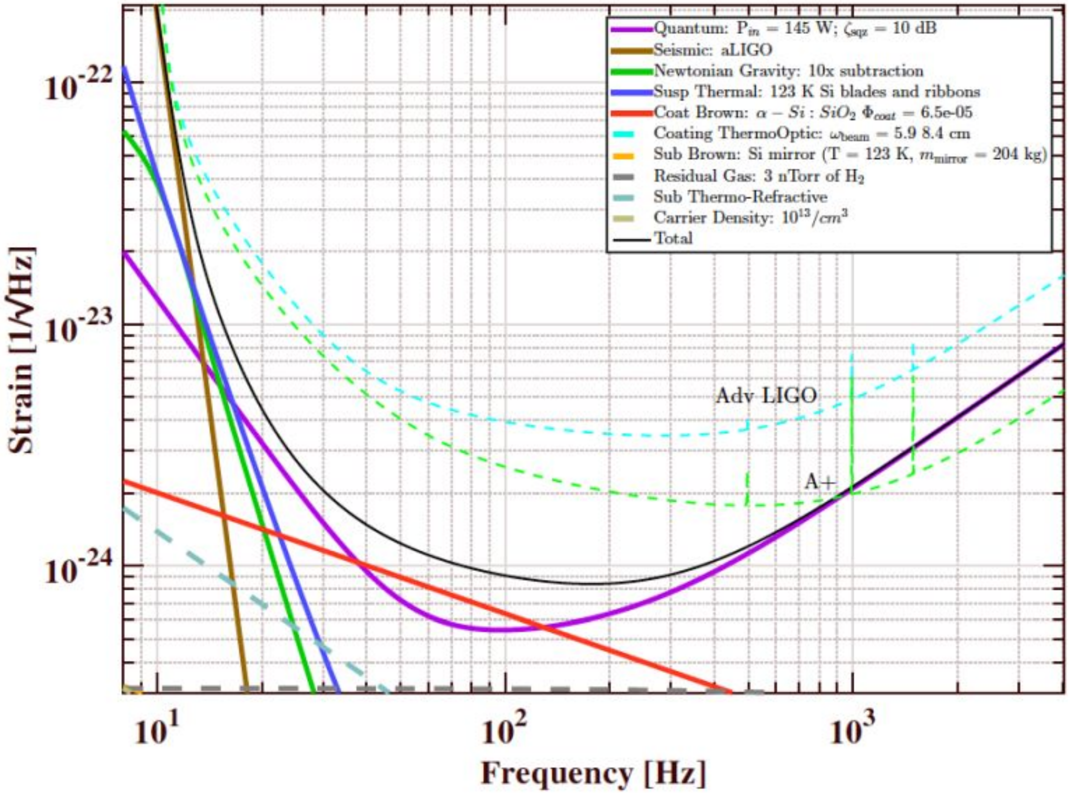
Thermal Conductance and Bond Strength Measurements for LIGO Voyager

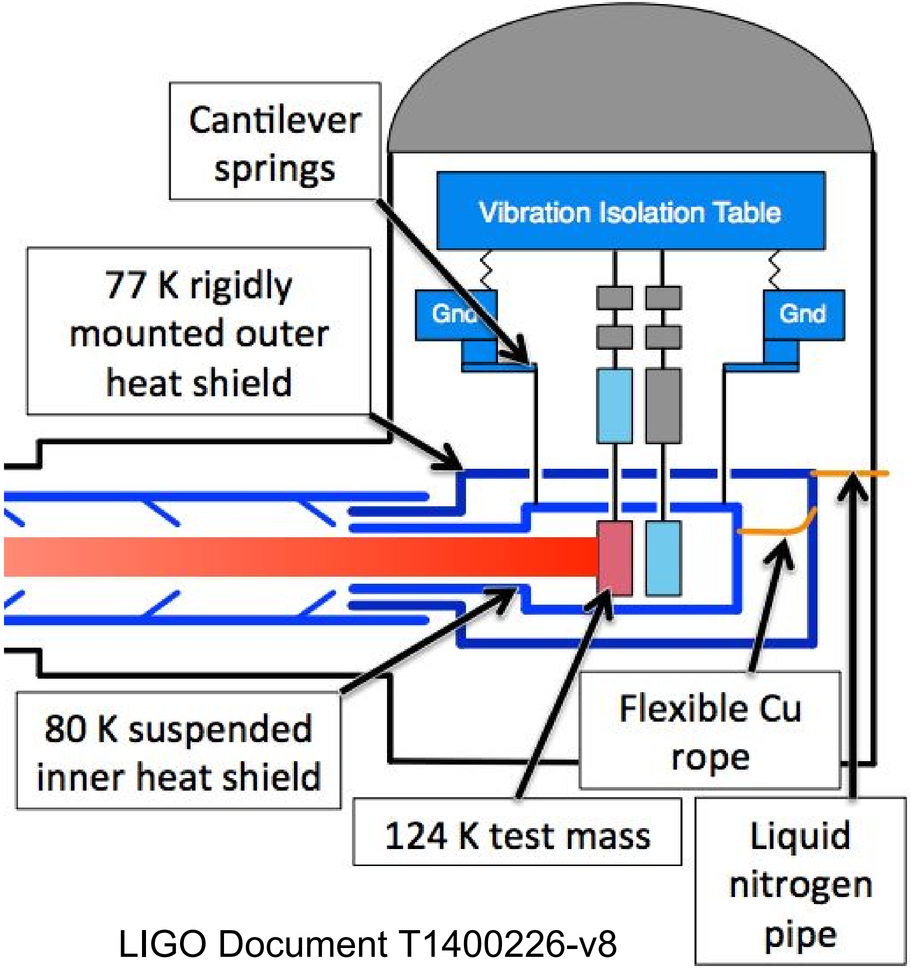
Adele Zawada
Mentors: Christopher Wipf and Johannes Eichholz

