Thermal Pad Tests

Introduction

This whole study came about because I was building an amplifier which displayed some thermal problems, and I decided to investigate the issue. I had initially used some low cost, off the shelf Chinese sourced silicone thermal pads from a kit purchased for general purpose use. The active device was discovered (painfully!) to be operating at high temperature.

A range of materials was chosen with a view to improving the situation and I realised "*I'm going to have to science the sh*t out of this*" (thanks, Matt Damon!) and test them.

I have revised the write up of this study to include some additional materials of interest as well as improvements to the method of measuring the comparative thermal performance of the materials. Additional data is also provided.

I should also add that this study is entirely independent, and I have no affiliations with any of the manufacturers or vendors mentioned. It is not meant to be a completely exhaustive review of everything available on the market and is limited to what I needed to know for this particular project at the time.

Materials

1. Chinese silpads

https://www.ebay.co.uk/itm/403711124212

These are around 300µm thick, composition is unknown but feels like silicone with perhaps some unknown filler in it. Light blue colour. Unknown thermal conductivity. For the tests, I used the 20mm x 26mm pads supplied in the kit.

Figure 1. Chinese Silpads.

2. Bergquist SP400-0.007-00-104

https://www.mouser.co.uk/ProductDetail/Bergquist-Company/SP400-0.007-00-104?qs=jQRjkUoUCJcSyLJh2yRkNg%3D%3D

Datasheet:

https://www.mouser.co.uk/datasheet/2/48/BERGQUIST_SIL_PAD_TSP_900_en_GL-3432587.pdf

These measure 19.05mm x 25.4mm are consistently about 170µm thick. Composition claimed to be silicone rubber with fiberglass reinforcement. Grey in colour. Reported thermal conductivity 0.9W m-1 K-1.

Figure 2. Bergquist SP400-0.007-00-104 Pads.

3. Kapton Film 25µm

https://www.aliexpress.com/item/1005005875080898.html?spm=a2g0o.order_list.order_list_main.23.527d1802N7NY3B

These are cut out from a sheet of material that comes with a backing film that is removed before use. The pads were cut 22mm x 25mm. The thickness measures 26 to 28µm. Thermal conductivity is *estimated* to be around 0.2 W m-1 K-1 for ordinary polyimide film. There are other grades of Kapton (polyimide) films that have enhanced thermal conductivities for electronics uses. See here https://www.dupont.com/electronics-industrial/polyimide-films.html/general/H-38479-4.pdf#headingacc0

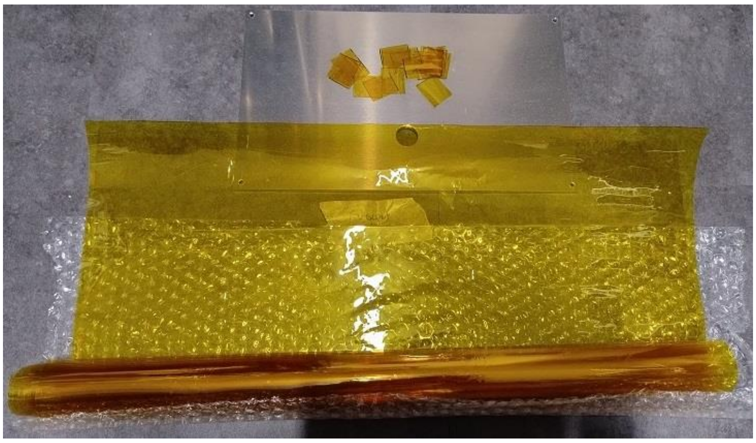


Figure 3. Kapton Film as supplied in a roll, and pads cut from it.

4. Kapton Film 15µm

As above, but 15µm film. Measures 18µm.

5. Alumina thermal pads.

https://www.aliexpress.com/item/1005005855916976.html?spm=a2g0o.order_list.order_list_main.29.527d1802N7NY3B

From the item description:

Material:97% White Aluminum Oxide（AL2O3）, Thermal Conductivity:29.3 W m-1 K-1, Isolation Voltage：≤22.5KV, Heat resistance：1600℃, Density: 3.6g/cm^3, CTE：0.000003

These measure 20mm x 25mm with a thickness from 650µm to 675µm.

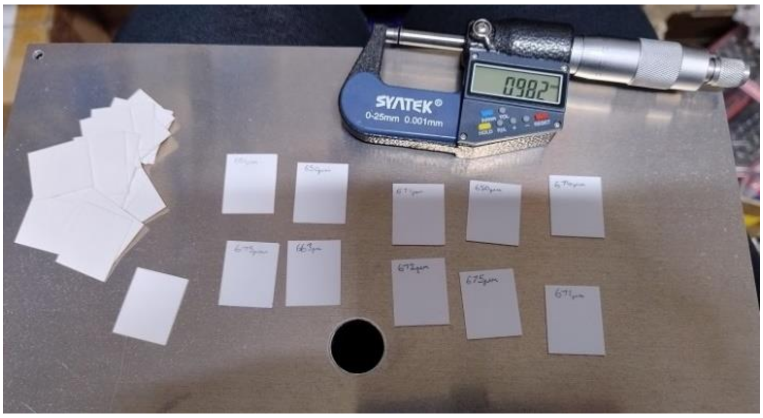


Figure 4. Alumina pads.

6. Mica sheet 25µm

https://www.aliexpress.com/item/1005003621234384.html?spm=a2g0o.order_list.order_list_main.35.527d1802N7NY3B

Pads are cut with scissors from these 50mm x 50mm sheets. Pad tested measured 25mm x 25mm. Thickness measured 25µm to 40µm, however the thickness across a single sheet only deviated by a few microns. Thermal conductivity is 0.71W m-1 K-1.

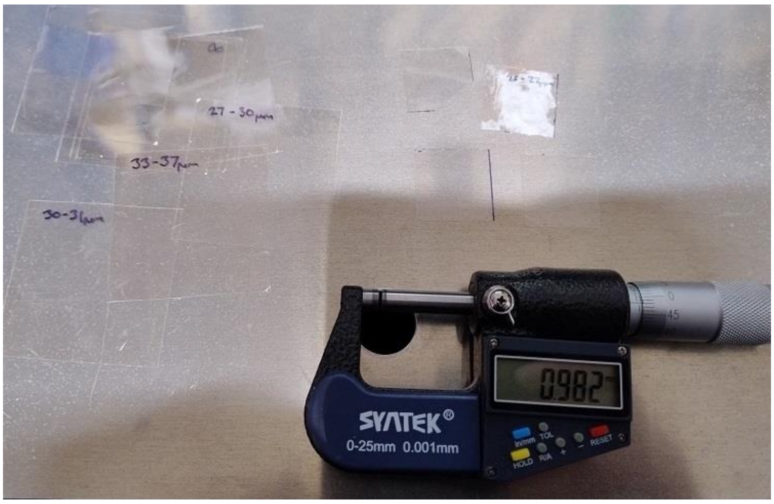


Figure 5. Mica sheet as supplied and cut to form smaller pads.

7. Mica Insulators (Aliexpress)

https://www.aliexpress.com/item/1005007203212163.html?spm=a2g0o.order_list.order_list_main.59.527d1802N7NY3B

These were poor quality, with wildly variable thickness (all were way too thick), and many were clearly damaged or partially delaminated. Not worth testing.

Figure 6. Mica insulators as supplied.

8. Mica Insulators NOS.

Farnell 520-214 TO247 mica washers. Supplied with nylon bush isolators. Pad tested measured 15mm x 19mm. Measured with micrometer, had thicknesses ranging from 62 to 124µm.

Figure 7. Mica insulators NOS as supplied.

10. Aluminium Nitride Pads

https://www.aliexpress.com/item/1005001896184063.html?spm=a2g0o.order_list.order_list_main.22.7647180256Ctgo

Much like the alumina pads, except these are reportedly Aluminium Nitride. Two sizes were purchased for testing: 25mm x 20mm and 28mm x 22mm.

The 25mm x 20mm measure 626µm to 635µm, and the 28mm x 22mm measure 628µm to 647µm. Appearance is beige.

The vendor states that the thermal conductivity is 190-260W m-1 K-1 and insulation performance is 15kV mm-1.

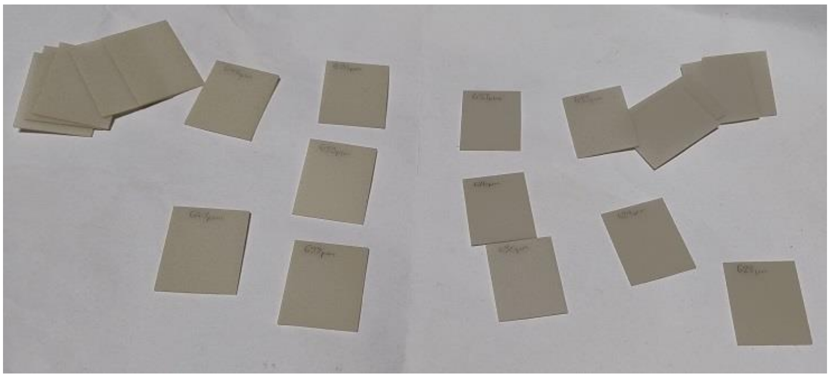


Figure 8. Aluminium nitride pads.

11. Bergquist HF625-0.005-AC-104

https://www.mouser.co.uk/ProductDetail/Bergquist-Company/HF625-0.005-AC-104?qs=unwgFEO1A6vF8NWPIu0hJA%3D%3D&srsltid=AfmBOopxFJ3aX8V_aKEOS4ThCo8GuoiXllhgBL8nOWHGapNiWcVky72M

These measure 19.05mm x 25.4mm and have a thickness ranging 148µm to 164µm.

Reportedly a thermally conductive 65°C phase change material on an electrically insulating film. Thermal conductivity is 0.5W m- K-1.

Datasheet:
https://www.mouser.co.uk/datasheet/2/48/BERGQUIST_HI_FLOW_THF_500_en_GL-3433239.pdf

Supplied on a backing paper carrier. Appearance is light green.

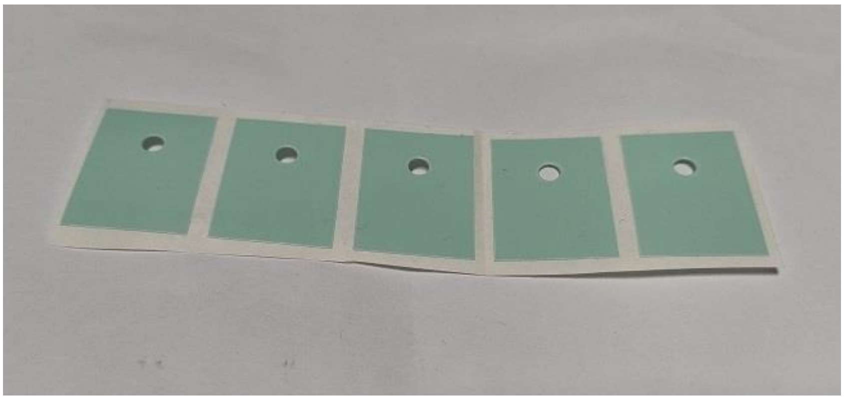


Figure 9. Bergquist HF625-0.005-AC-104 thermal pads.

12. Copper heatpipes 11mm x 3mm x 220mm length.

https://www.aliexpress.com/item/4000008952935.html?spm=a2g0o.order_list.order_list_main.29.11b61802WxsKZf

I was curious to see what sort of improvement could be gained from using heatpipes as a heat spreader. I did initially try to acquire some sort of vapour chamber, but one was not so easily obtainable off the shelf. The heatpipes, however, are similar in operation and are easily obtained.

Figure 10. Copper heatpipes used in Experiments 16 and 17.

Thermal Grease

Thermal grease used in experiments (unless otherwise stated) was RS 554-311 https://uk.rs-online.com/web/p/thermal-grease/0554311?srsltid=AfmBOoocv8Sn_K4eOSRXv7OPJfPlNyTwzD7T5AxHMlUU58fQ2Ee-Tvzj

Datasheet: https://docs.rs-online.com/6cf4/A700000008000600.pdf

Mine was purchased many years ago. Thermal conductivity is reported to be 0.65W m-1 K-1.

Figure 11. Thermal Grease.

Chemtronics CW7250 Boron Nitride Heat Sink Grease

https://www.mouser.co.uk/ProductDetail/Chemtronics/CW7250?qs=IjV9znPSaN2bVYU6q2%252By8g%3D%3D

Datasheet: https://www.mouser.co.uk/datasheet/2/69/CHEM_S_A0002541018_1-2539441.pdf

I wanted to assess what improvements could be made by using a Boron Nitride based thermal grease. Thermal conductivity is reported to be 1.85W m-1 K-1. No indication is given on the crystal structure of the Boron Nitride (cubic, hexagonal etc.) used in the grease.

Figure 12. Chemtronics CW7250 Boron Nitride Thermal Paste.

Fehonda Thermal Putty LPT81

https://www.aliexpress.com/item/1005005955748270.html?spm=a2g0o.order_list.order_list_main.35.11b61802WxsKZf

To ensure a good thermal interface between the heatpipes and the main heatsink, the above thermal putty was purchased. According to the manufacturer it is a grey coloured silicone based gap filler putty. No indication is given as to the filler(s) used in it's composition. From the manufacturer:

Thermal Conductivity: 18.0W m-1K-1, Density: 3.85±0.2 g cc-1 (ASTM D792)

Hardness: Shore C 15±3 (ASTM D2240), Breakdown Voltage:＞9 Kv mm-1 (ASTM D149)

Volume Resistivity: ≥10^12 Ω cm-1 (ASTM D257), Temperature Range: -40°C to 180℃.

