Update on thermal studies of silicon tracker cooling

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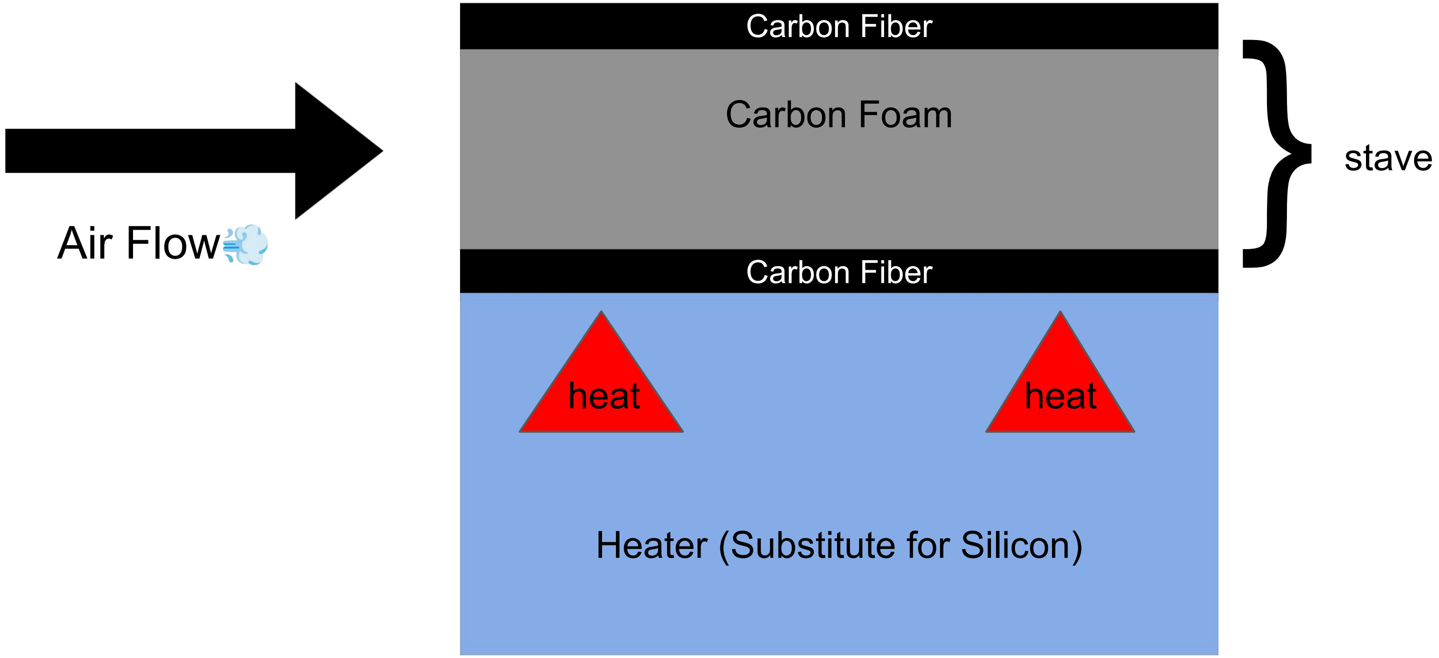
Introduction

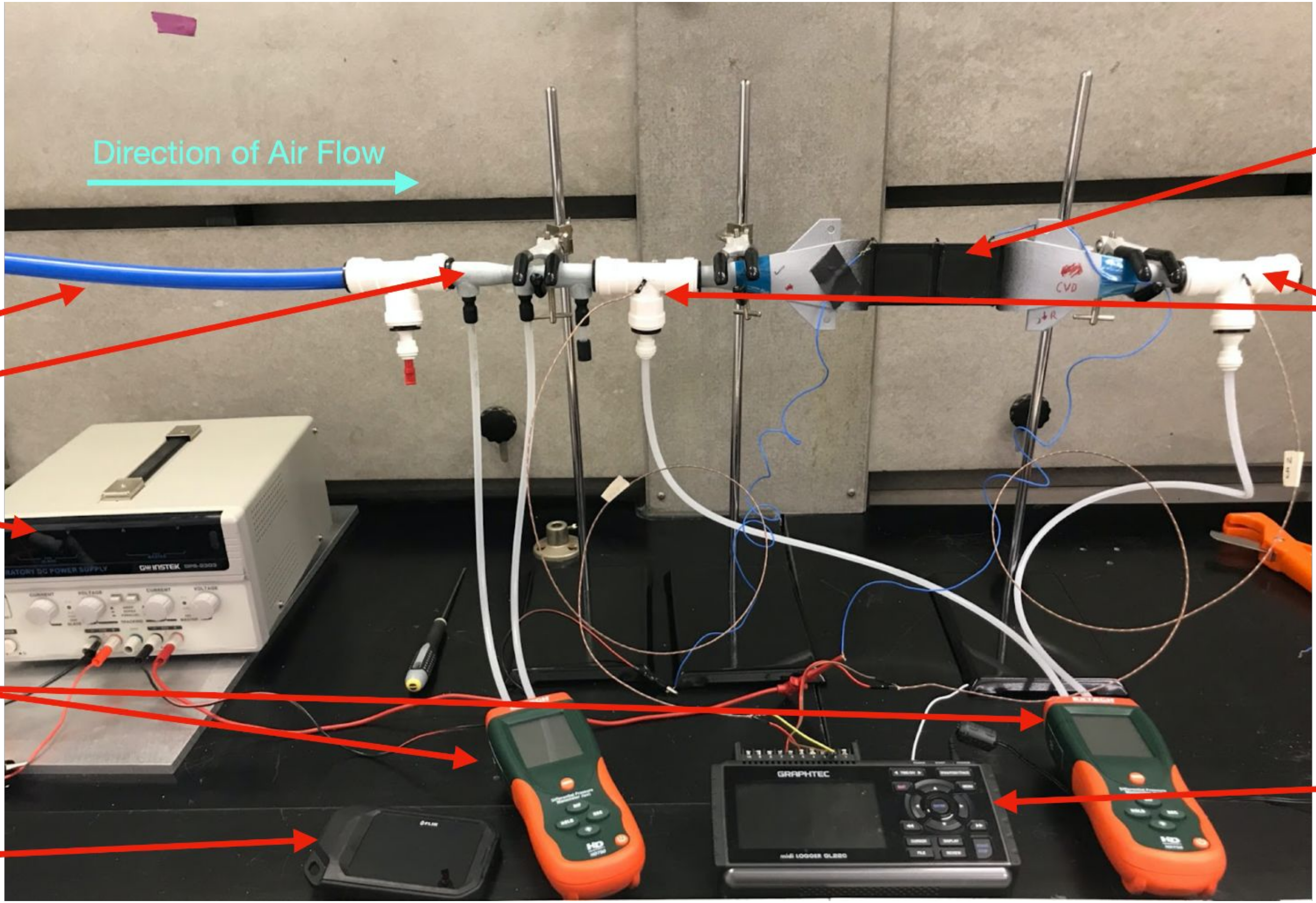
- What are we doing?
  - Test on air cooling method on “staves” made from **Carbon Fiber** & carbon foam
- Why Cooling?
  - Because there is always going to be **heat generated by silicon tracker**, we don’t want to melt anything 🫠 and we want to keep temperatures consistent
  - That’s also why we tested glue!
- Why Air Cooling?
  - To reduce material budget in order to reduce multiple scattering
  - Choosing material based on the cooling properties as well as material budget
- Procedures
  - Take a dark temperature of the measuring spots for ΔT calculation
  - We apply **power** to the peripheral region of the stave to imitate **heat deposit** into the **tracker**
  - Blow air through the carbon foam and measure the temperature difference across the **stave**
  - Look at how different materials ΔT and how and different air flows affect cooling