SURF Summer 2017

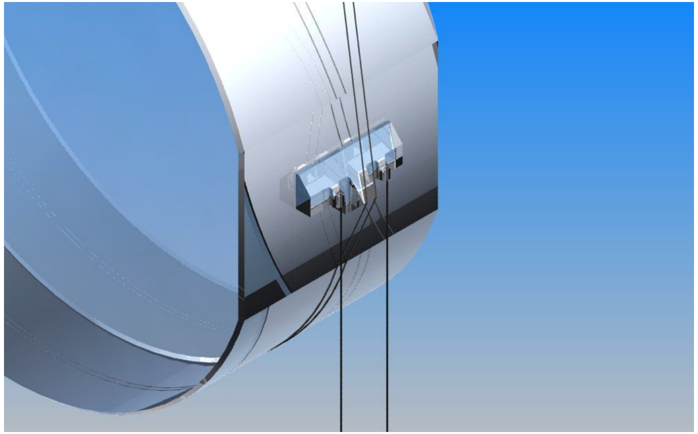
LIGO Voyager



- ➔ aLIGO Noise Budget: limited by thermal noise
- ➔ Why cryogenic Silicon mirrors?
  - Silicon has **high thermal conductivity**, reduces thermal lensing
  - **Thermal expansion is ZERO** at 123K, eliminates thermoelastic component of thermal noise



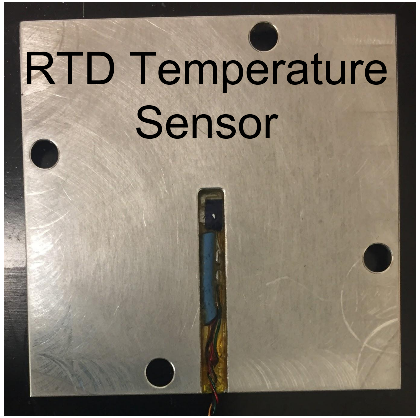
LIGO Document T1400226-v8

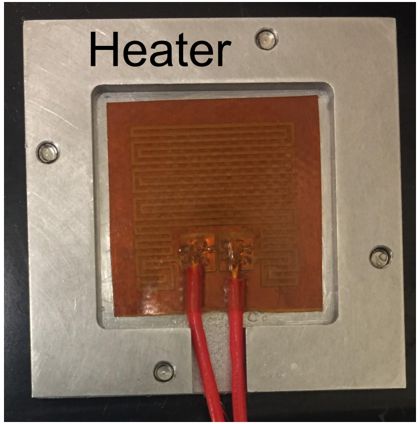


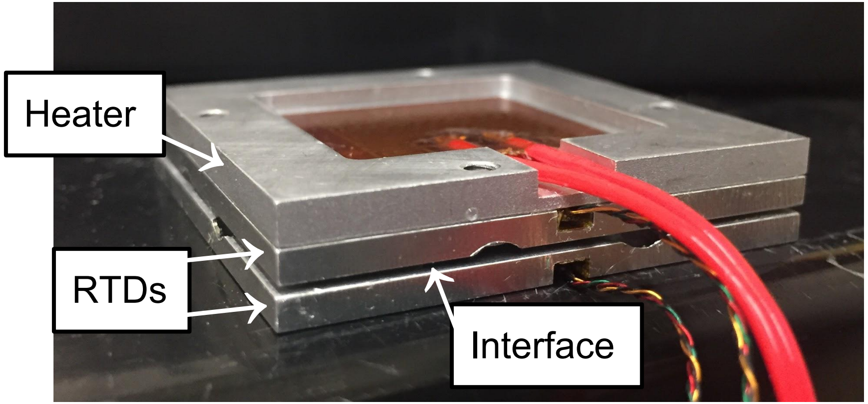
Heat switch:

