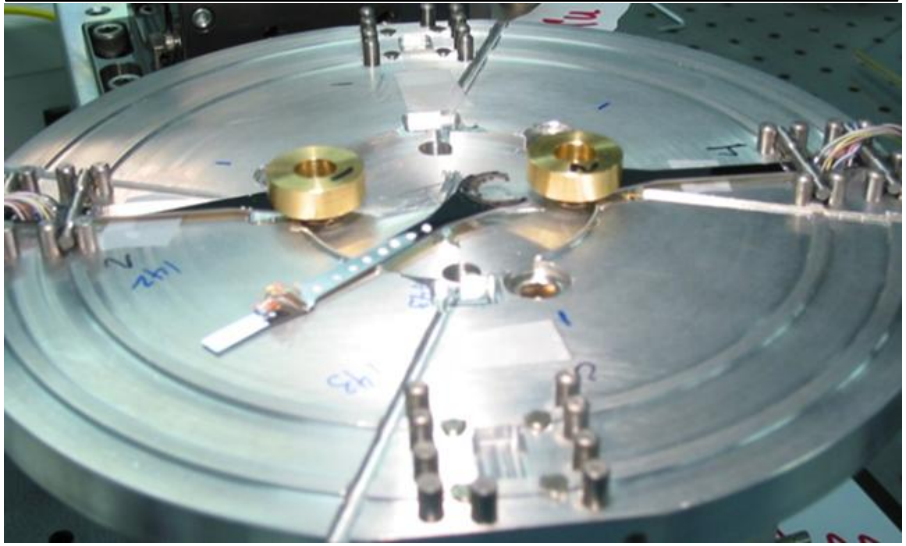
- Could be used with a higher viscosity adhesive
- Depends on surface tension and to some extent on viscosity

### Uniformity by fixing the gap

- Machined bump on the TMP flange
- Allow the adhesive to wick in after dry alignment

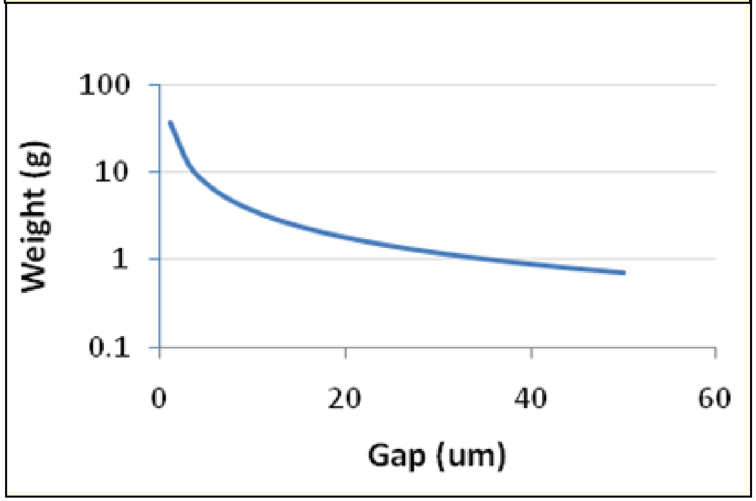
# Thickness control using squeezing flow

