Cryogenic Thermal Conductance Measurements of Candidate Materials and Components for WFIRST

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Introduction

- WFIRST is the next generation space telescope after JWST. The IR detectors works at Cryogenic temperature.
- Materials for cryogenic instrument thermal design
  - High conductivity material to reduce the temperature difference between the cooling source (radiator or cryocooler) and the instrument.
  - Low conductivity material to reduce parasitic heat (support structure, wires).
- Characterization of materials and joint conductance for cryogenic system design
  - Accurately predict parasitic heat, Delta T
  - Accurately analyze temperature gradient of detector/mirror/lens

List of tests

- Component tests
  - Annealed pyrolytic graphite (APG) conductance bar
  - Al 1100 Bonded Joint
  - Al 1100 Welded Joint
  - Bolted joint conductance
  - Harness
- Thermal conductivity tests
  - Al 6101
  - Al 1100-H14
  - CuW (20/80)

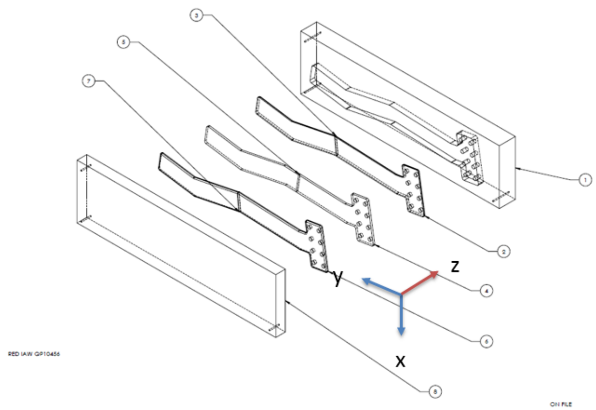
Annealed pyrolytic graphite (APG) Bar

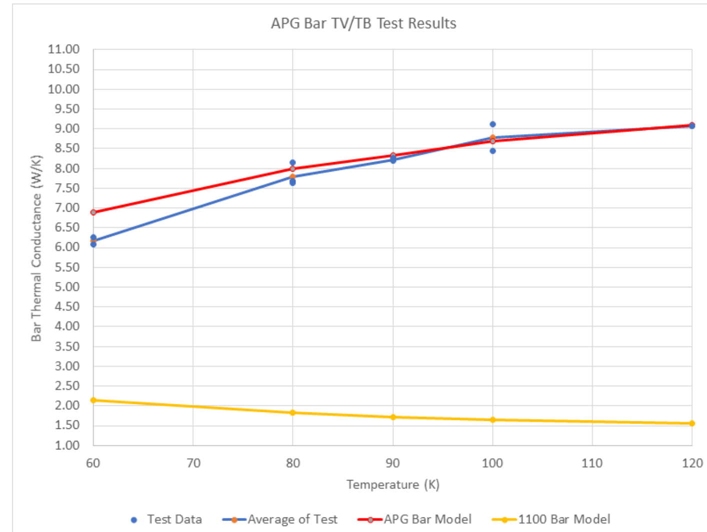
- APG bar: high performance thermal conductance bar.
  - K-core®
- Annealed pyrolytic graphite
  - Primarily used as a heat spreader for the thermal management;
  - An anisotropic material with extremely high in-plane thermal conductivity, and low through-thickness conductivity;
  - Very poor mechanical properties

Instrumentation & Techniques

- Calibrated Diodes
  - Bar end-to-end performance
  - Paired at joint for joint conductance
- 2nd order differential Measurement
  - To reduce errors caused by parasitic heat, and sensor inaccuracy, temperature changes were measured at two significantly different heat loads
    - $G = \frac{\Delta\,(Q)}{\Delta\,(dT)}$