- More efficient / faster cooling through conduction
- Challenges with design
  - Limited area for contacting
  - Must detach during operation to avoid coupling seismic noise

Bond Quality and Thermal Conductance





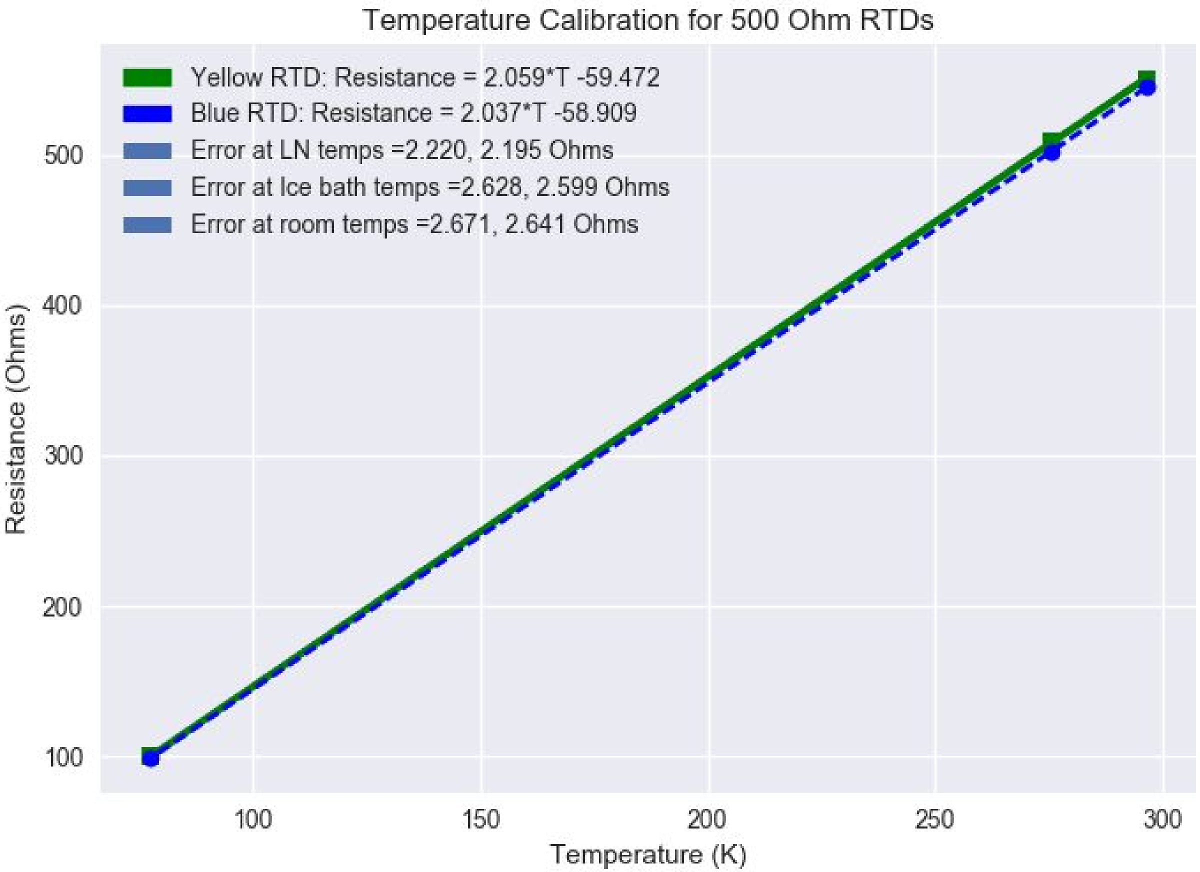


Higher thermal conductance of an interface indicates a better / stronger contact

Measuring thermal conductance (*k*):

1. Place temperature sensors on both sides of an interface
2. Heat one side and wait for the system to reach steady state
3. $$k = \frac{Q_{SteadyState}}{\Delta T} \left[\frac{W}{K}\right]$$