**Force applied is limited by silicon arm toughness**

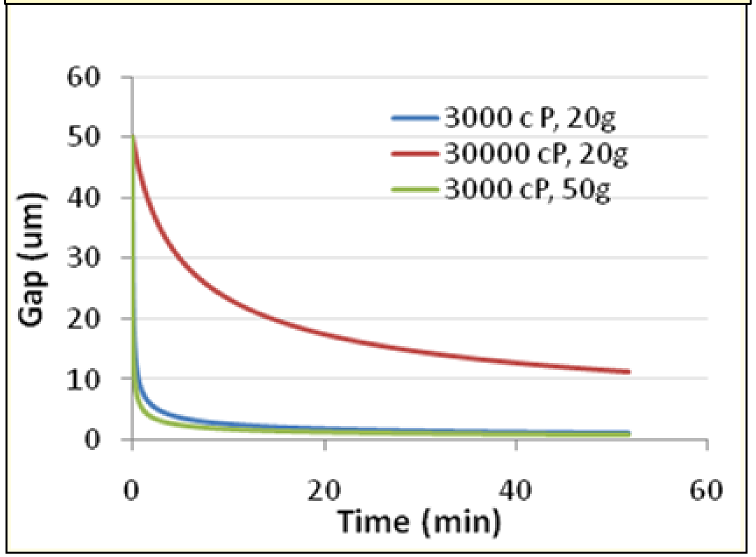


**Viscosity should be <10,000 cP**

**Gap due glue vs force (model)**

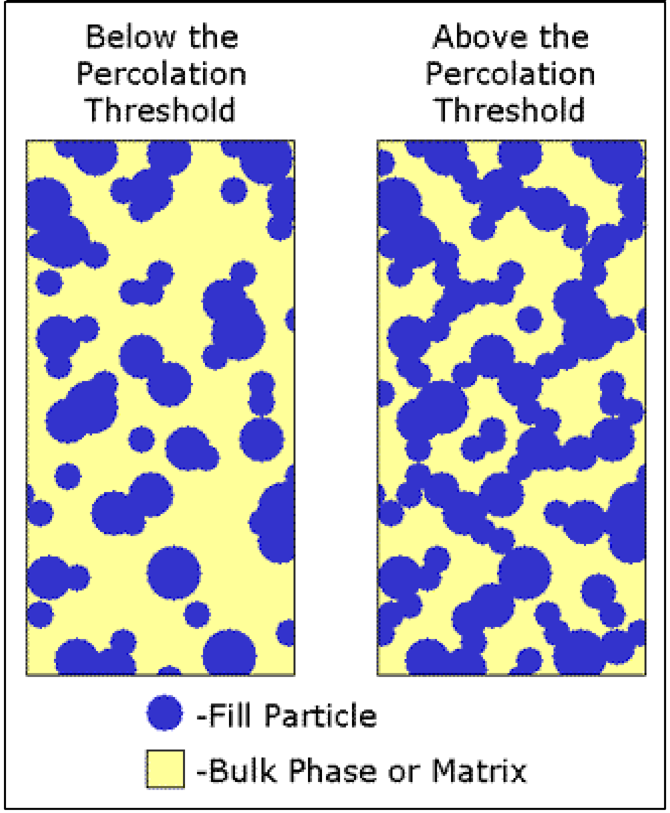



**Kinetics of flow (model)**

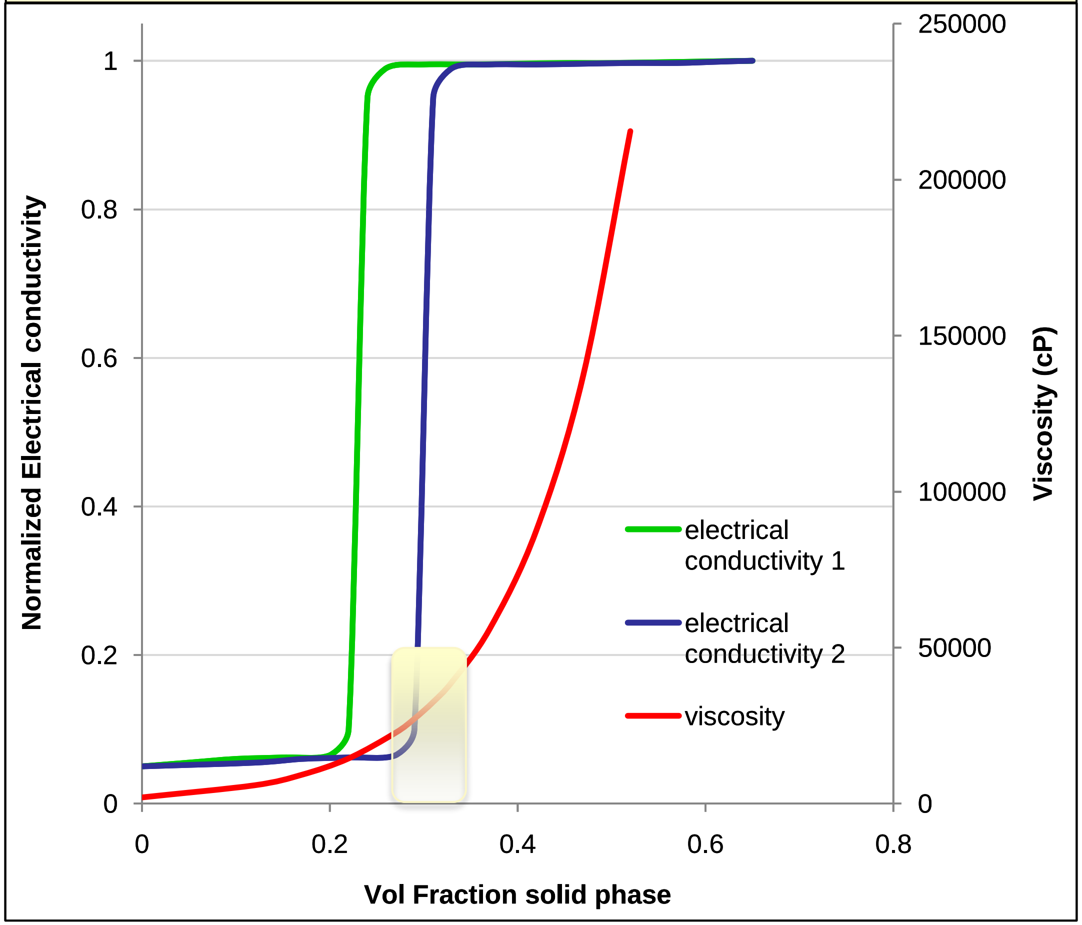


# Composite adhesive- percolation

**Percolation threshold is critical in filled systems**



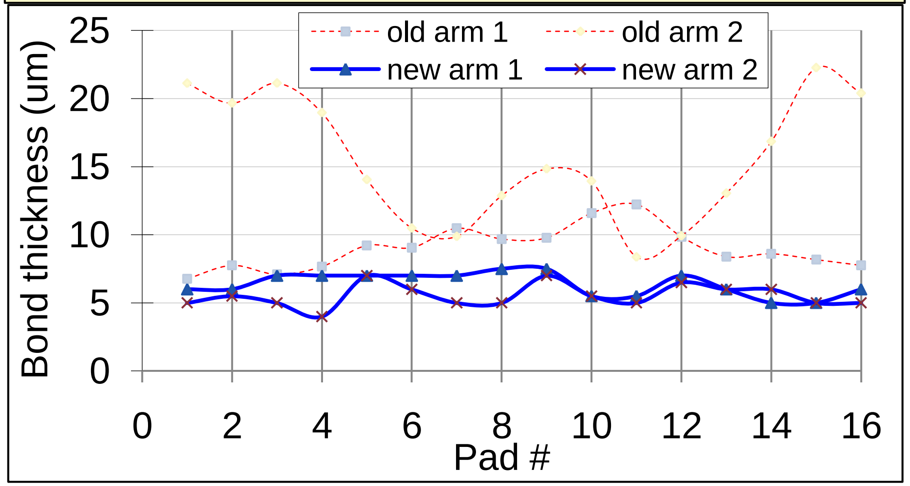

