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 cheap, 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.

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.

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:

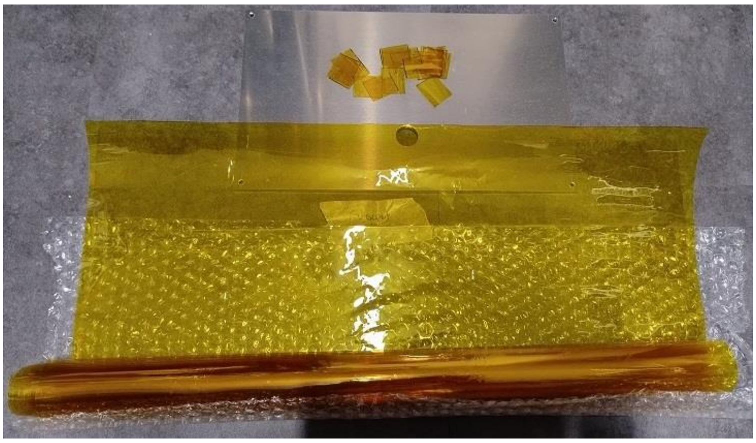
https://www.mouser.co.uk/datasheet/2/48/BERGQUIST_SIL_PAD_TSP_900_en_GL-3432587.pdf

These 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.

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 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



4. Kapton Film 15µm

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

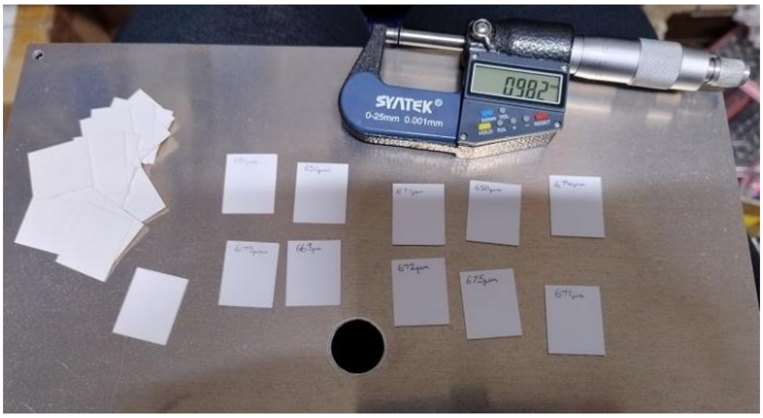
5. Alumina thermal pads. 20mm x 25mm x 0.6mm

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

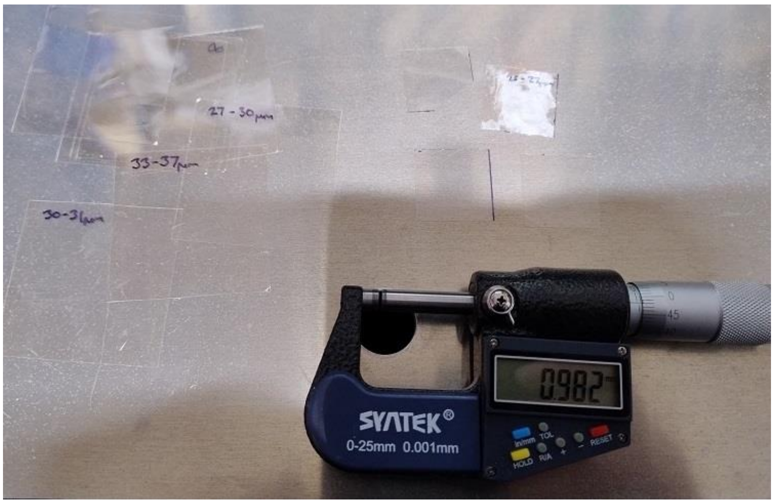
These measure from 650µm to 675µm.



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. 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.



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.

8. Mica Insulators NOS.

Farnell 520-214 TO247 mica washers. Supplied with nylon bush isolators. Measured with micrometer, had thicknesses ranging from 62 to 124µm.

Thermal Grease

Thermal grease used in experiments 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.

