PHASE CHANGE MATERIAL TRANSIENT HEATSINK FOR POWER SEMICONDUCTOR

Final Presentation

Team 9:

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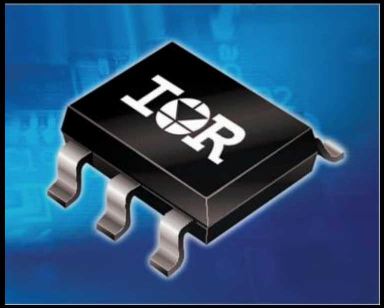
Sponsor: Unison Industries
Industry Contact: Kevin Walker

OUTLINE

- Motivation and Objectives
- Background Research and Design Concept
- Numerical Simulation and Design Selection
- Prototype/Test Bed Fabrication
- Test Results
- Manufacturing Plan
- Conclusion and Future Work

MOTIVATION



- Power Semiconductors
  - Found in jet engine's ignition units and power regulators
- Customer's need
  - Highly reliable, low-weight heat dissipation solution for these power semiconductors

OBJECTIVES

- Identify ideal PCM for heatsink
  - Given operating temperature range 115-125°C
- Numerical model to iterate through design concepts
  - Identify critical design parameters
- An experimental rig to test heatsink performance
  - Validate numerical model

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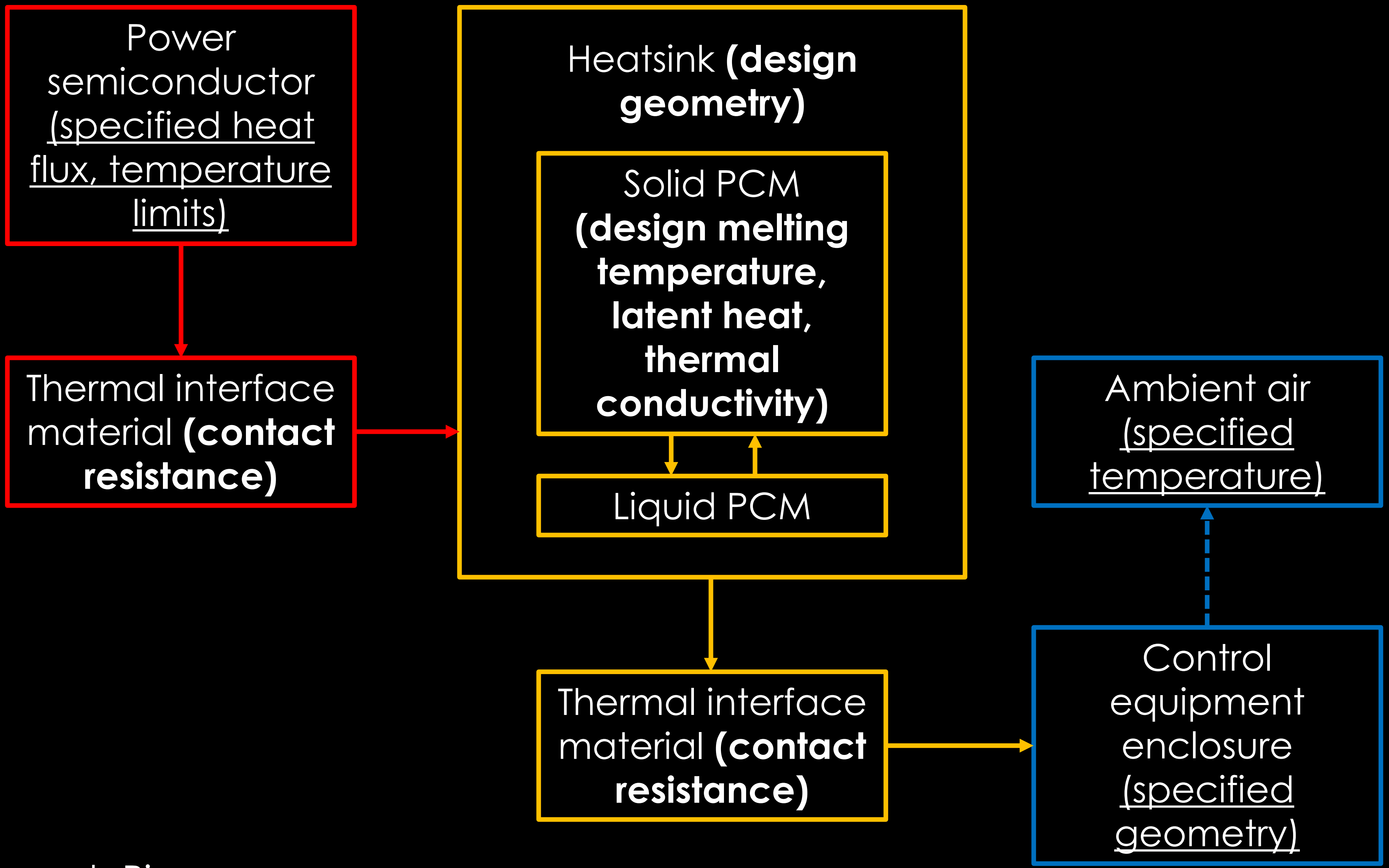
BACKGROUND RESEARCH

- Necessary to avoid IP conflicts and avoid designs known to be unworkable
- **Patent search** showed that phase change materials (PCMs) have been designed into heatsinks
  - **Limited design space** to geometries and materials not already patented
- **Technical articles**[1,2] gave quantitative evidence that **PCMs are a viable solution** for electronics cooling

[1]Krishnan, Purdue University Publications, 2005.
[2]Leland and Recktenwald, Portland State University, 2005.

DESIGN CONCEPT



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PCM SELECTION

	Material						
	Solders					Other	
	52In-48Sn	Bi50-Pb28	In75-Cd25	Bi46.1-Pb34.2	Bi55.5-Pb44.5	Sulfur	Wax
Melting Point (°C)	118	109	120	123	124	115	~60
Thermal Conductivity (W/m*K)	34	-	-	-	4	0.205	2
Latent Heat of Fusion (kJ/kg)	28.47	-	-	-	-	-	-

- data not available

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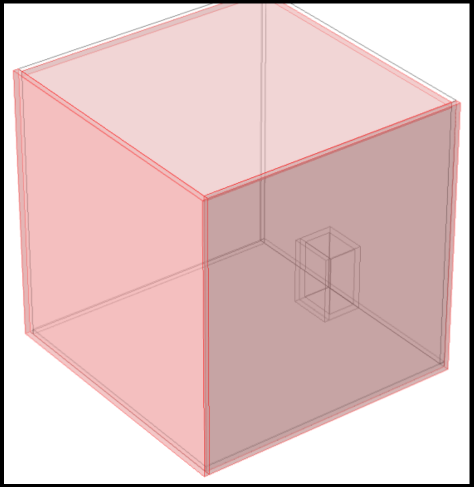
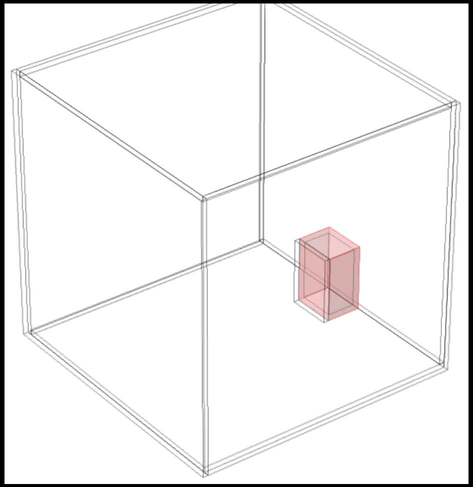
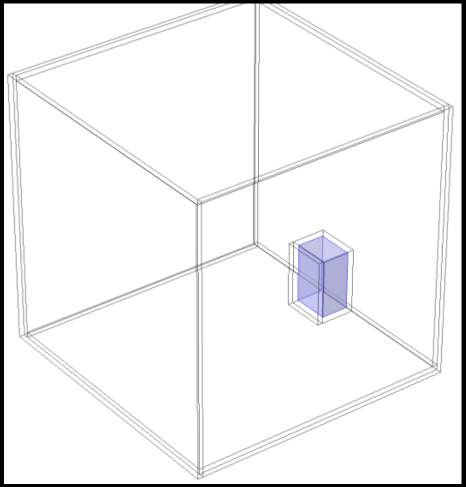
NUMERICAL SIMULATION