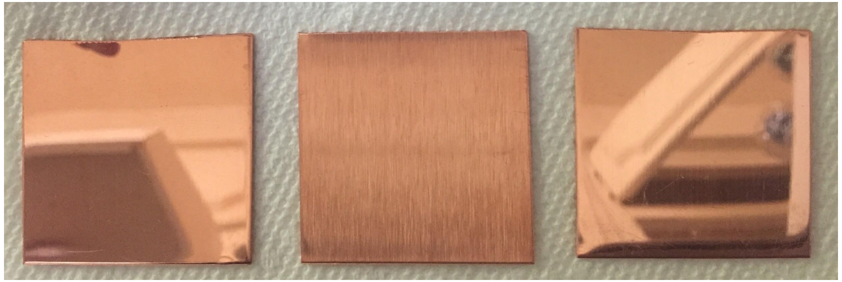
RTD Calibration



- Applied a current and measured the voltage across each RTD at 3 different temperatures (room, ice water, liquid nitrogen)
- Temperature vs. Resistance for RTDs is known to be linear

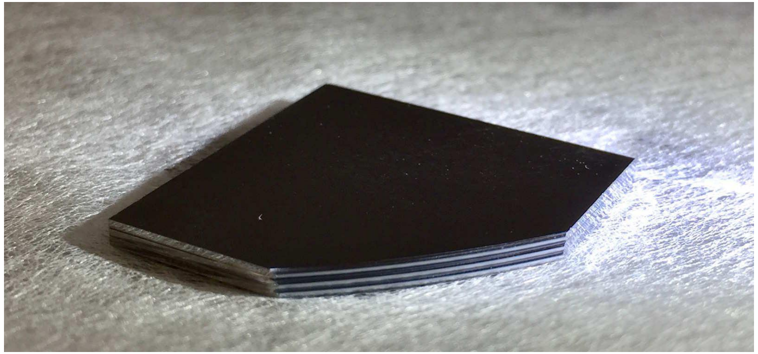
Interfaces I tested this summer

1. Silicon / Copper
   - Application: interface between heat switch and test mass
   - Tested three types of finishes

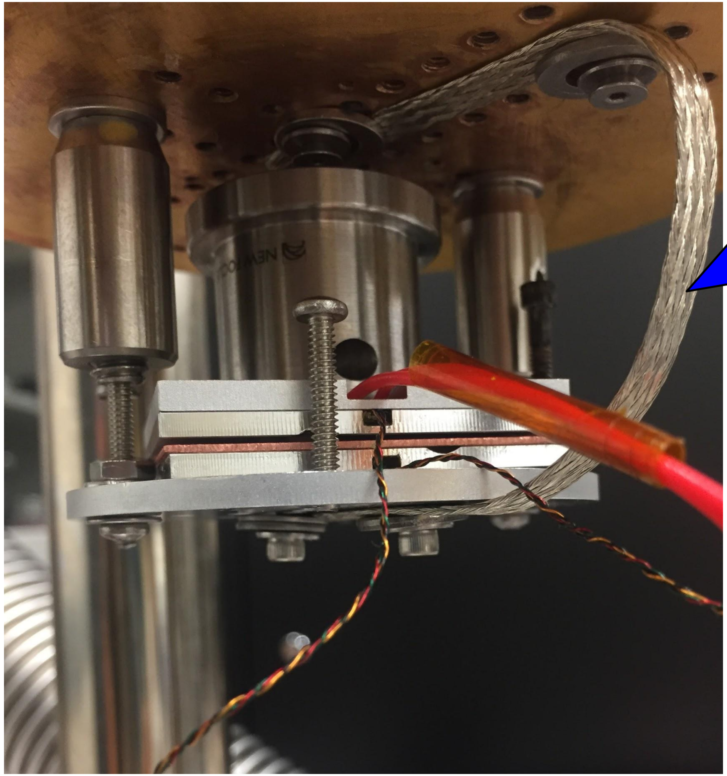


Mirror Brush Polish

2. Silicon / Silicon Optical Contact
   - Doesn’t require glue or etching
     - Low mechanical loss
   - Possible application: attach mirrors to spacers