Annealed pyrolytic graphite (APG) Bar





End to end thermal conductance

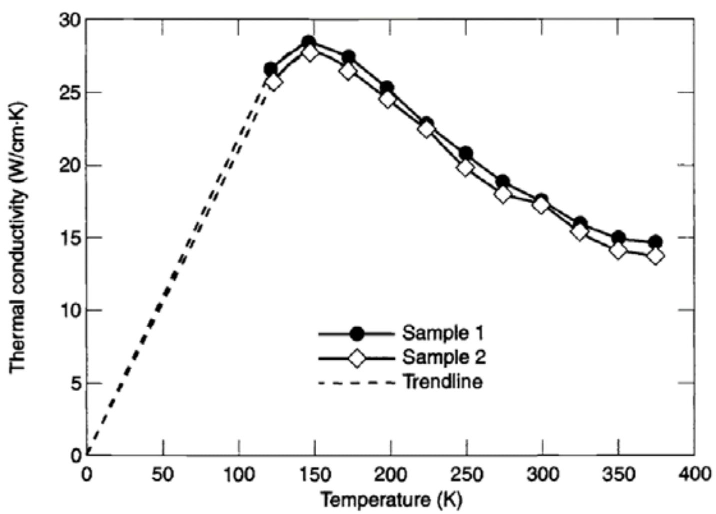
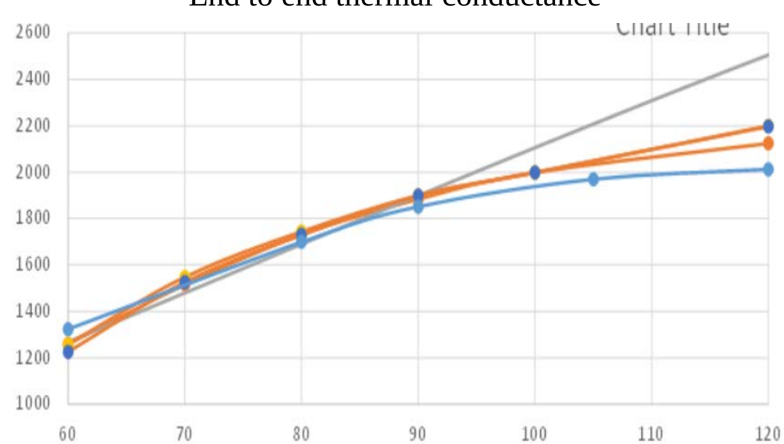


Fig. 22.24. In-plane thermal conductivity for annealed pyrolytic graphite.[22.21]

Reference: Spacecraft thermal Control handbook



APG thermal conductivity (In Plane)

Al 6101 (HIP) Thermal Conductivity

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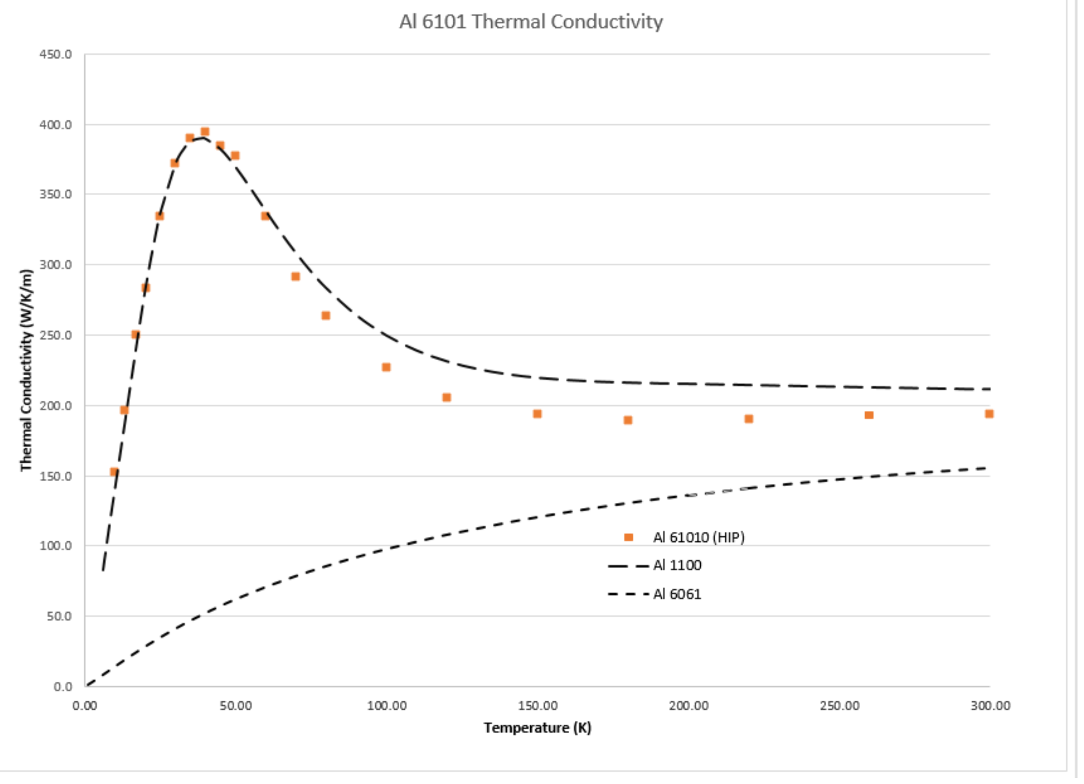
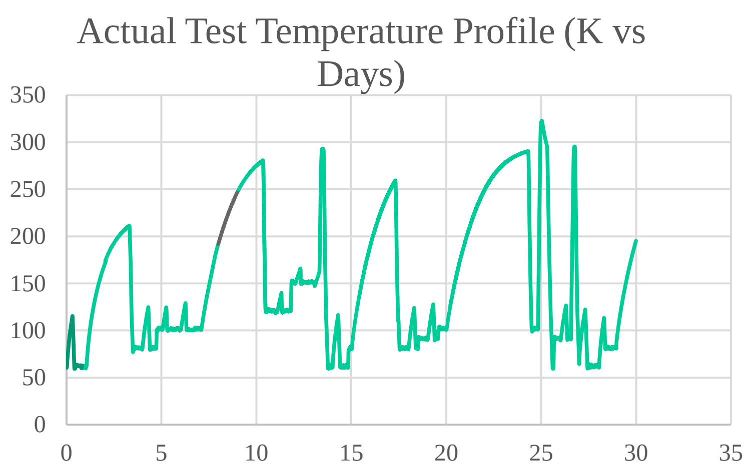
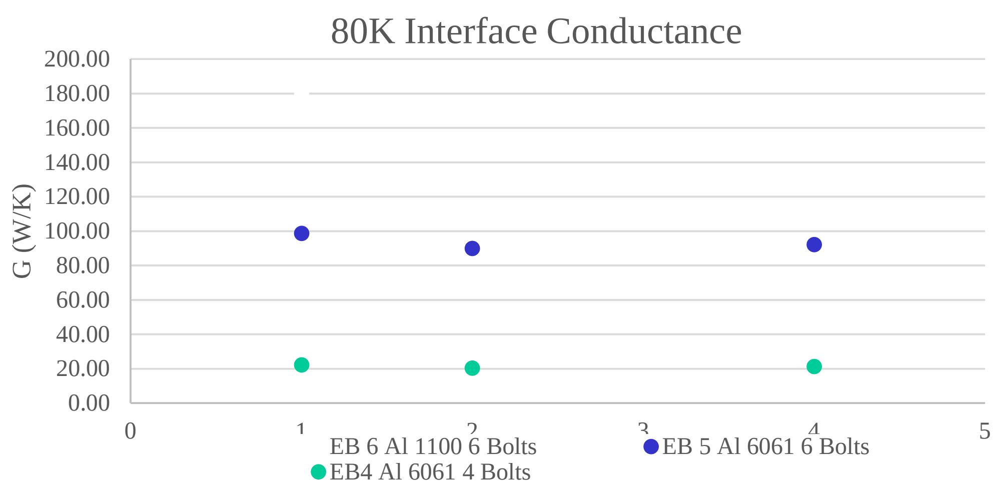
- Al 6101 is used as to encapsulate APG. The bar was treated with high temperature and high pressure.