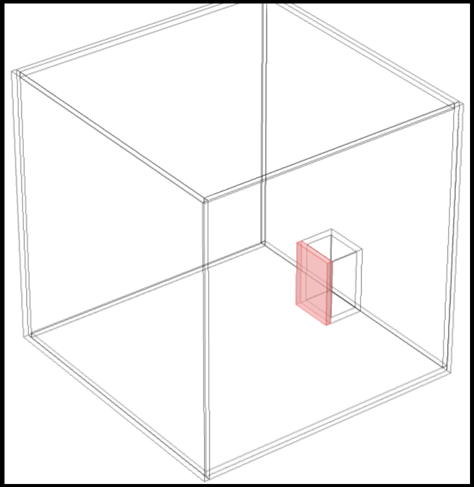
Aluminum Housing (natural convection)



Aluminum Heatsink (adiabatic)



PCM (0.65W heat absorption)



Molybdenum Base (1W & 2W heat generation)

RESULTS

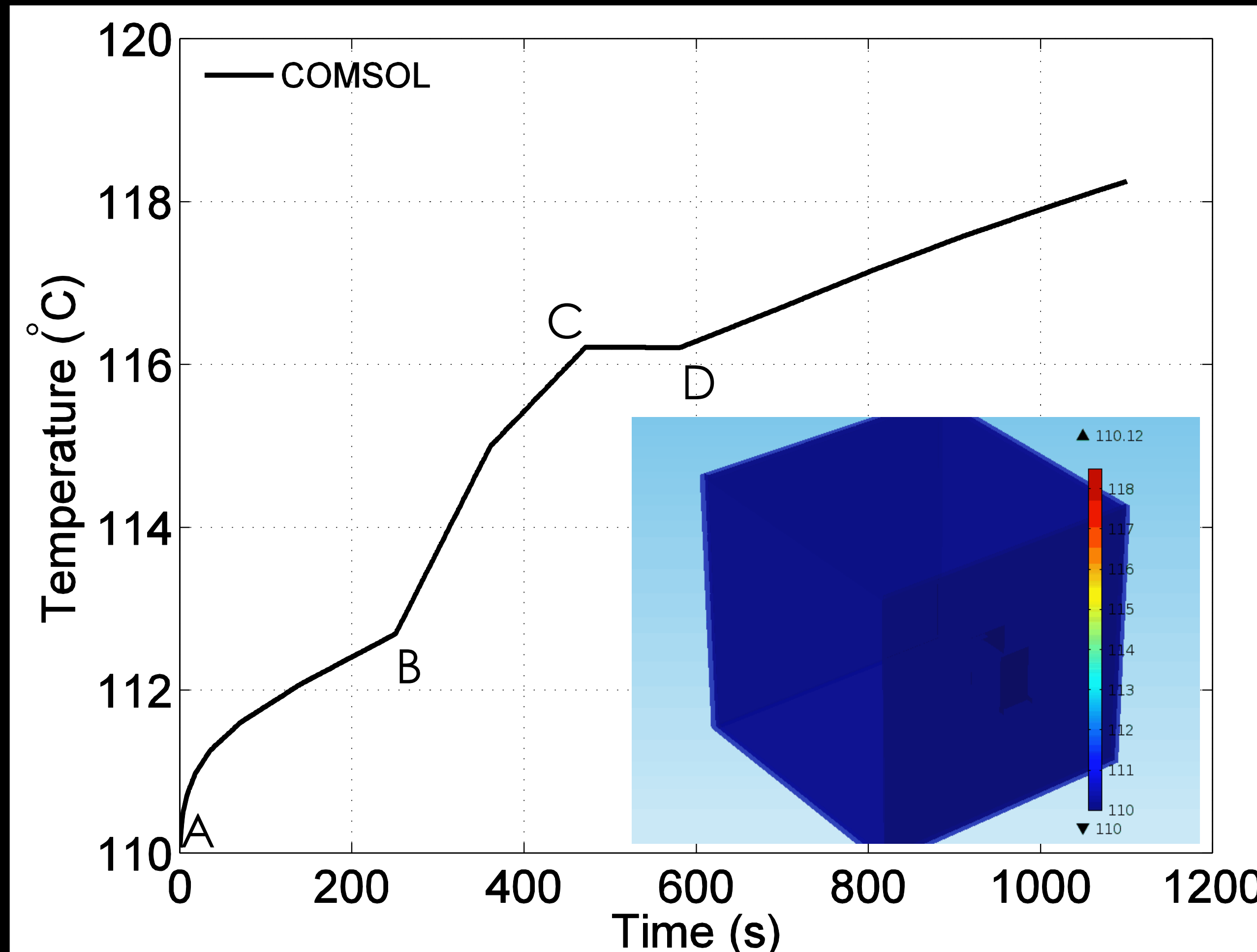
Volumetric average of molybdenum base

A – initial condition, begin 1W

B – jumps to 2W

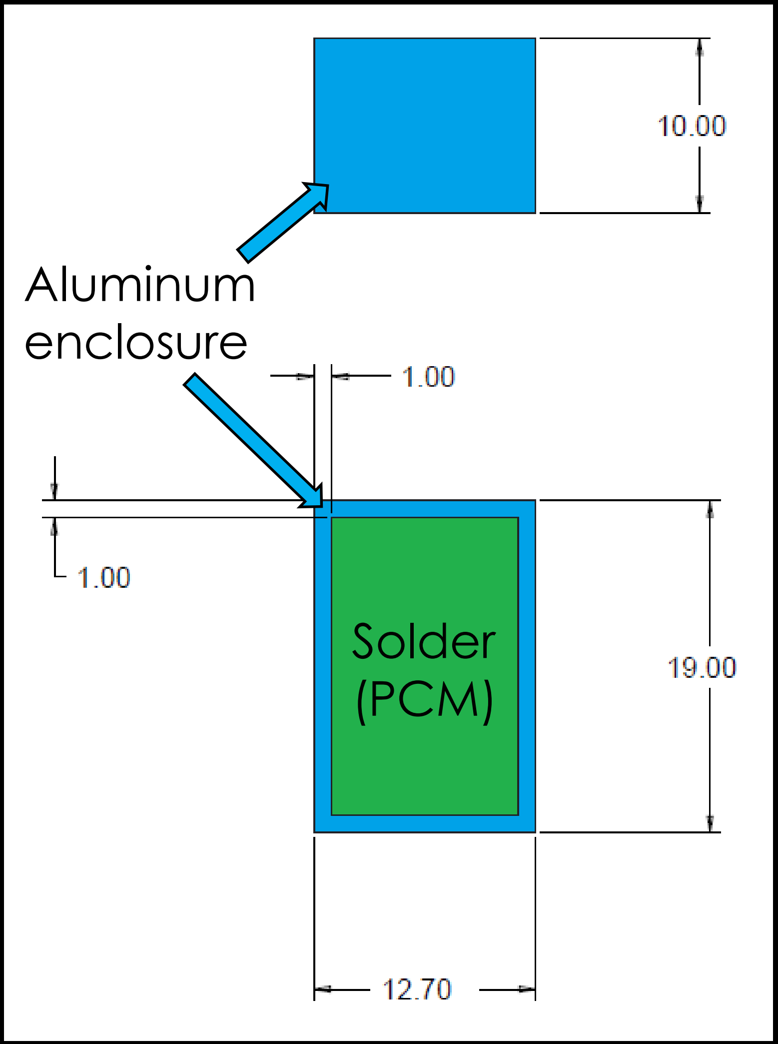
C – melting begins, heat absorption

D – heat absorption continues, liquid begins to heat up



ENCLOSURE SELECTION

- Iterations of COMSOL model led to these dimensions
- Designed to have a heat capacity of 300J
- Matches the dimension of the molybdenum base
- Dimensions are in mm