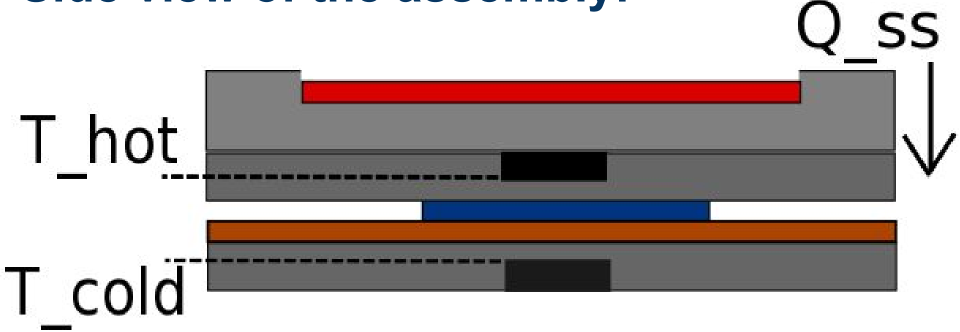


Copper / Silicon Interface

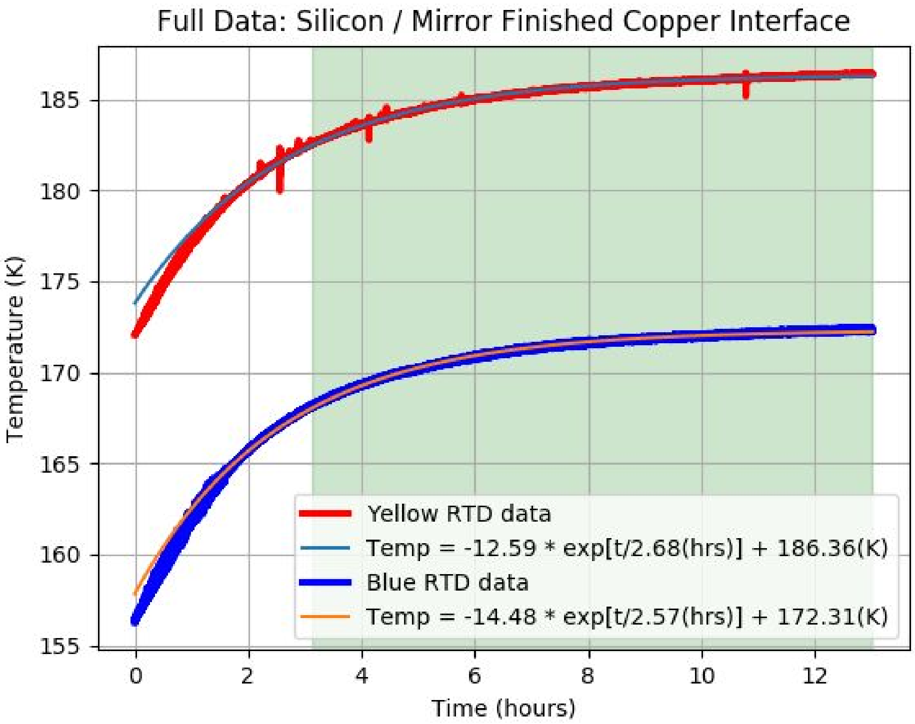


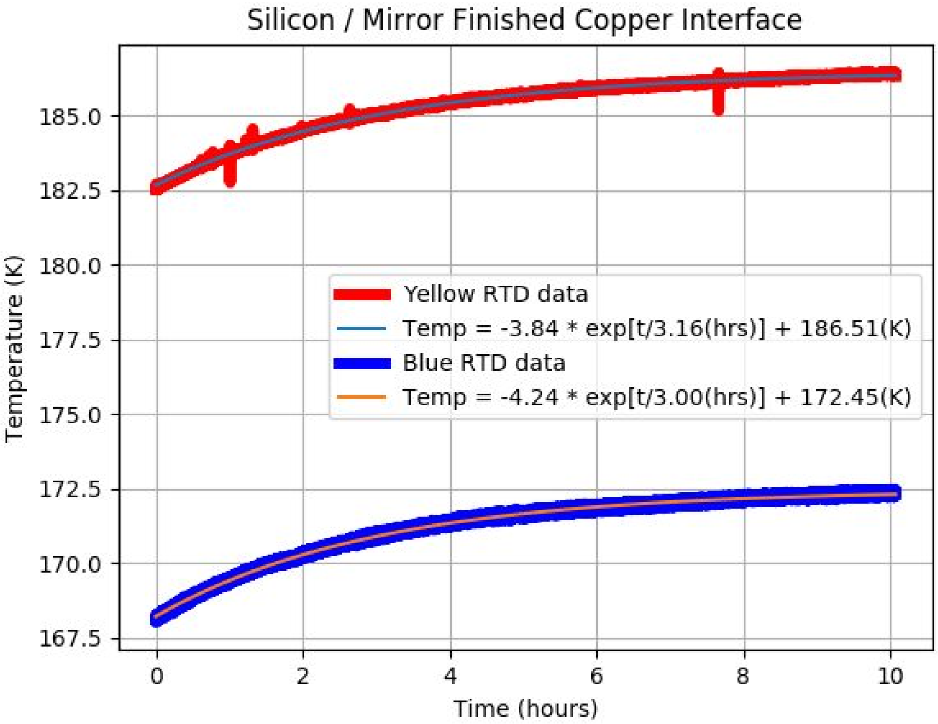
- Operated at LN temperatures
- Thermal strap used to accelerate the cooldown of the working plate
- Applied 0.15 W of heating power once the sensors reached a minimum value