Joint conductance

- Factors that affect joint conductance
  - Materials
  - Interface roughness & flatness
    - Indium
    - Grease
    - Coating
  - Preload
  - CTE & compensator





Material Test Configuration

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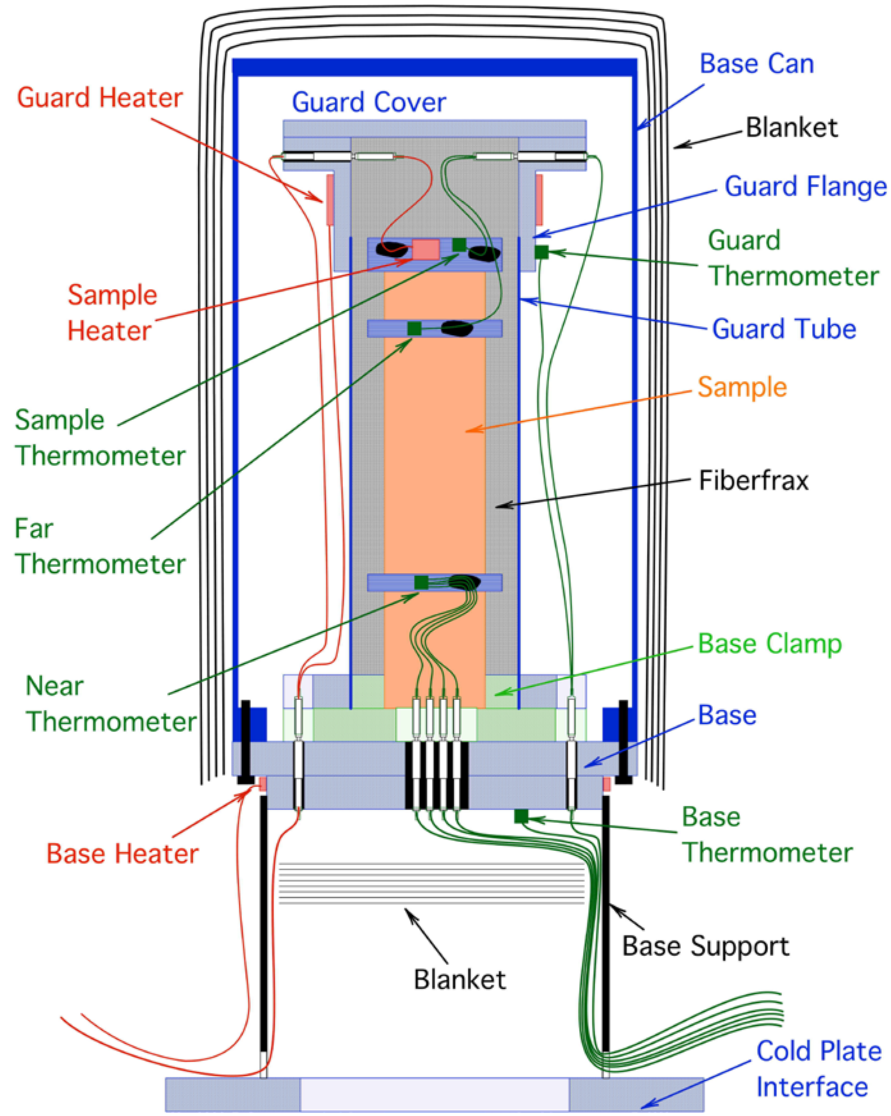
- Based on approach described in 1973 Moore, Williams and Graves RSI paper
- Guard surrounds sample:
  Controlling $T_{\text{Guard Top}} = T_{\text{Sample Top}}$
  reduces sample heat radiation
- “Fiberfrax” insulation eliminates remaining sample radiation
- Intermediate thermometers eliminate joint resistance effect
- Optimizing sample heater and leads minimizes ohmic heating in leads
- Lead heat-sinking minimizes lead heat conduction