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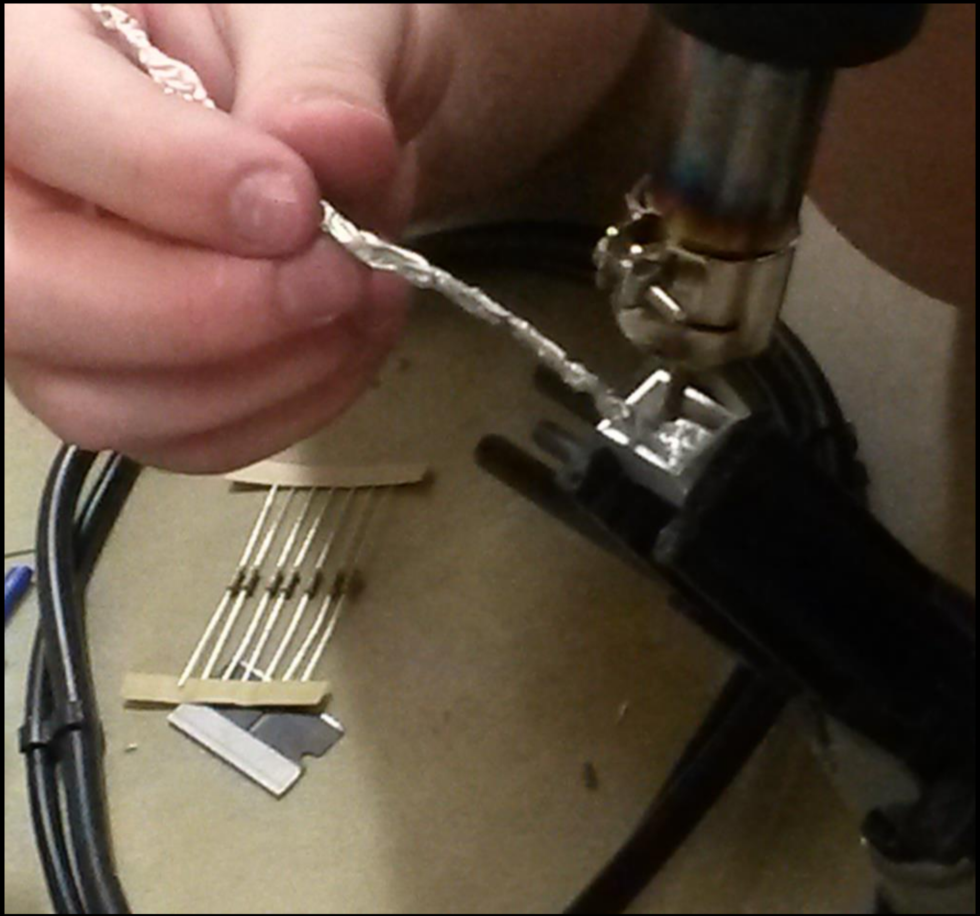
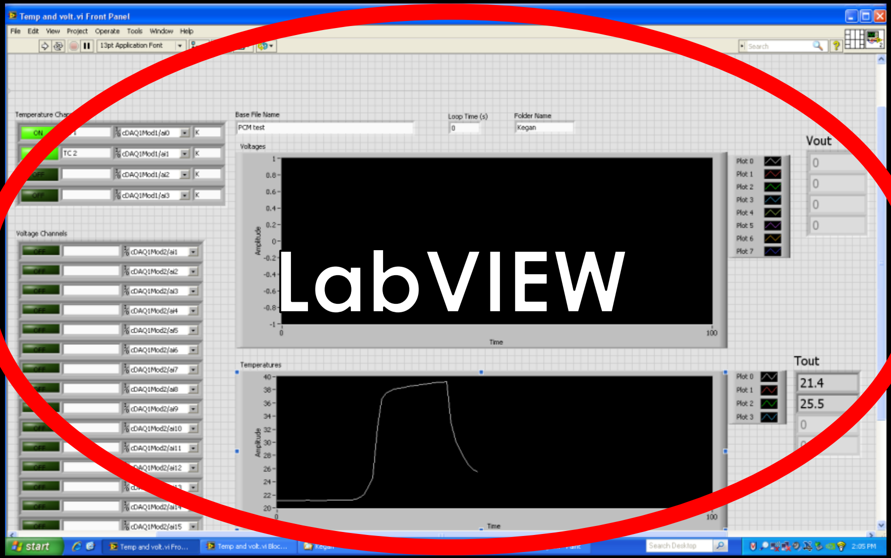
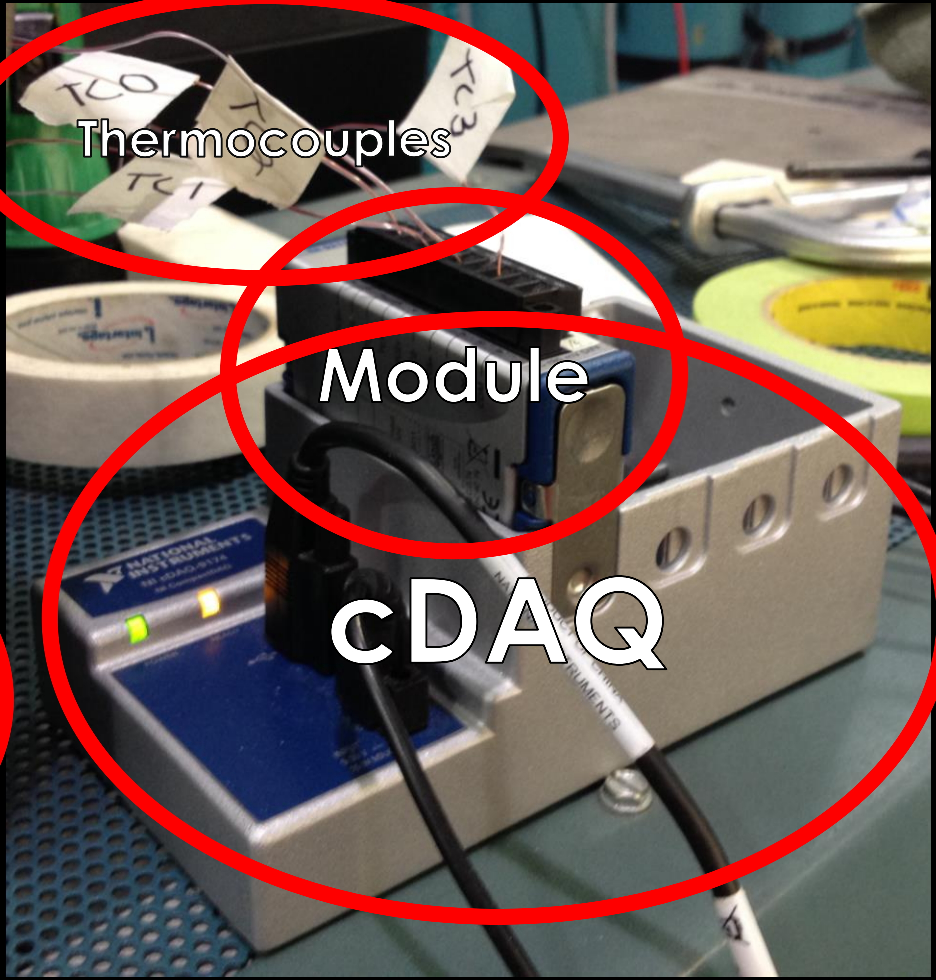
HEATSINK PROTOTYPING



TESTING EQUIPMENT

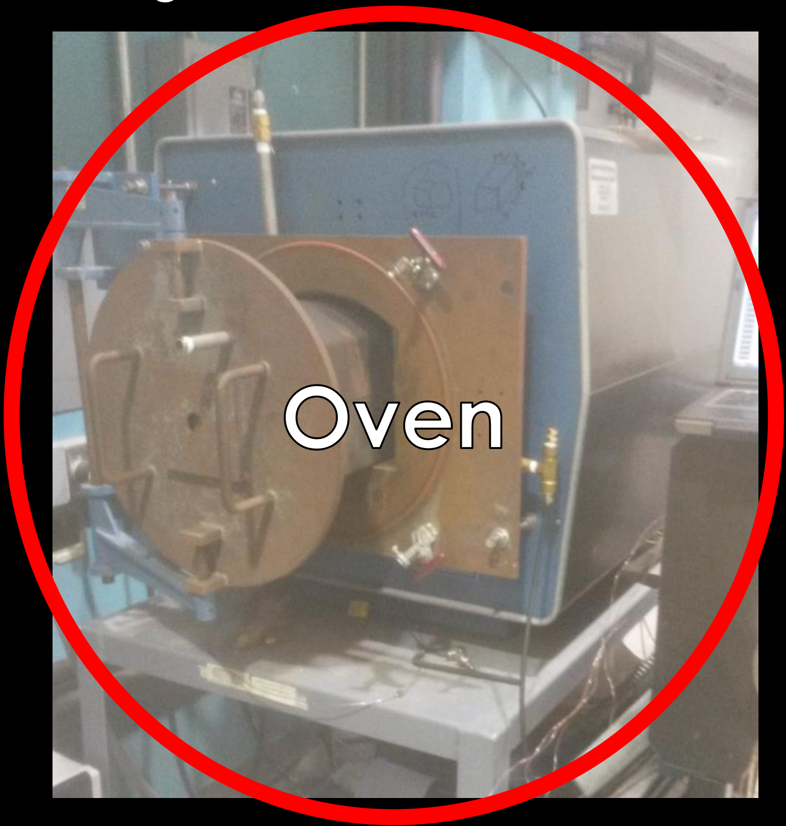
- Thermocouples – provided by Unison
- National Instruments NI module – supplied by Mag Lab
- NI cDAQ – supplied by Mag Lab
- LabVIEW – provided by Mag Lab