**Typical behavior of percolated systems**



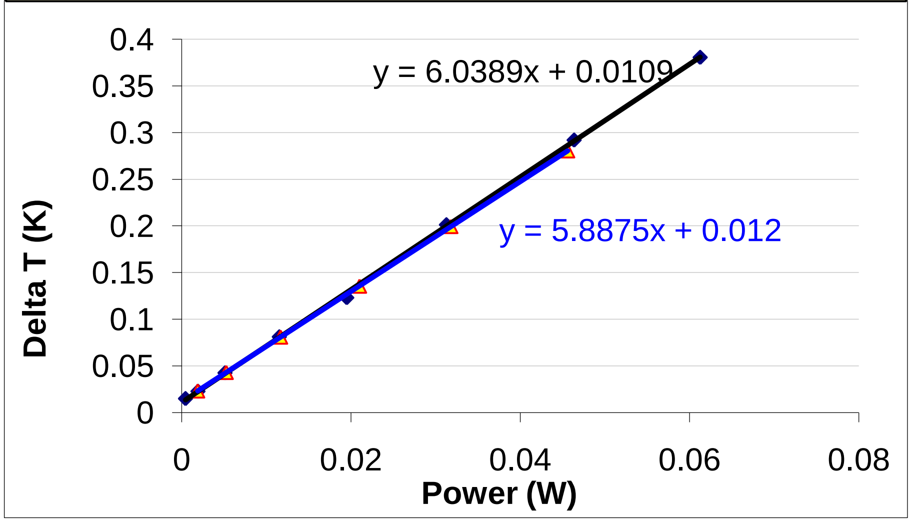
# Thermal impedance of a TMP sub-assembly

- We used a silver filled adhesive that met these requirements:
  - √ Volume fraction - 35% (82wt%)
  - √ viscosity 3200 cP
  - √ particle size sub-micron
- Both critical parameters were optimized
  - – Cryogenic thermal impedance of the filled adhesive
  - – Bond thickness uniformity

