Heater Chip

1.1 Working with Bridge Diodes for temperature detection -

Using the Bridge diode configuration shown below I will use the fact that the bridge uses a 10:1 resistor ratio with the Shockley Diode Equation to solve for the temperature.

$$I = I_s\left(\exp\left(\frac{qV}{nk_bT}\right) - 1\right)$$

Note that $I_s << I$ the reverse saturation current is much less than the forward current through the diodes.

$$(I - I_s) = I_s \exp\left(\frac{qV}{nk_bT}\right) \quad \rightarrow \quad \ln\left(\frac{I}{I_s}\right) = \frac{qV}{nk_bT} \quad \rightarrow \quad V(T) = \frac{nk_bT}{q}\ln\left(\frac{I}{I_s}\right)$$

Since there are 2 diodes in parallel along with a 10:1 resistor ratio, the current will distribute accordingly through the diodes with the same 10:1 ratio.

$$V_1(T) = \frac{nk_bT}{q}\ln\left(\frac{I_1}{I_s}\right), \quad V_2(T) = \frac{nk_bT}{q}\ln\left(\frac{I_2}{I_s}\right)$$

Taking the difference in voltages gives us -

$$\Delta V = V_2(T) - V_1(T) = \frac{nk_bT}{q}\ln\left(\frac{I_2}{I_1}\right), \quad T(V) = \frac{q\Delta V}{nk_b}\frac{1}{\ln(10)}$$

Since the diode and the resistor are in series the current through them should be the same so from this we can determine the current through the diodes as a 10:1 ratio. n is the ideality factor since this is a silicon diode (indirect semiconductor), we can set this to 1.

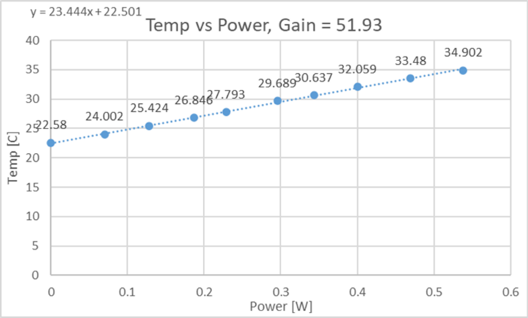
Final Expression: $T[K] = \frac{q\Delta V}{k_b}\frac{1}{\ln(10)} \approx 5035.3 \cdot \Delta V$

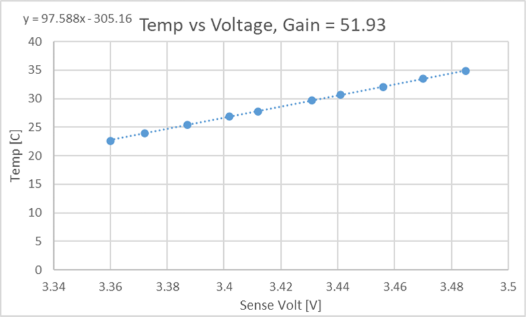
Heater Chip

1.2 Testing Bridge Chip

Driving the circuit with 4 mA I saw $\approx 62mV$ difference in voltage across the sense readout pins. Plugging this into the Diodes equation we derived above, we see that the Absolute Temp $\approx 42°C$. This is a bit higher the expected $22°C - 25°C$. However to avoid this, since $V \propto T$ relationship is linear i just subtract $26°C$ to obtain an measurement value of room temp to be $20°C$.