Figure 13. Fehonda LPT81Thermal Putty.

Methods

Circuit is a choke loaded mosfet source follower with International Rectifier IRFP250NPBF TO247 as the active device. As per MoFo article by Mike Rothacher. Choke was Hammond 193V and circuit was initially biased at 2A at 24V (50W) in initial build before thermal pad investigation.

The biasing potentiometer was left unchanged during the testing and between each material for the first 8 experiments. Experiment 9 (re-biasing the circuit to 2.5A, 60W dissipation) involved resetting the bias potentiometer. Thereafter, for the following experiments 10,11,12,13 and 14, the bias potentiometer was reset to the bias point of the first 8 experiments, using experiment 3 as a reference. Following these experiments, the bias point was reset to the higher 24V 2.5A (60W) point using the alumina pad setup to provide a reference point for experiments 15, 16,17 and 18.

The main, large heatsink was purchased from Earlsmann, Tiverton, Devon stock no. 500-50712 surplus stock sold on Ebay. Original manufacturer believed to be ABL (Aluminium Components) Ltd, Wednesdbury, West Midlands, Type 177AB black anodised aluminium 300mm x 300mm x 83mm, 0.138° C W-1 passive cooling. Mosfet was mounted in the middle of heatsink with the M3 mounting hole equidistant from the edges.

Mosfet was either mounted with the conventional nylon insulation spacers and a M3 stainless steel cap head bolt, or with an aluminium heatsink clamp 50mm x 21mm x 17mm depth made from an ET60 heatsink. M4 mounting holes were drilled and countersunk with a 40mm pitch aluminium spacers 10mm diameter, 4mm bore, 4.8mm length were machined as stand-offs to allow a small amount of flex (0.2mm) to apply pressure on the TO247 device package while preventing overtightening and crushing. Additional spacers of 5.4mm length were machined to accommodate the thicker 600µm pads.

Heatsink was drilled on a milling machine and tapped by hand. A small sanding block was used in conjunction with some 240 grit wet and dry sandpaper (wet with water/surfactant then dried) to remove some of the high spots created during the extrusion manufacturing process of the heatsink. The mating surface of the overhead clamp was wet lapped (240 grit) on a granite surface plate.

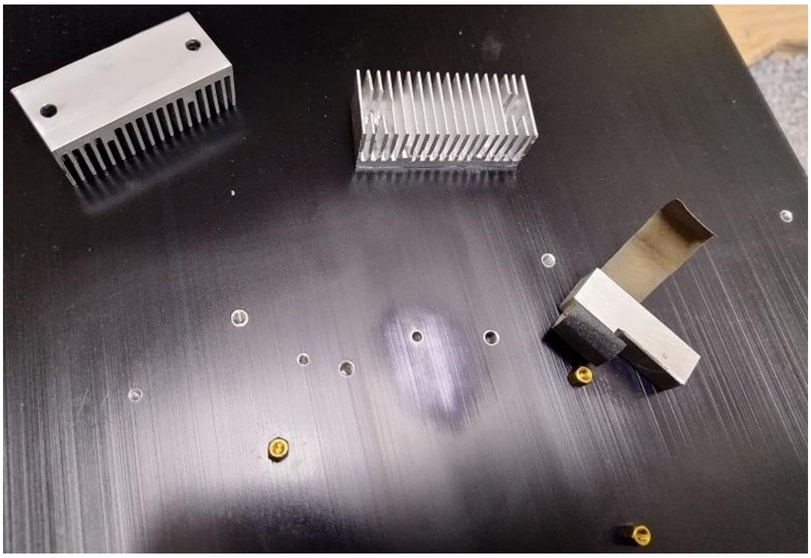


Figure 14. Main heatsink and overhead clamps.

For the first 8 experiments, two PT100 (385) probes were set up, one placed upon the exposed “substrate” in the semi-circular recess of the TO247 package to give as fast as possible readings on the temperature as close to the operational device within the TO247 package as possible. Epoxy adhesive (Devcon 5 minute Epoxy) was used to fix the probe in place.

The second probe was placed in contact with the heatsink at 30mm away from the M3 mount hole on the TO247 package. This was held in place with a nylon M3 fixing and a small amount of thermal grease was used to enhance the surface thermal interface between the heatsink and probe.

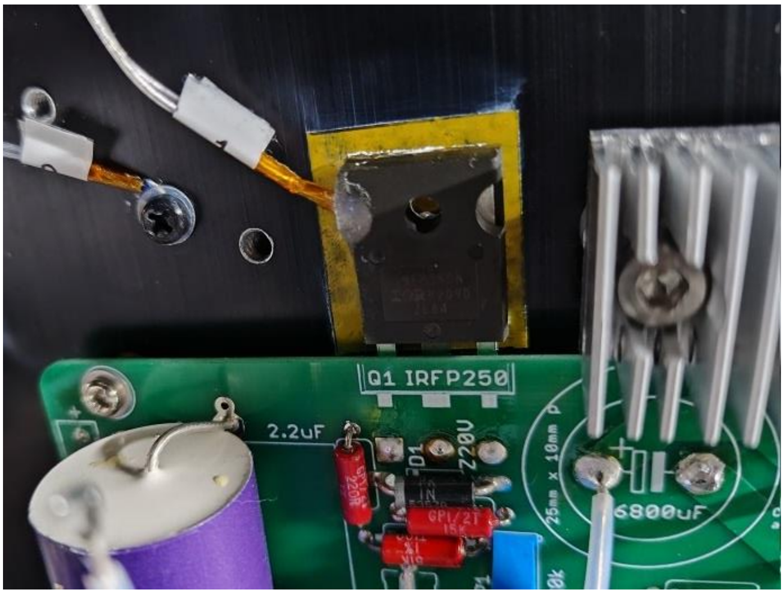


Figure 15. Close up of position of probes for TO247 and main heatsink.

Figure 16. Overhead clamp in place.

To investigate the thermal profile of the overhead clamp heatsink in experiments 10 to 19, an additional, third PT100 probe was placed into the overhead clamp between the fins, held in place by a M3 bolt.

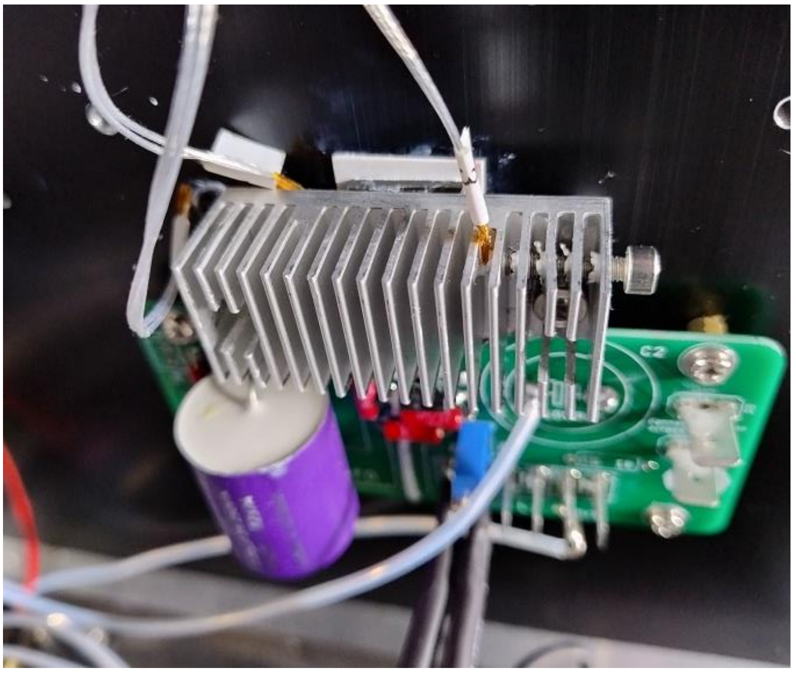


Figure 17. Temperature probe position for overhead clamp.

To investigate the thermal profile of the copper heatpipes, a fourth PT100 probe was placed at 30mm from the standard M3 mounting hole of the TO247 device. This serves as a direct comparison to the main heatsink probe which is also at 30mm. Probe was placed in contact with the copper heatpipe and fixed in place with Devcon 5 minute epoxy.

The copper heatpipes were covered on the heatsink side with Fehonda LTP1 thermal putty. The pipes were bent slightly so that they are slightly concave along their length from the heatsink side to ensure contact with the main heatsink along their length when force is applied with the overhead clamp.

Figure 18. Setup for Experiments 16 and 17.

Power to the circuit was supplied by RIDEN 6018 lab bench PSU.

As experiments were carried out on different days and times, the ambient temperature of the room could vary. In most cases, the test setup was allowed to equilibrate with the surroundings before commencing each test, although, for practical reasons (ie time) this ended up varying slightly. To take some of the deviation into account, the ambient air temperature and the initial start temperature for the heatsink, device etc was logged. The difference in temperature (ΔT) between the start temperature and the maximum temperature of the different components then provides a more accurate picture of what is going on during an experiment.

Values for start at t=0s and end t=~1800s (30 minutes) ΔT(heatsink), ΔT(to247), ΔT(overheadclamp).

Of particular interest is the value of ΔT(heatsink-to247), (temperature difference between the main heatsink and the TO247 package). In most cases this was taken after 28 minutes on runtime, to allow for stabilisation. This gives an idea of how good the thermal coupling is between the main heatsink and the TO247 DUT and takes into account *some* of the previously mentioned variables.

Datalogger:

https://www.aliexpress.com/item/1005008019197850.html?spm=a2g0o.order_list.order_list_main.17.527d1802N7NY3B#

4 channel Modbus RS485 datalogger interfaced with ModbusScope software. https://github.com/ModbusScope/ModbusScope

Figure 19. Datalogger used in experiments.

Probes:

https://www.aliexpress.com/item/32867617470.html?spm=a2g0o.order_list.order_list_main.41.527d1802N7NY3B

PT100 (385) 2mm x 2mm probes on 2 lead leadouts.

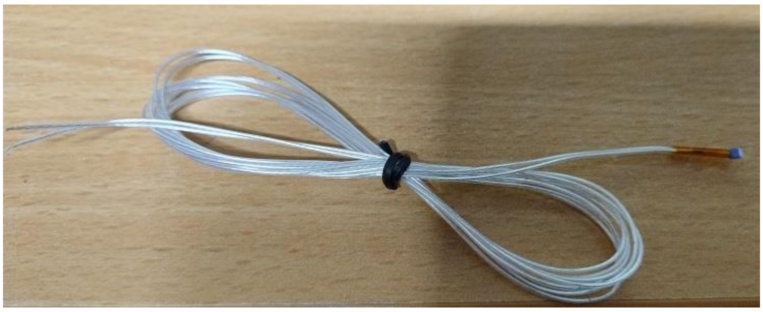


Figure 20. One of the PT100 probe used in the experiments.

Results:

1. 25µm Kapton Film.

Using overhead heatsink clamp. Thin films of thermal grease (RS 554-311) applied to heatsink/Kapton pad interface and Kapton pad/Mosfet interface.

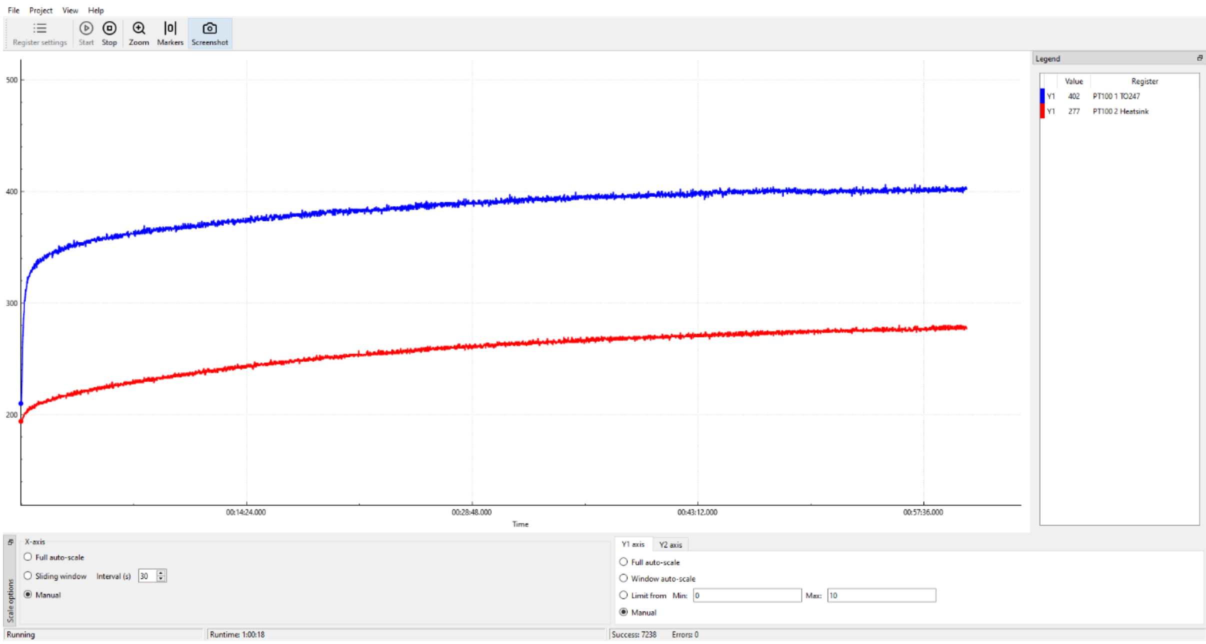


Figure 21. Thermal profile of Kapton 25µm.