**Uniformity with improved fixturing**



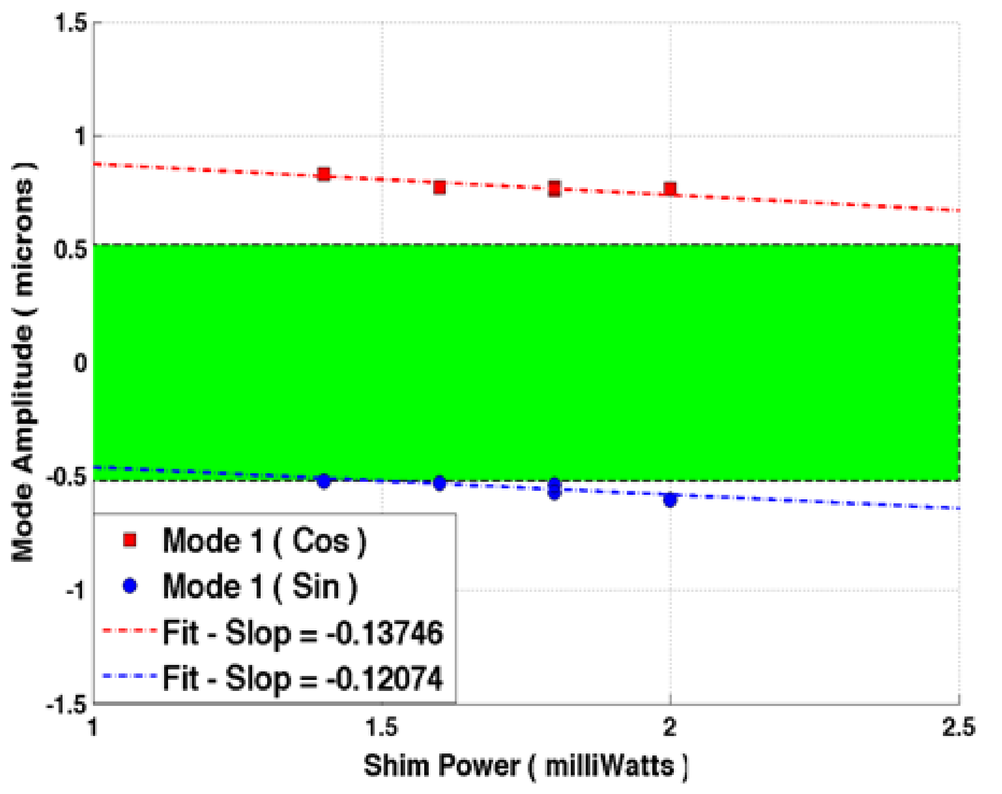

**Impedance of arm-can bond: Ag glue**



# Ice layer center has been sufficiently stable while shimming for all low mode specs

One more improvement was required- heat leak from leads to shim heaters