Methods

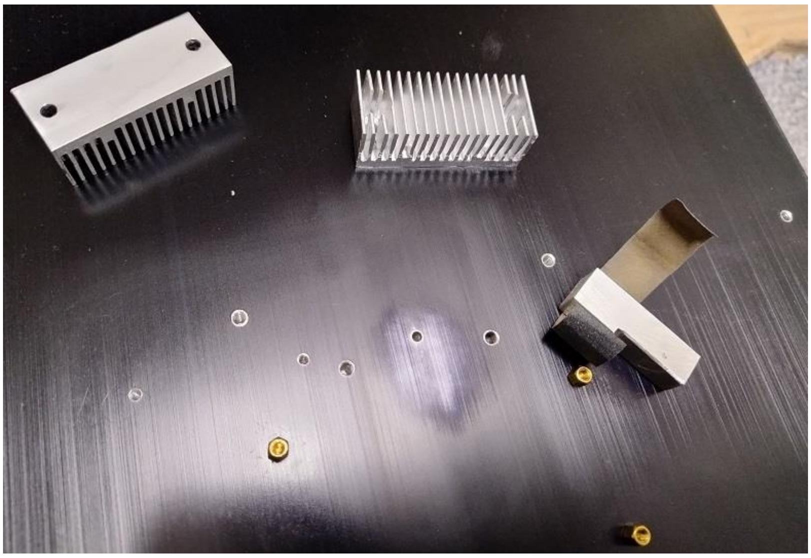
Circuit is a choke loaded mosfet source follower with International Rectifier IRFP250NPBF TO247 as the active device. As per MoFo article by Mike Rothacher. Choke was Hammond 193V and circuit was initially biased at 2A at 24V (50W) in initial build before thermal pad investigation.

The biasing potentiometer was left unchanged during the testing and between each material. Only the last test (re-biasing the circuit to 2.5A, 60W dissipation) involved resetting the bias potentiometer.

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.

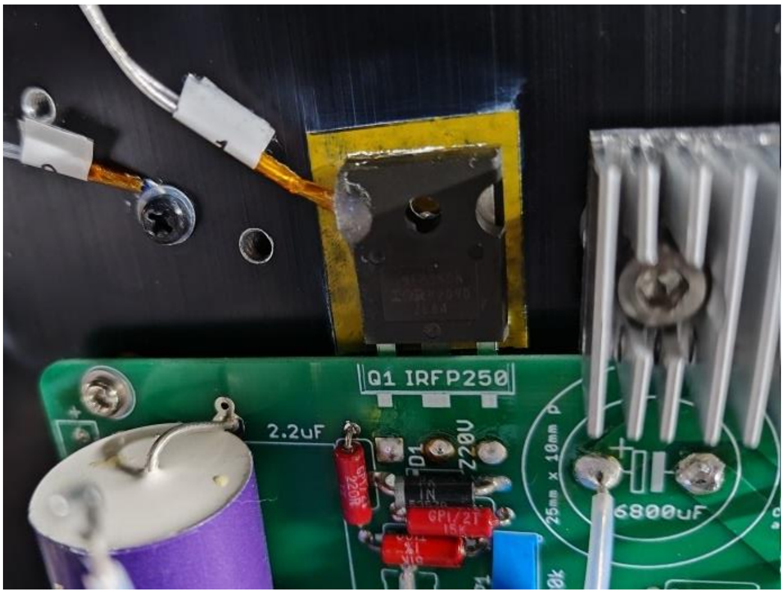
Mosfet was either mounted with the conventional nylon insulation spacers and a M3 stainless steel cap head bolt, or with an aluminium heatsink clamp 50mm x 21mm x 17mm depth made from an ET60 heatsink. M4 mounting holes were drilled and countersunk with a 40mm pitch Aluminium spacers 10mm diameter, 4mm 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.

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.



2 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.



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

Datalogger:

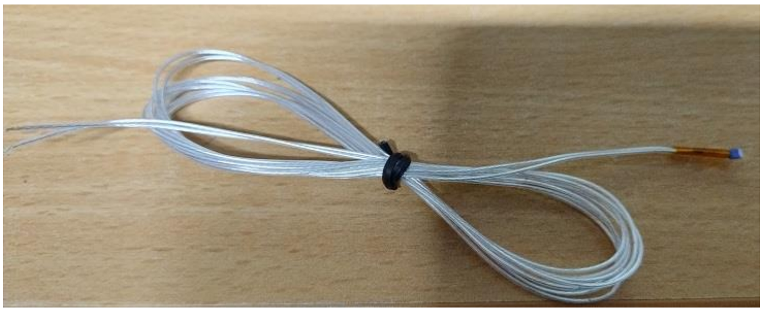
https://www.aliexpress.com/item/1005008019197850.html?spm=a2g0o.order_list.order_list_main.17.527d1802N7NY3B#

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

Probes:

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

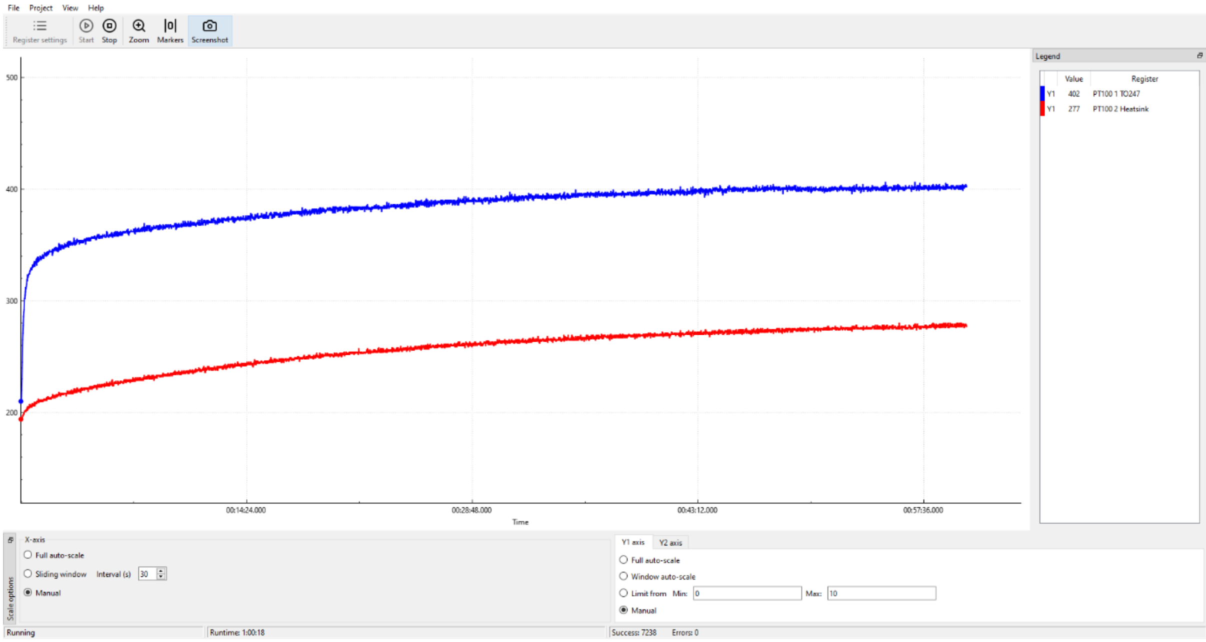
PT100 (385) 2mm x 2mm probes on 2 lead leadouts.



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.



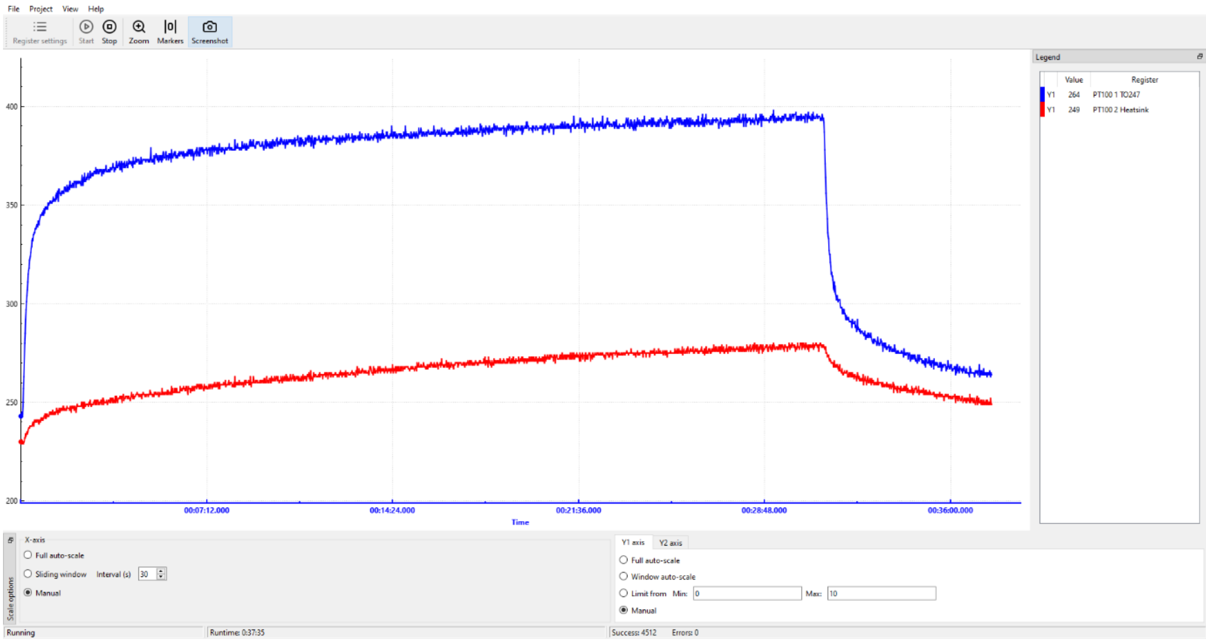
PSU reports 24V 1.65A (39.6W) upon initial stabilisation. After 60 minutes PSU reports 24V 1.63A (39.10W).