What does the setup look like in general?

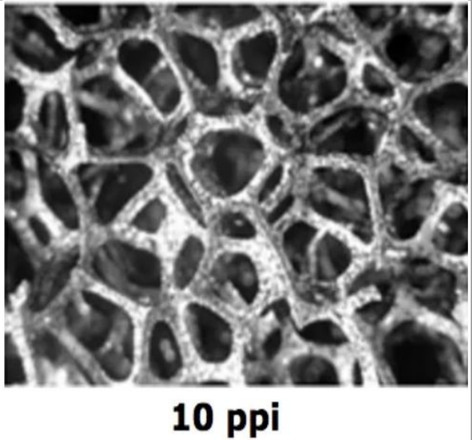
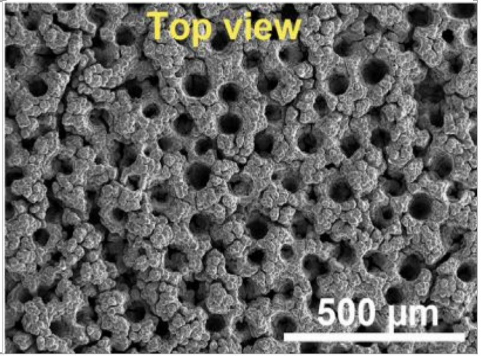


- Rough goal: ΔT<10°C for 1 meter stave

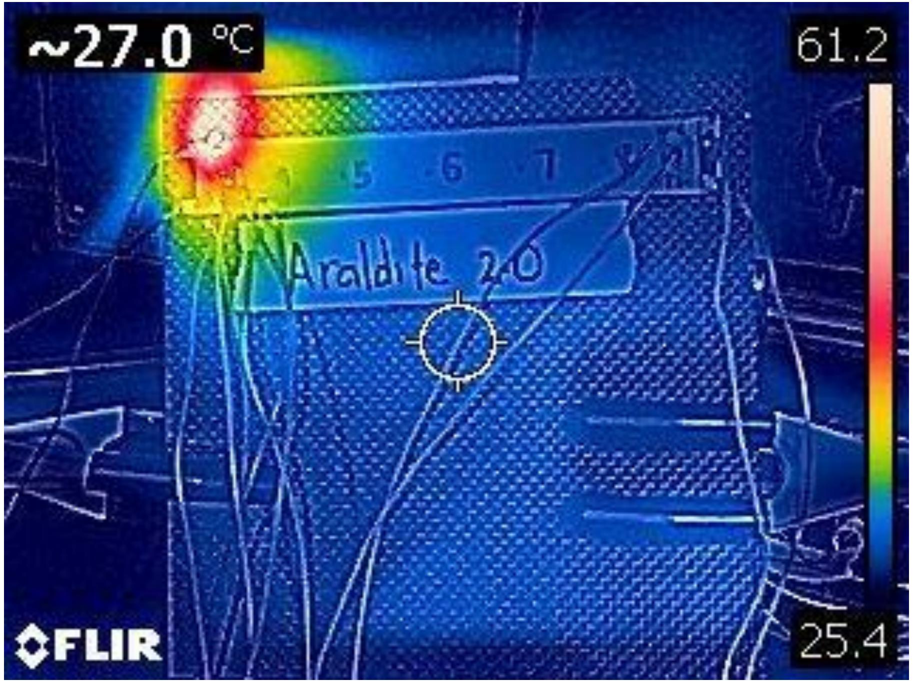
Real life Set up



Carbon Foam: RVC vs. CVD

	Full Name	Features	View
RVC	Reticulated Vitreous Carbon	**Thermally insulating** Less dense than CVD Stable at high temperatures & Resistant to thermal shock Low thermal expansion Various porosity	
CVD	Chemical Vapor Deposition graphene foam	**Intrinsic thermal conductivity** "Acts as an ultra-thin coating that enhances heat dissipation and diffusivity on substrates with thermal conductivity equal to or lower than that of SiO_2" Various porosity	