TESTING EQUIPMENT

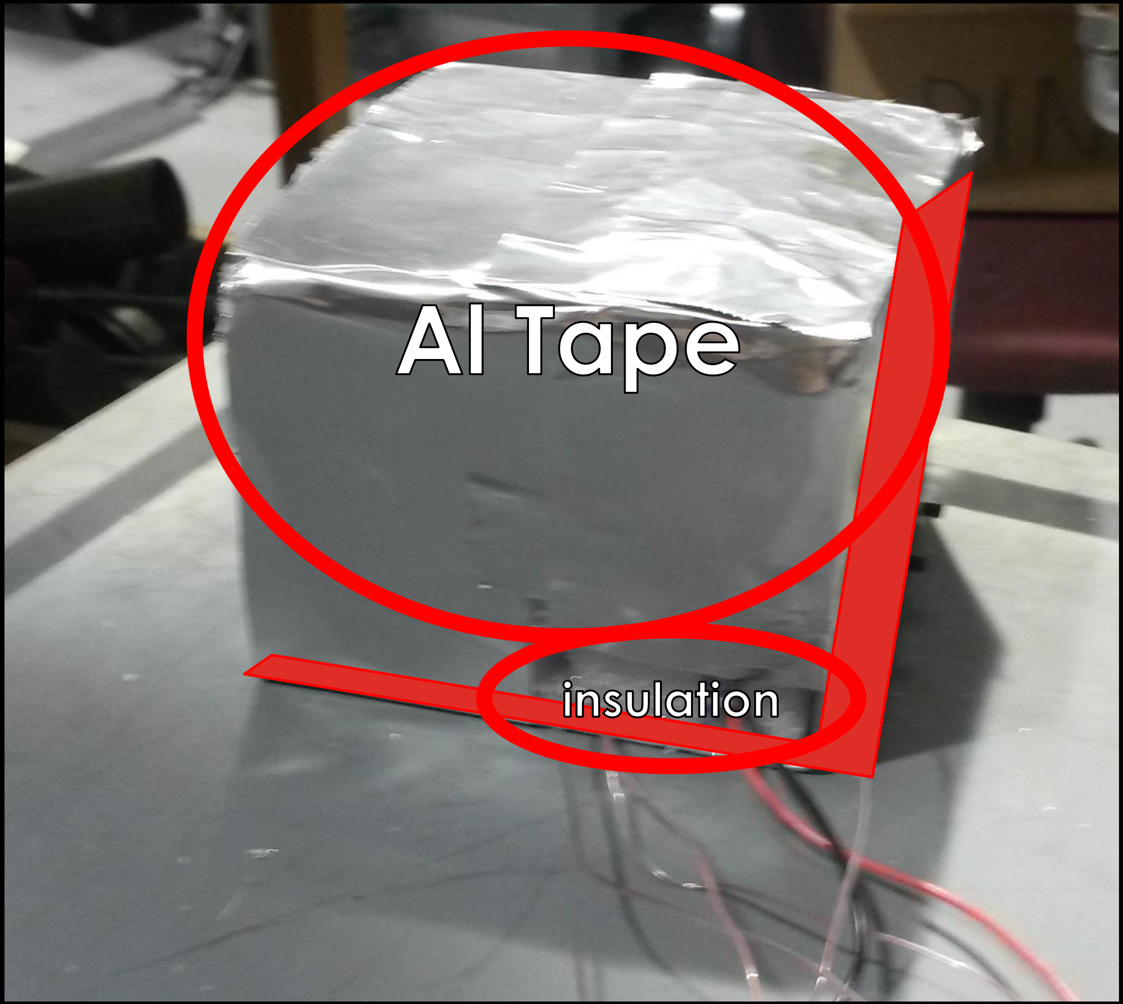
Lab oven – supplied by the Mag Lab



DC Power supply – provided by the STRIDE lab

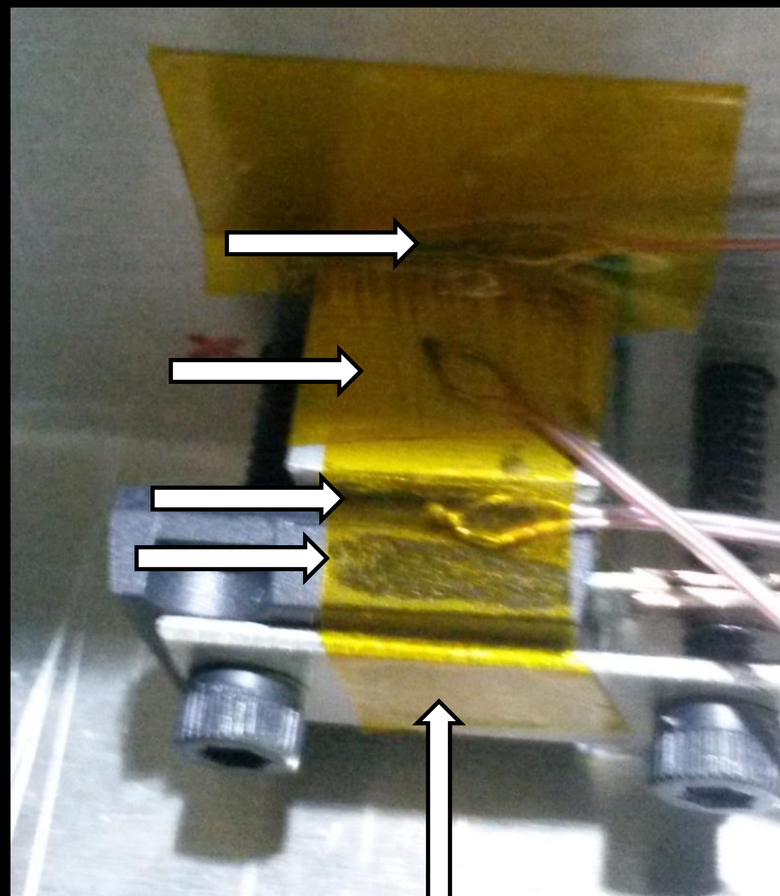
EXTERIOR ASSEMBLY SETUP

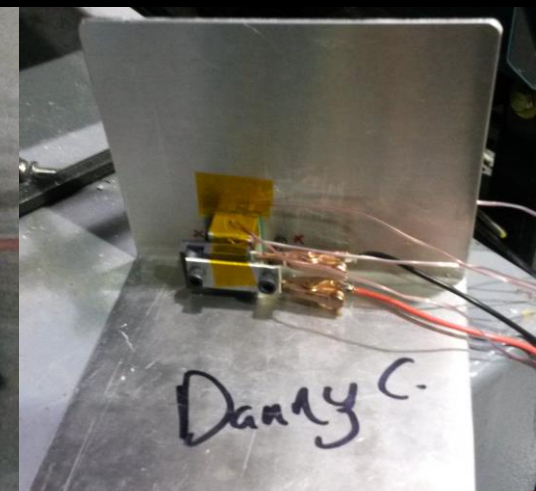
- **Aluminum enclosure** – provided by Unison
- **Aluminum tape** – simulate 4 other walls of enclosure
- **Styrofoam Insulation** – simulate adiabatic conditions

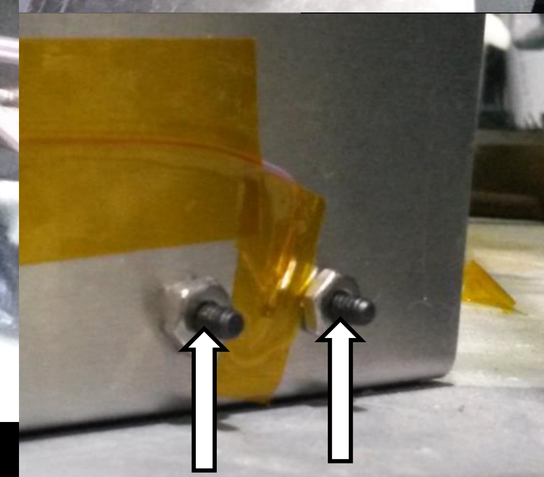


INTERIOR ASSEMBLY SETUP

- **100Ω Resistor** – generate heat
- **PCM Heatsink** – our prototype
- **Thermal interface material** – reduce contact resistance
- **Bracket** – ensure thermal interface material working optimally