PSU reports 24V 1.65A (39.6W) upon initial stabilisation. After 60 minutes PSU reports 24V 1.63A (39.10W).

Start temperatures: Heatsink: 19.4° C. TO247: 21.0° C.

Final maximum temperatures: Heatsink 28.0° C, TO247 40.6° C.

ΔT(heatsink): 8.6°C, ΔT(to247): 19.6°C, ΔT(heatsink-to247): 12.8°C.

Ambient air temperature 21.8°C

This was the first measurement, had a 60-minute runtime, and data does not include the cooling profile.

2. 15µm Kapton Film

Using overhead heatsink clamp. Thin films of thermal grease (RS 554-311) applied to heatsink/Kapton pad interface and Kapton pad/Mosfet interface.

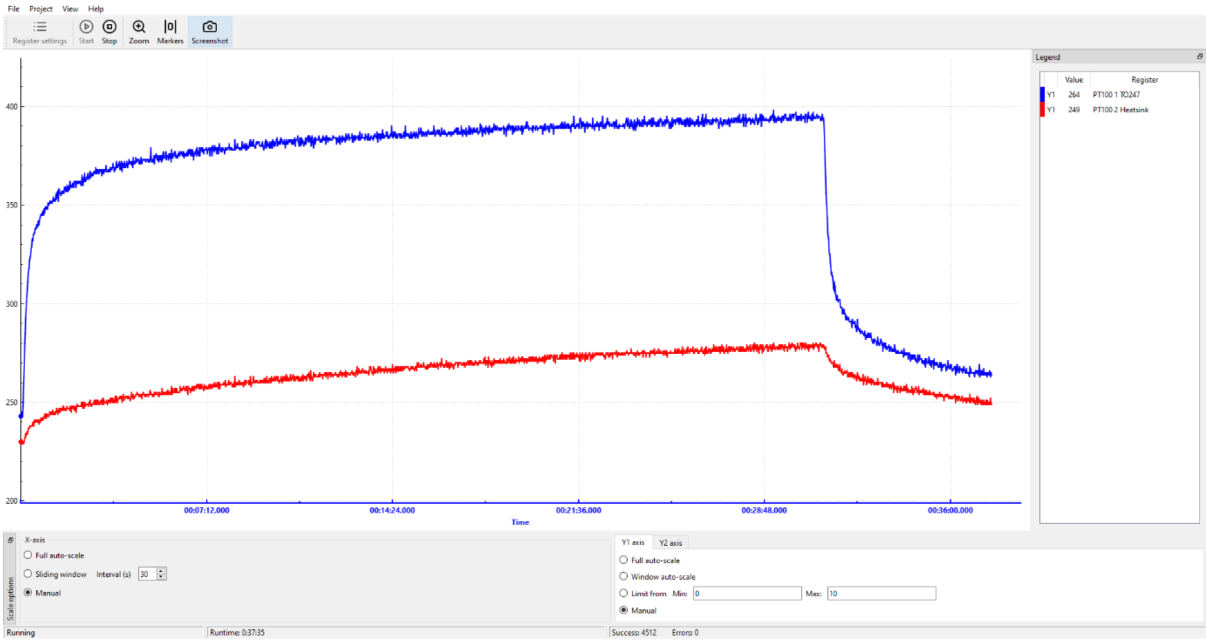


Figure 22. Thermal profile of Kapton 15µm.

PSU reports 24V 1.64A (39.37W) upon initial stabilisation. After 30 minutes, 24V 1.63A (39.13W).

Start temperatures: Heatsink: 23.0° C. TO247 : 24.3° C.

Final maximum temperatures: Heatsink 28.0° C. TO247 39.8° C.

ΔT(heatsink): 5.0°C, ΔT(to247): 15.5°C, ΔT(heatsink-to247): 11.7°C.

Ambient air temperature 21.5°C

Film was very fragile and difficult to handle and place. Easy to damage or crease.

3. Alumina pads

Using overhead heatsink clamp. Thin films of thermal grease (RS 554-311) applied to heatsink/Alumina pad interface and Alumina pad/Mosfet interface.

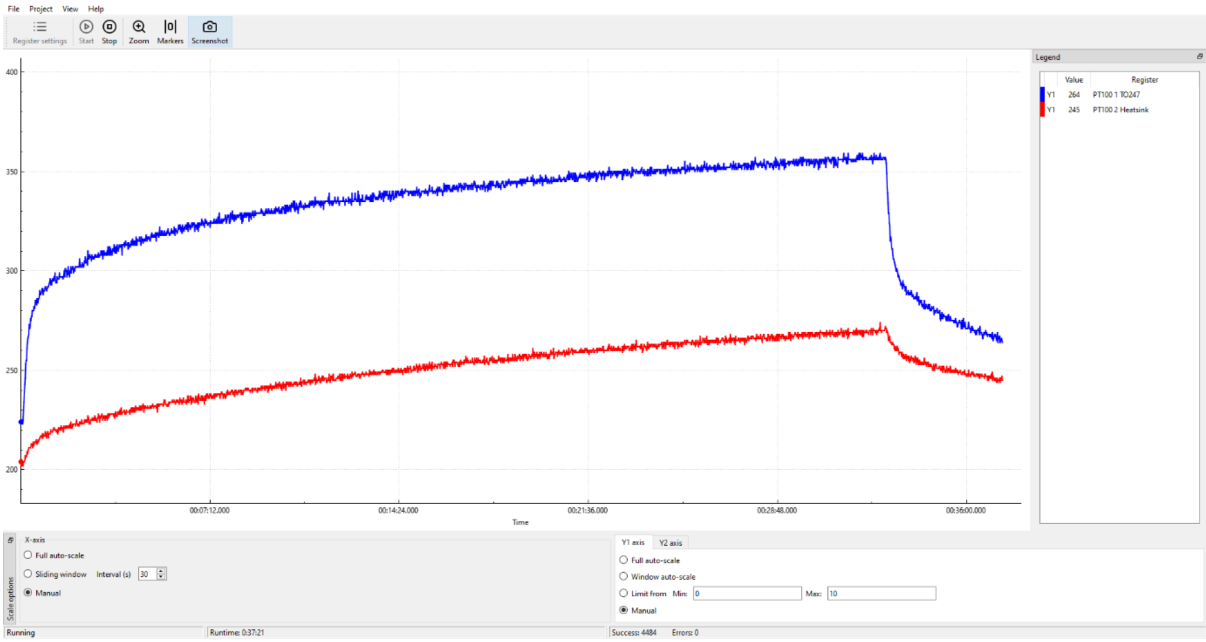


Figure 23. Thermal profile of Alumina 650μm thermal pads.

PSU reports 24V 1.62A (38.89W) upon initial stabilisation. After 30 minutes, 24V 1.61A (38.65W).

Start temperatures: Heatsink: 20.4° C. TO247: 22.4° C.

Final maximum temperatures: Heatsink 27.4° C. TO247 35.9° C.

ΔT(heatsink): 7.0°C, ΔT(to247): 13.5°C, ΔT(heatsink-to247): 8.6°C.

Ambient air temperature 21.7°C

Despite being much thicker than the other non-ceramic materials, this displays very good performance. Slightly worse lag than 15μm Kapton on cooldown.

4. Mica Pads 25µm.

Using overhead heatsink clamp. Thin films of thermal grease (RS 554-311) applied to heatsink/mica pad interface and mica pad/Mosfet interface.

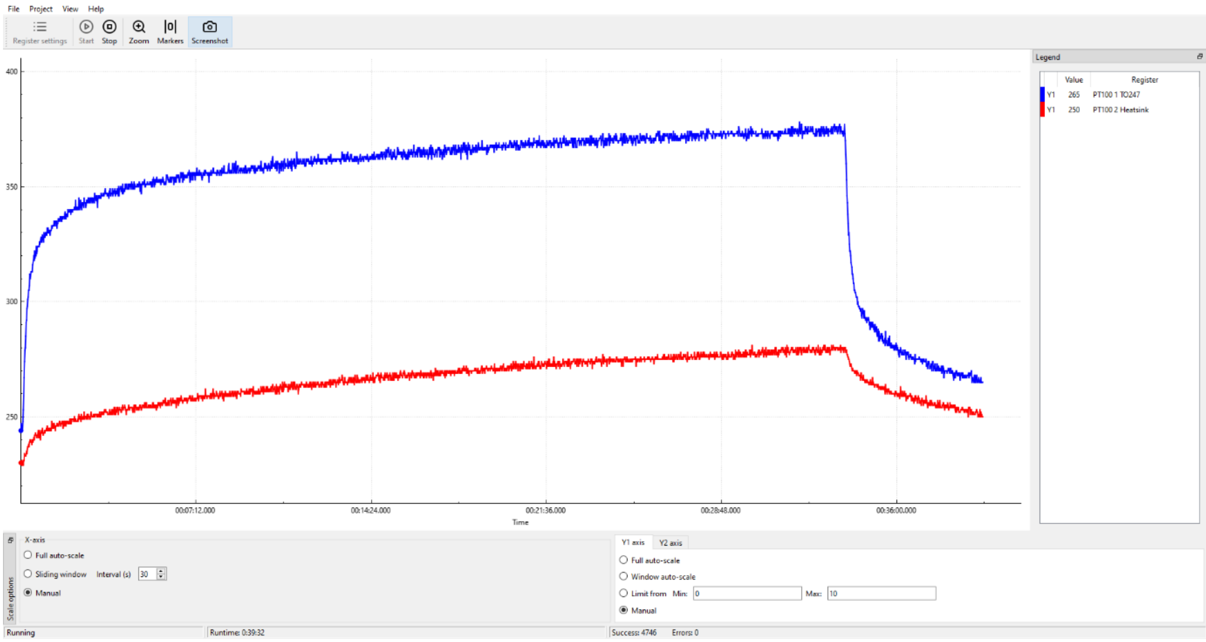


Figure 24. Thermal profile of Mica 25µm.

PSU reports 24V 1.63A (39.13W) upon initial stabilisation. After 30 minutes, 24V 1.62A (38.89W).

Start temperatures: Heatsink: 23.0° C. TO247: 24.4° C.

Final maximum temperatures: Heatsink 28.1° C. TO247 37.8° C.

ΔT(heatsink): 5.1°C, ΔT(to247): 13.4°C, ΔT(heatsink-to247): 9.7°C.

Ambient air temperature 21.2°C

50mm x 50mm sheet cut into 4 pieces with scissors. 1 piece shattered – very delicate.

5. Bergquist SP400-0.007-00-104

Using overhead heatsink clamp. No thermal grease applied.

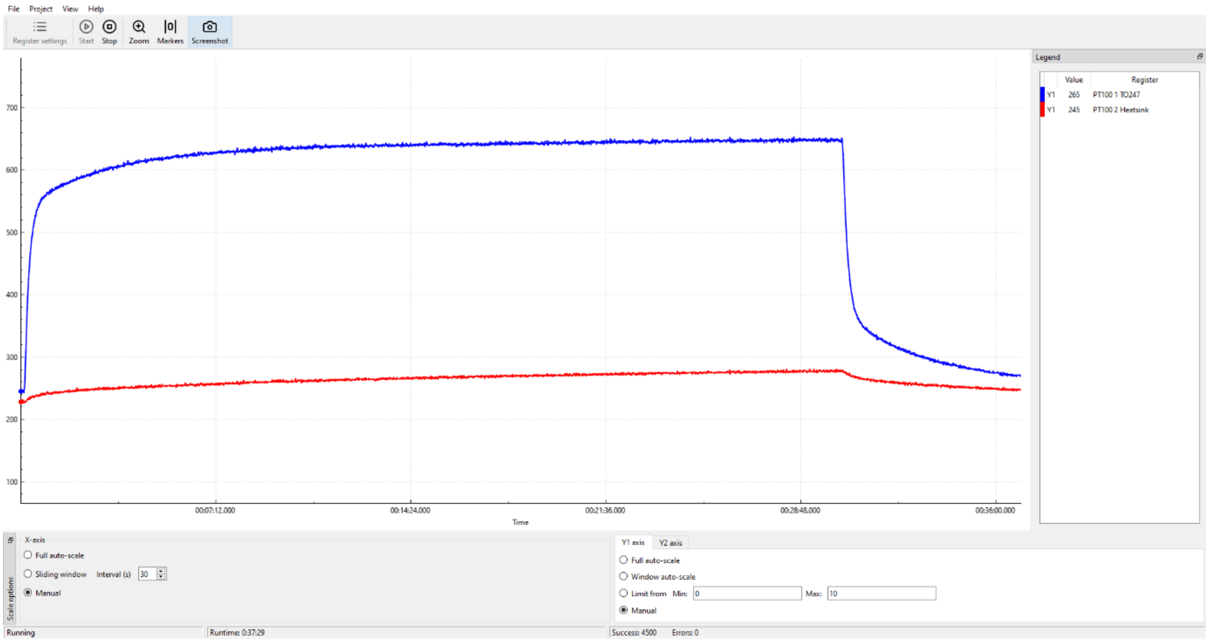


Figure 25. Thermal profile of Bergquist SP400-0.007-00-104 thermal pads using overhead clamp.

