Senior Design Group May14-03

Design and implementation of a cryogenic electrical characterization system for organic photovoltaic cells

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Client: ISU Nanolab, Dr. Chaudhary and John Carr

Project Description

MOTIVATION, GOALS, AND OVERVIEW

Organic Photovoltaic Cells

A promising new energy technology…

…but only if **efficiency** can be improved!

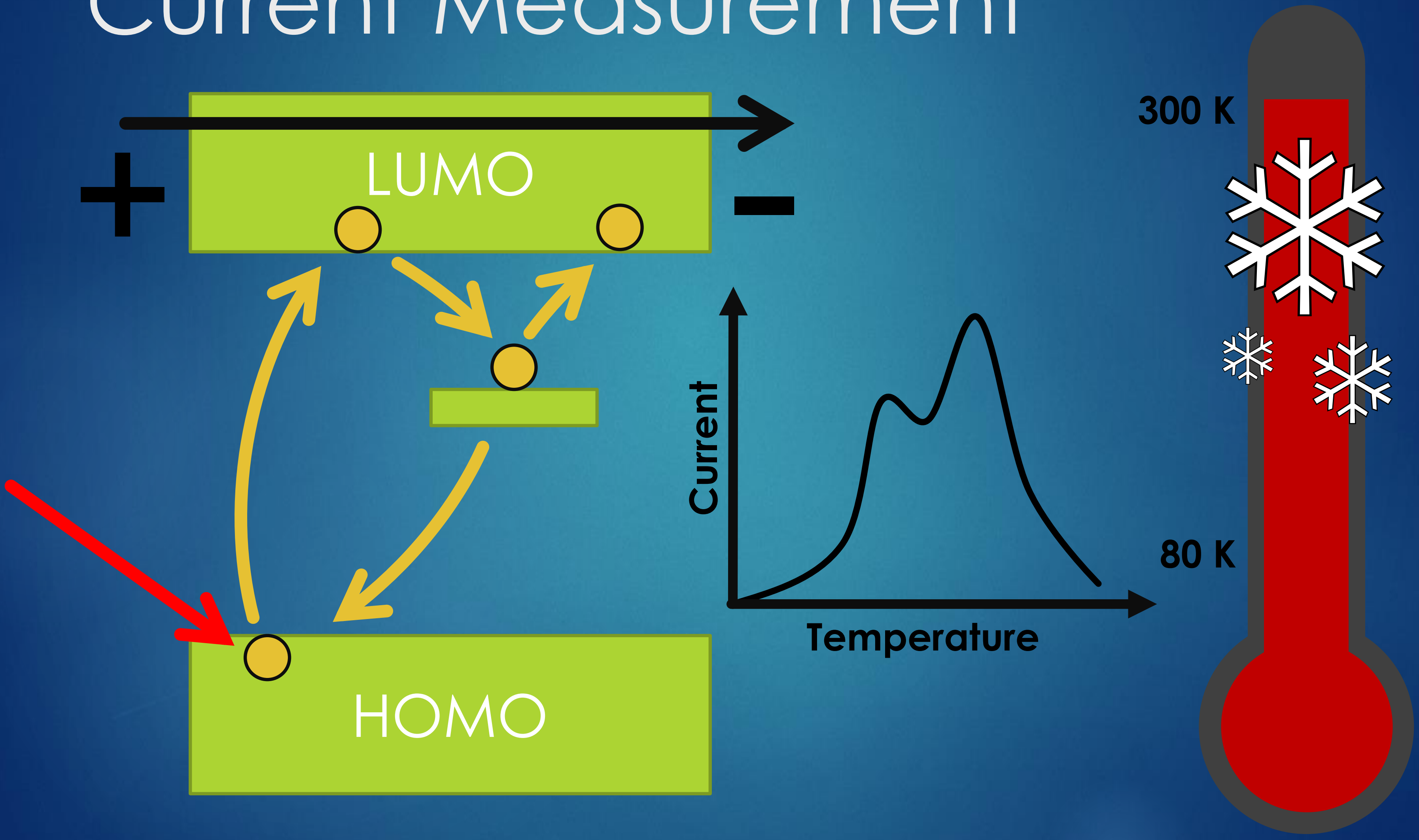
Electronic defects are one major obstacle

The method of **Thermally Stimulated Currents (TSC)** can help us examine those defect states…

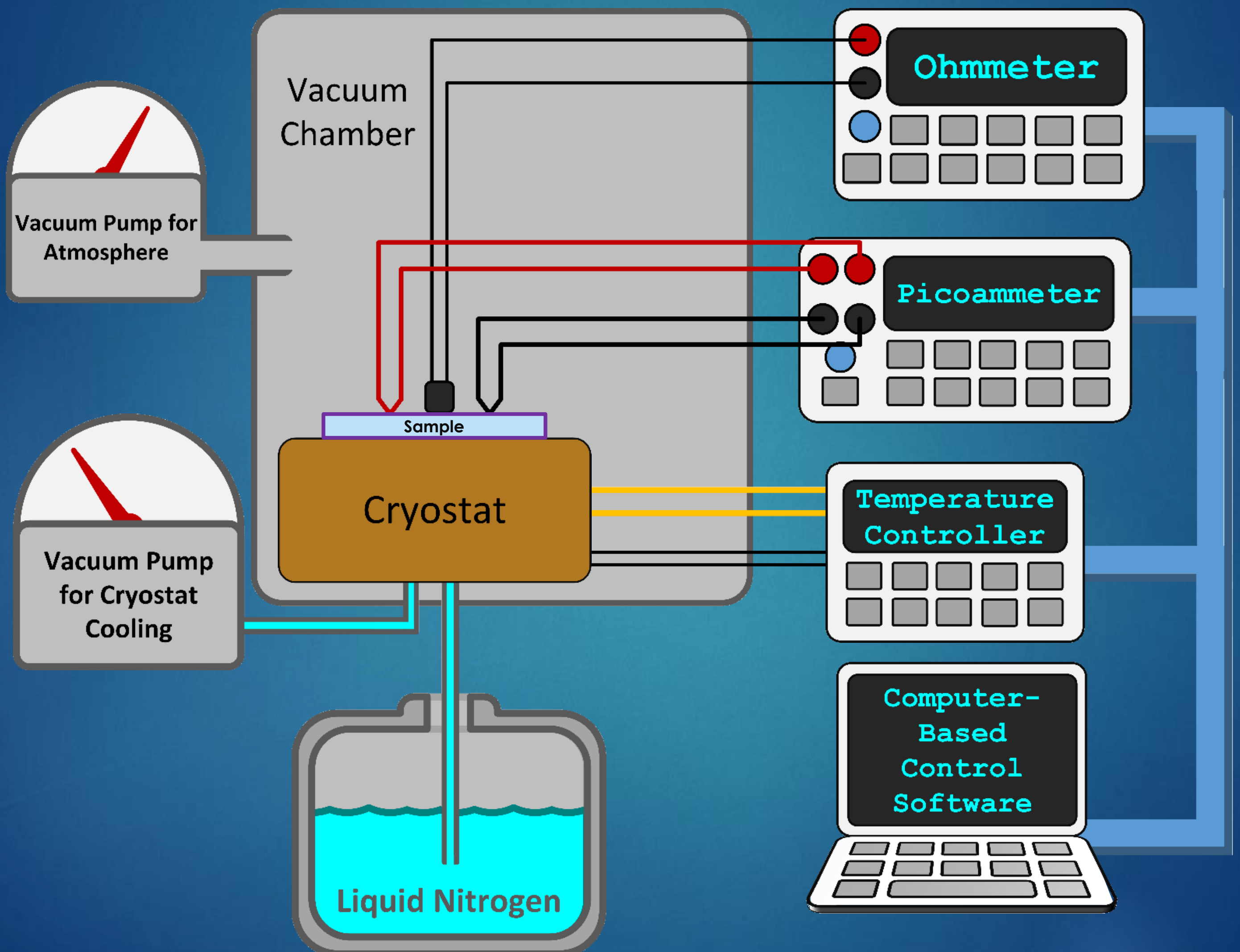
…but setups are expensive and complicated!