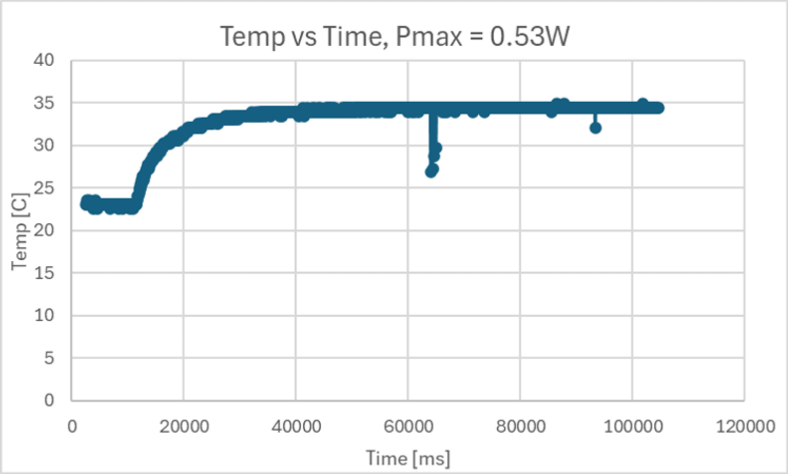
Heater Chip





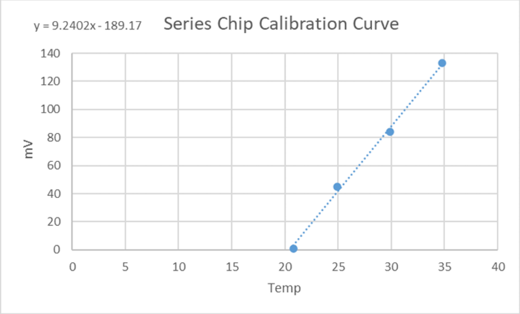
- Slope exactly that of the Temp(volt) = (5035/Gain)*volt as expected

Heater Chip



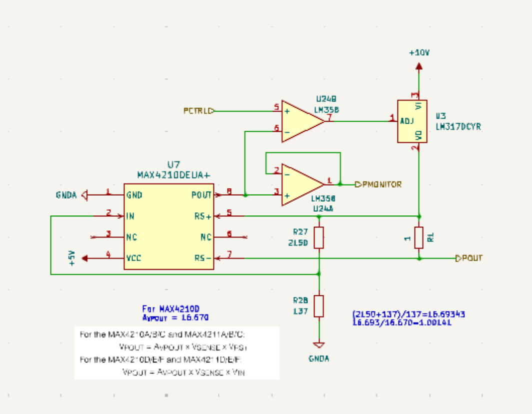
- Temperature increase with constant 0.53 watts running through heater strip levels out to a constant temp of ∼34°C

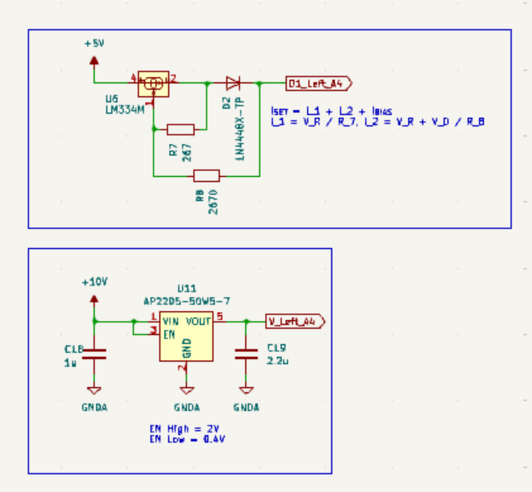
Heater Chip



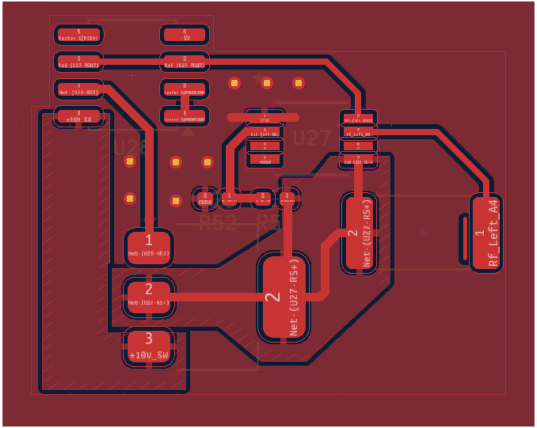
- Calibration for series chip (to show equivalent results as data sheet)
- Slope 10mV (expected for 2mV/C per series diode)
- Data not yet taken with series chip