Reference: Cryogenic Thermal Conductivity Measurements on Candidate Materials for Space Missions by Jim Tuttle, Ed Canavan, and Amir Jahromi



Instrumentation & Techniques

- Thermometers
  - LakeShore Cryotronics SD-package Cernox™ sensors
  - Calibrated (resistance vs. *T*) from 1 to 325 K
- Heaters
  - Sample heaters are resistors sized by required Q (heat flux).
  - Base and guard heaters: 50 W
    - made by winding stainless steel wire around flange
    - we don't measure the power for these heaters
- Temperature readout/control boxes
  - Cryogenic Control Systems Cryocon Model 32B Controller
- Heater voltage and current readout
  - Keithley Model 2000 6.5-digit multi-meters
- Thermal desktop models
  - Pretest plan (size heaters)
  - Post test data analysis

Al 1100 – H14

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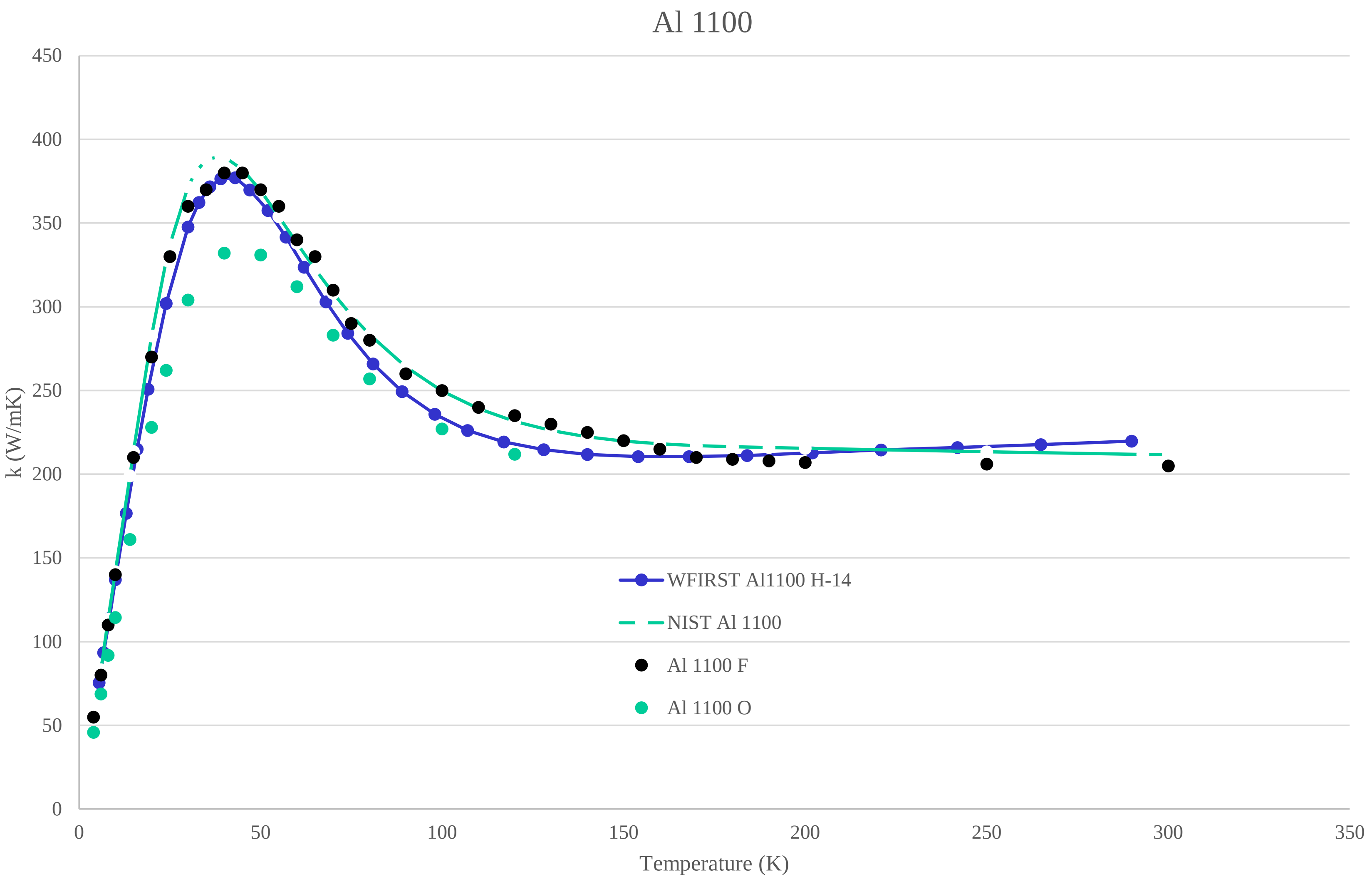
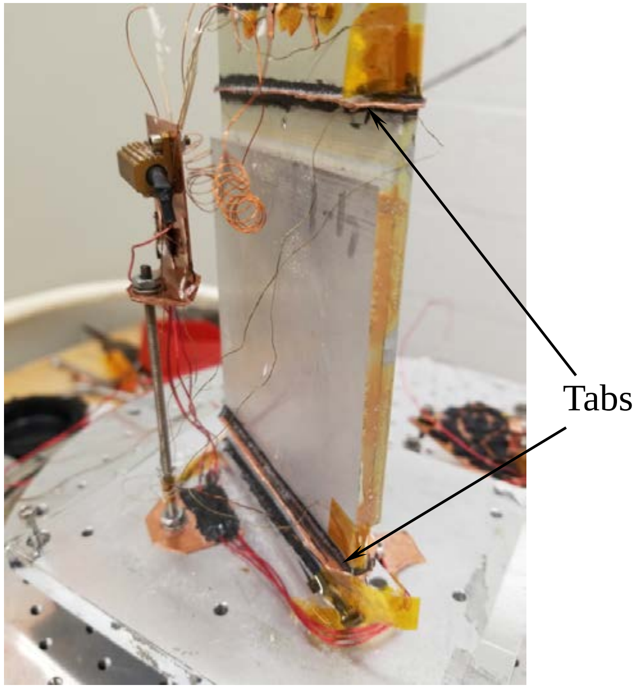
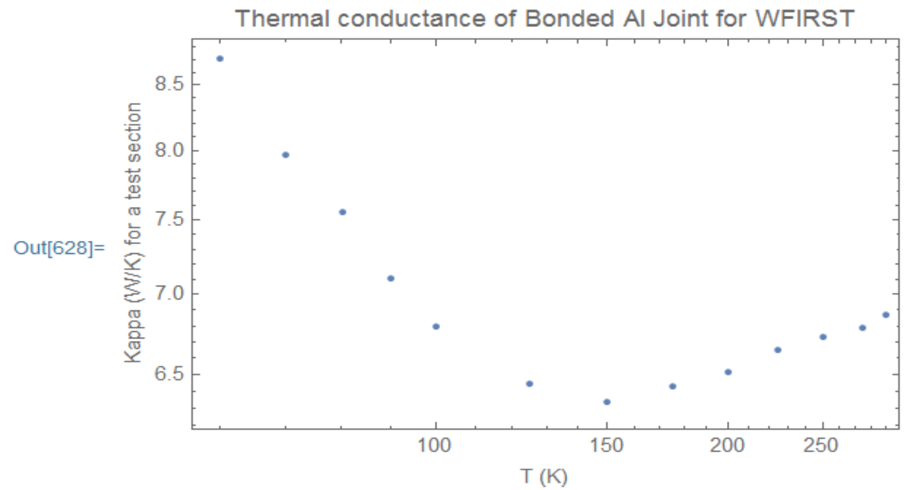
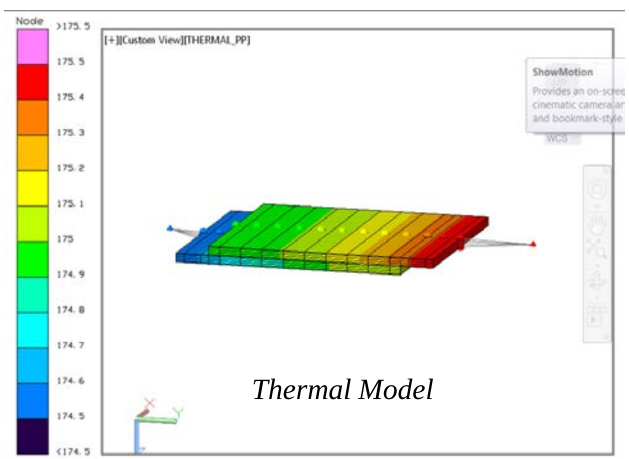