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



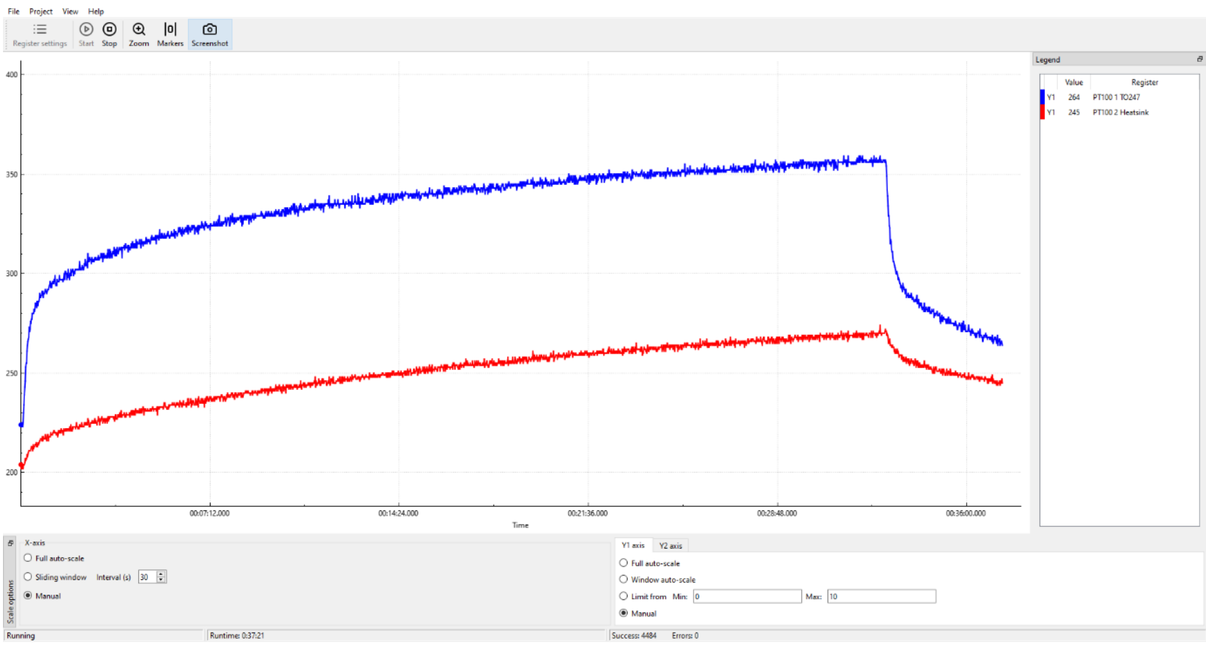
PSU reports 24V 1.64A (39.37W) upon initial stabilisation. After 30 minutes, 24V 1.63A (39.13W).