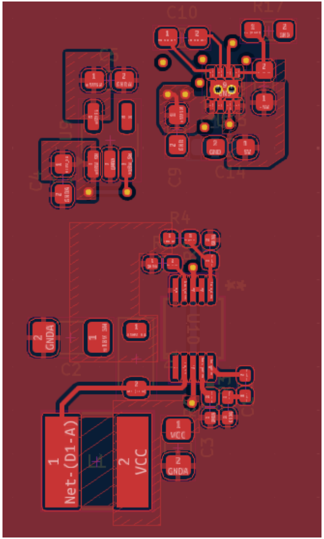
Stave Readout Board





Stave Readout Board

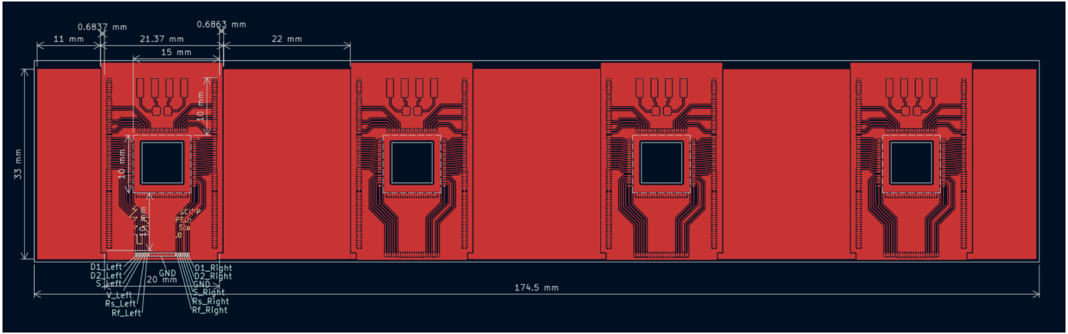




Interposer Board

New Flex

- Added holes for heater chips to be filled with thermal paste
- Footprints for RTD and 4-pin edge connector
- In production through JLCPCB



Materials

Key metrics: through-plane thermal conductivity and board thickness

Material classes:

- Polymer laminates (FR-4, Polyimide, Rogers)
- Metal-core PCBs (polymer dielectric + metal base)
- Ceramic substrates (Al_2O_3, AlN)

Generally:

$$k_{\text{polymer}} \ll k_{\text{ceramic}} \ll k_{\text{metal}}$$

Metals require dielectric isolation.

Materials

Material	Thermal Cond. (W/m·K)	Dielectric Const. ε_r	Typical Thickness
FR-4	0.3–0.4	4.2–4.8	0.2–3 mm
Polyimide	0.12–0.35	3.5–4.2	25–250 μm
MCPCB (Al core)	$\sim$200 (core)	—	0.8–2.5 mm
Alumina (Al_2O_3)	20–30	$\sim$9.4	0.25–2 mm
Alum. Nitride (AlN)	140–180	$\sim$8–9	0.25–1.5 mm
Copper (reference)	$\sim$400	—	—

Interpretation:

- Polymers limit vertical heat flow
- Polymer dielectrics dominant
- Ceramics enable efficient heat extraction while insulating electrically

Material Costs

- Price scales with thermal performance
- Polymer-based boards cost-efficient but thermally limiting
- Aluminum backed boards cheap and widely available — thicker than FR4 but Aluminum can be as thin as 200μm if control not vital
- AlN provides best heat conduction but costly and suppliers limited
- Ceramics scale favorably with order size —> not great for prototyping, but may be viable for full demonstrator

PCB Material	Cost Range[1] (\$/cm^2)	Relative vs FR-4
FR-4	0.01–0.05	1$\times$
Polyimide (flex)	0.05–0.20	3–6$\times$
Metal-core (Al)	0.05–0.30	3–8$\times$
Ceramic (Al_2O_3)	0.20–1.00	10–30$\times$
Ceramic (AlN)	1.00–5.00+	50–150$\times$

[a] JLCPCB cost comparison: `https://jlcpcb.com/blog/custom-pcb-cost`

FR-4 / Polyimide

- Mature fabrication, low cost, thin
- Thermal bottleneck for power density $>$ few W/cm^2

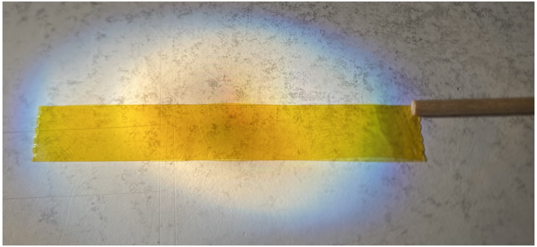
Metal-Core PCB

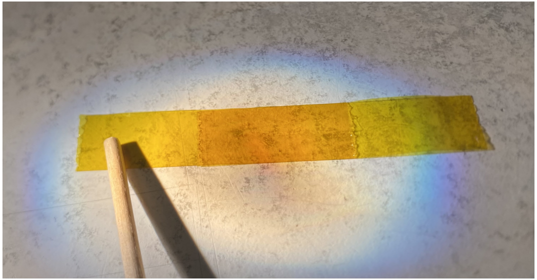
- Good for prototyping and moderate heat loads
- Performance limited by thin polymer dielectric layer