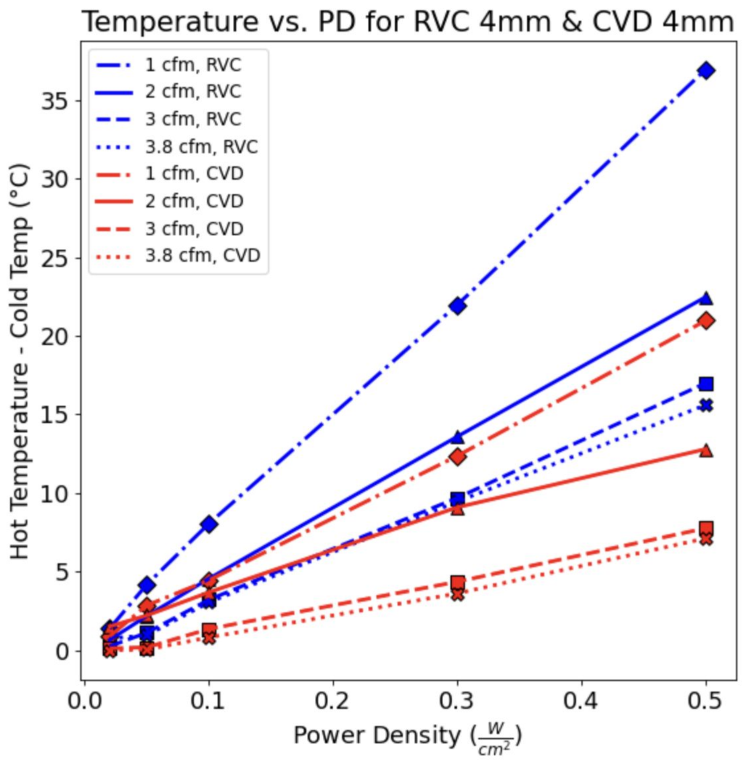
Thermal Camera (FLIR) Set Up



Temperature measurement with Thermal Camera (FLIR)

- Please note the red spot on the figure showing excessive high temperature.
    - It includes the soldering spot and the spot with excess glue
        - It had more glue than other areas because it tipped off once so we had to add more glue for adhesion

ΔT(°C) Measurement of RVC vs CVD using thermal camera



We applied power density we expect from the sensor.

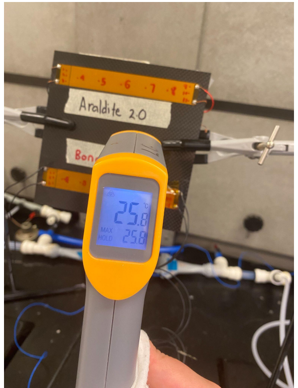
Data shows CVD performs better thermally

For the same power density applied, RVC has a higher ΔT than CVD.

ΔT = bright temp-dark temp

Long stave & Temp gun/thermal gun

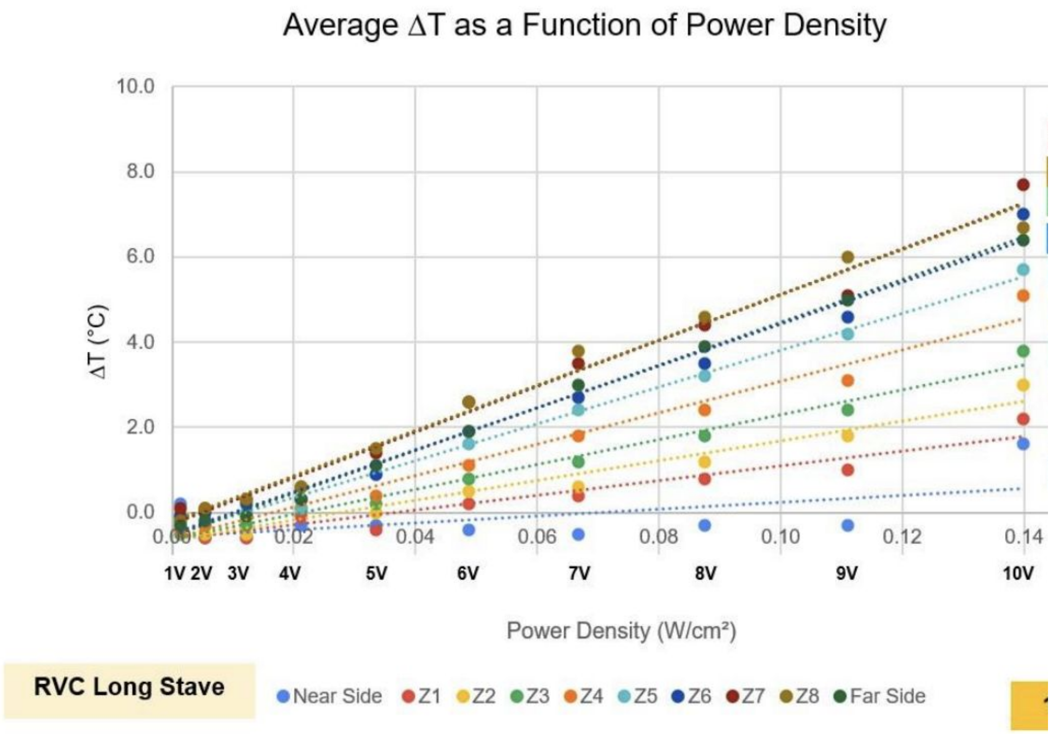
We proceeded to long stave for temperature measurement after done with short RVC and short CVD



Thermal gun we used for temperature measurement

Want to check thermal gradient along stave

Long stave RVC ΔT(°C) Measurement with max airflow



Z1 is the center of the nearest ceramic

Near side is where air flows through

Applied with maximum airflow (2.867 cfm)

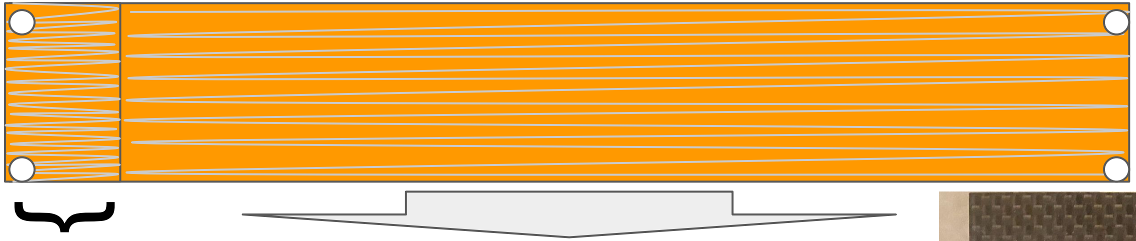
Air flows from the left rear end of the stave

- Air cooling does kept the near side temperature to be stable
- ΔT increases farther from inlet

Current progress: Stave → Kapton Heater

- Original **Staves**
  - Ceramic heating
  - Applied one power density across the stave, but NOT realistic
  - Tested 2 different materials: CVD vs. RVC
- **Kapton Heater**
  - To mock how the **silicon sensor** processes particle information and dissipates **heat**
  - Material is closer to the real **silicon sensor** but can by supplied with a **cheaper** price
  - Different heating zones, MORE realistic
- Next step…
  - Glue the Kapton heater onto the carbon fiber and blow air
  - So we are now also testing the glues (taking measurements without blowing air)