Our project is to design and build a system that can simplify TSC measurements for our client.

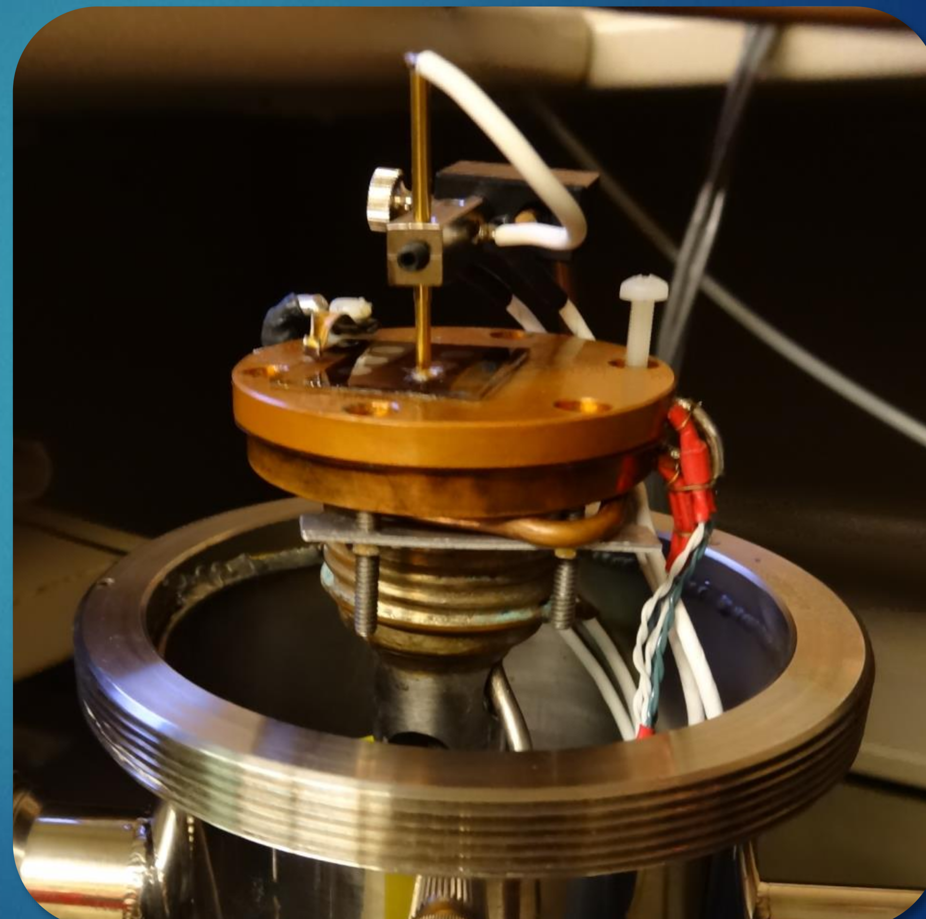
Thermally Stimulated Current Measurement



System Overview



System Overview



Project Goals

Where we started

- Liquid nitrogen cryostat and vacuum chamber
- No temperature verification
- Current meter with 10 pA resolution
- Manually controlled instrumentation setup

What was needed

- Must be able to bring sample to 80 K
- Need a method of real-time measurement
- Need 1000x better current resolution
- Experiment operation and data collection must be automated

Market and Literature Survey

- No dedicated commercial systems for TSC exist!
- High quality cryostats cost $30,000 or more

- Most research papers publish very few details

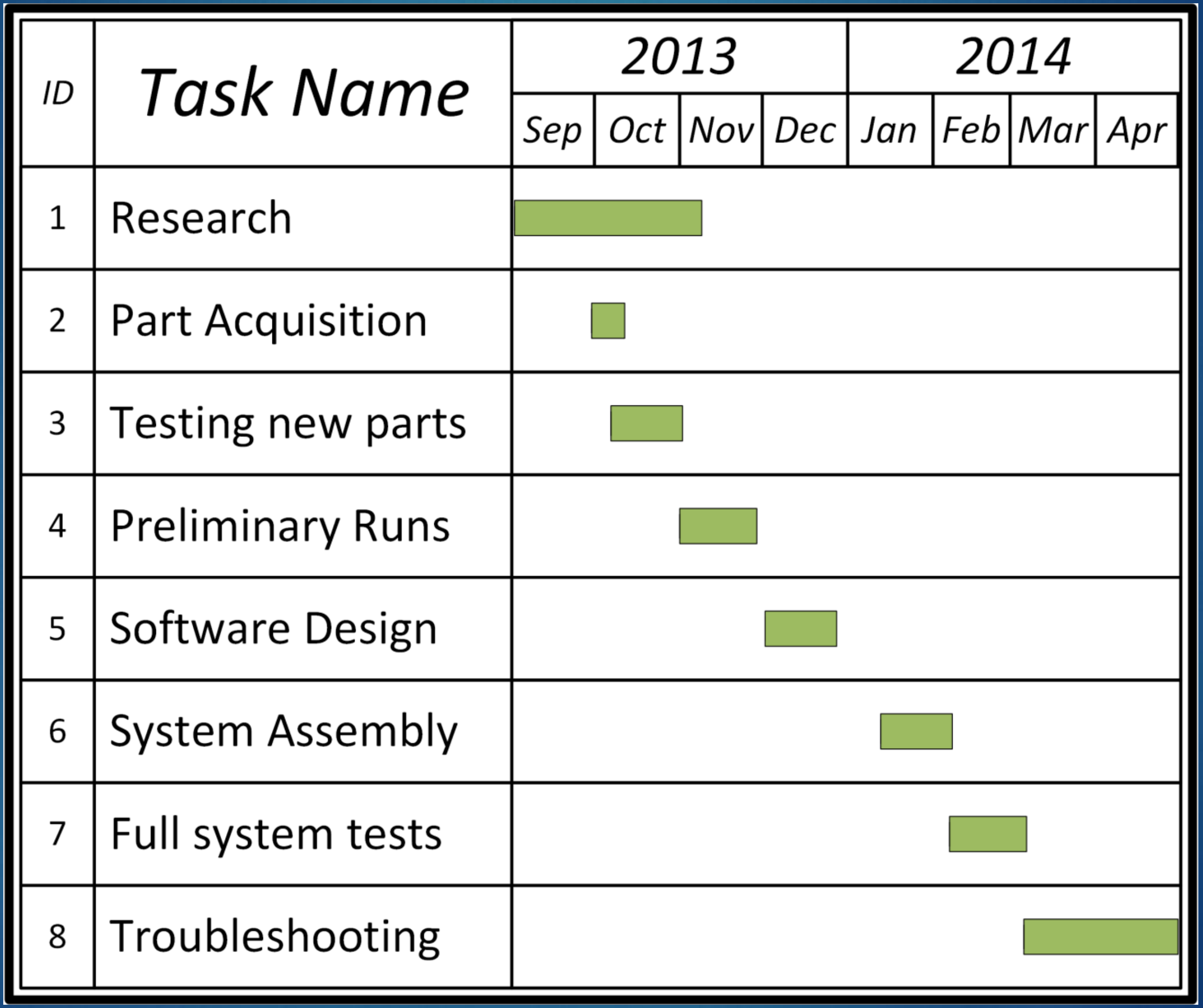
- Spoke with researchers in physics department
  - Significant experience with cryogenic systems

- Researched one individual component at a time
  - Temperature Sensors
  - Thermal interface materials
  - Insulation
  - Low current measurements