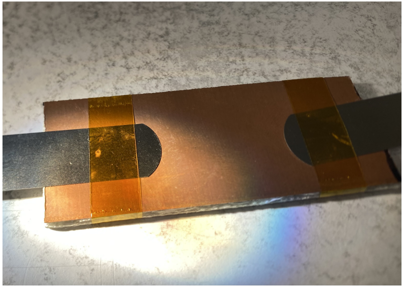
Ceramic Substrates (Al_2O_3, AlN)

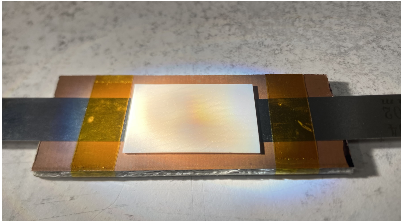
- Ceramic acts as dielectric $+$ thermal conductor
- Thin, electrically insulating, dimensionally stable
- AlN provides $\sim$5–10$\times$ higher heat conduction than alumina
- Higher cost, brittle, specialized processing

Initial Glue Tests: Setup

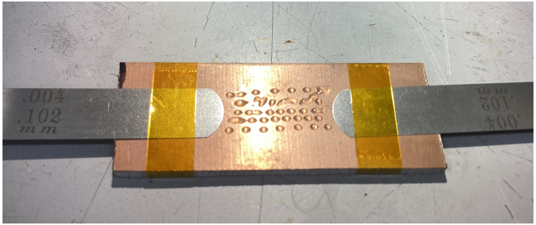


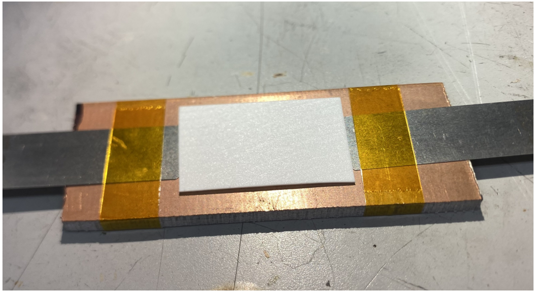


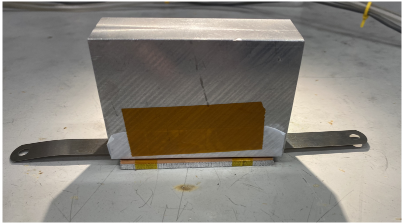


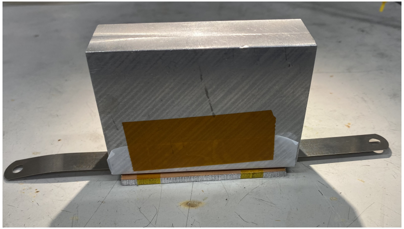


Initial Glue Tests: Dispensing









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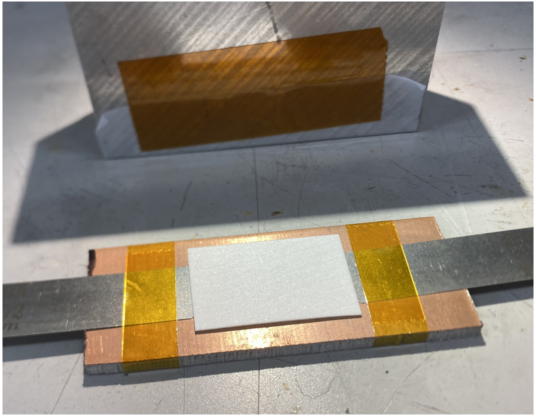

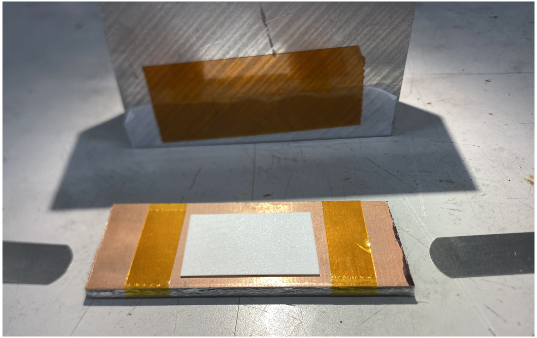

Initial Glue Tests: Results

Initial Glue Tests: Results

Initial Glue Tests: Comments and Improvements

- Used 100μm shims with 3cm x 2cm cardstock in place of sensor
- 30 second UV gun exposure from side
- 150μm transparent PVC plate and UV protective film on order for see-through sensor replacement
- Will perform larger parallel tests with various shim thicknesses