Side view of the assembly:



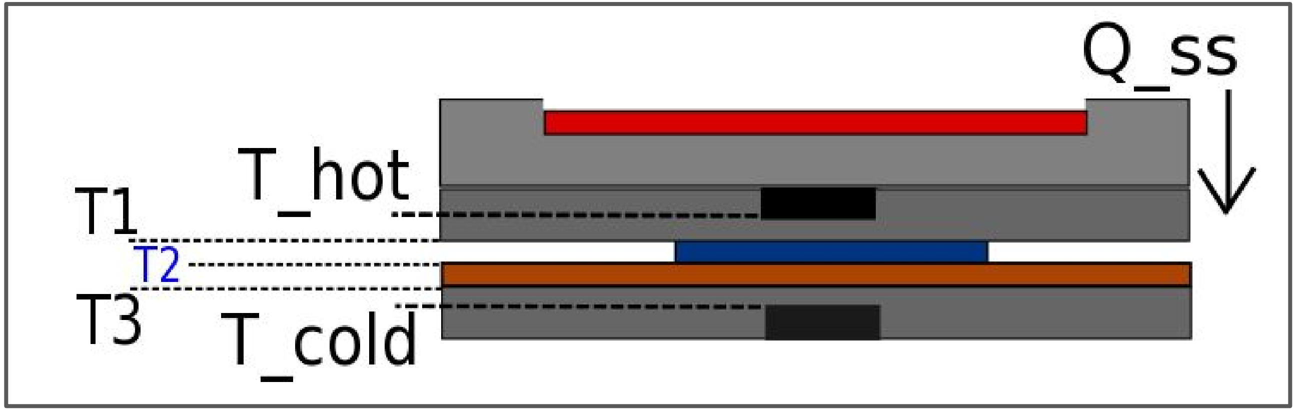
Analysis





- Eliminate first hour of data to allow background processes to reach steady state
- Use exponential fits to extrapolate the final temperatures

Analysis



$$Q_{SS} = k_{sample}(T_1 - T_3)$$

Conductivity (λ [$\frac{W}{m \cdot K}$]) of copper and silicon are known ⇒ *k* = λ * (A/d)

$$\frac{1}{k_{sample}} = \frac{1}{\lambda_{silicon} \cdot \frac{A_S}{d_S}} + \frac{1}{\lambda_{copper} \cdot \frac{A_C}{d_C}} + \frac{1}{k_{bond}}$$

(Solve for k_{bond})

Results / Conclusions

Type of finish	Thermal Conductance. (W/K)
Brush	0.00908 ± 0.00043
Polish	0.01363 ± 0.00069
Mirror	0.01657 ± 0.00086

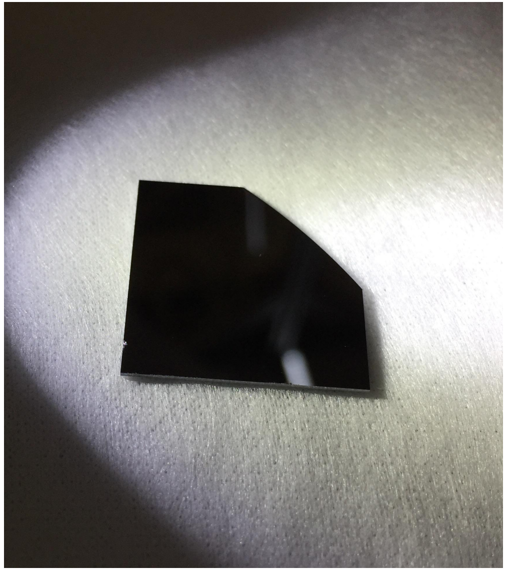
- More polished surface = better contact
- How long to cool the Si mirrors (300□123K):
  - Brush finish contact: **~12 hrs**
  - Polish finish contact: **~8.2 hrs**
  - Mirror finish contact: **~6.8 hrs**

Next Question: What amount of applied pressure achieves highest quality bond?