PSU reports 24V 1.76A (42.25W) upon initial stabilisation. After 30 minutes, 24V 1.75A (42.01W).

Start temperatures: Heatsink: 22.8° C. TO247: 24.5° C.

Final maximum temperatures: Heatsink 28.0° C. TO247 65.3° C.

ΔT(heatsink): 5.2°C, ΔT(to247): 40.8°C, ΔT(heatsink-to247): 37.0°C.

Ambient air temperature 21.3°C

Clamp heatsink became quite warm.

6. Bergquist SP400-0.007-00-104

Using conventional M3 through hole fixing with nylon insulation spacers. No thermal grease applied.

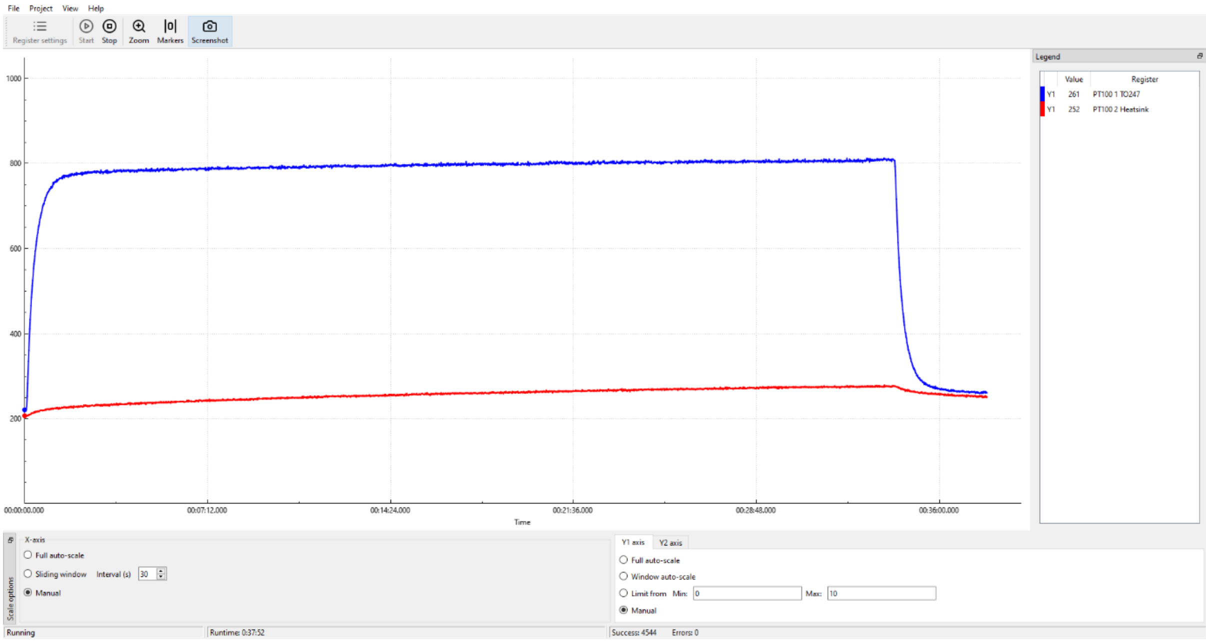


Figure 26. Thermal profile of Bergquist SP400-0.007-00-104 thermal pads using M3 fixing.

PSU reports 24V 1.85A (44.41W) upon initial stabilisation. After 30 minutes, 24V 1.83A (43.92W).

Start temperatures: Heatsink: 20.7° C. TO247: 22.1° C.

Final maximum temperatures: Heatsink 27.9° C. TO247 81.2° C.

ΔT(heatsink): 7.2°C, ΔT(to247): 59.1°C, ΔT(heatsink-to247): 53.2°C.

Ambient air temperature 21.3°C

Poor performance compared to most of the others.

7. Chinese Silpad

Using conventional M3 through hole fixing with nylon insulation spacers. No thermal grease applied.

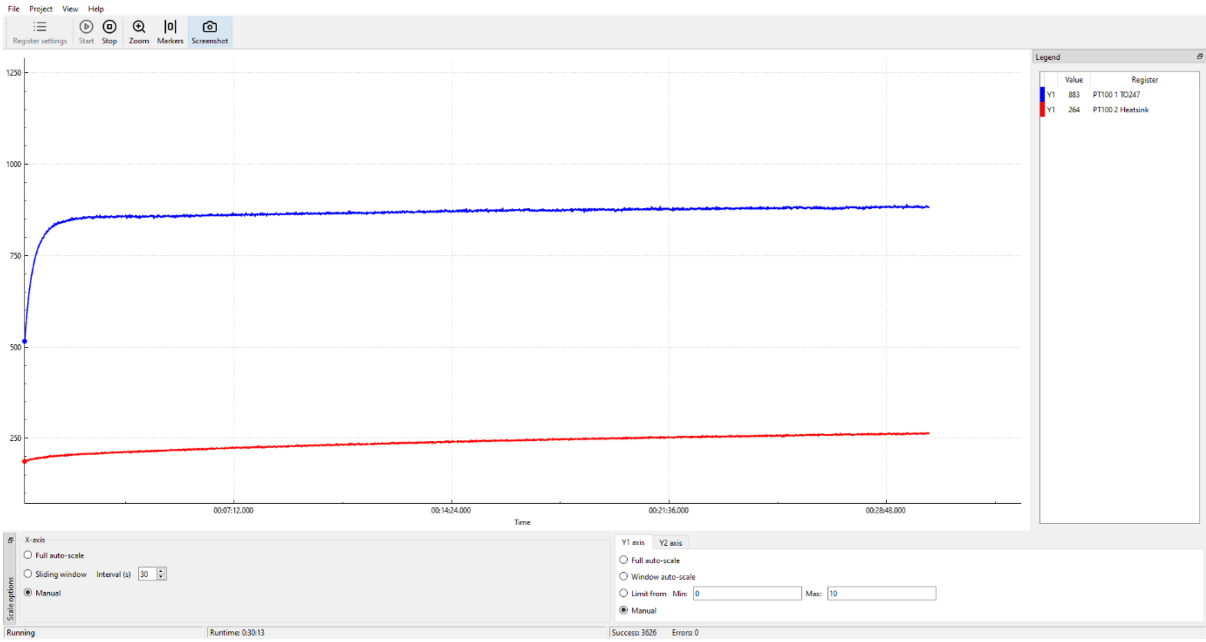


Figure 27. Thermal profile of Chinese Silpads using M3 fixing.

PSU reports 24V 1.91A (45.85W) upon initial stabilisation. After 30 minutes, 24V 1.88A (45.13W).

Start temperatures: Heatsink: 18.3° C. TO247: 20.0° C.

Final maximum temperatures: Heatsink 26.6° C. TO247 88.9° C.

ΔT(heatsink): 8.3°C, ΔT(to247): 68.9°C, ΔT(heatsink-to247): 62.0°C.

Ambient air temperature 21.2°C.

The original silpad used for the initial build of the amplifier. This was the second to be measured. Temperature on TO247 package was noted to drop quickly to below 30° C within 60 seconds of power cut. Future measurements to include cooldown data. Worst result in group.

8. Mica Pads 87µm as purchased Farnell 520-214 New old stock.

Using overhead heatsink clamp. Thin films of thermal grease (RS 554-311) applied to heatsink/mica pad interface and mica pad/Mosfet interface.

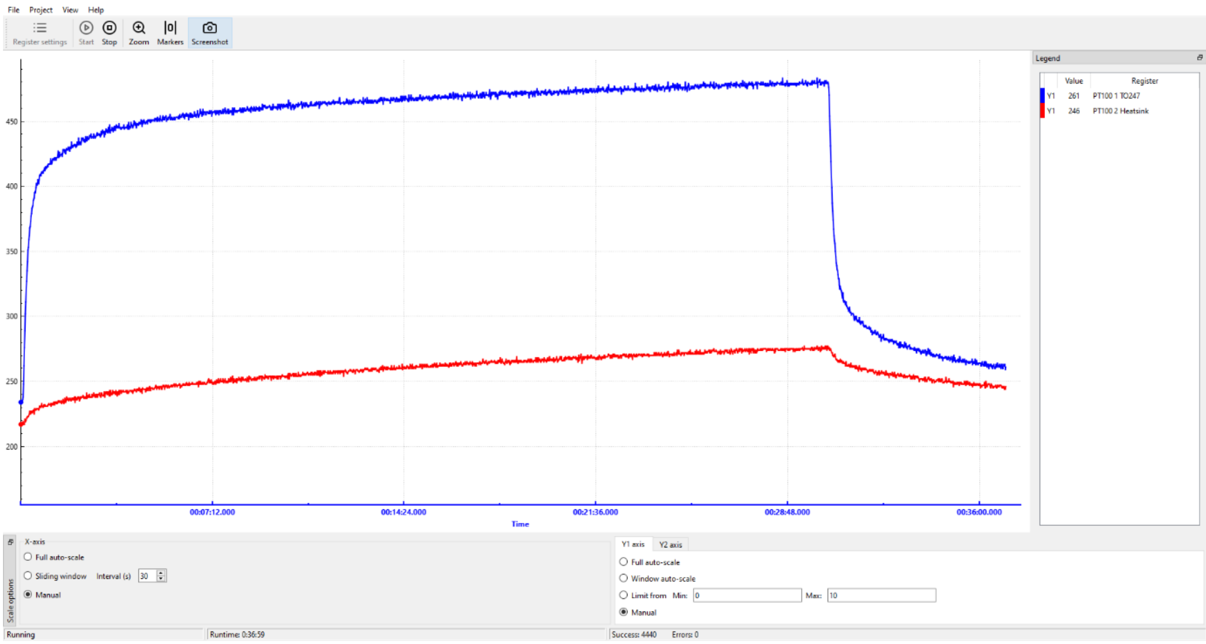


Figure 28. Thermal profile of 87µm Mica washers.

PSU reports 24V 1.68A (40.33W) upon initial stabilisation. After 30 minutes, 24V 1.67A (40.08W).

Start temperatures: Heatsink: 21.7° C. TO247: 23.4° C.

Final temperatures: Heatsink 27.7° C. TO247 48.3° C.

ΔT(heatsink): 6.0°C, ΔT(to247): 24.9°C, ΔT(heatsink-to247): 20.4°C.

Ambient air temperature 21.4°C.

Standard as supplied NOS mica washers.

9. ReBiasing Mofo using Alumina Pads.

Using overhead clamp and RS thermal grease.

24V 2.5A 60W dissipation.

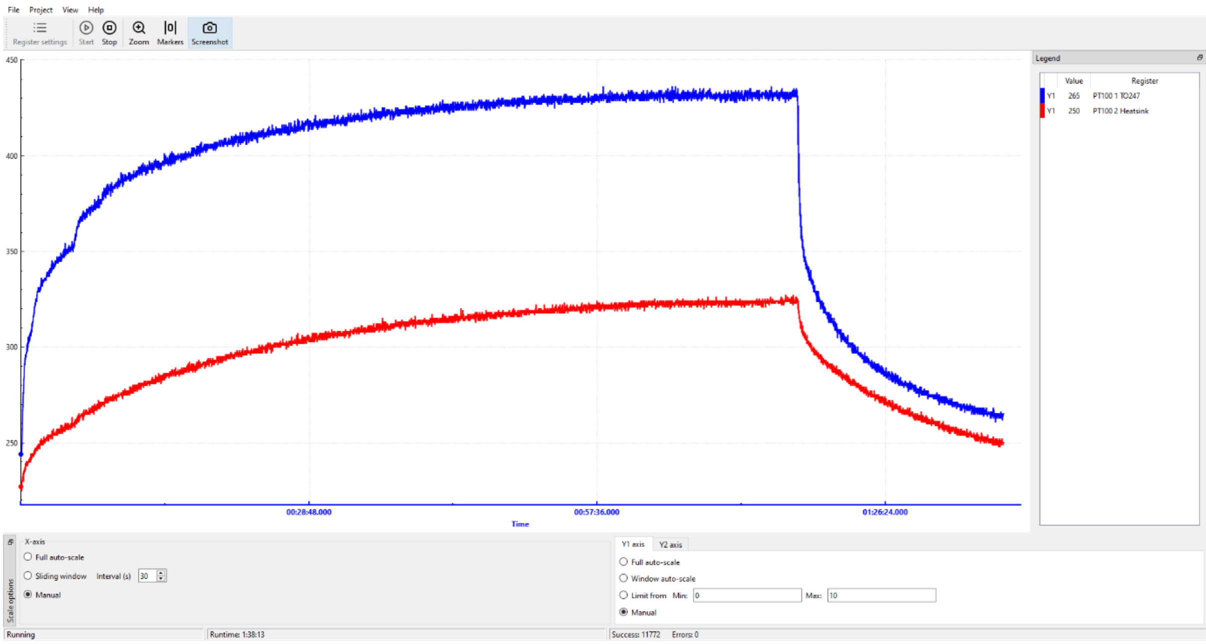


Figure 29. Thermal profile of rebiasing circuit to 24V 2.5A with Alumina pads.

Start temperatures: Heatsink: 22.7° C. TO247: 24.4° C.

Final maximum temperatures: Heatsink 32.6° C. TO247 43.5° C.

ΔT(heatsink): 9.9°C, ΔT(to247): 19.1°C, ΔT(heatsink-to247): 11.1°C

Ambient air temperature 21.1°C.