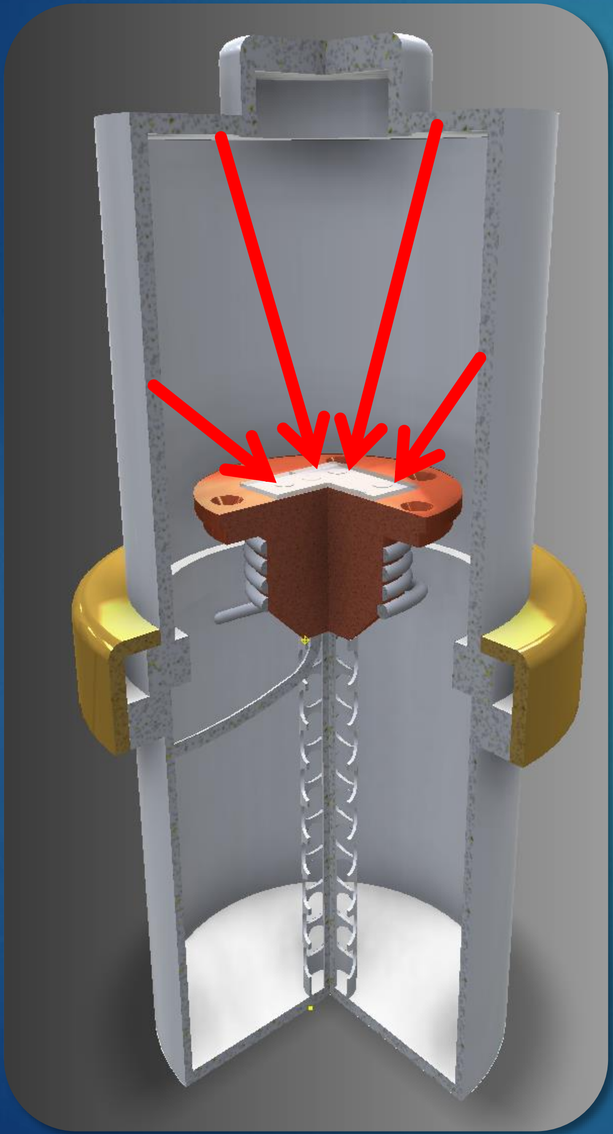
Project Implementation

HOW WE HAVE SOLVED THE PROBLEM

Project Schedule



Cold Shroud



- Radiative heating is one of the largest problems
- Solution: mask with a reflective, cold surface

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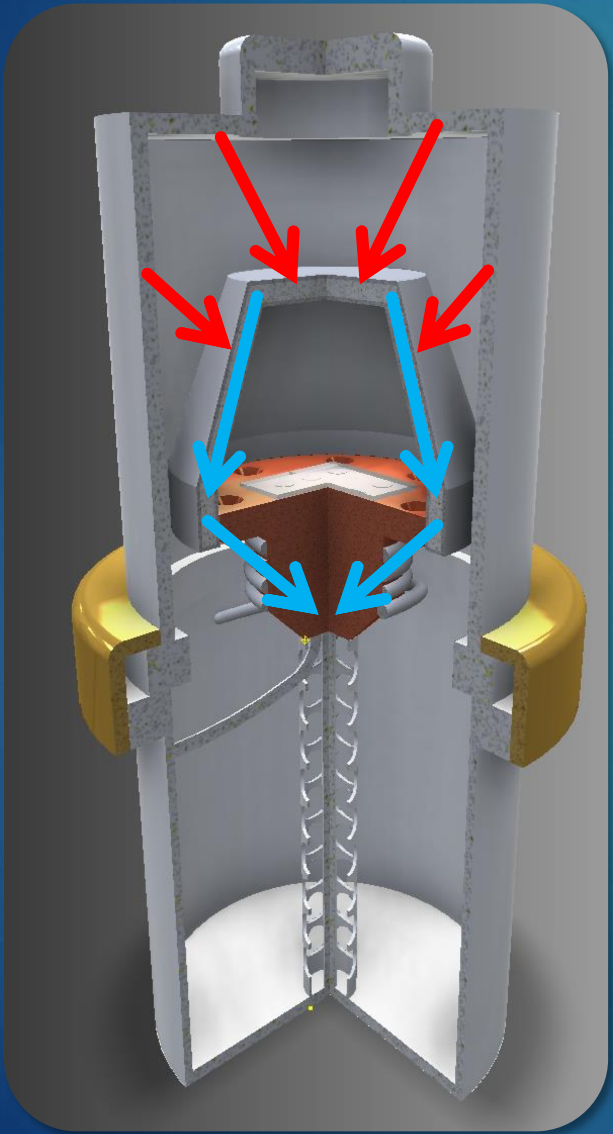
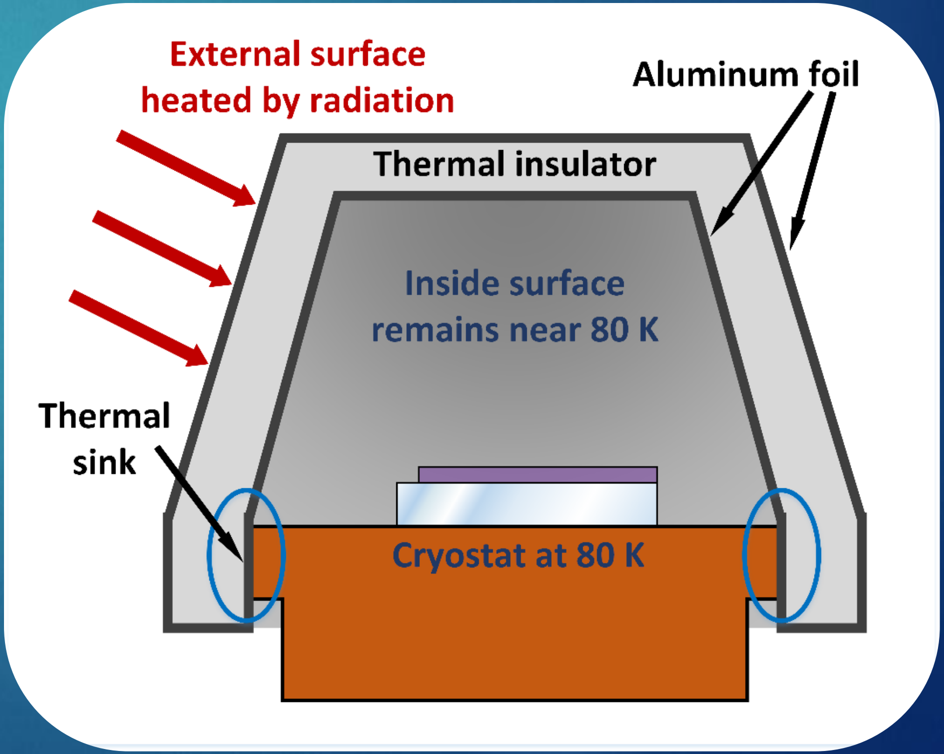
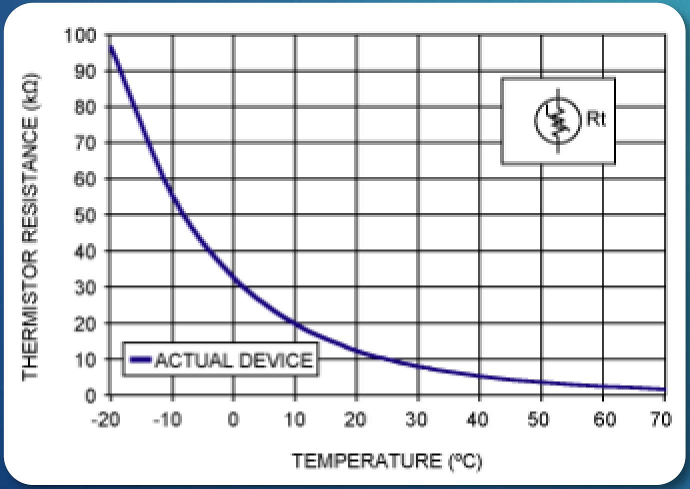