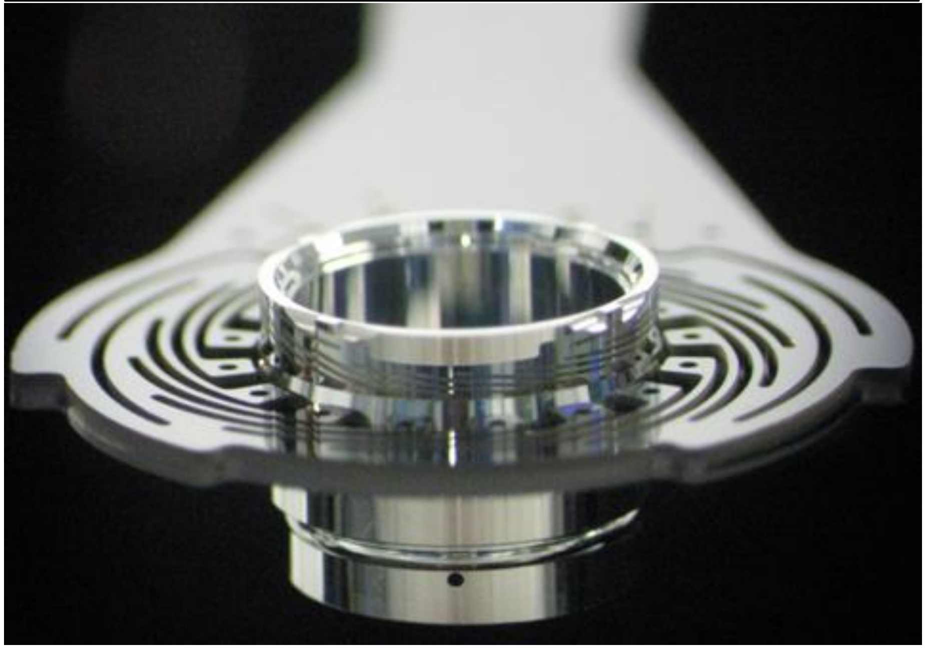
**Ice location vs. shim power**



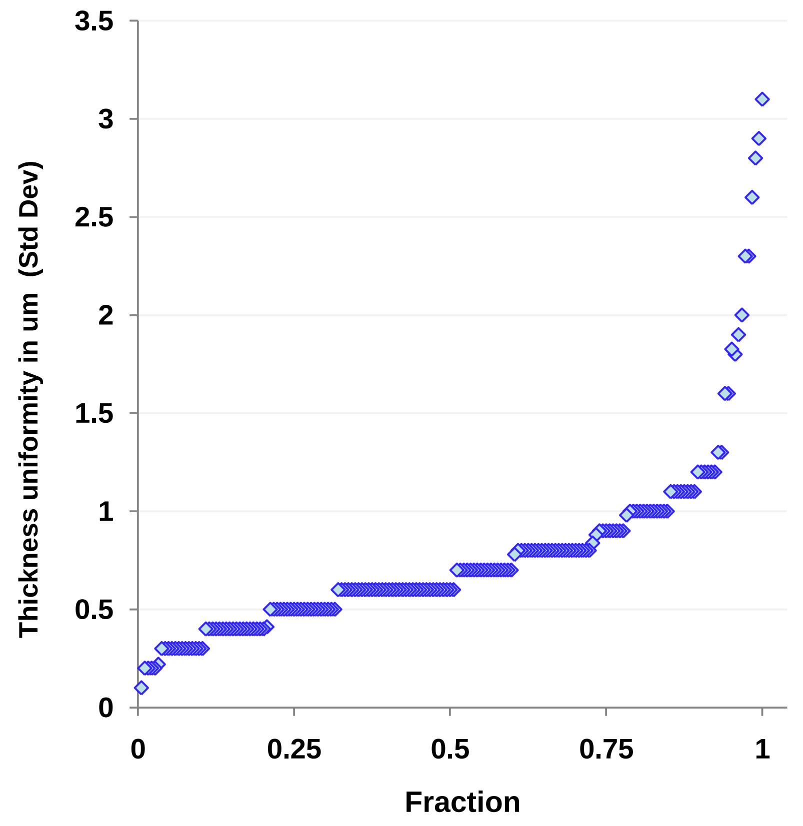

**The remaining ~1 micron of ice position error due to capsule position. It can be adjusted with trim heaters if necessary**