Circuit was re biased during first few minutes to 2.5A. This can be seen from the irregularities in the initial ramping of the temperature curve. 78 minutes runtime before power off. This setup can easily handle 60W dissipation. The overhead clamp heatsink becomes only lukewarm even after an hour of operation.

10. Repeat of Experiment 3 (20mm x 25mm x 650µm Alumina Pads) with Overhead Clamp sensor.

To serve as a comparison to further testing with the Aluminium Nitride and Phase Change pads, give some insights into the thermal profile of the overhead clamp, and check the consistency of the measurements, the circuit was re-biased to the original operating point of the first 8 experiments and fitted with a third PT100 sensor onto the overhead clamp.

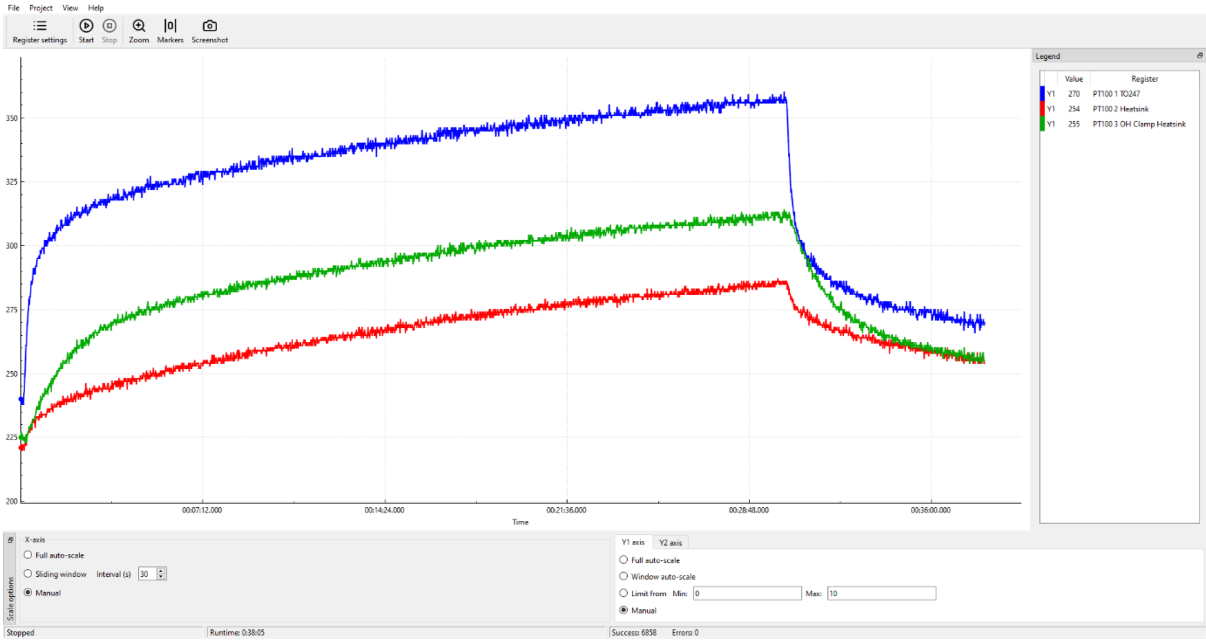


Figure 30. Thermal profile of repeat of Experiment 3 with overhead clamp sensor.

PSU reports 24V 1.61A (38.65W).

Start temperatures: Heatsink: 22.1° C. TO247: 24.0° C. Overhead Clamp: 22.5°C.

Final maximum temperatures: Heatsink 28.7° C. TO247 36.0° C. Overhead Clamp 31.4°C.

ΔT(heatsink): 6.6°C, ΔT(to247): 12.0°C, ΔT(overhead clamp): 8.9°C, ΔT(heatsink-to247): 11.1°C

Ambient air temperature 20.8°C.

11. Aluminium Nitride 20mm x 25mm x 650µm Pads.

Using overhead heatsink clamp. Thin films of thermal grease (RS 554-311) applied to heatsink/alumina pad interface and alumina pad/Mosfet interface.

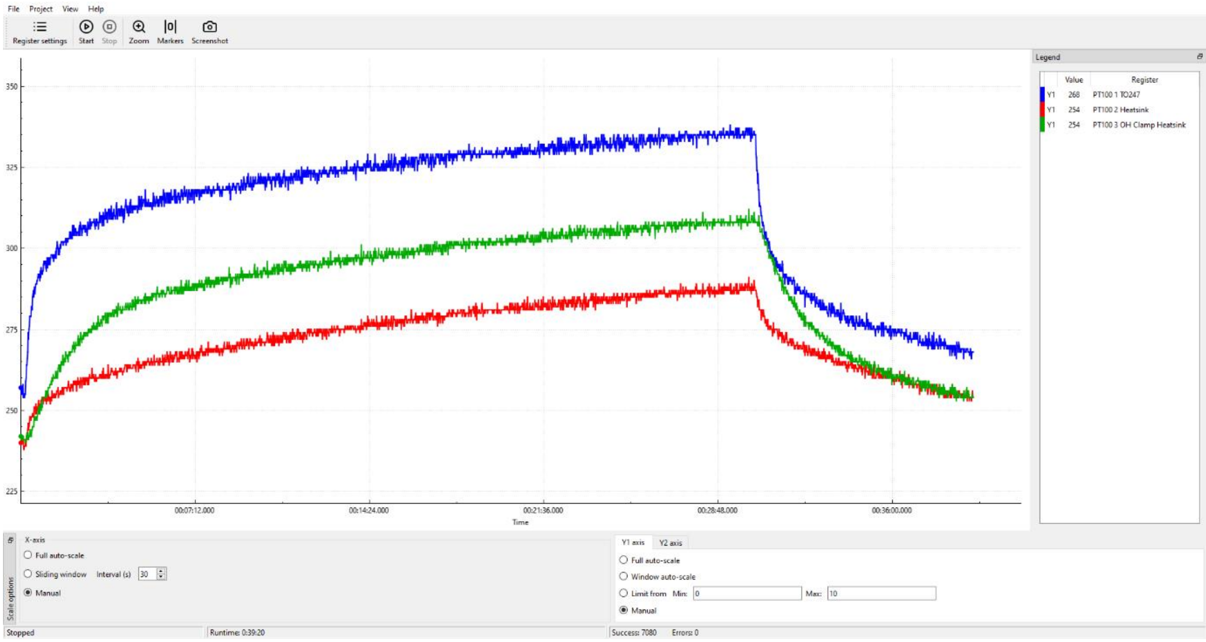


Figure 31. Thermal profile of Aluminium Nitride 20mm x 25mm x 650µm pads, RS thermal grease.

PSU reports 24V 1.59A (38.17W) upon initial stabilisation. After 30 minutes, 24V 1.58A (37.93W).

Start temperatures: Heatsink: 24.0° C. TO247: 25.7° C. Overhead Clamp: 24.2°C.

Final maximum temperatures: Heatsink 29.1° C. TO247 33.8° C. Overhead Clamp 31.2°C.

ΔT(heatsink): 5.1°C, ΔT(to247): 8.1°C, ΔT(overhead clamp): 7.0°C, ΔT(heatsink-to247): 4.7°C

Ambient air temperature 20.7°C.

12. Aluminium Nitride 22mm x 28mm x 650µm Pads.

Using overhead clamp and RS thermal grease.

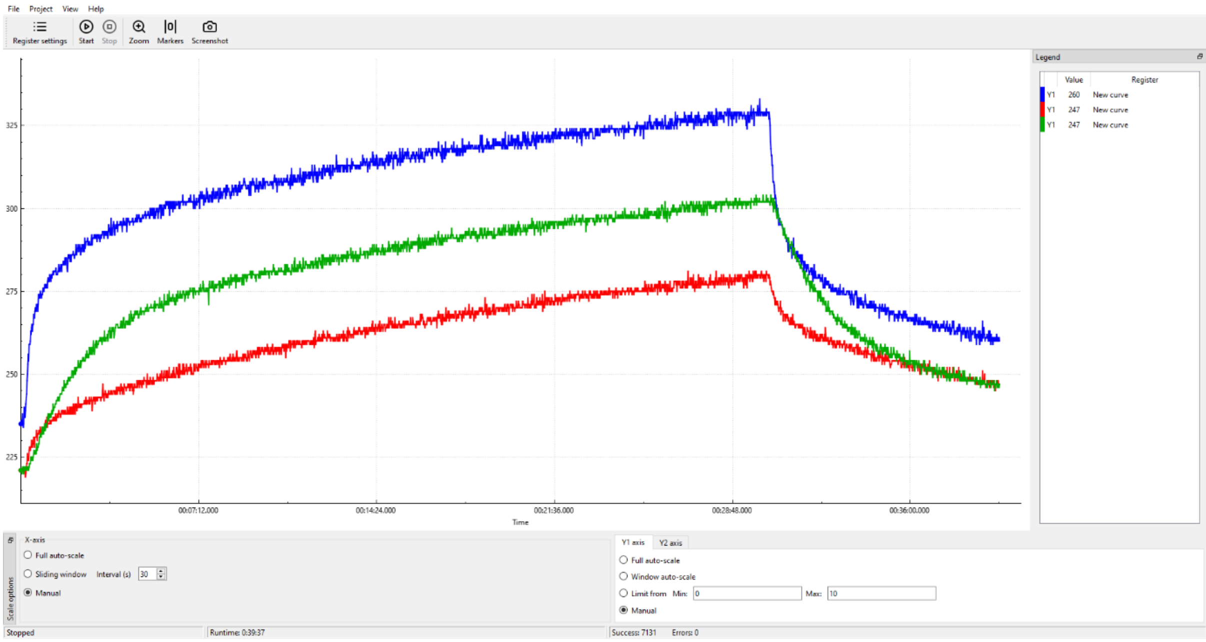


Figure 32. Thermal profile of Aluminium Nitride 22mm x 28mm x 650µm pads, RS thermal grease.

PSU reports 24V 1.58A (37.93W) upon initial stabilisation. After 30 minutes, 24V 1.57A (37.69W).

Start temperatures: Heatsink: 22.1° C. TO247: 23.5° C. Overhead Clamp: 22.1°C.

Final maximum temperatures: Heatsink 28.1° C. TO247 33.3° C. Overhead Clamp 30.4°C.

ΔT(heatsink): 6.0°C, ΔT(to247): 9.8°C, ΔT(overhead clamp): 8.3°C, ΔT(heatsink-to247): 4.8°C

Ambient air temperature 20.4°C.

13. Bergquist HF625-0.005-AC-104 Phase Change Thermal Pads.

Using overhead clamp. All thermal grease was removed.

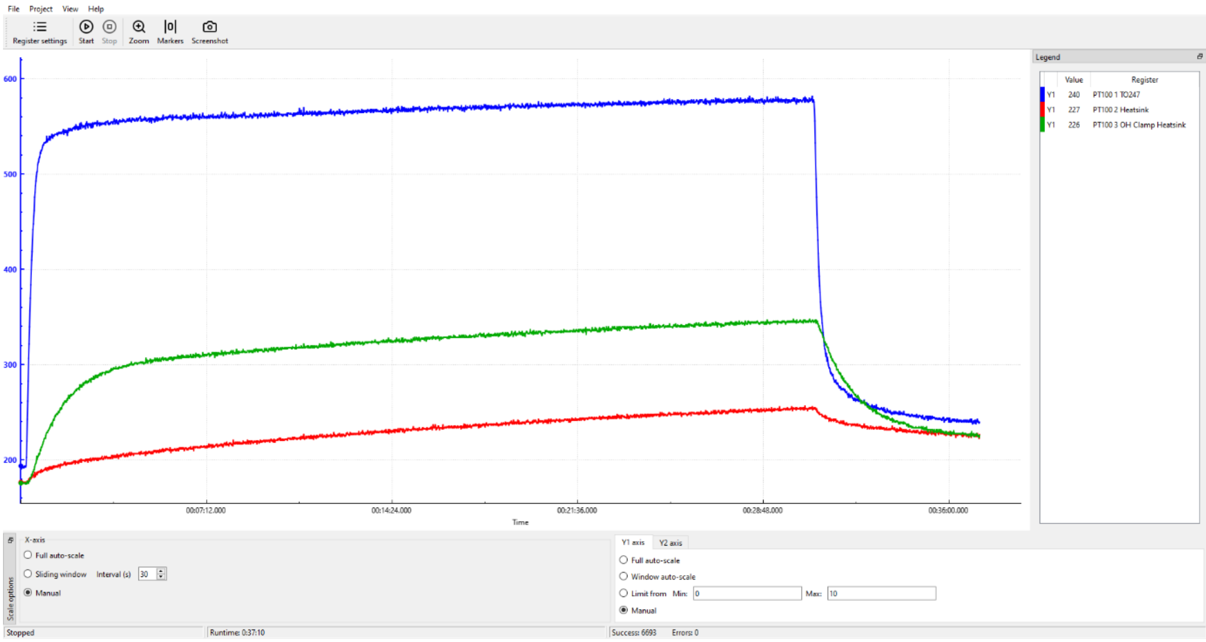


Figure 33. Thermal profile of Bergquist HF625-0.005-AC-104 Phase Change thermal pads.

PSU reports 24V 1.79A (42.97W) upon initial stabilisation. After 30 minutes, 24V 1.75A (42.00W).

Start temperatures: Heatsink: 17.7° C. TO247: 19.4° C. Overhead Clamp: 17.6°C.

Final maximum temperatures: Heatsink 25.7° C. TO247 58.2° C. Overhead Clamp 34.8°C.