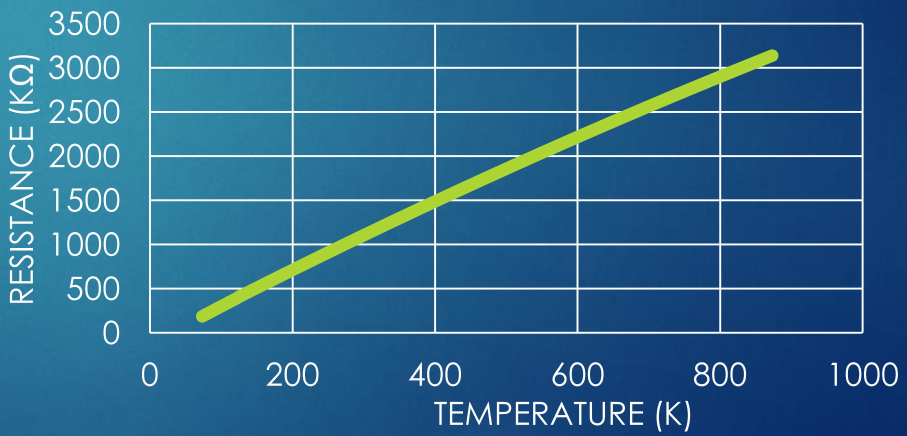


Temperature Sensors

- Thermocouples
- Silicon Diodes
- Thermistors
  - NTC Semiconductor
  - PTC Metal

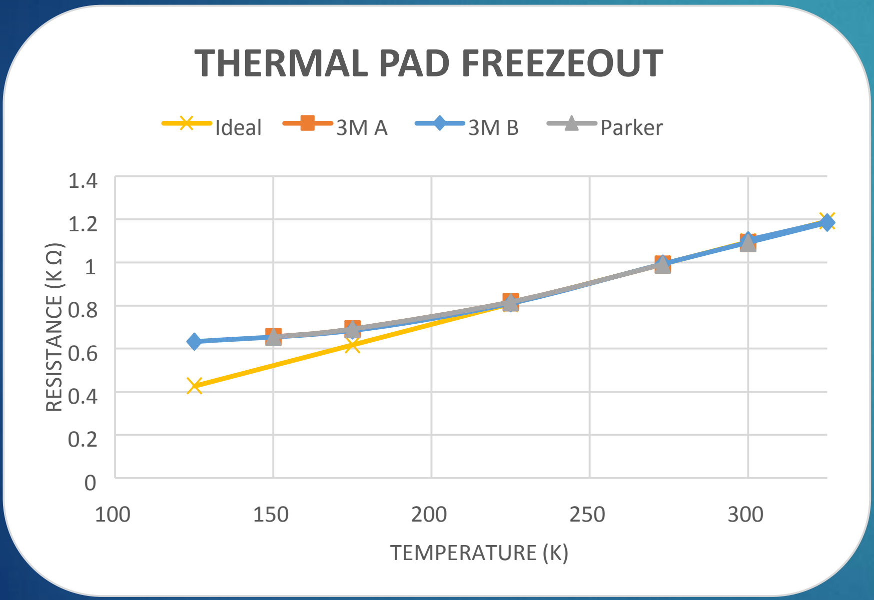


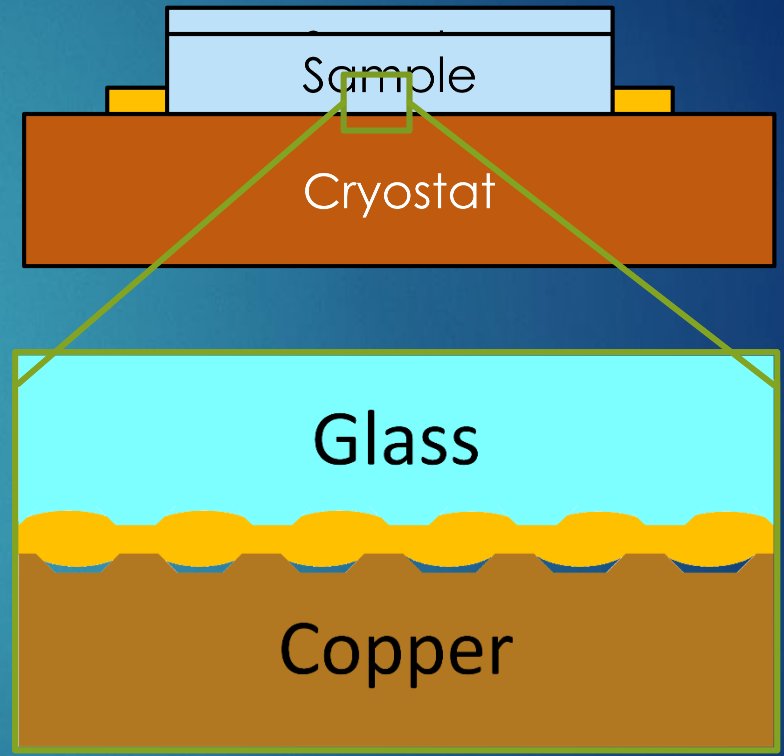
Platinum RTD



Thermal Interface Materials

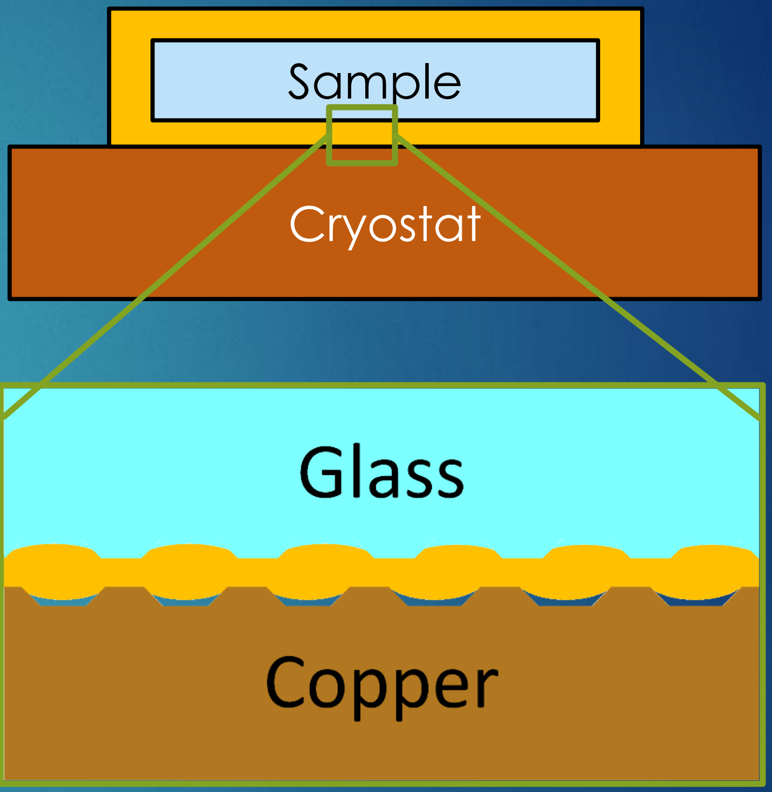
- Conformable Pads
  - Parker Chomerics
  - 3M