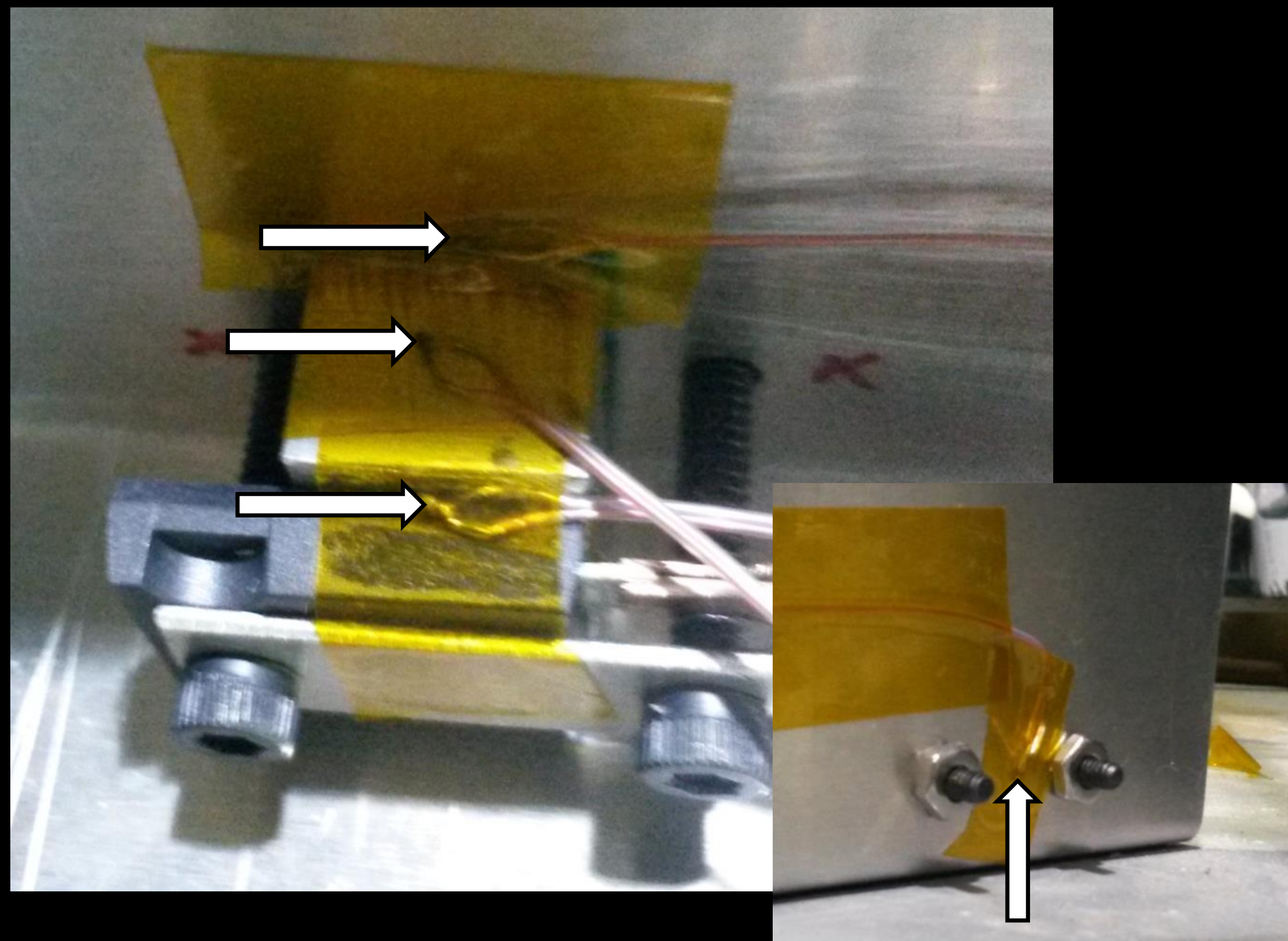






INTERIOR ASSEMBLY SETUP

- **Resistor-heatsink interface** – closest temperature of semiconductor
- **Heatsink** – indicate stage of thermal control
- **Inside Enclosure** – double check thermal network
- **Outside Enclosure** – dissipation of heat to ambient



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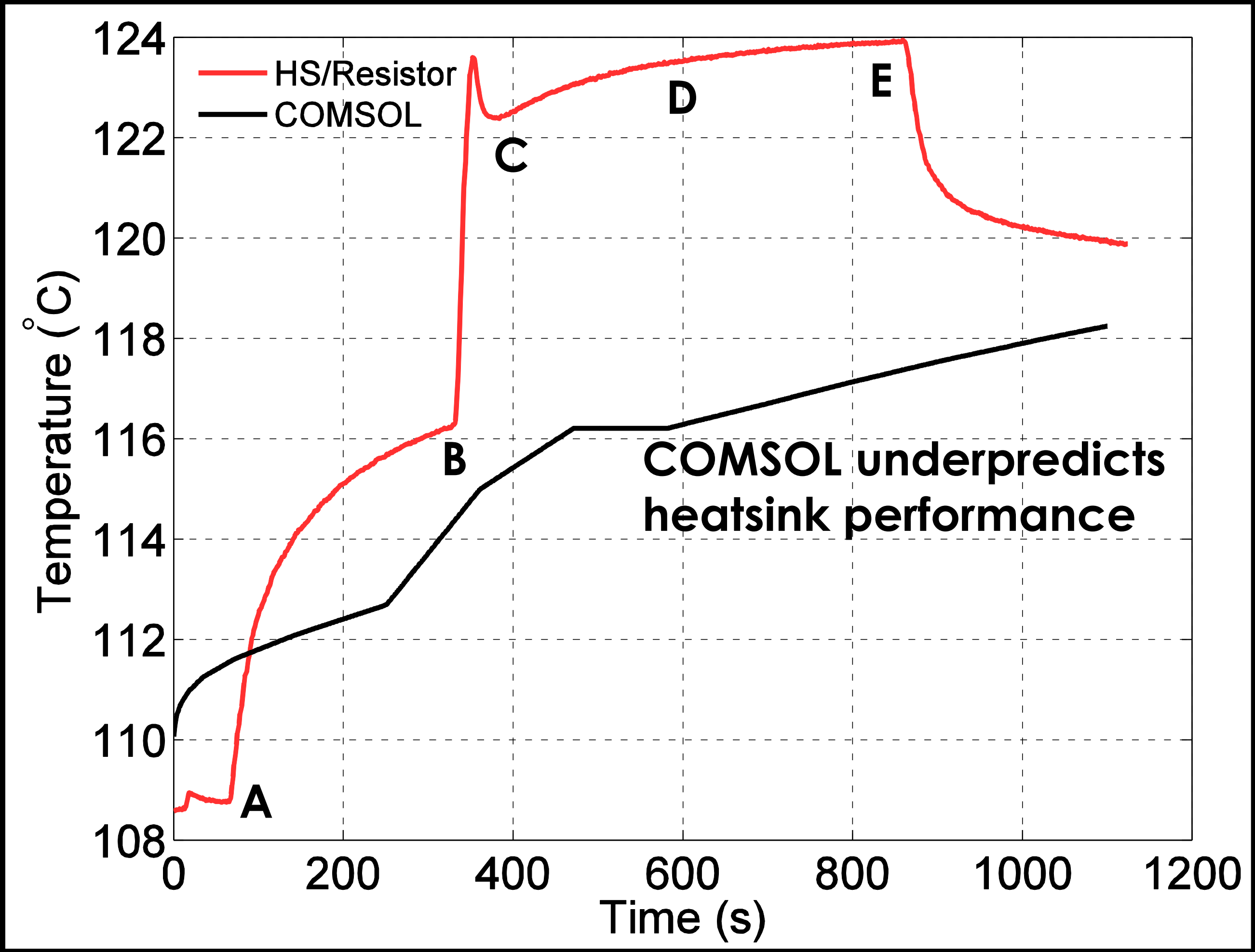
TEST RESULTS