# This approach was used in production of NIF targets

Can-Arm sub-assembly



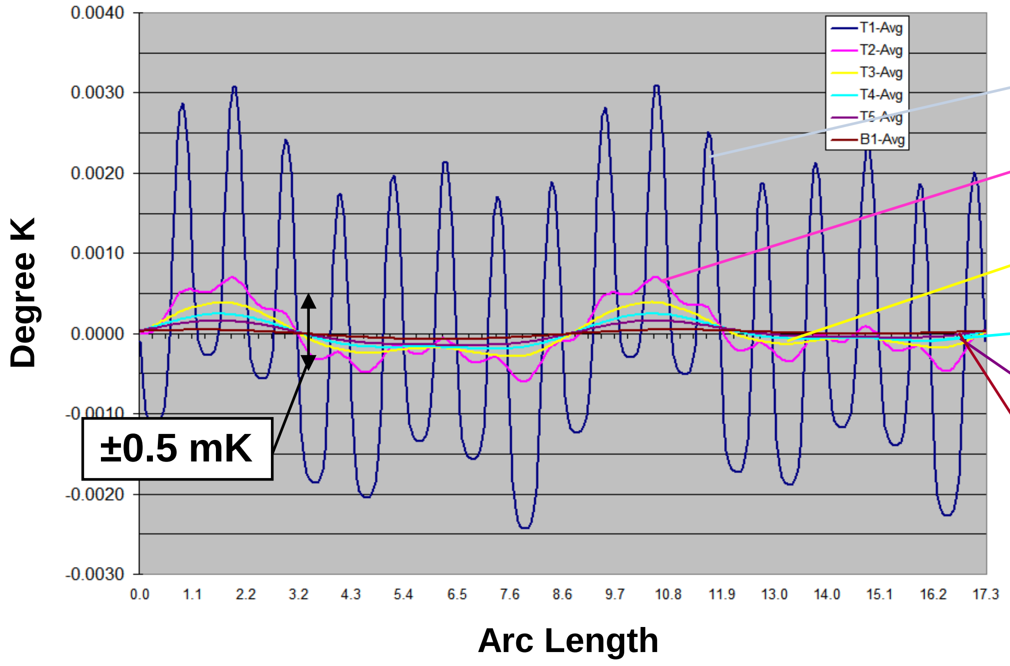
Over 300 sub-assemblies

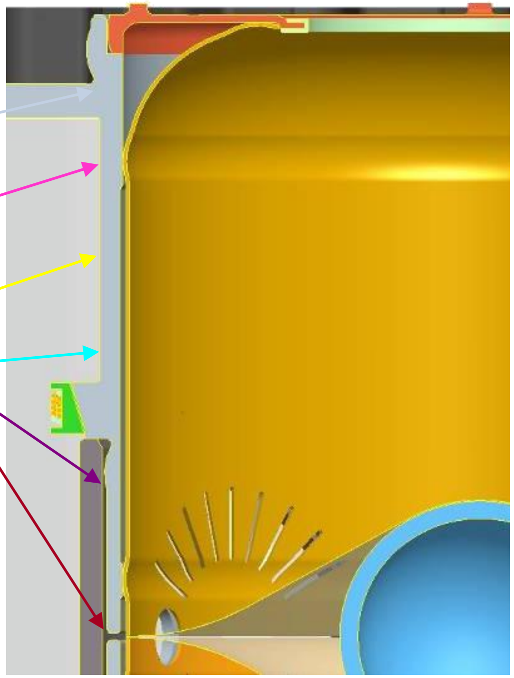



**Statistics for controlling arm to can bond thickness have been excellent**


NIC

# Thermal axisymmetry is critical



**Signature of flexure (16x) attenuates in TMP**