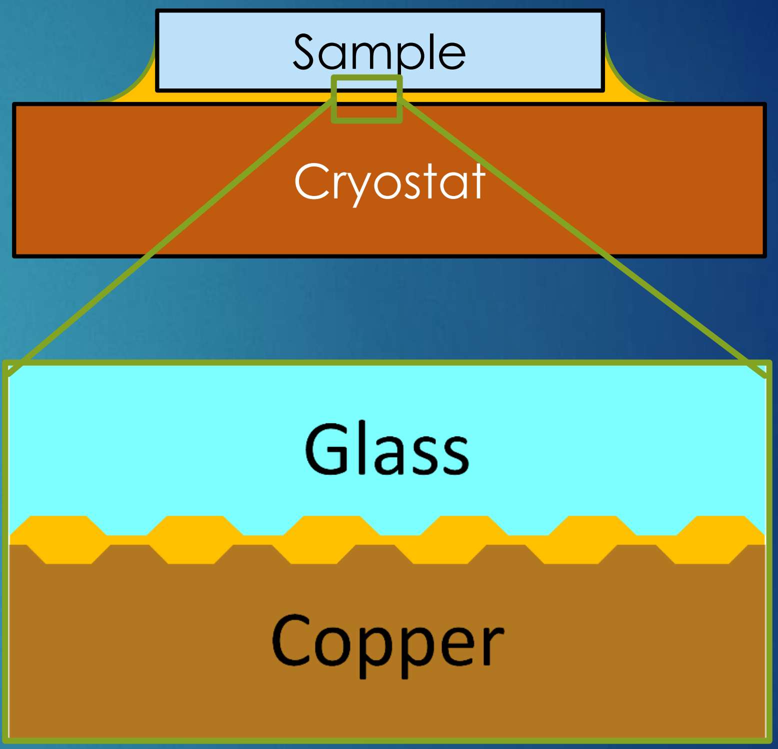
Thermal Interface Materials

- Conformable Pads
  - Parker Chomerics
  - 3M
- Cryogenic Epoxy
  - Stycast 1266
  - Reacted with organic layer!

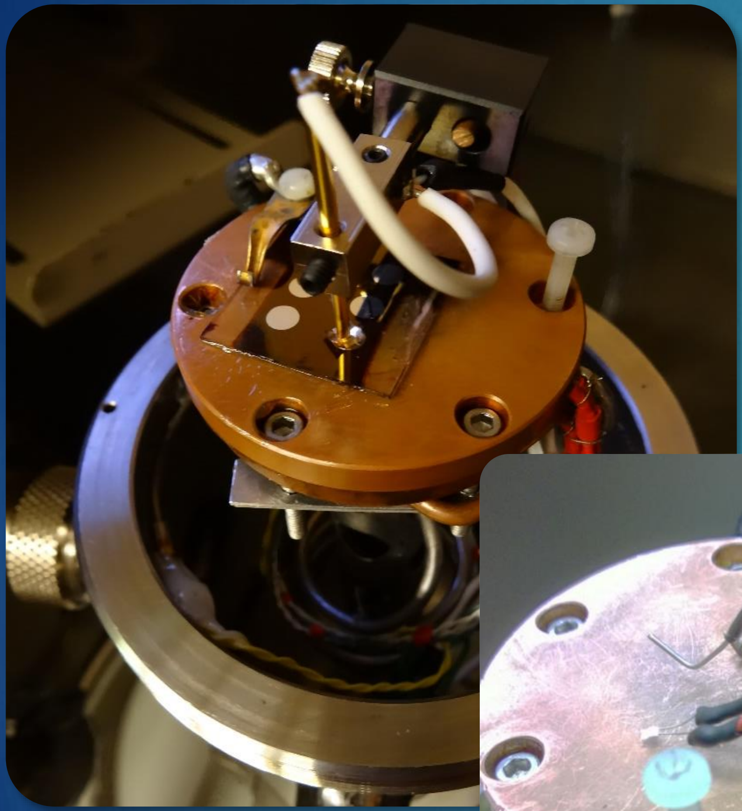


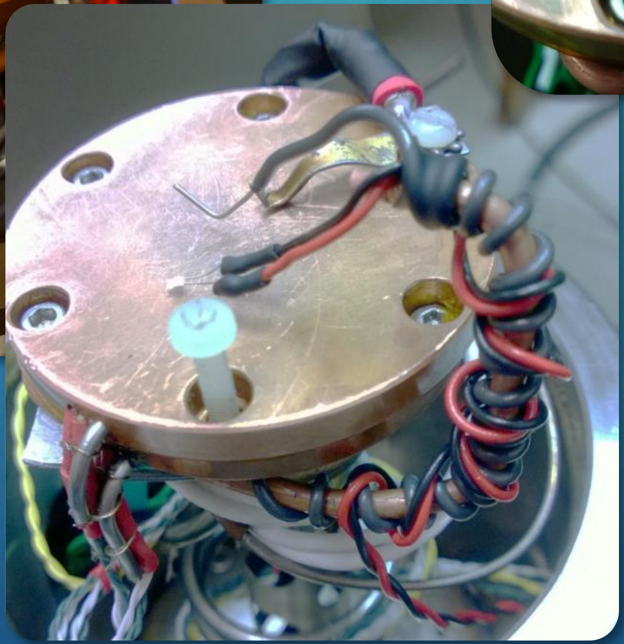
Thermal Interface Materials

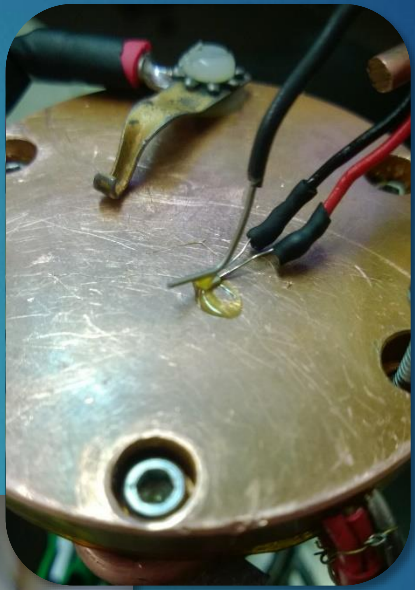
- Conformable Pads
  - Parker Chomerics
  - 3M
- Cryogenic Epoxy
  - Stycast 1266
- Cryogenic Vacuum Grease
  - Apiezon N Grease
- Cryogenic Varnish
  - Lakeshore VGE-7031