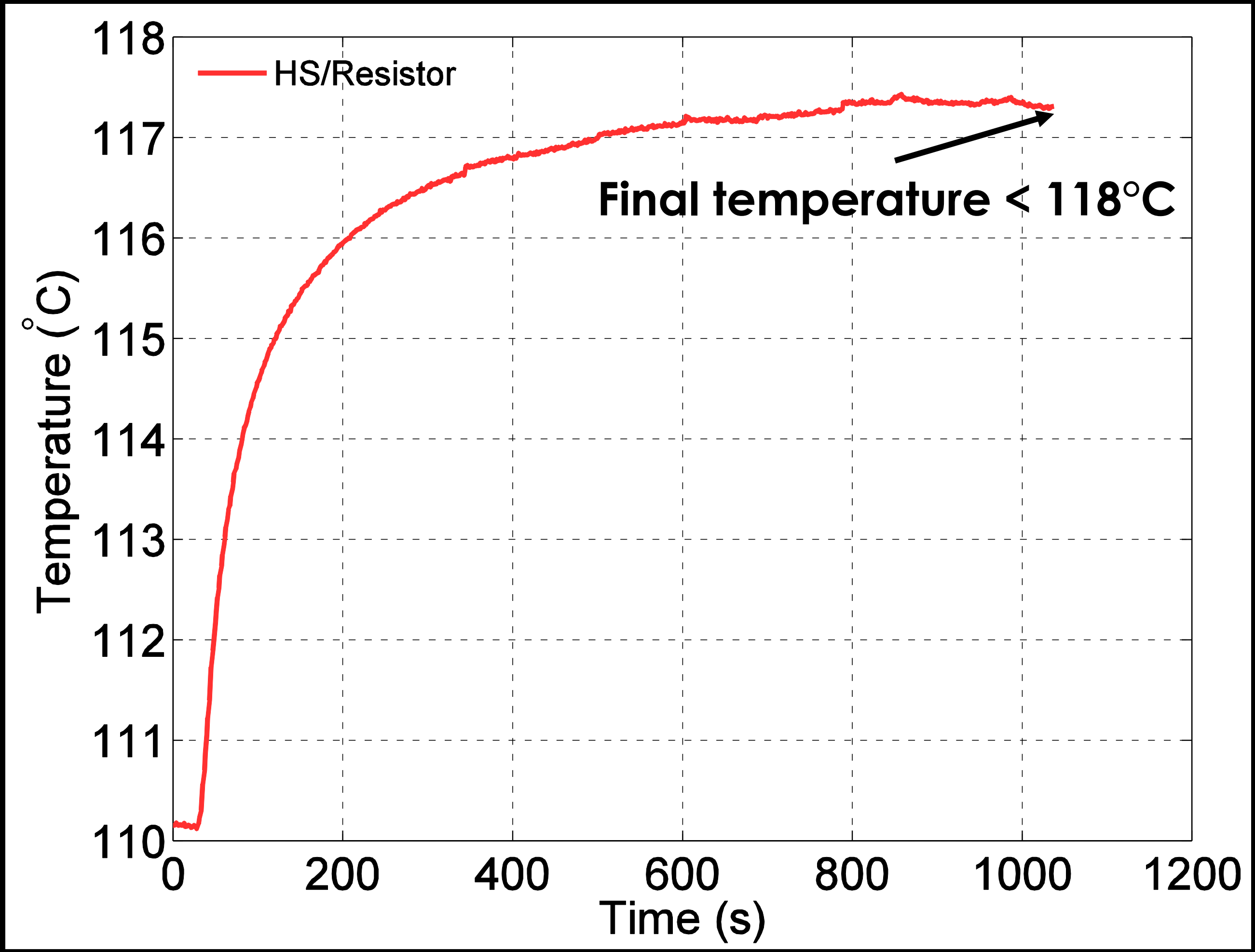
- **Experiment shows that prototype exceeds performance specifications:**



A: Resistor set to 1 W, oven turned off
B: Resistor accidentally set to 4 W
C: Resistor set to 2 W
D: Phase change occurring
E: Resistor set back to 1 W

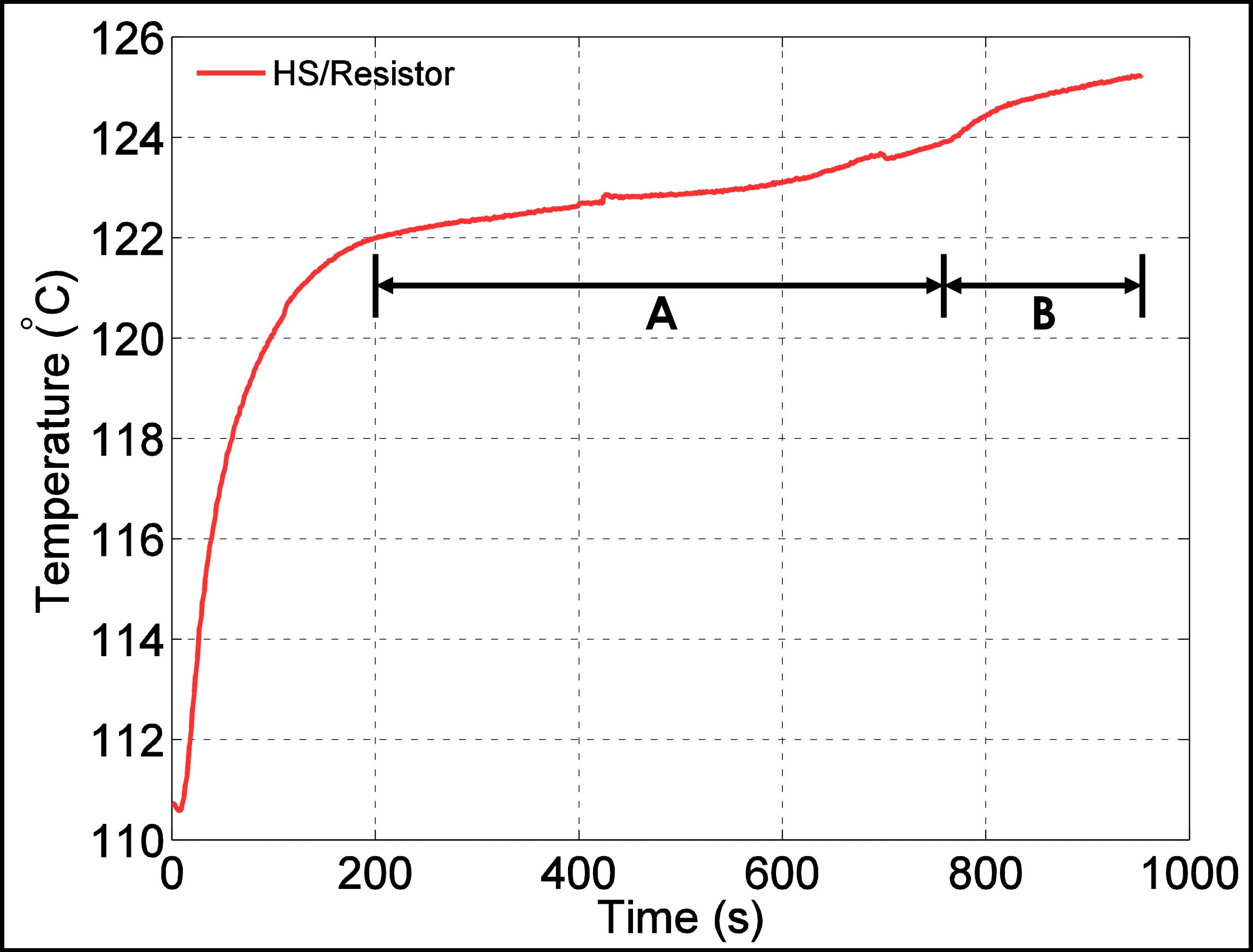
TEST RESULTS

- **Steady-state (1W dissipation) does not cause PCM to melt:**



TEST RESULTS

- **Overdrive (2W dissipation) confirms occurrence of phase change:**



A: Phase change occurring

B: PCM fully liquefied

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MANUFACTURING PLAN

- Enclosure: Hudson Technologies
    - Use deep-drawing to make **open box with close-fit lid**
- PCM: IndiumCorp
    - Purchase **solder ingots** for direct insert into enclosure
- Assembly: Unison
    - Insert ingot into open box, then **seal box using epoxy** (either as a preform or as a manually-applied paste)
        - Allows for **batch processing**: Batch of heatsinks inserted into oven at 150°C for 40 minutes to cure epoxy and break in PCM

MANUFACTURING PLAN

- Reliability concerns: Avoid cascade failure
  - Enclosure/solder durability: Necessitates **fatigue testing**
  - Part-to-part variability: Need a batch of parts for statistical analysis
    - Enclosure: Hudson guarantees accuracy to ±0.05 mm (**2% of smallest dimension**)
    - Solder: IndiumCorp's length/width and thickness tolerances lead to **maximum variance in total heat capacity from 282 J to 324 J (nominal is 300 J)**
    - Assembly:
      - Epoxy: Preforms would eliminate human factor
      - Oven processing: Unison **ovens are accurate to ±10°F (±5.56°C)**

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CONCLUSION

- Our team was tasked with developing a heatsink for power semiconductors in high ambient temperatures
  - Identified a PCM to serve as a thermally capacitive material
  - Used COMSOL to determine an appropriate PCM volume and enclosure geometry
  - Designed and used test platform to verify heatsink performance

FUTURE WORK

- Improve COMSOL model
- Develop adjustable test platform
- Source a better lab oven
- Implement thermocouples in array
- Source/develop less costly PCM
- Soakback (elevated ambient temperature) testing