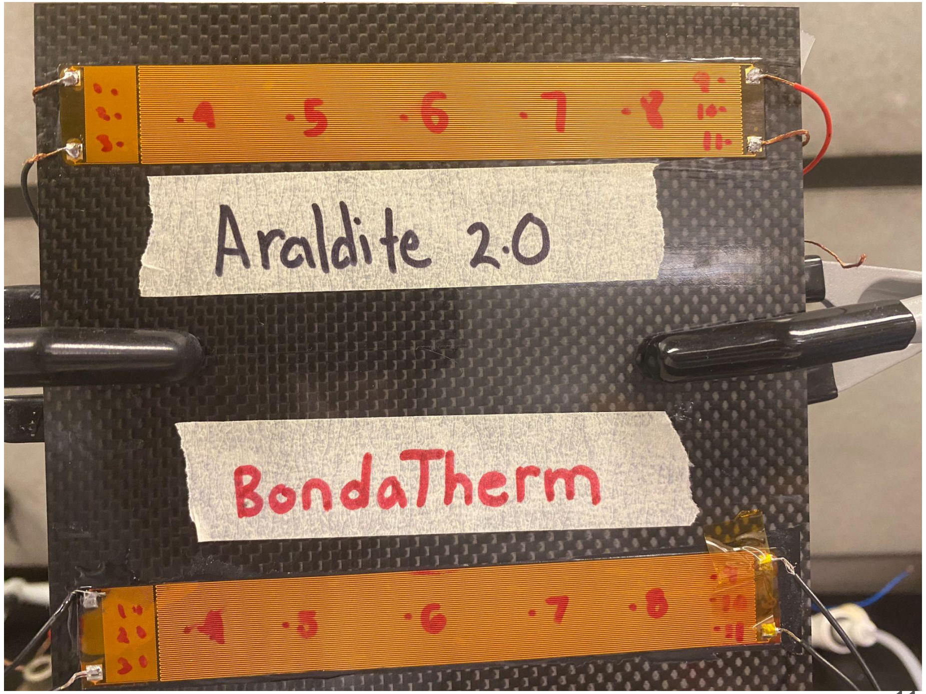
Kapton heater



○ Possible power supply connection

Periphery:
High power due to signal processing (Higher heat dissipation)

Pixel matrix: Low Power
Particles pass through for detection and measurement



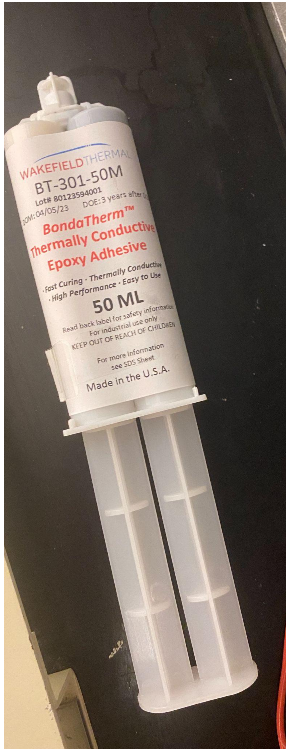
Actual Kapton heater set-up with 2 different glues

● Temperature measurement spot

Glue

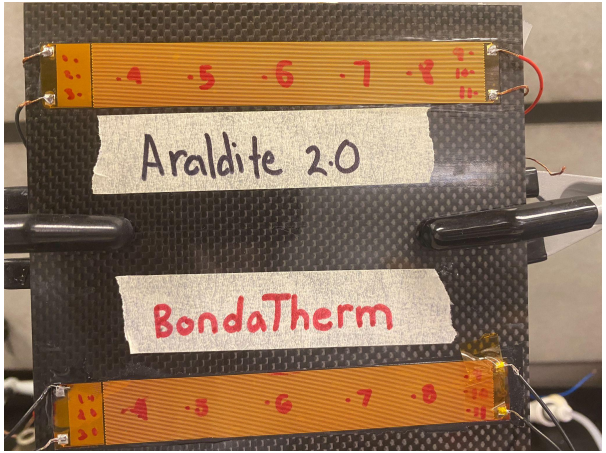
- Why are we using different glues?
  - We are using 2 different epoxy glues: Araldite and Bondatherm
  - Bondatherm is thermal epoxy (specifically produced for thermal heat conduction)
  - We want to know which glue performs better in the following perspectives:
    - Thermally
    - Ease of application
    - Adhesive properties
    - Radiation hardness (later)
- Notes when temperature taking:
  - Higher temperature when lot of glue

Araldite epoxy



BondaTherm epoxy

Glues results measured by temp gun



Temperature readings difficult to take with temp gun:

- Readings affected by where laser is pointed, highly susceptible to human error
- Extra glue: We applied more glue to certain areas after it got tipped off (We did see more glue → higher temp in thermal camera)
- Reflection: The laser could be reflected to the soldering point with an angle (not perpendicular to the surface)
- Radiation: excess heat from the soldering point

Updating our temperature measurements

- Significant error in temperature measurement
  - FLIR standard deviation: 0.2°C
  - laser gun standard deviation: 0.4°C

  } around what the manufacturers specifies
  - Constantly seeing a 1-2°C difference in temperature between the camera and the laser
- PT-100 gives a smaller temperature measurement fluctuation
  - But too delicate
- PT-100 pictures