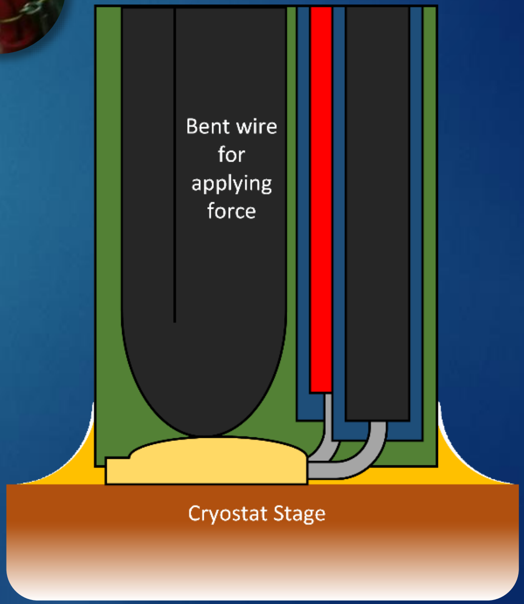


Probe Effects









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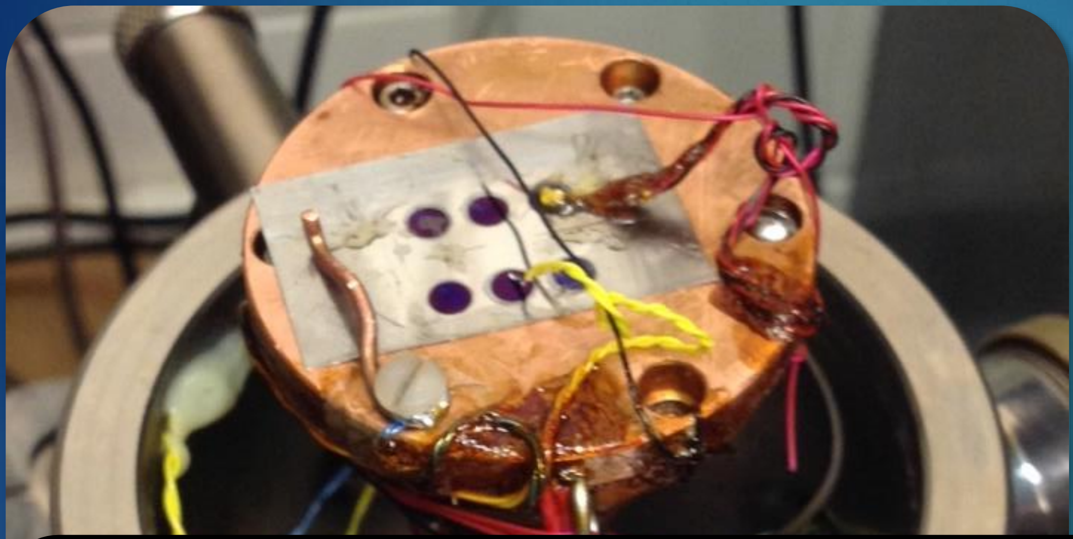
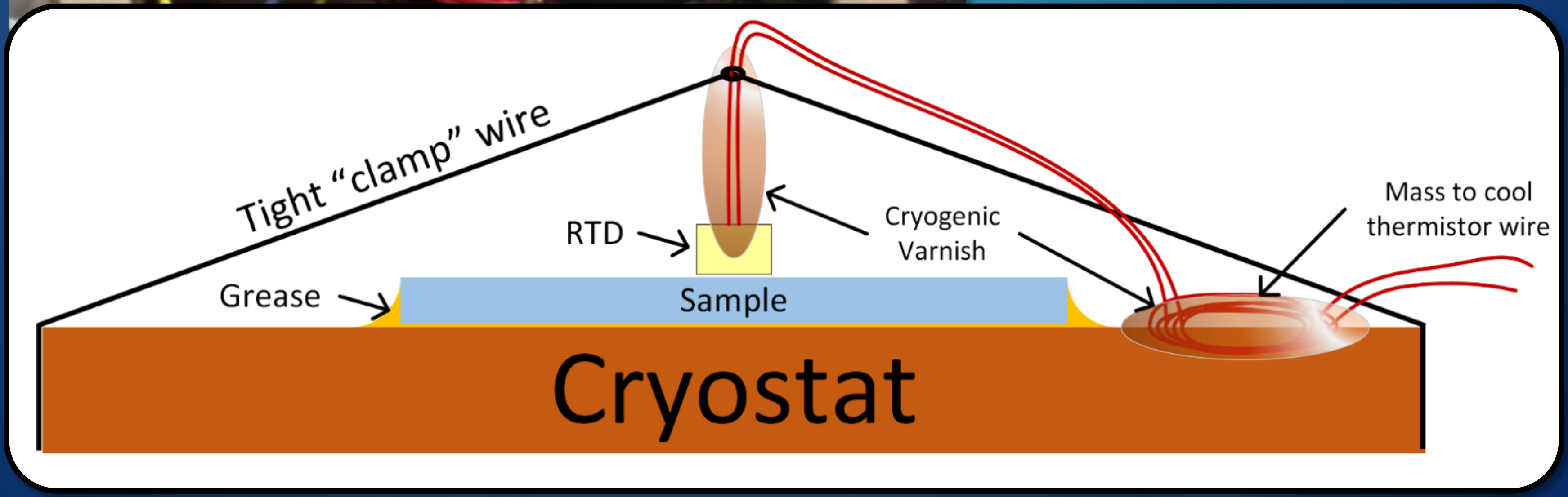


- Thinnest wires possible, cooled on cryostat
- Wire tension used to hold tip down
  - Separated from sample surface



Automation Software

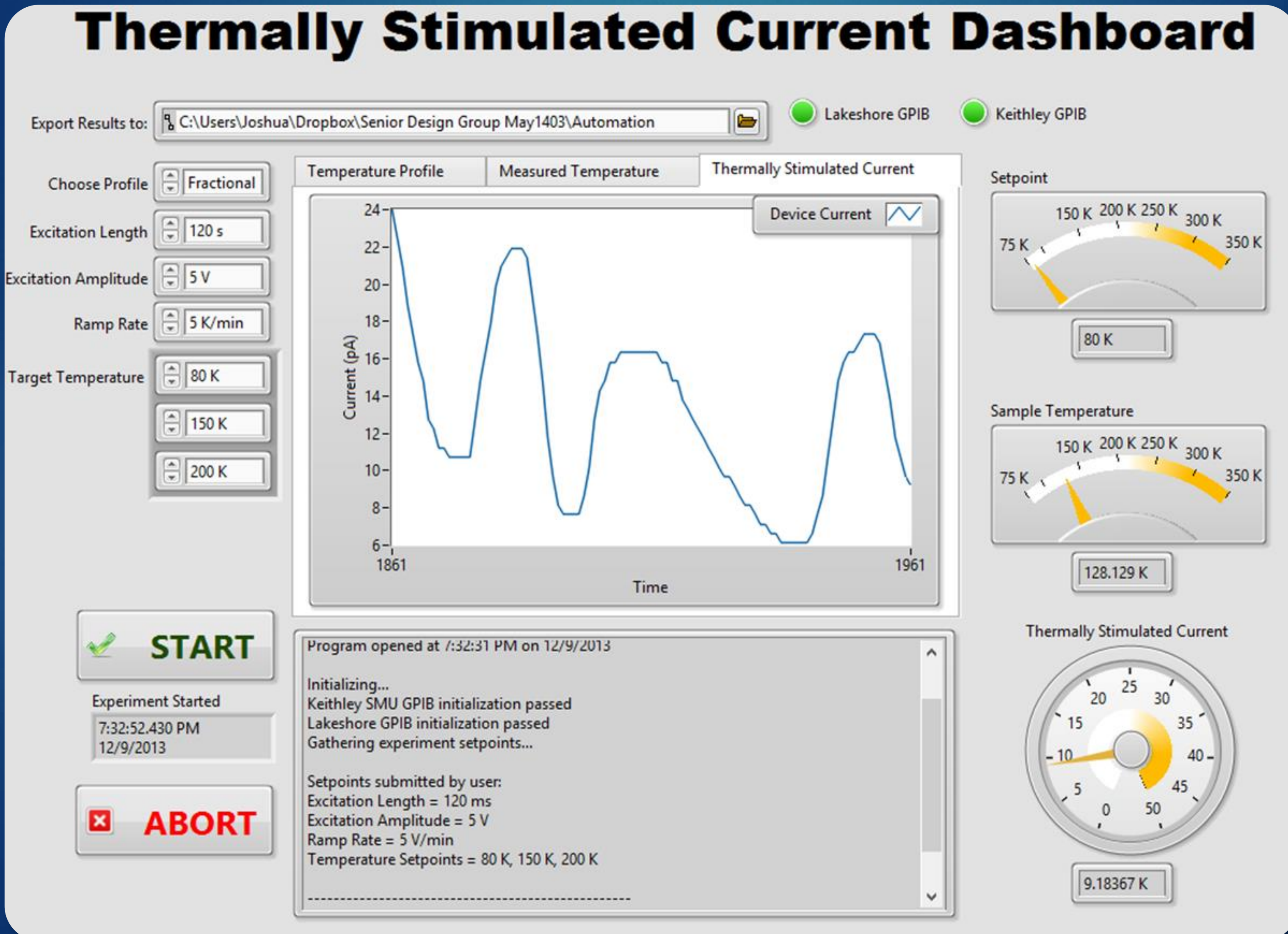
Flexible
- Allow for experiment customization
- Support multiple modes

Robust
- Elegantly handle problems
- Keep user safe

Accessible
- Intuitive GUI
- Legible output

NATIONAL INSTRUMENTS LabVIEW™

Automation Software



Conclusion

- We have designed a setup that cools the sample thoroughly close to 80 K
- We are able to reliably measure the temperature in real time
- We have a working probe setup
- All individual components of the system are up and running

Next Semester

- Full system assembly
  - GPIB control and data collection
  - Institution of new picoammeter
- Continual improvements in insulation
- Optimization of experimental procedures
  - Cooling rates, excitation profiles, soak times

Questions?