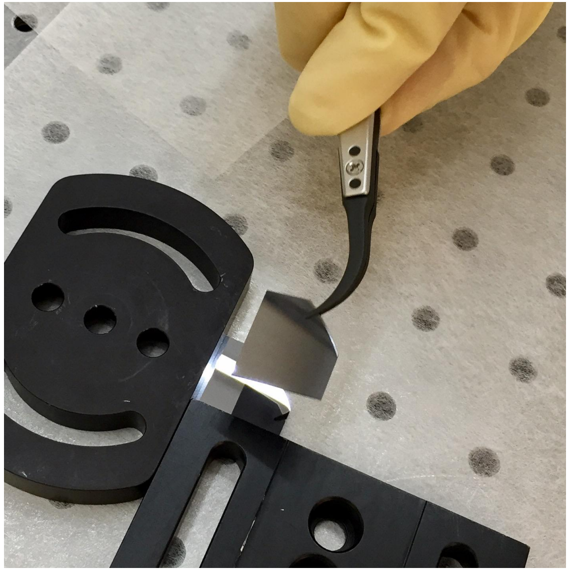
- Determine the relationship between applied force and thermal conductance
- Is this amount of pressure reasonable to achieve with a clamping mechanism?

Optical Bonding and Curing Process

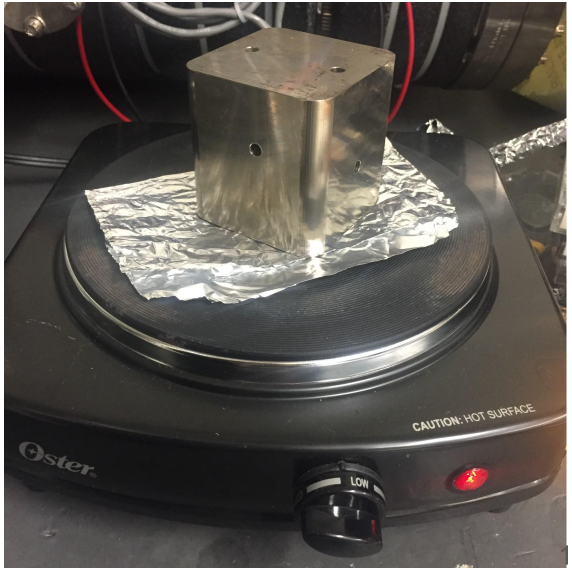
Clean wafers with first contact solution



Stack clean sides on top of each other in a corner and apply pressure



Cure the samples with heat and/or pressure for 24 hr



Results / Conclusions

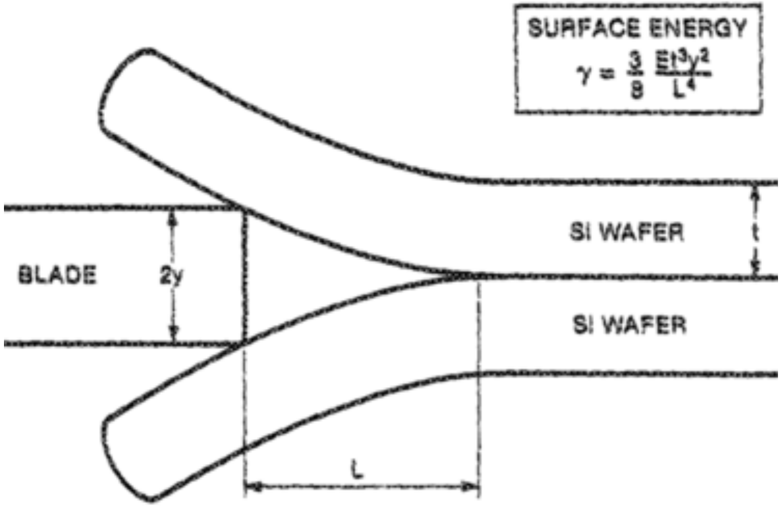
- Calculated the bond conductance for each sample
- Higher pressure / temperature indicates a stronger bond
- No curing process has weakest bond
- Both heat and pressure improve bond