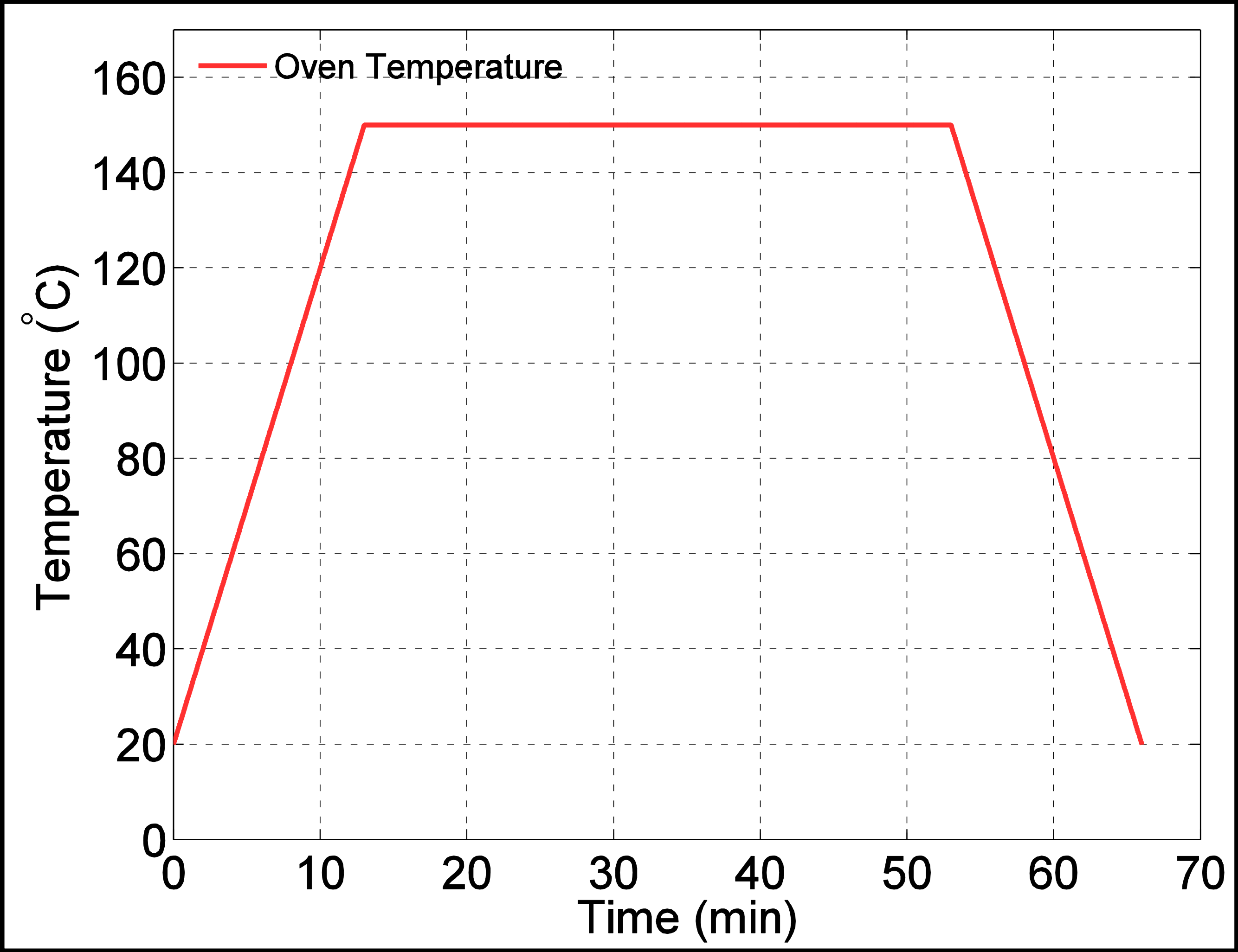
ACKNOWLEDGEMENTS

- Kevin Walker (Unison): Technical guidance, material provisions, and feedback on presentations
- Dr. Taira (AME): Technical guidance and feedback on presentations
- Dr. Shih and Dr. Amin (FSU): Feedback on presentations and reports, class organization
- Charlie Carbiener (STRIDe): Prototype fabrication
- James Gillman (CoE Machine Shop): Prototype fabrication
- Dustin McRae and Bob Walsh (NHMFL): Experimental setup

QUESTIONS?