Al 1100 Bonded Joint

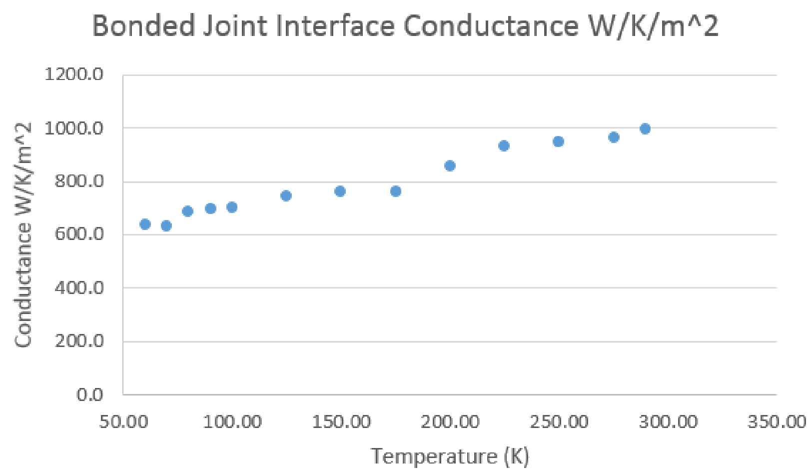




Thermal conductance of the sample between tabs

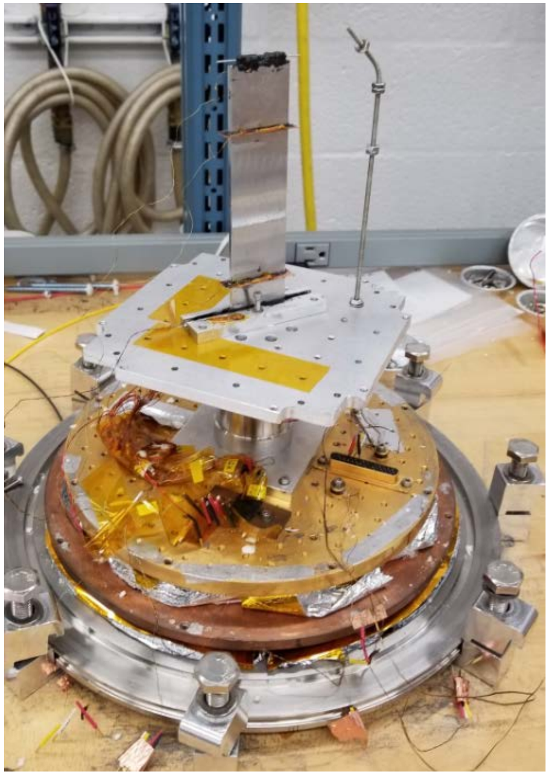


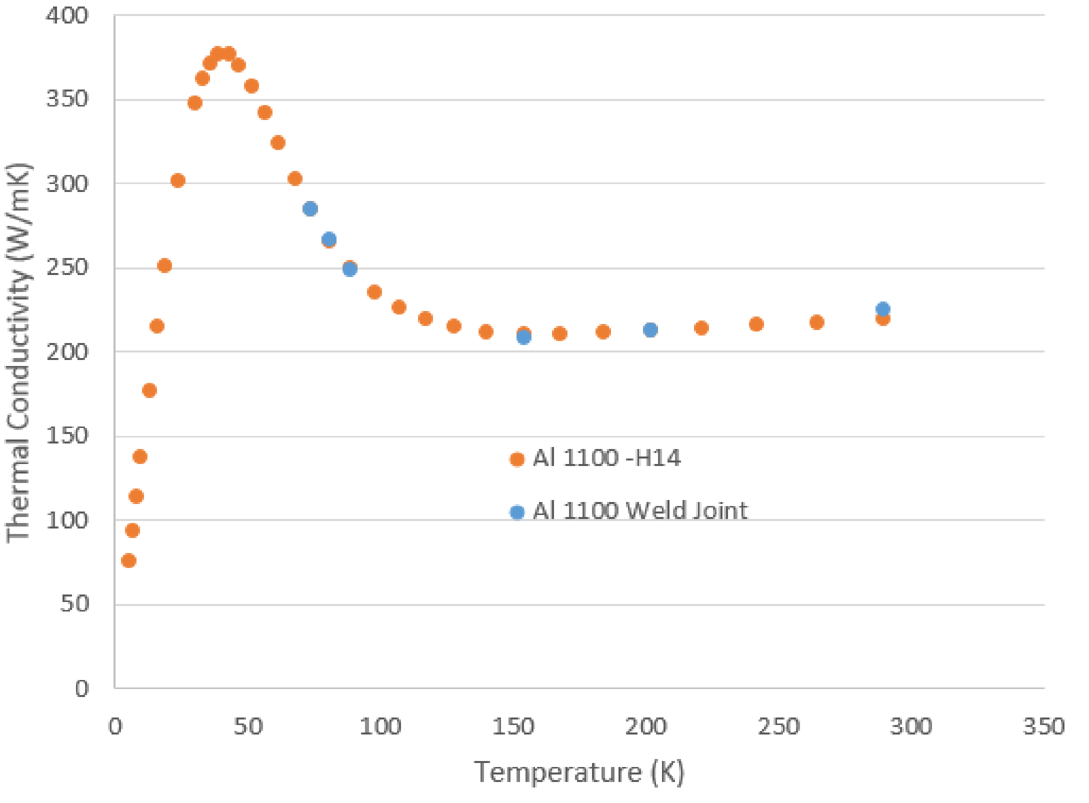
Thermal Model