THANK YOU FOR YOUR TIME!

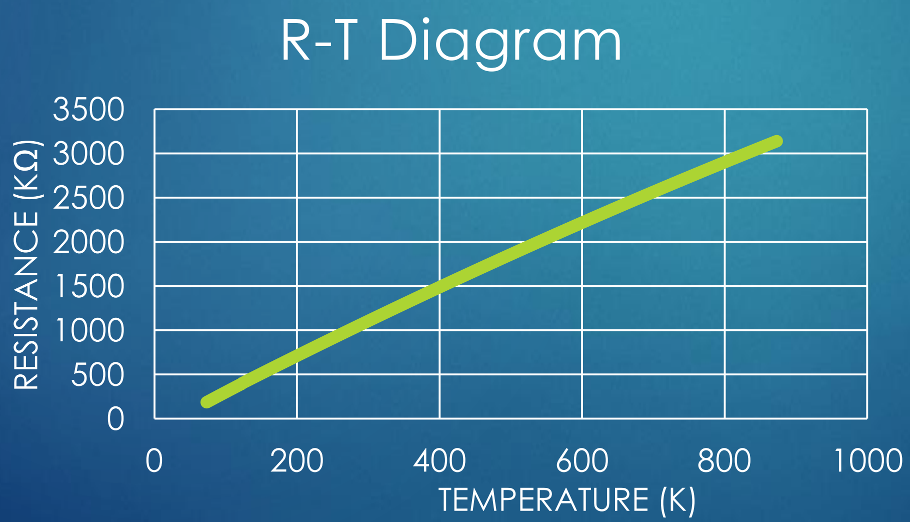
Appendices

References

- T. Benanti & D. Venkataraman. "Organic solar cels: An overview focusing on active layer morphology". Photosynthesis Research, Vol. 87, 2006, pp. 73-81.
- J. Ekin. *Experimental Techniques for Low-Temperature Measurements: Cryostat Design, Material Properties, and Superconductor Critical-Current Testing*. New York: Oxford University Press, 2006.
- T.W. Kerlin. *Practical Thermocouple Thermometry*. North Carolina: Instrument Society of America, 1999.
- M. Kim. *Understanding Organic Photovoltaic Cells: Electrode, Nanostructure, Reliability, and Performance*. Doctoral Dissertation. University of Michigan, 2009.
- V.I. Mikla, V.V. Mikla. *Trap Level Spectroscopy in Amorphous Semiconductors*. London: Elsevier, 2010.
- J. Moore, C. Davis, M. Coplan, S. Greer. *Building Scientific Apparatus, Fourth Edition*. New York: Cambridge University Press, 2009, pp. 600-621.
- R.G. Scurlock. *Low Temperature Behavior of Solids*. New York: Dover Publications, 1966.
- S. Sun, N.S. Sariciftci. *Organic Photovoltaics: Mechanisms, Materials, and Devices*. Boca Raton: CRC Press, Taylor & Francis Group, 2005.

US Sensor PPG102A6

- 1000 Ω ± 0.06%
- Range: -200°C to +600°C (73.15 K to 873.15 K)
- Platinum-Nickel Leads
- Linear TCR: 3,850 ppm/K
- $22.00 each

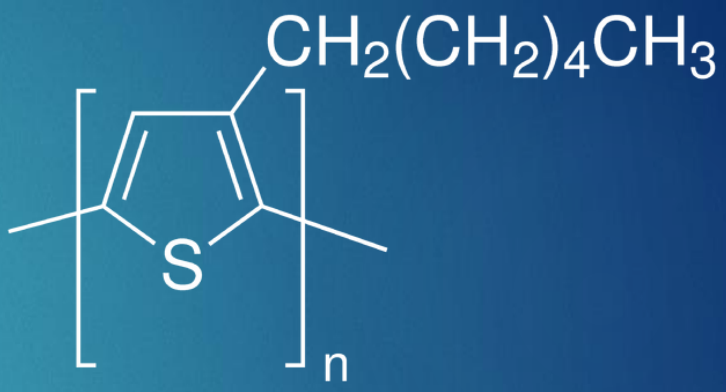


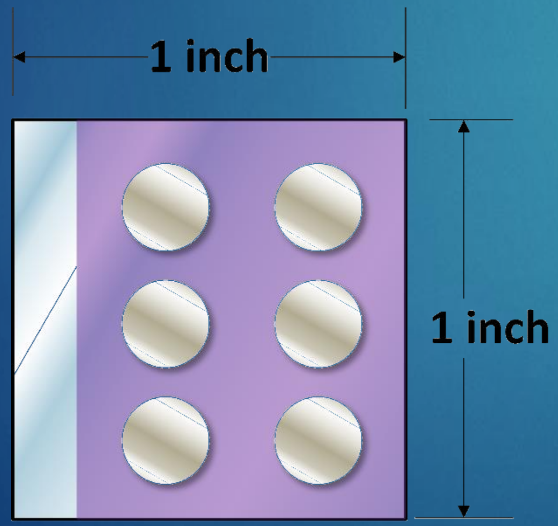
Apiezon N Grease

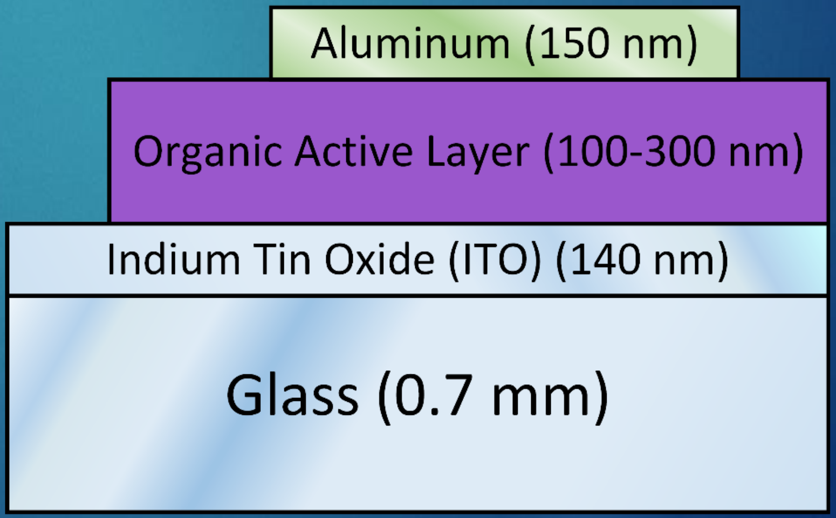
- Temperature Range: 0.15 K to 300 K
- Thermal Conductivity (80 K) = 0.1 W m^{-1} K^{-1}
- Vapor Pressure (273 K) = 2.67 x 10^{-7} torr
- Volume Resistivity 2 x 10^{16} Ω m