ΔT(heatsink): 8.0°C, ΔT(to247): 38.8°C, ΔT(overhead clamp): 17.2°C, ΔT(heatsink-to247): 32.5°C

Ambient air temperature 20.3°C.

14. Aluminium Nitride 20mm x 25mm x 650µm Pads/Chemtronics CW 7250 Boron Nitride Thermal Paste.

Using overhead clamp.

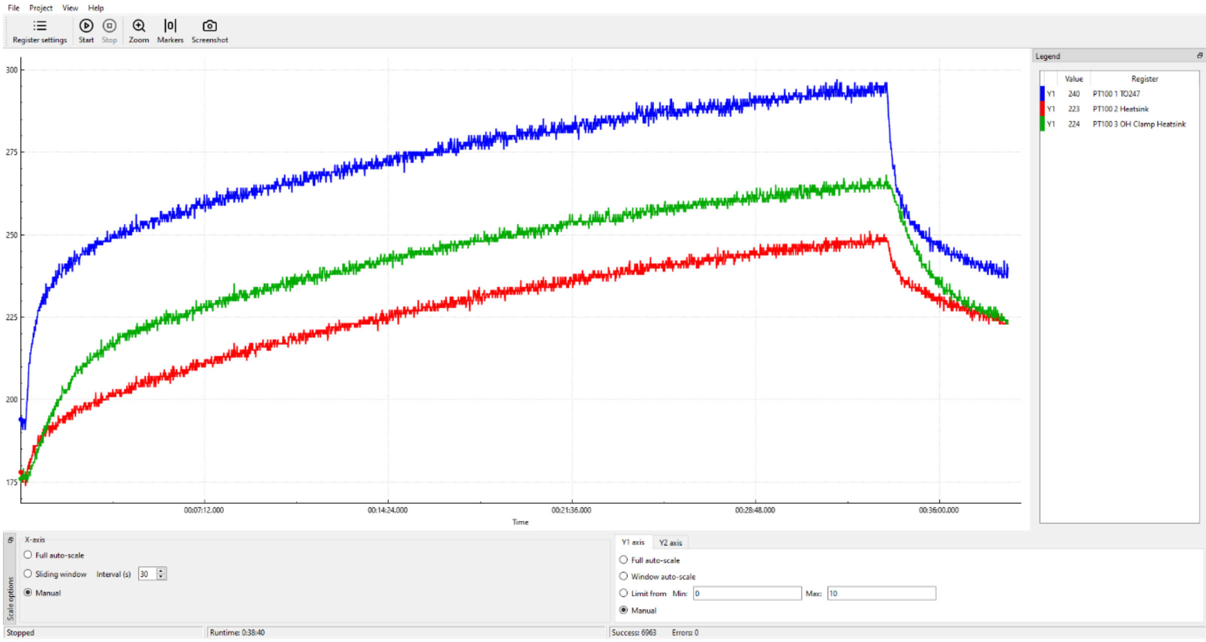


Figure 34. Thermal profile of Aluminium Nitride 20mm x 25mm x 650µm pads, Chemtronics CW7250 Boron Nitride thermal paste.

PSU reports 24V 1.60A (38.40W) upon initial stabilisation. After 30 minutes, 24V 1.59A (38.17W).

Start temperatures: Heatsink: 17.8° C. TO247: 19.4° C. Overhead Clamp: 17.6°C.

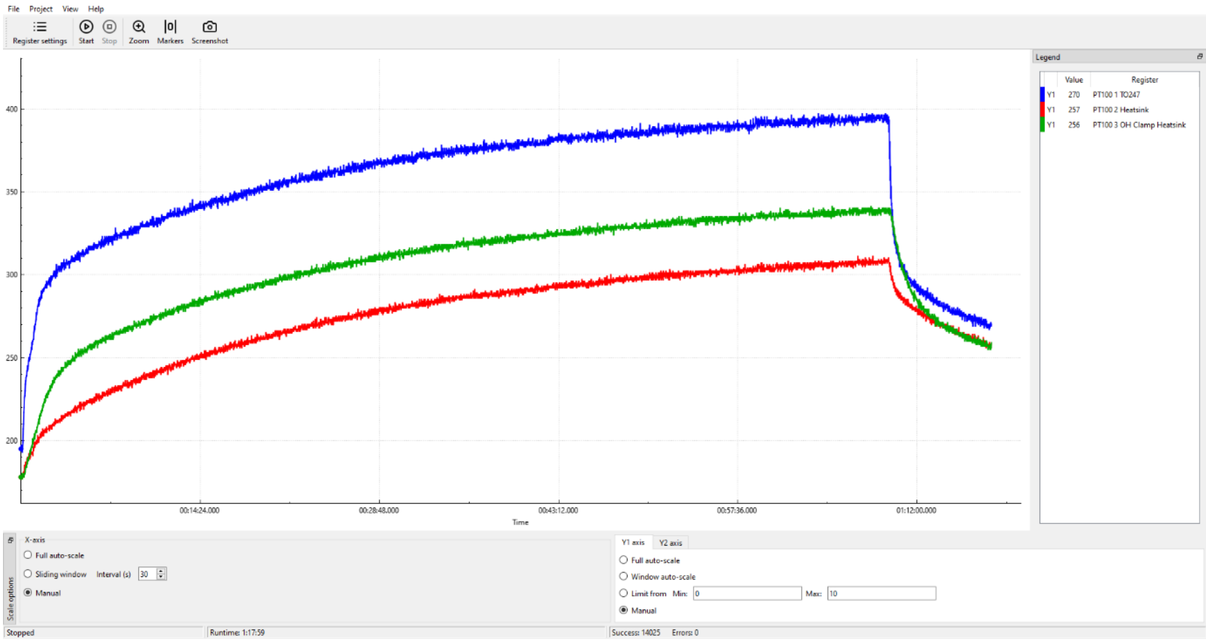
Final maximum temperatures: Heatsink 25.1° C. TO247 29.7° C. Overhead Clamp 26.8°C.

ΔT(heatsink): 7.3°C, ΔT(to247): 10.3°C, ΔT(overhead clamp): 9.2°C, ΔT(heatsink-to247): 4.4°C

Ambient air temperature during test: 19.8°C.

<u>The following experiments were conducted after carefully resetting the bias to 24V 2.5A (60W) with the alumina pad as per Experiment 9.</u>

The thermal profile graph, and data from this run is included for completeness.



<u>Figure 35. Rebiasing the circuit again to 24V 2.50A (60W).</u>

Start temperatures: Heatsink: 17.8° C. TO247: 19.5° C. Overhead Clamp: 17.8°C.

Final maximum temperatures: Heatsink 31.1° C. TO247 39.7° C. Overhead Clamp 34.1°C.

ΔT(heatsink): 13.3°C, ΔT(to247): 20.2°C, ΔT(overhead clamp): 16.3°C, ΔT(heatsink-to247): 8.9°C

Ambient air temperature 19.1°C.

It should be noted that although this shows lower maximum temperatures than experiment 9, the start temperature was lower, in fact to the same extent, confirming the need to account for changes in ambient and starting temperatures. It also gives an insight into the accuracy and repeatability of the data obtained from these experiments.

15. Aluminium Nitride 20mm x 25mm x 650μm Pads/Chemtronics CW 7250 Boron Nitride Thermal Paste, Higher Bias Point.

Using overhead clamp.

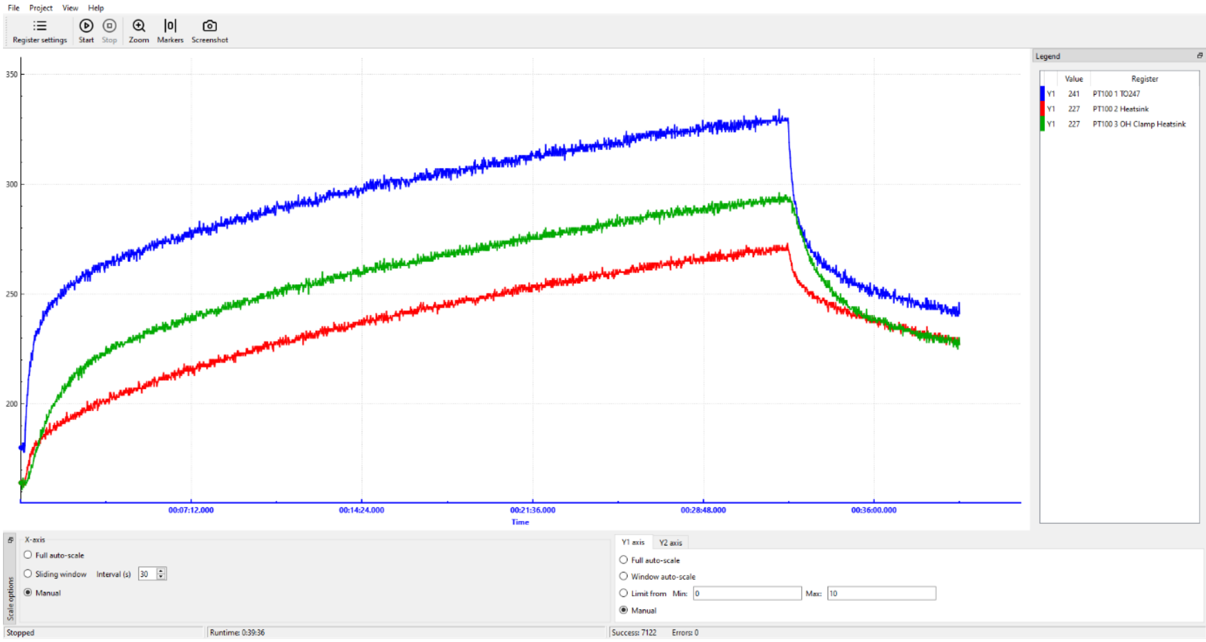


Figure 36. Thermal profile of Aluminium Nitride 20mm x 25mm x 650μm pads, Chemtronics CW7250 Boron Nitride thermal paste. Higher Bias Point.

PSU reports after 30 minutes, 24V 2.48A (59.40W).

Start temperatures: Heatsink: 16.4° C. TO247: 18.0° C. Overhead Clamp: 16.4°C.

Final maximum temperatures: Heatsink 27.3° C. TO247 33.4° C. Overhead Clamp 29.6°C.

ΔT(heatsink): 10.9°C, ΔT(to247): 15.4°C, ΔT(overhead clamp): 13.2°C, ΔT(heatsink-to247): 5.7°C

Ambient air temperature 18.8°C

16. Alumina 20mm x 25mm/RS Thermal Grease/ 2x Copper heatpipe 11mm x 3mm x 220mm/ Fehonda LTP1 18.0W m-1 K-1 thermal putty, Higher Bias Point.

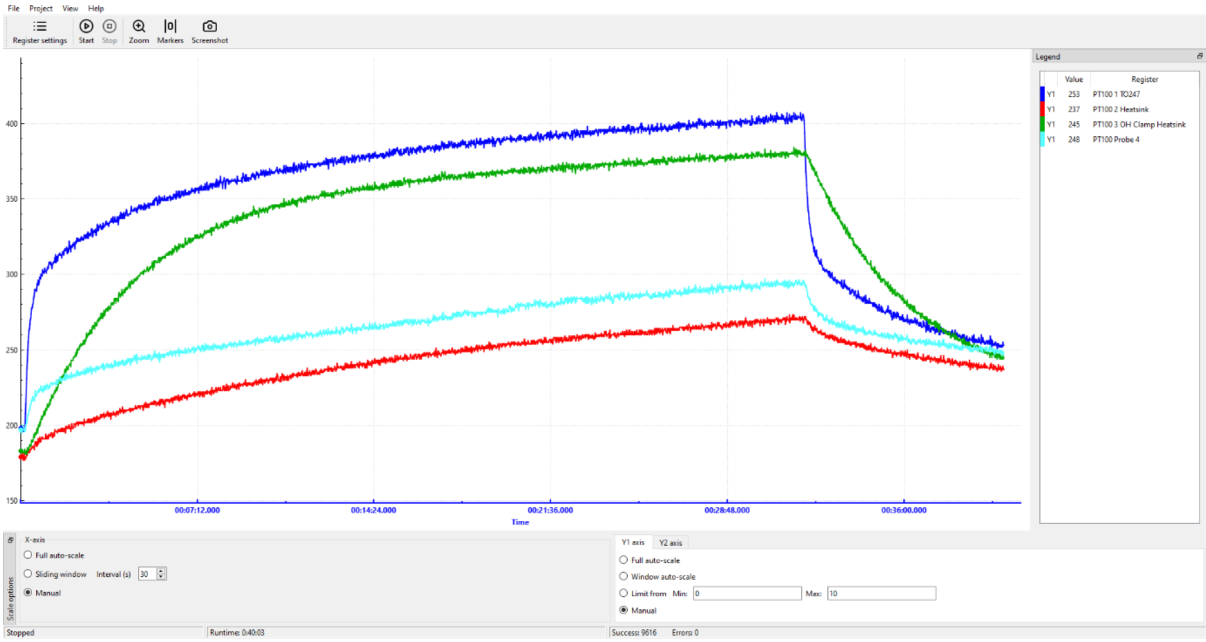


Figure 37. Thermal profile of Alumina 20mm x 25mm pad with RS Thermal Grease between TO247 and pad, 2x Copper heatpipe 11mm x 3mm x 220mm with Fehonda LTP1 18.0W m-1 K-1 thermal putty, Higher Bias Point. Light blue “PT100 Probe 4” is the copper heatpipe probe.