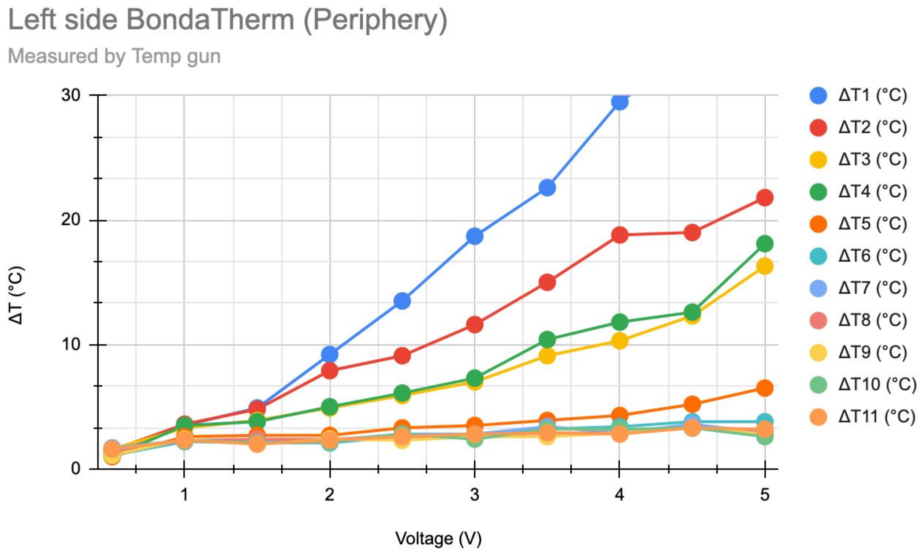
Summary

- Shown that the foam can work thermally
- Trade off between thermal & material budget
- ΔT increases at far end of stave
- Working on more realistic heater (kapton)
- Testing different glues
- Improving thermal measurements (PT100s, coming in Malika’s talk)

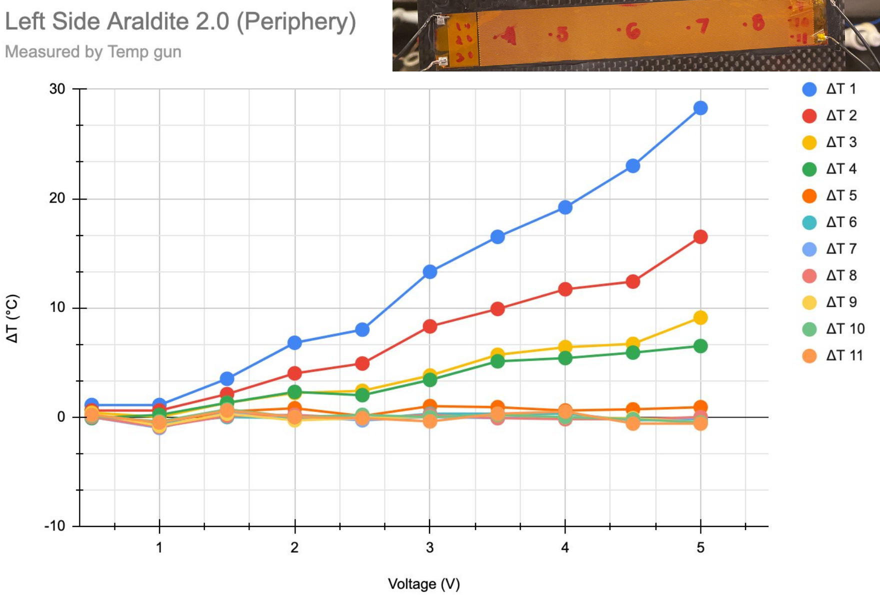
BACK UPS

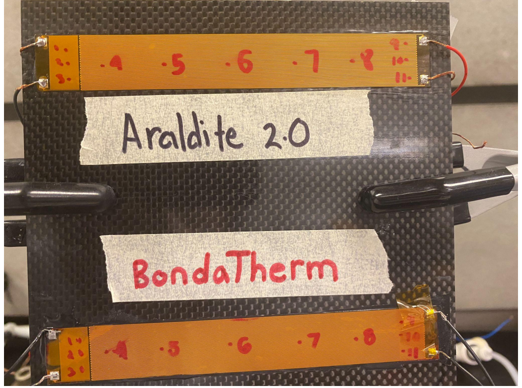
Let's see how it looks if we don't consider ΔT1

Bondatherm:



Araldite:

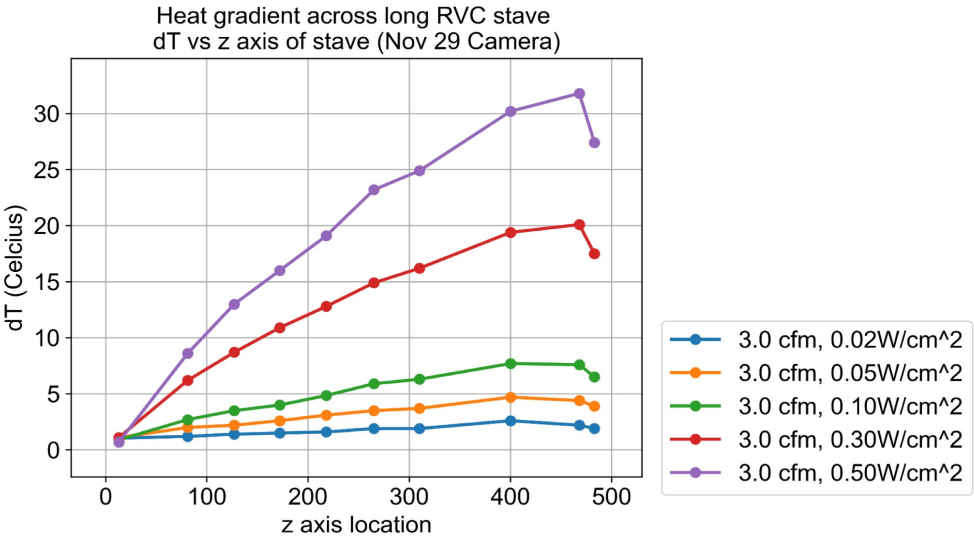




Since spot 1,2, and 3 are fairly close to each other geographically so we could conclude that data clearly shows that BondaTherm has a better thermal conductivity due to smaller ΔT under the same voltage applied.