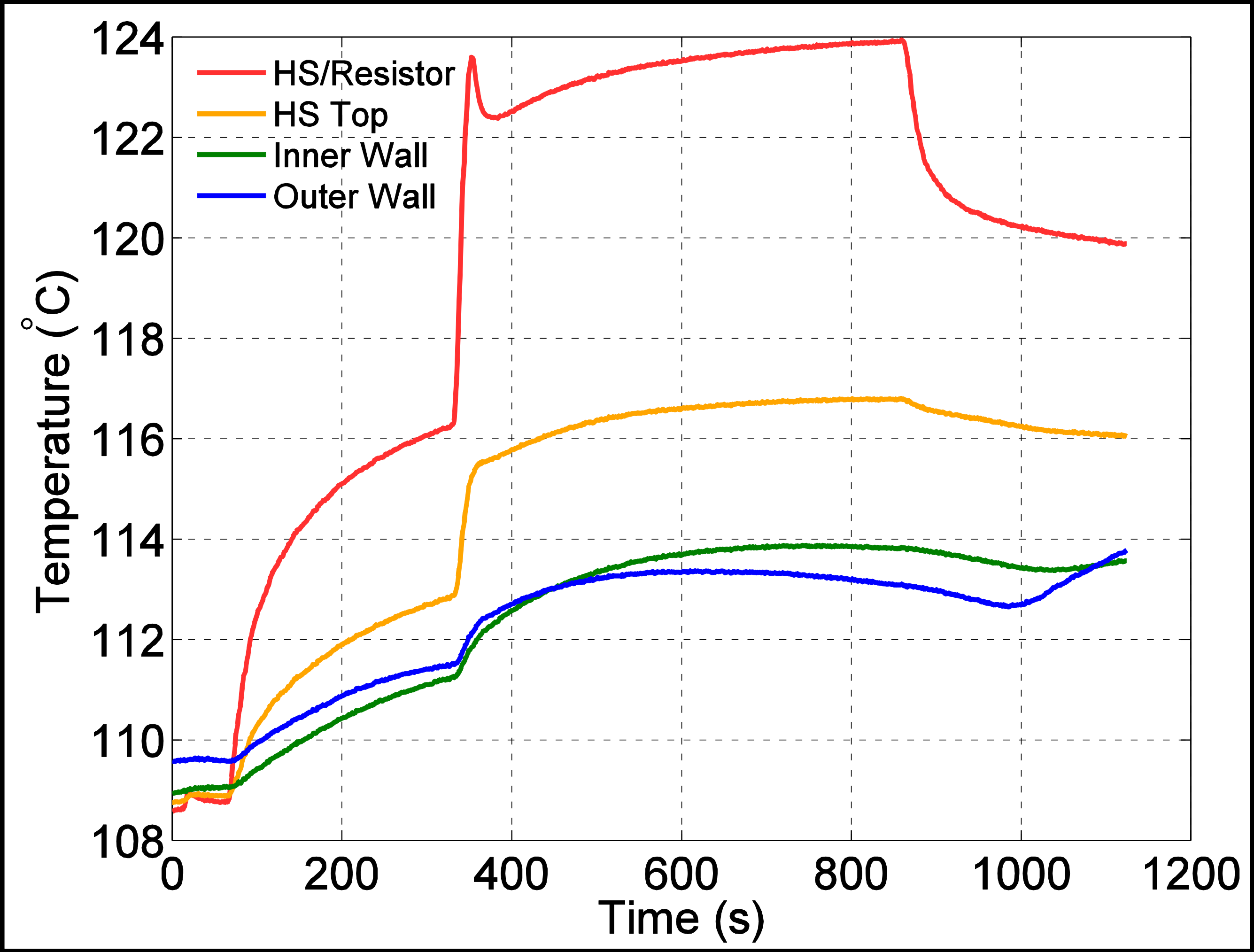
APPENDIX

- **Heat treatment profile for epoxy curing and PCM break-in:**



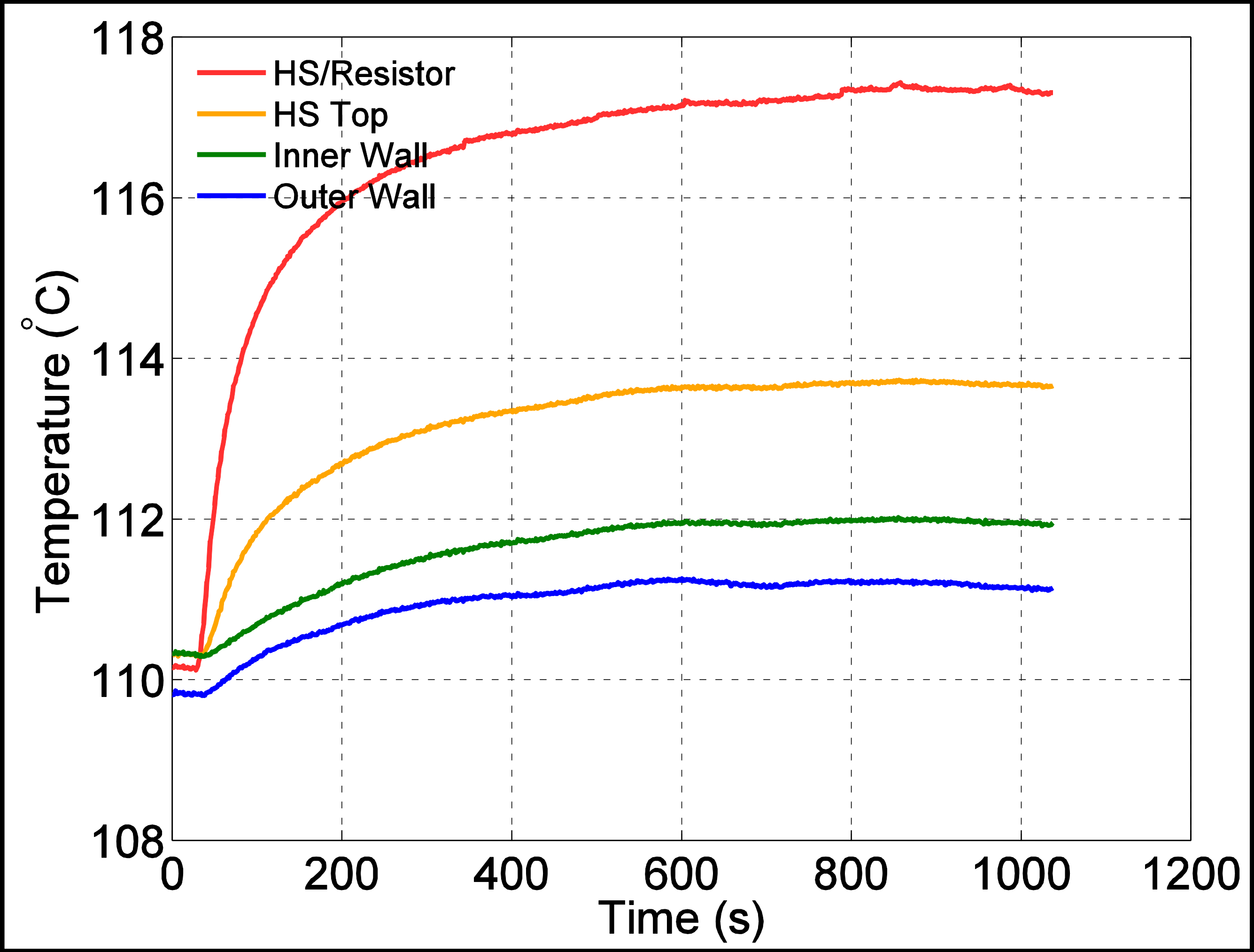
APPENDIX

- **Full duty cycle test (all thermocouples):**



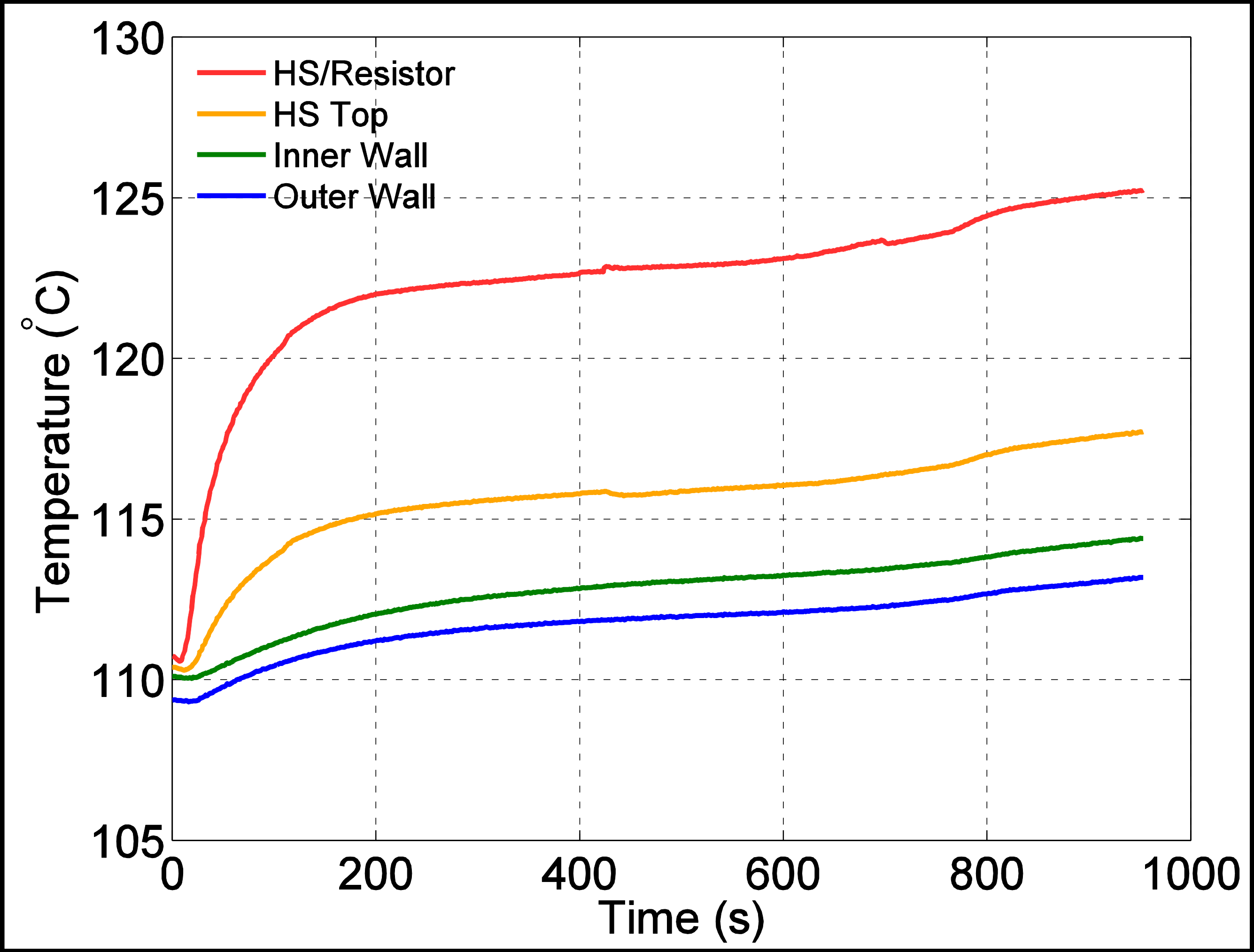
APPENDIX

- **Steady-state (1W) test (all thermocouples):**



APPENDIX

- **Overdrive (2W) test (all thermocouples):**



APPENDIX

Starred items obtained at no cost

Material/Equipment	Vendor	Amount	Unit Cost (USD)	Total Cost (USD)
MP9100 resistor	Digi-Key	1 pc.	10.90	10.90
52In-48Sn solder	IndiumCorp	3 ft	**265.00**	795.00
Aluminum tape	eBay	1 spool	40.00	40.00
Hi-Flow 300P*	Orion	1 pc.	48.00	48.00
NI 9211*	National Instruments	1 pc.	351.00	**351.00**
cDAQ 9174*	National Instruments	1 pc.	762.00	**762.00**
LabView Full	National Instruments	1 license	2699.00	**2699.00**
DC power supply*	Digi-Key	1 pc.	489.00	**489.00**
Lab oven*	Mellen	1 pc.	2499.99	**2499.99**
Type K thermocouple*	Omega	4 pcs.	30.00	120.00
Aluminum bar*	Various	26 cu. in.	5.00	5.00
Thermal contact tape*	eBay	1 spool	4.50	4.50
Machining*	N/A	2 hours	20.00	40.00
Remaining Budget (including starred items):				**-5864.39**
Remaining Budget (excluding starred items):				**1154.10**

- Allocated budget was $2,000
  - Majority of cost would be incurred in purchasing testing equipment: One-time capital investments
  - Well under-budget (excluding starred items) and do not anticipate any other major purchases