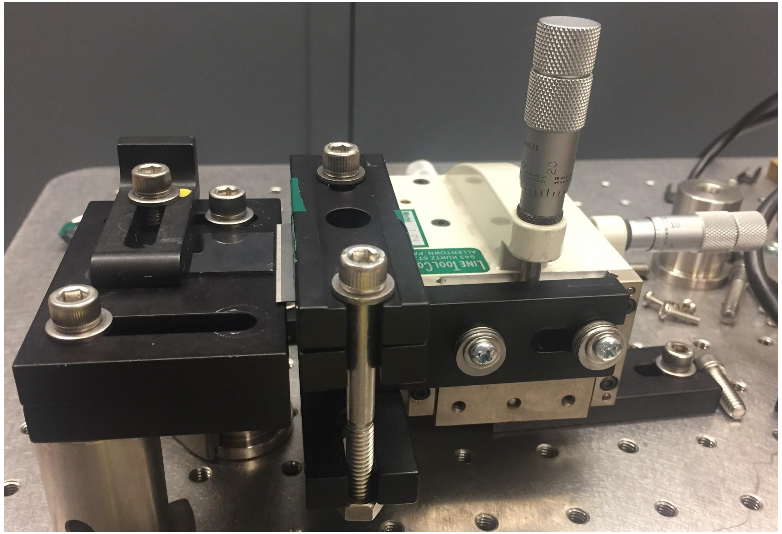
Sample Curing Process	**Thermal Cond. (W/K)**
325 C, 3kg	0.1106 ± 0.0350
35 C, 1kg	0.0539 ± 0.0093
275 C, no weight	0.0538 ± 0.0093
No heat, 2.25 kg	0.0511 ± 0.0084
No heat, no weight	0.0388 ± 0.0053

Future and Ongoing Work

Razor Blade Method

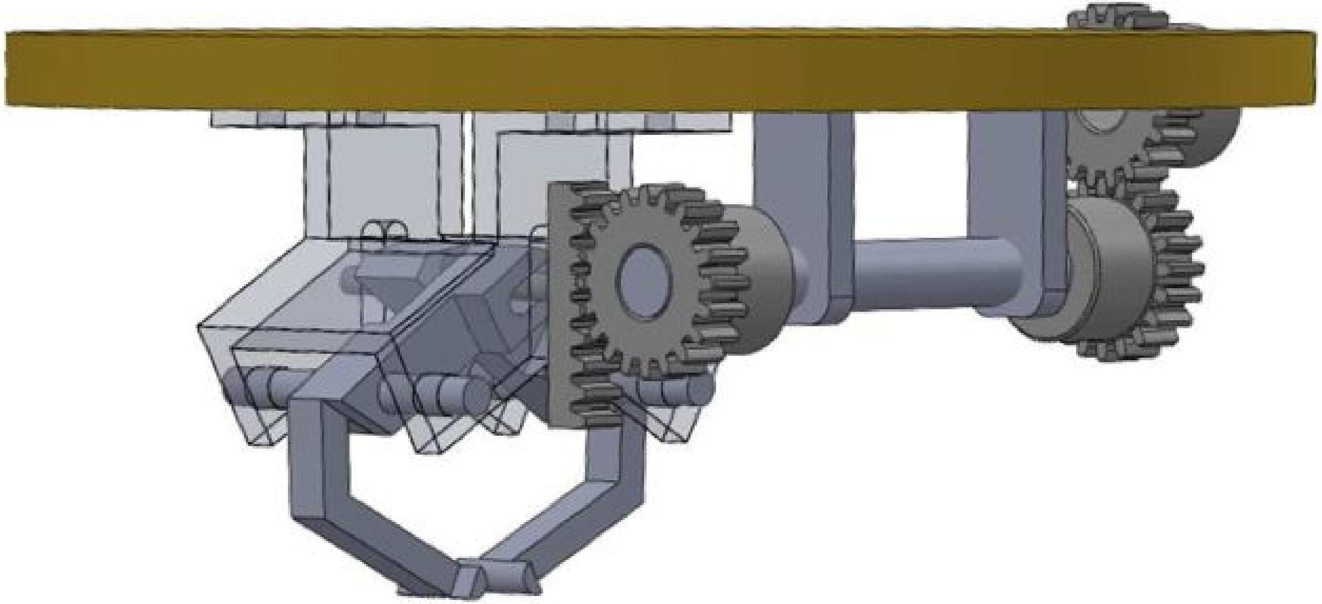
- Inserting a blade into the interface and measuring how deep a gap is opened
- Determine the relationship between conductance and depth of gap





If I had more time this summer….

I started designing a clamping mechanism that could attach to a 1” silicon sample and then detach once it was cooled



Acknowledgements

- Johannes Eichholz
- Christopher Wipf
- Rana Adhikari
- NSF
- LIGO SURF program

Thank you!