Joint Conductance by thermal analysis

Al 1100 Welded Joint





Friction Stir Welding by Marshall Spaceflight Center

CuW (20/80)

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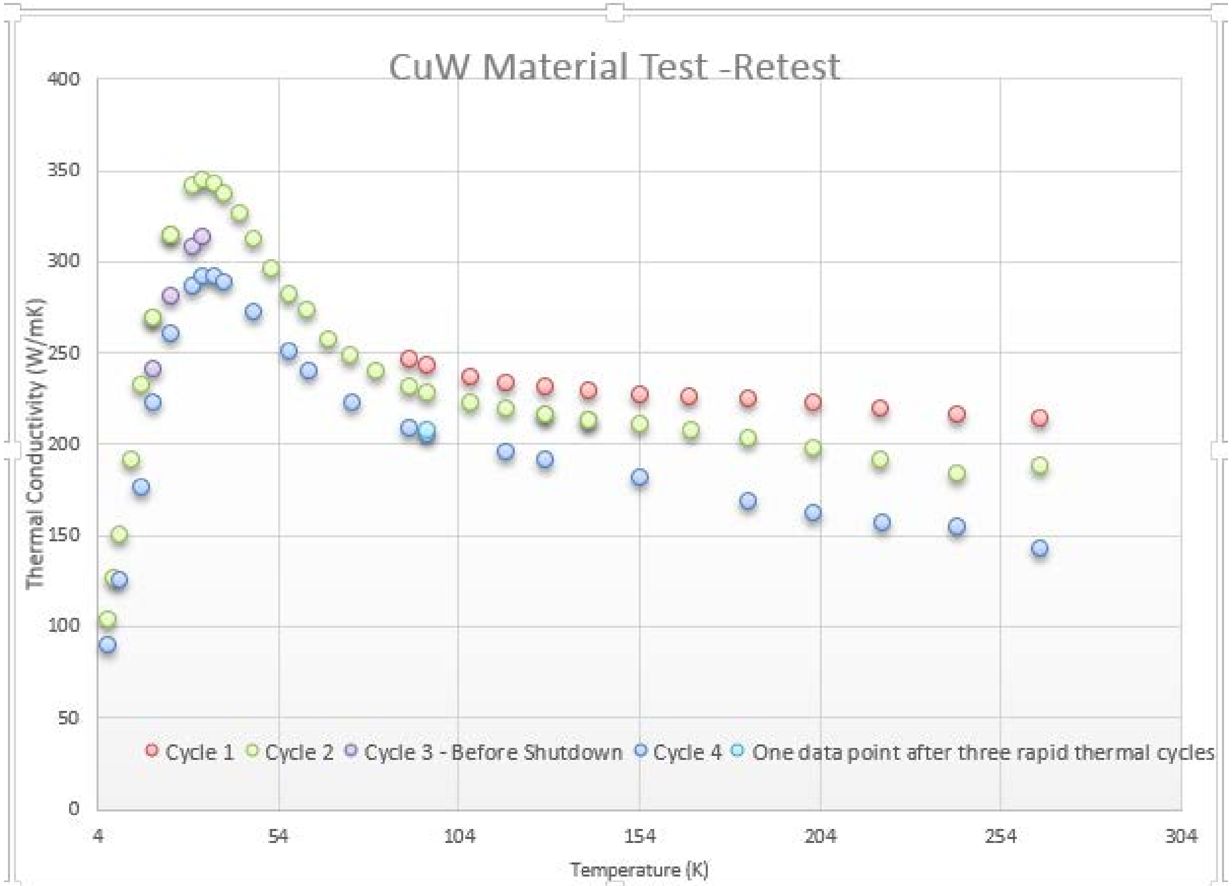