Solar Cell Samples

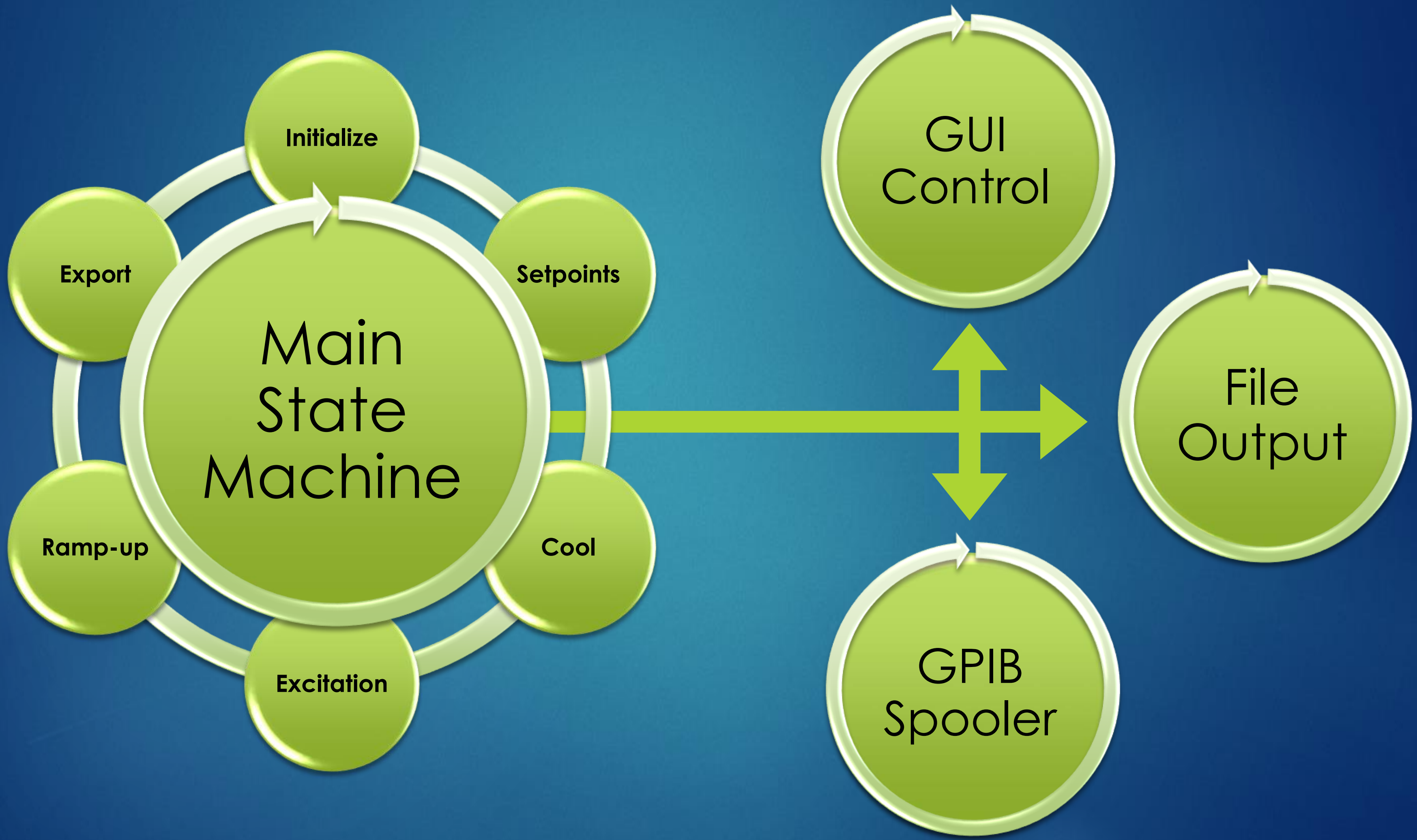
- Poly-3-hexylthiopene
- Bulk heterojunction
- Manufactured onsite using glass slides pre-deposited with ITO







Software Architecture



Lakeshore Temperature Controller

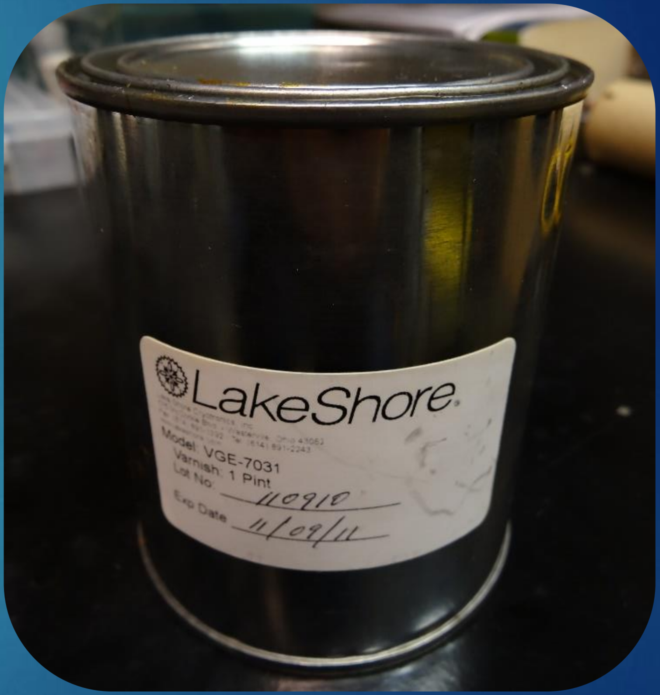
- Two cryogenic temp. sensors embedded in cryostat
- 3-mode variable power heater, 50 W
- Accurate down to 1.2 K
- Thermal EMF compensation for resistive sensors

Keithley 6485 Picoammeter

- 5½ digit display
- Resolution: 10 fA
- 1000 reads per second
- Accuracy: ±0.4%
- Coaxial hookups, triax adapters for low currents
- $1,660 (with educational discount)

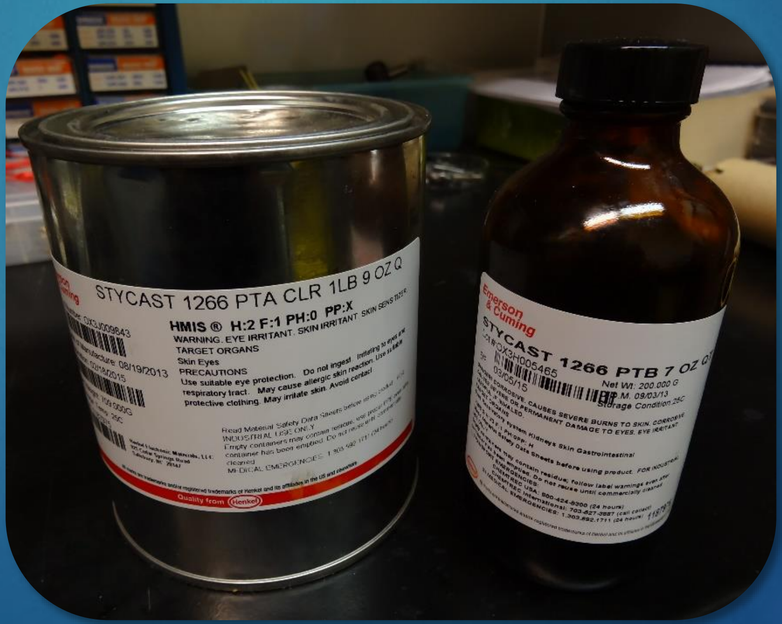
VGE-7031 Cryogenic Varnish

- Clear modified phenolic
- Easy to apply and remove
- Rigid when dry, dissolves in alcohol
- Vacuum compatible to 10^{-9} Torr



Stycast 1266 Cryogenic Epoxy

- 2-part formula, 100 : 28 mix ratio by weight
- Low viscosity, lowered still by applied heat
- 30 minute working life, 8-16 hr. cure at 300 K
- Optically clear, electrically insulating



Conformal Thermal Pads

- 3M:
  - 5519S, 5591S
- Parker Chomerics:
  - Therm-A-Gap G579

- All three highly conformable, slightly tacky, electrically insulating
- Thermal conductivity (300K) 1-3 $Wm^{-1}K^{-1}$