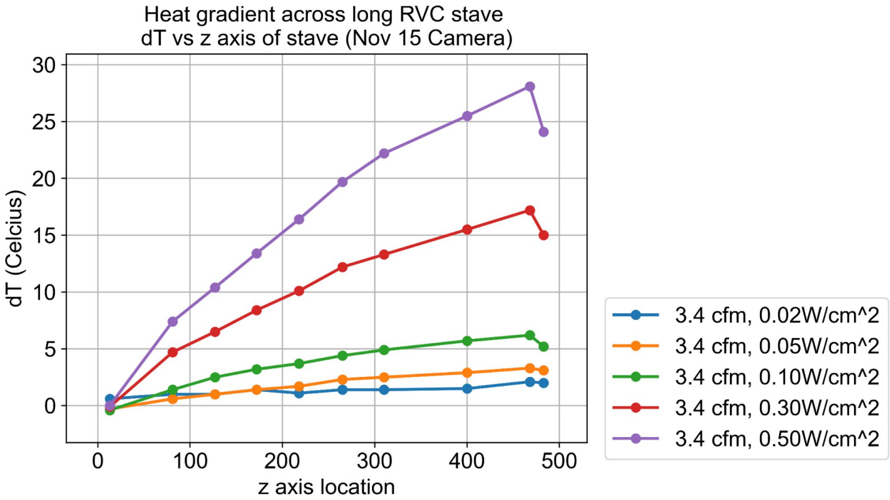
Long stave cooling results from last year

3.0 cfm, RVC Foam



For power densities up to 0.10 W/cm^2, ΔT <10°C

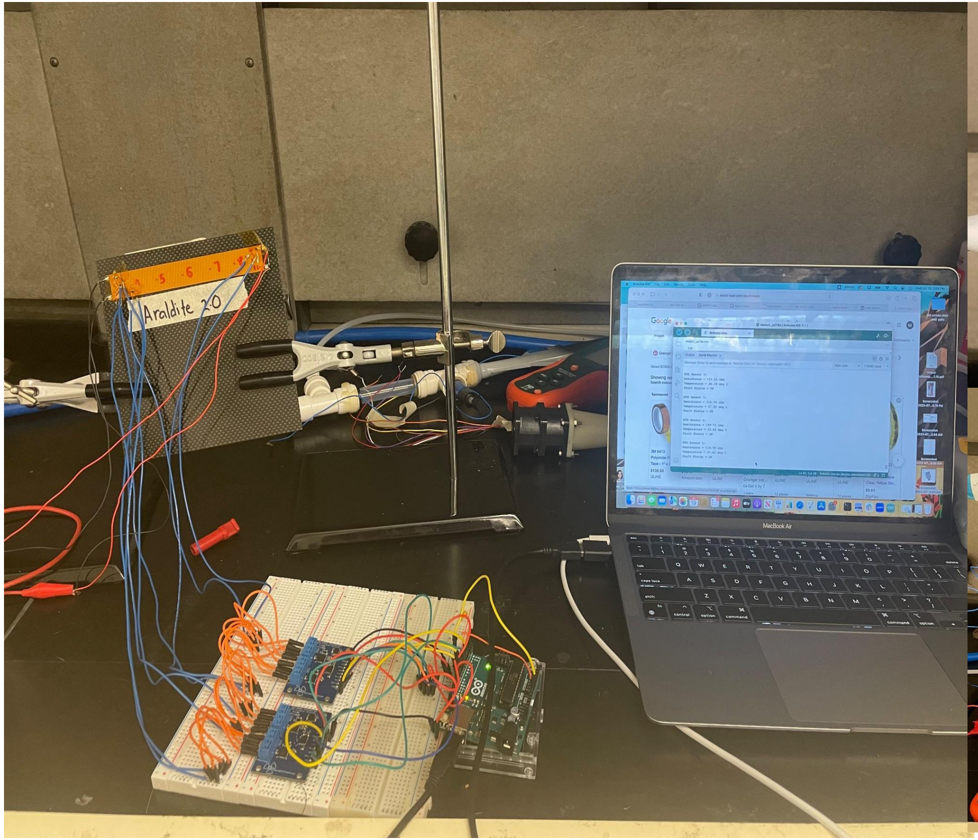
3.4 cfm, RVC Foam



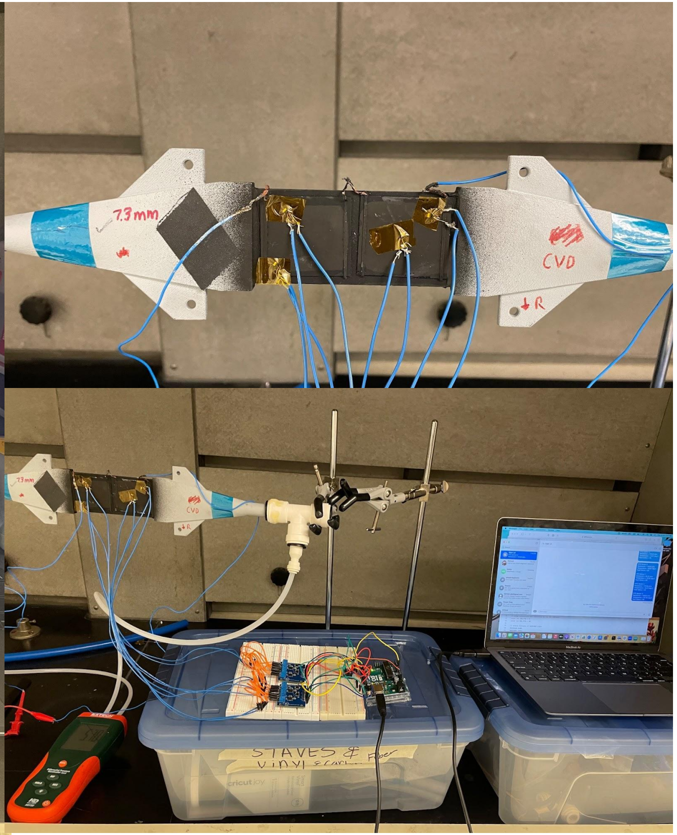
For power densities up to 0.10 W/cm^2, ΔT <10°C