American Metal INC.
80% Tungsten 20% Copper

CuW Mechanical Tests

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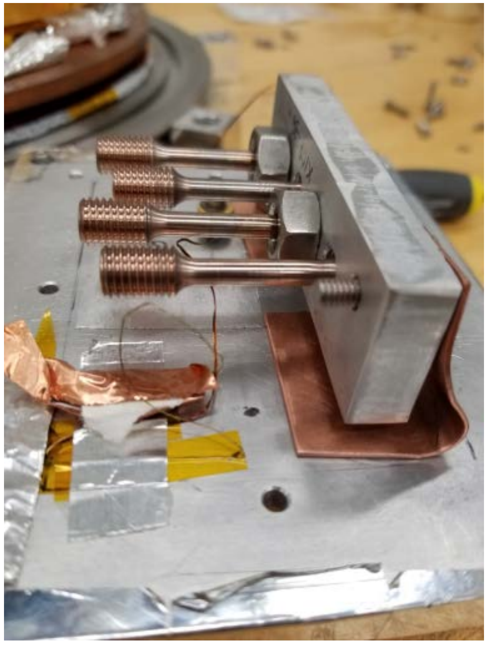

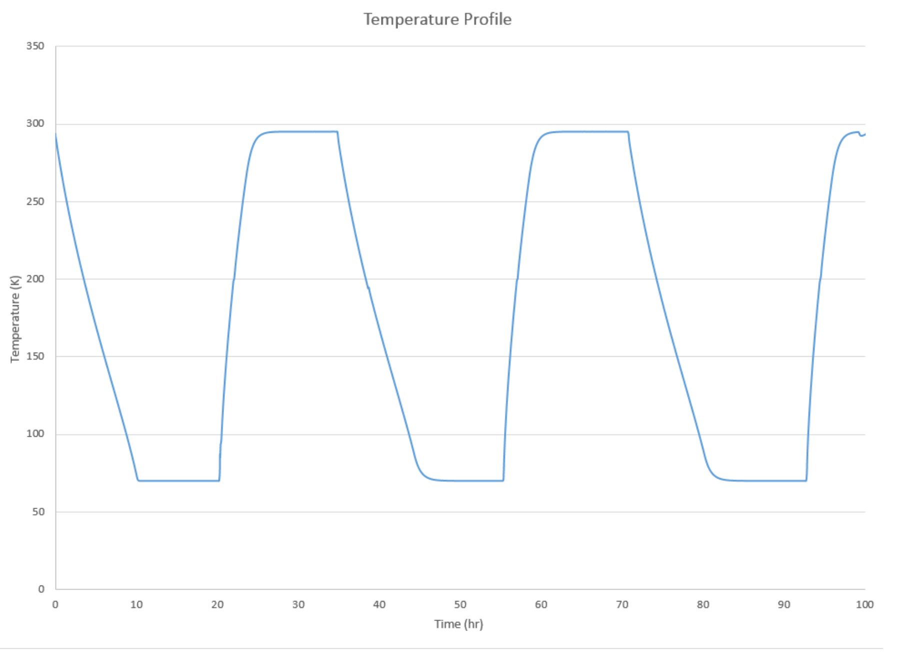

Thermal cycling effects are temporary and the material restores its original material properties after a specific amount of time after exposure to room temperature.

CuW Discussion

- Thermal cycle may cause micro-cracking because of CTE difference between Cu and W. Micro-cracking can cause the degradation of the thermal conductivity.
- Recommendation
  - New sample test with extensive dwelling time at room temperature
  - Microscopic examination of the sample after cryogenic thermal test

Summary

- Several thermal components and materials were tested for WFIRST project.
  - Encapsulated APG thermal conductivity is 1650W/Km at 95K.
  - The conductance of FM300 bonded joint is 650 W/K/m2 at 70K.
  - Friction Stir welding was used to weld two Al 1100 plates, and there is degradation of the conductance at the joint.
  - CuW thermal conductivity varies with thermal cycles, and more CuW tests were recommended.