PSU reports after 30 minutes, 24V 2.51A (60.26W).

Start temperatures: Heatsink: 17.9° C. TO247: 19.8° C. Overhead Clamp: 18.3°C. Heatpipe: 19.7°C.

Final maximum temperatures: Heatsink 27.3° C. TO247 40.7° C. Overhead Clamp 38.4°C. Heatpipe: 29.7°C.

ΔT(heatsink): 9.4°C, ΔT(to247): 20.9°C, ΔT(overhead clamp): 20.1°C, ΔT(heatpipe): 10.0°C. ΔT(heatsink-to247): 13.4°C

Ambient air temperature 19.7°C

17. Alumina 20mm x 25mm/RS Thermal Grease/ 2x Copper heatpipe 11mm x 3mm x 220mm/ Fehonda LTP1 18.0W m-1 K-1 thermal putty, Higher Bias Point.

Rerun of experiment 16, except the Fehonda LTP1 between the alumina thermal pad and the copper heatpipes has been removed and replaced with RS thermal grease. A small amount of LTP1 has been left to form a gap filler between the two heatpipes to provide a flat surface to interface with the thermal grease/alumina pad.

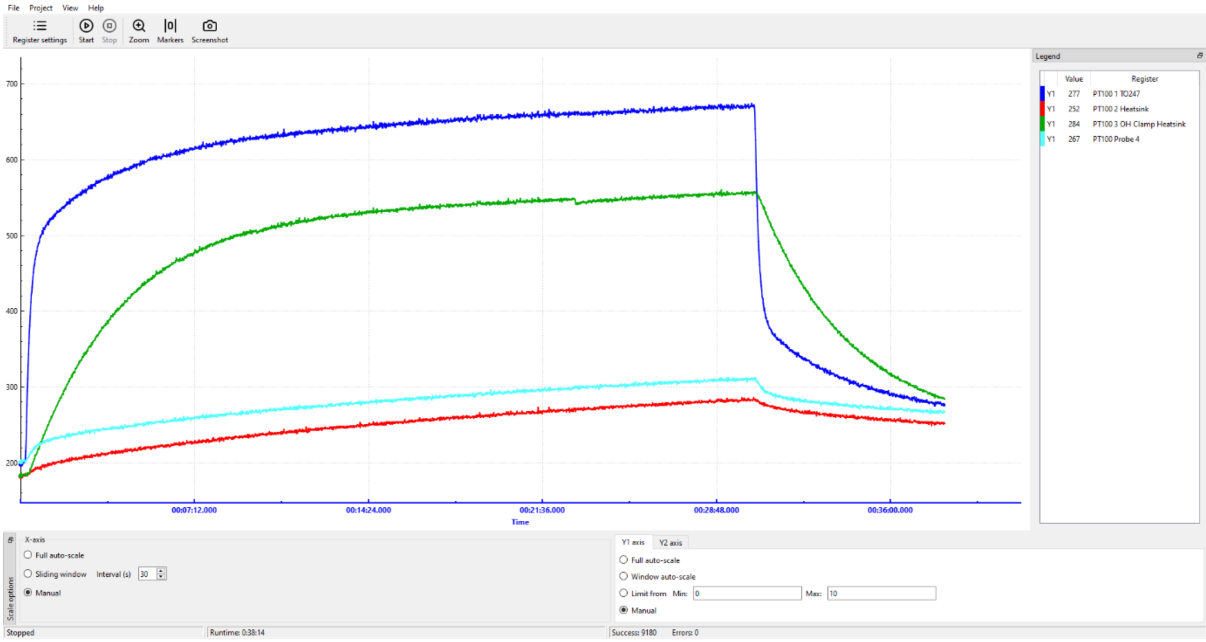


Figure 38. Thermal profile of Alumina 20mm x 25mm pad with RS Thermal Grease between TO247 and pad, 2x Copper heatpipe 11mm x 3mm x 220mm with Fehonda LTP1 18.0W m-1 K-1 thermal putty and RS thermal grease between the Alumina pad and copper heatpipes. Higher Bias Point. Light blue “PT100 Probe 4” is the copper heatpipe probe.

PSU reports after 30 minutes, 24V 2.51A (60.26W).

Start temperatures: Heatsink: 18.2° C. TO247: 19.8° C. Overhead Clamp: 18.3°C. Heatpipe: 20.1°C.

Final maximum temperatures: Heatsink 28.6° C. TO247 67.4° C. Overhead Clamp 56.0°C. Heatpipe: 31.2°C.

ΔT(heatsink): 10.4°C, ΔT(to247): 47.6°C, ΔT(overhead clamp): 37.7°C, ΔT(heatpipe): 11.1°C. ΔT(heatsink-to247): 39.1°C

Ambient air temperature 19.8°C

18. Bergquist HF625-0.005-AC-104 Phase Change Thermal Pads, Higher Bias Point.

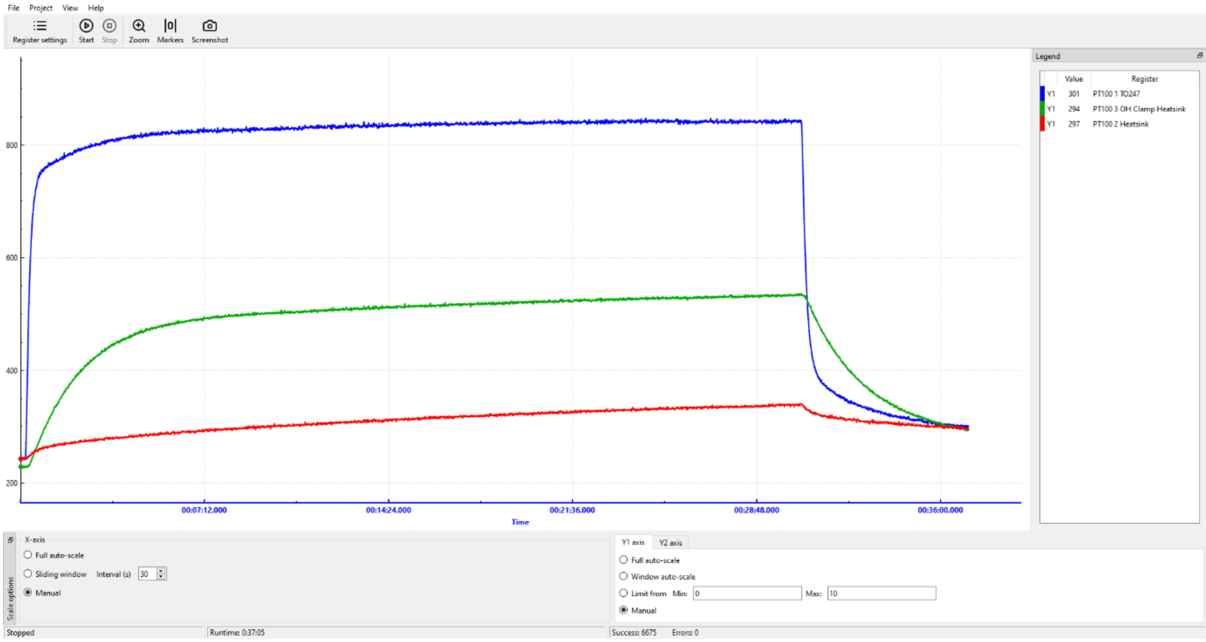


Figure 39. Thermal profile of Bergquist HF625-0.005-AC-104 Phase Change thermal pads.

PSU reports after 30 minutes, 24V 2.65A (63.62W).

Start temperatures: Heatsink: 24.3° C. TO247: 24.3° C. Overhead Clamp: 22.9°C.

Final maximum temperatures: Heatsink 34.1° C. TO247 84.7° C. Overhead Clamp 53.6°C.

ΔT(heatsink): 9.8°C, ΔT(to247): 60.4°C, ΔT(overhead clamp): 30.7°C, ΔT(heatsink-to247): 50.5°C

Ambient 23.8°C

Results Comparison

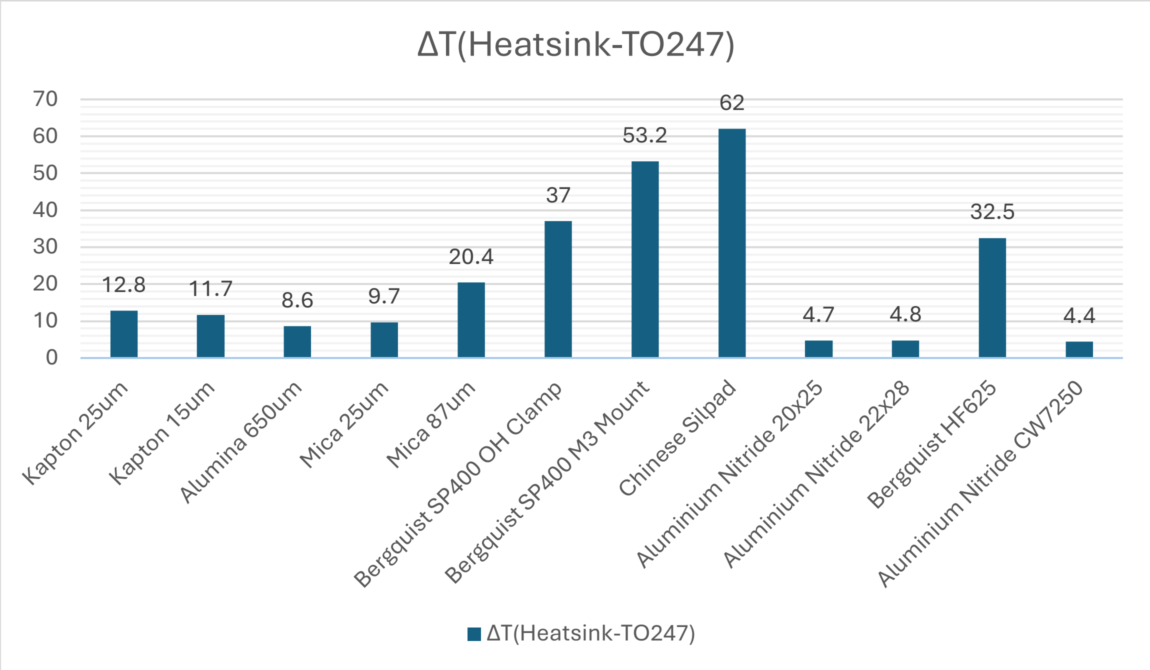


Figure 40. ΔT(Heatsink-TO247) comparisons for the lower bias group.

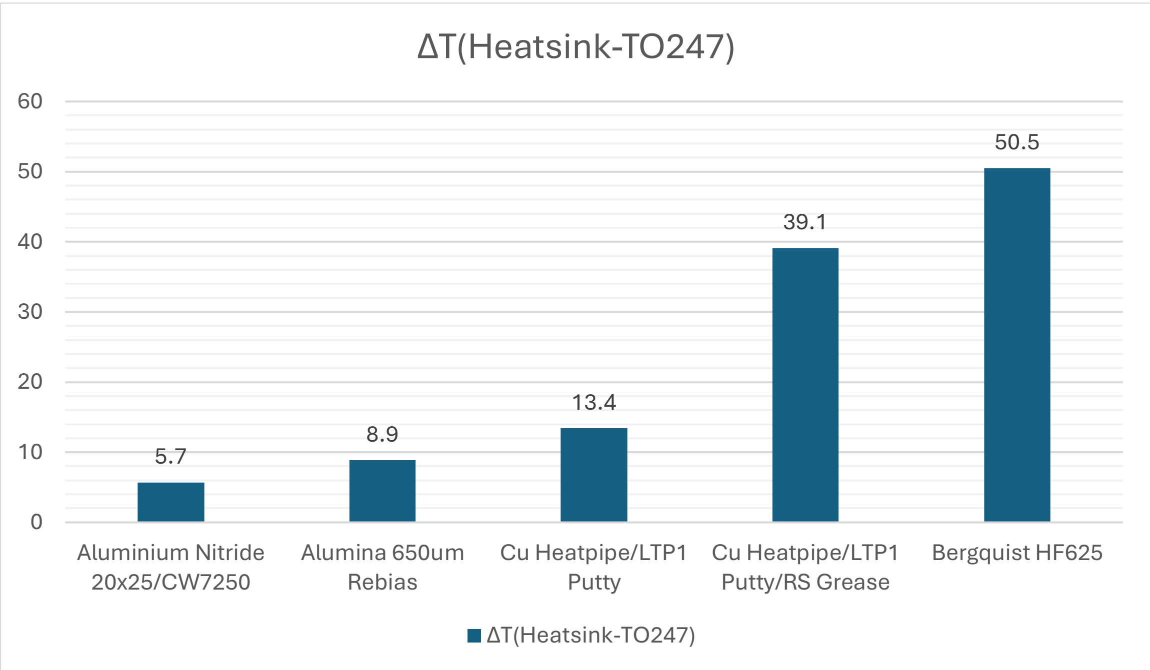


Figure 41. ΔT(Heatsink-TO247) comparisons for the higher bias group.

Discussion

The use of the overhead clamp instead of the conventional M3 mounting improved heat transfer substantially, bringing the TO247 substrate temperature down by 15.9°C, as can be seen from the comparison between the two Bergquist SP400 tests. This will reduce the rate of chemical reactions in the device to less than half, increasing longevity and reliability, although it is likely to be less effective as the thermal interface between the main heatsink and device are improved, due to thermodynamic effects. Whether the enhanced performance, and the extent to which each factor plays, is due to the thermal conduction of the overhead clamp on the plastic top face of the TO247 package and/or the enhanced contact provided by the clamp to the main heatsink, cannot be ascertained without further tests.