Higher flow rate → lower temperatures across the same power densities

PT-100 Temperature measurement using Arduino



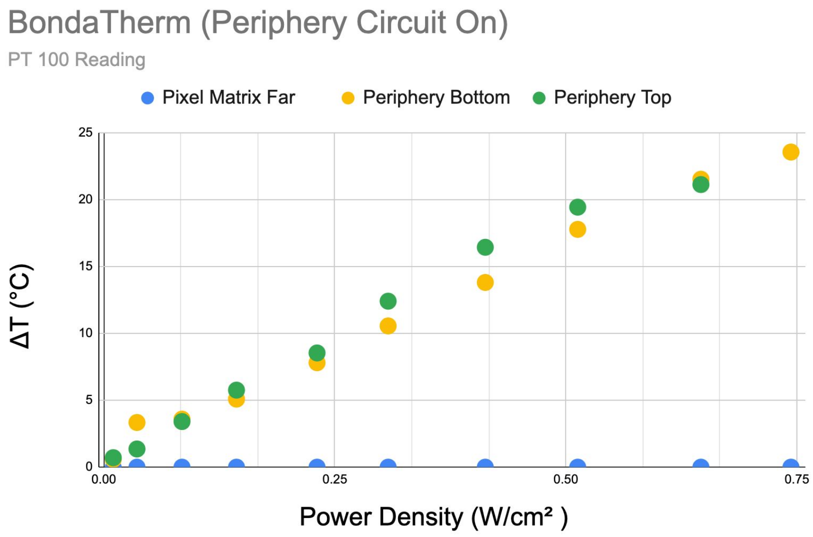
PT-100 measurement on Kapton Heater

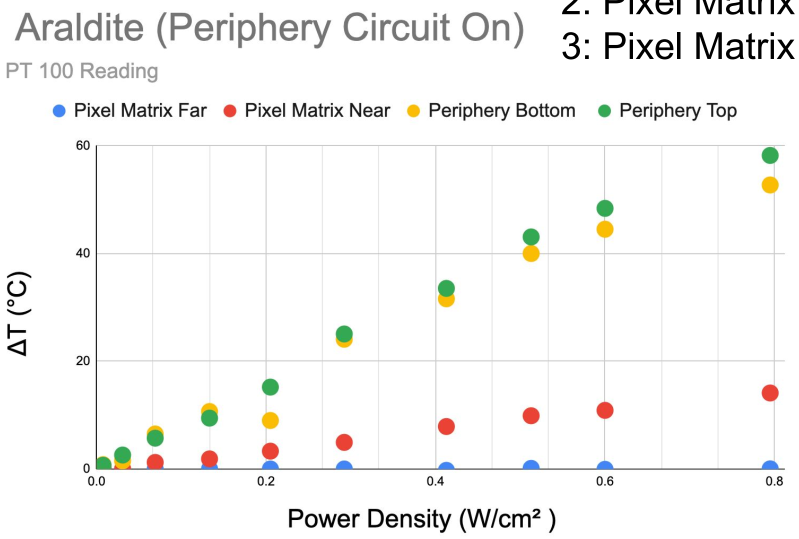


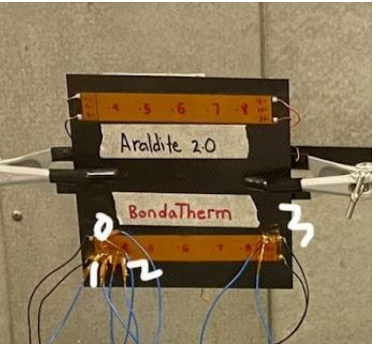
PT-100 measurement on **Stave**

Verifying Glues results measured by PT-100

0: Periphery Top
1: Periphery Bottom
2: Pixel Matrix near
3: Pixel Matrix far



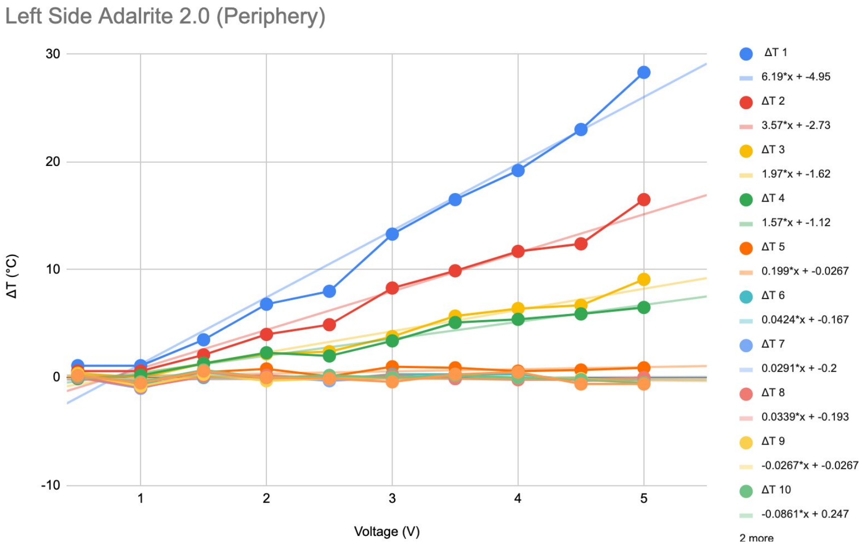


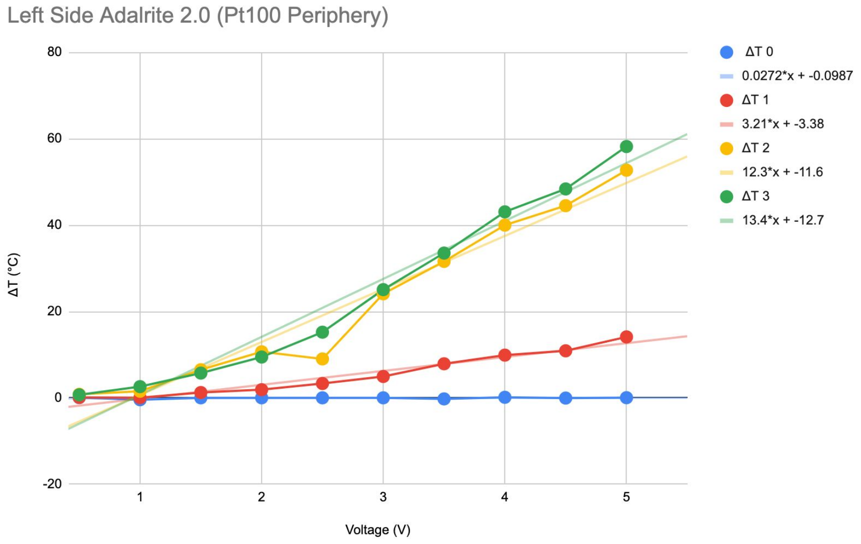


- We are seeing ΔT differences between PT-100 and temp gun measurements on Araldite under the same power densities.
  - Human error
    - different people taking at different times
    - Different distance from gun to spot
- PT-100 calibration