With regards to lapping and general surface preparation for optimised thermal contact, the optimum solution would be to use a surface grinder to grind away the extrusion marks on the heatsink / overhead clamp to provide a flat surface free from irregularities. Unfortunately, my surface grinder needs a rebuild, so I had to resort to lapping on an engineering surface plate for the overhead clamp or using a sanding block to remove the extrusion marks in the main heatsink. The TO247 polymer front face can also be lapped, however, it may be prudent to observe antistatic protocols if attempting this.

The thickness of the insulation material does effect performance. However, as can be seen from the two Kapton film tests, a practical limit is evident with regards to film robustness and ease of handling where thicknesses less than 25µm become problematic. In practical terms, the 15µm Kapton only produced a limited improvement in thermal performance compared to the 25µm Kapton.

For mica, off the shelf thicknesses in the range 62µm upwards are probably supplied due to the same robustness issue rather than performance. Tests using a previously unused razor blade to carefully cleave the thicker mica pads in an attempt to produce thinner ones, while possible, was fiddly, time consuming and produced a lot of waste mica material due to breakage.

Alumina pads, tested here, are typically 650 to 675µm and are considerably more robust and/or easier to handle than the 15µm Kapton and the 25µm Mica. There is also a performance advantage. Being a thin film ceramic, they are however brittle, so some care should still be taken during handling.

For the comparison between the two sizes of Aluminium Nitride pads, I was curious to see if any difference could be made with the slightly larger pad. Although it is questionable whether any of the slight apparent advantage was due to the slight drop in ambient temperature due to the domestic heating going off between the two experiments (11 and 12 were done on the same evening in order) is unproven, yet it would provide an explanation. The larger surface area will be more demanding on the flatness of the area on the main heatsink where it makes contact. The added thermal mass is miniscule and unlikely to make a measurable difference with the setup used here.

Interesting to note that DIY Audio forum sell Kerafol Keratherm silicone/ceramic/glass fibre composite pads. https://diyaudiostore.com/products/keratherm-transistor-insulators datasheet: https://cdn.shopify.com/s/files/1/1006/5046/files/kerafol_keratherm_red.pdf. Reported thermal conductivity 6.5W m-1 K-1.

These appear similar to the Bergquist SP400, however, it would also appear that the addition of the ceramic filler to the silicone matrix in the Keratherm Red pads enhances the thermal conductivity substantially. The SP400 thermal conductivity is reportedly 0.9W m-1 K-1. No information on any filler used in the Bergquist SP400 could be found. Although Intertronics quote unfilled silicone thermal conductivity of 0.2W m-1 K-1 here https://www.intertronics.co.uk/wp-content/uploads/2016/11/TB2007-12-Thermally-Conductive-Silicones.pdf .

A note on the importance of even clamping of the device, even with overhead clamping:

The following first run of experiment 10, (Alumina 650μm), was aborted when it was discovered during the experiment that the clamp had not been evenly bolted down due to use of the shorter 4.8mm length spacers, causing a higher temperature to occur on the DUT. In fact, it was the anomalous higher temperature during this run that led to its discovery. The uneven contact between the DUT and the heatsink/pad was barely detectable by eye. It is easy to see on the graph the point where the two bolts are being adjusted to improve the contact between surfaces, due to the rapid temperature drop.

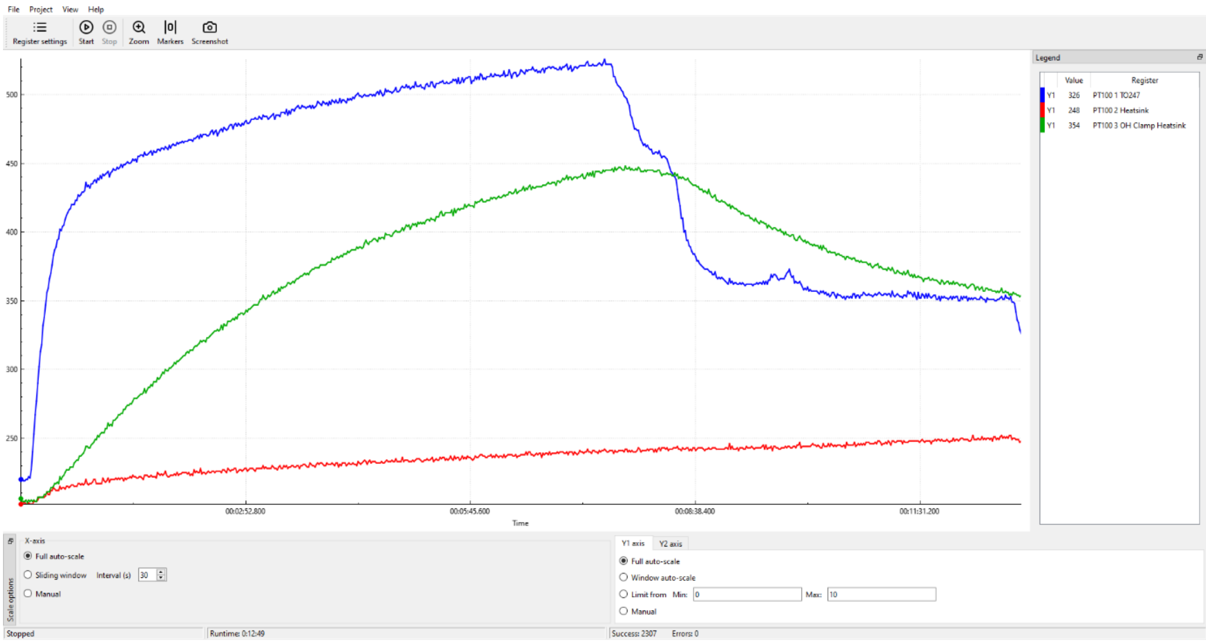


Figure 42. Thermal profile of aborted run of experiment 10, (Alumina 650μm).

For experiment 13, (Bergquist HF625 phase change pad), despite showing a small drop in power dissipation during the experiment, it is noted that the reported phase change temperature of this material is 65°C, so further testing was warranted at a higher bias point to fully test the effectiveness of these pads. It is possible that some extent of phase change did occur, but at a slower rate than normal.

It also should be noted that the phase change material appeared to be on the backing strip/ self adhesive side of the pad. This was only evident after disassembly. See Figure below.

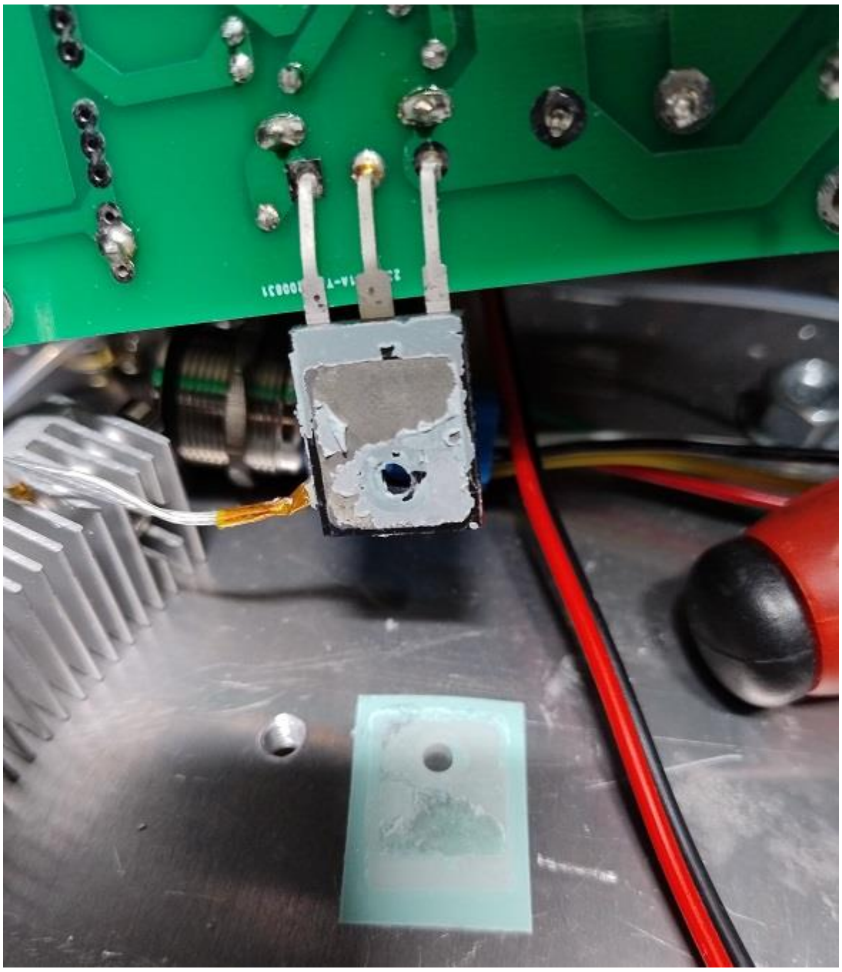


Figure 43. Dissassembly of Bergquist HF625 Phase Change experiment.

The additional experiment using the Bergquist HF625 phase change material was set up for experiment 18. This showed unsatisfactory performance for this application.

By experiment 14, it was becoming apparent that a limit was being reached in terms of reduction in operating temperature and thus internal resistances of the mosfet provided by the increasing performance of the thermal pad interface system between the DUT and the heatsink. Hence, a new series of experiments were embarked upon where the bias point of the circuit was increased to the standard 24V 2.5A (60W) using the alumina pads, as a reference.

Experiments 14 and 15 (Aluminium Nitride 650µm) show excellent performance and are the best in the group.

Experiments 16 and 17 were included to investigate whether heatpipes could be used as method of improving heat transfer to a heatsink from a device. This was taken in the context of where there is the possibly of retrofitting a heatsink/device assembly to accommodate them to try and improve performance, without the use of active (ie fan) based cooling. These experiments proved difficult to set up in comparison with the others. Not least because the LTP1 thermal putty was difficult to apply from the syringe due to the high viscosity and had been clearly formulated to have the maximum concentration of filler practical, making it very dry with very little or no wetting and hence was difficult to get to stick to the heatpipes when being applied.

Gap filling of the central area between the two heatpipes was of particular concern. This size of heatpipe and configuration was chosen because they were easily obtainable, low cost and were at least usable, if not optimal. Ideally, a single, larger width heatpipe with at least enough of a flat area to accommodate the full 16mm width of the TO247 package, or indeed a machined copper/aluminium block with multiple heatpipes and good thermal contact between the pipes and the block, (as featured on fan cooled CPU coolers), would have been much better. Despite this, performance was surprisingly good, but was not as good as direct coupling of the thermal pad to the heatsink. Further testing would have to be undertaken to ascertain whether a more appropriate heatpipe based system could offer any improvements in performance.

During experiment 16, it was apparent that the overhead clamp was dissipating more heat than usual, so an additional experiment 17 was set up, in an attempt to improve the interface between the alumina pad and the heatpipes, primarily by reducing the size of the gap by the use of the RS thermal grease.

Experiment 17 displayed poor performance, probably due to less effective gap filling of the thermal grease. Despite matching the closest two pipes for thickness, there was still 18μm difference between the two. Also, the top profile of the heatpipes was not entirely flat, as was discovered when a razor blade was used to scrape off the LTP1 putty from the pad facing surface in an attempt after experiment 16 to provide a flat surface for the next pad to mate to, revealing a concave shape across the width of the pipes. The slight kink in the overhead clamp thermal profile at around 22minutes is suspected to be the fracturing of the alumina pad during the experiment due to the snapping sound that happened at that time. The pad was confirmed to be broken upon disassembly.

Conclusions

25µm Kapton film in combination with thermal grease seems to be a good, semi robust solution to thermal interfacing active devices and heatsinks. It is less brittle, has a more consistent film thickness and is easier to handle than comparable thickness mica. It can also be successfully punched with a simple, low cost hole punch kit for mounting holes.

For higher performance, the combination of alumina sheet pads, thermal grease and overhead clamping is preferred. These pads can be delicate due to being ceramic in nature and thin, so need to be handled with care and not overtightened as they can crack. It is worth bearing this in mind when considering thermal expansion.

Better performance still is obtained from the Aluminium Nitride pads, but these are quite a bit more expensive and are still delicate.

The use of copper heatpipes is interesting, however more work would need to be done to optimise the setup to take full advantage of the thermal conductivity they offer. The added complication would make it even more difficult to use as an option for retrofitting to existing equipment without considerable effort and access to an engineering workshop.

All of these experiments confirm the importance of optimising the interface between material faces on the DUT, thermal pad and heatsink.

The limitations of these experiments are that the accuracy and repeatability are not as good as that which could be achieved by using an environmental chamber to control the ambient temperature (i.e. to achieve constant temperature) of the experiments. However, they represent a good idea of what can be expected from each material for practical applications.

Unsurprisingly, it was the setup in experiment 14 (Aluminium Nitride pad with Boron Nitride Paste) that I settled on using in my current amplifier build.

Misty Blue 10/12/2024

"*Using scientific investigations to conveniently avoid doing housework.......*"

"*Somehow, somewhere, I think I lost the original plot.......*"

I think I'll get back to building my amplifier now!