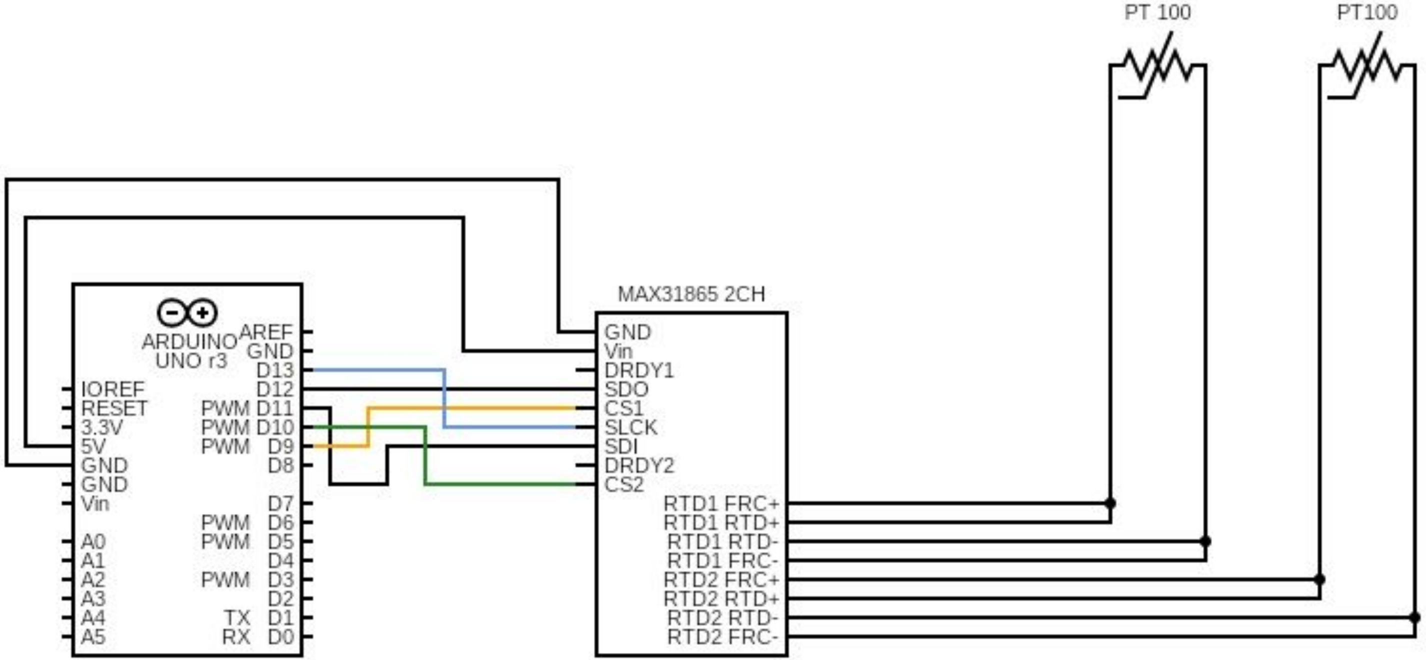
We propose that comparing the two temperature measurements, PT-100 is more reliable due to adhesive properties being applied on the stave for measurement.

Showing Consistency of Temp gun and PT-100 measurements





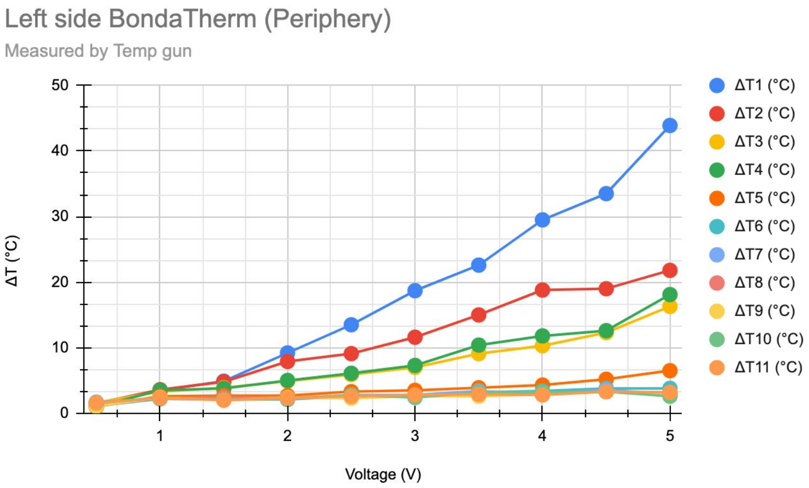
PT-100 2 Channel Configuration



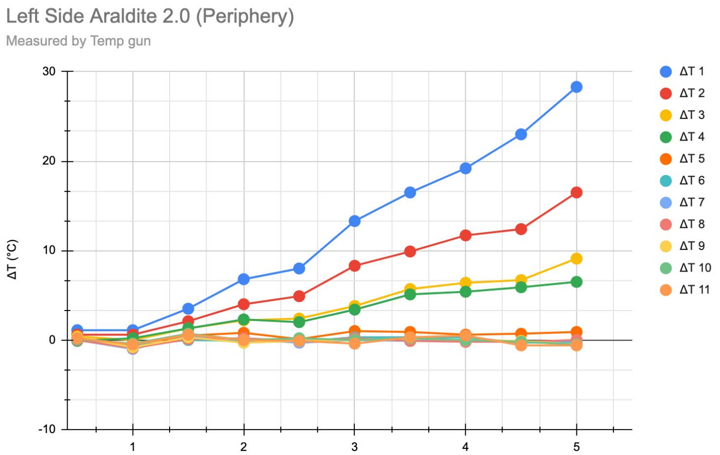
NOTE: You can use either the 5V or Vin on the ARDUINO
NOTE: The color scheme does not mean anything it is for ease of reading the diagram

Glues results measured by temp gun

Bondatherm:



Araldite:



ΔT1 for Periphery BondaTherm is not having an accurate reading for the following reasons (mostly human error):

- Extra glue: ΔT1 was taken at a spot with extra glue under the heater. We applied more glue onto the spot after it got tipped off (We did see more glue → higher temp in thermal camera)
- Reflection: The laser could be reflected to the soldering point when we pointed to spot 1 with an angle (not perpendicular to the surface)
- Radiation: excess heat from the soldering point