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



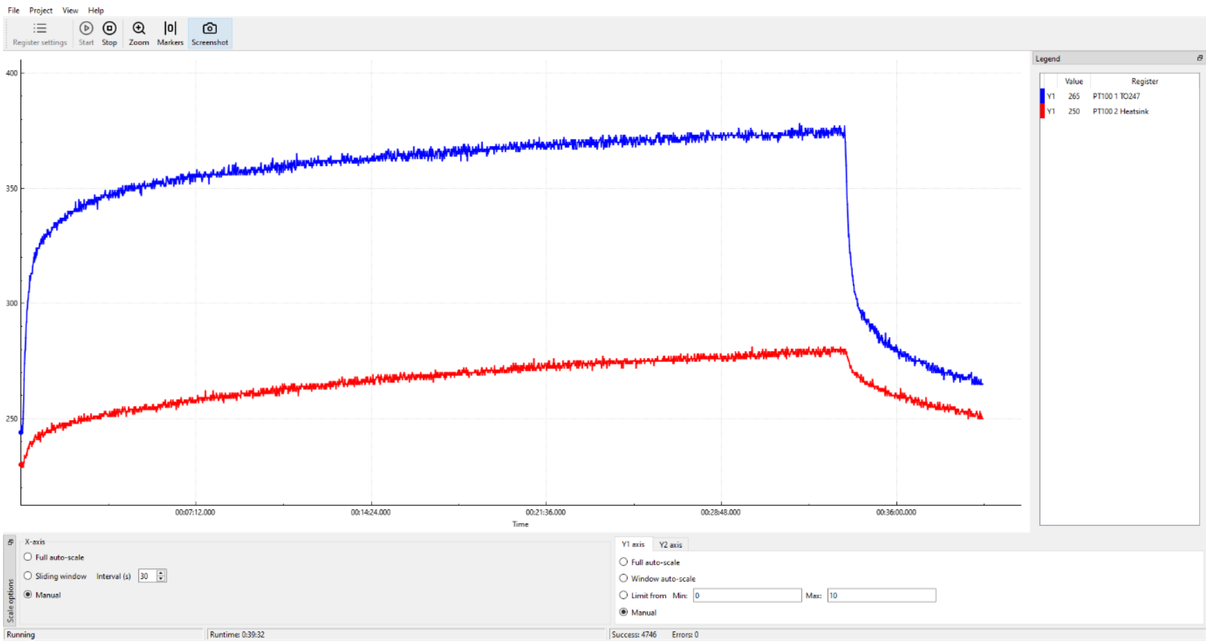
PSU reports 24V 1.62A (38.89W) upon initial stabilisation. After 30 minutes, 24V 1.61A (38.65W).

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

Thickest material of all. Highest performance in the group. Slightly worse lag than 15µm Kapton on cooldown.

<u>4. Mica Pads 25µm.</u>

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



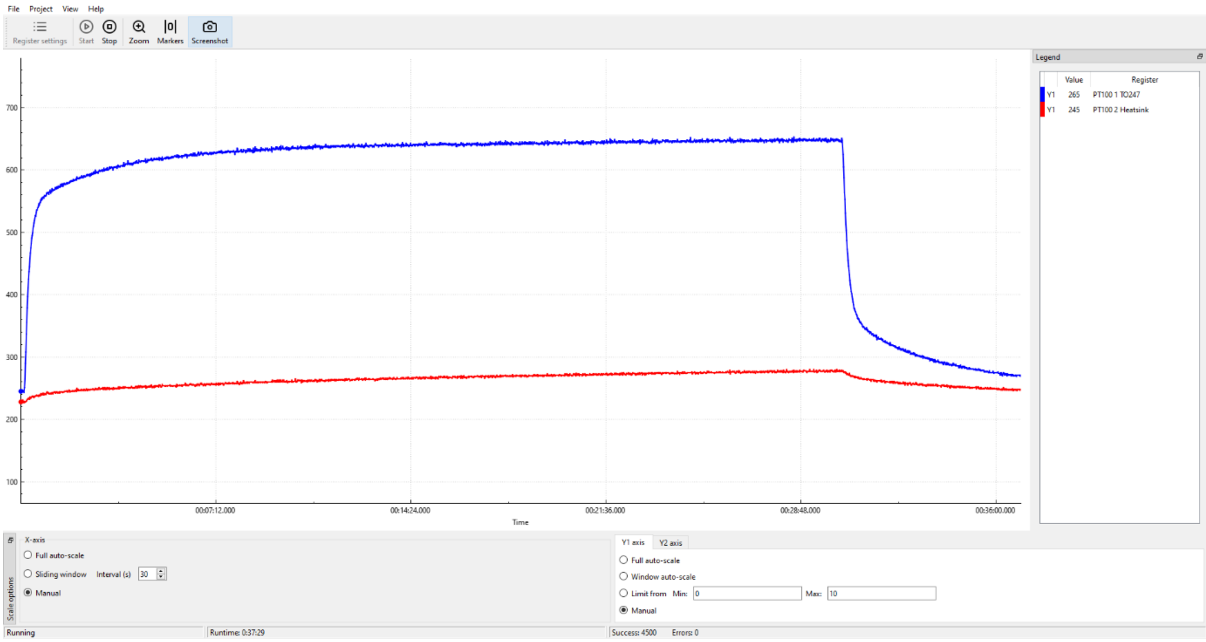
PSU reports 24V 1.63A (39.13W) upon initial stabilisation. After 30 minutes, 24V 1.62A (38.89W).

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



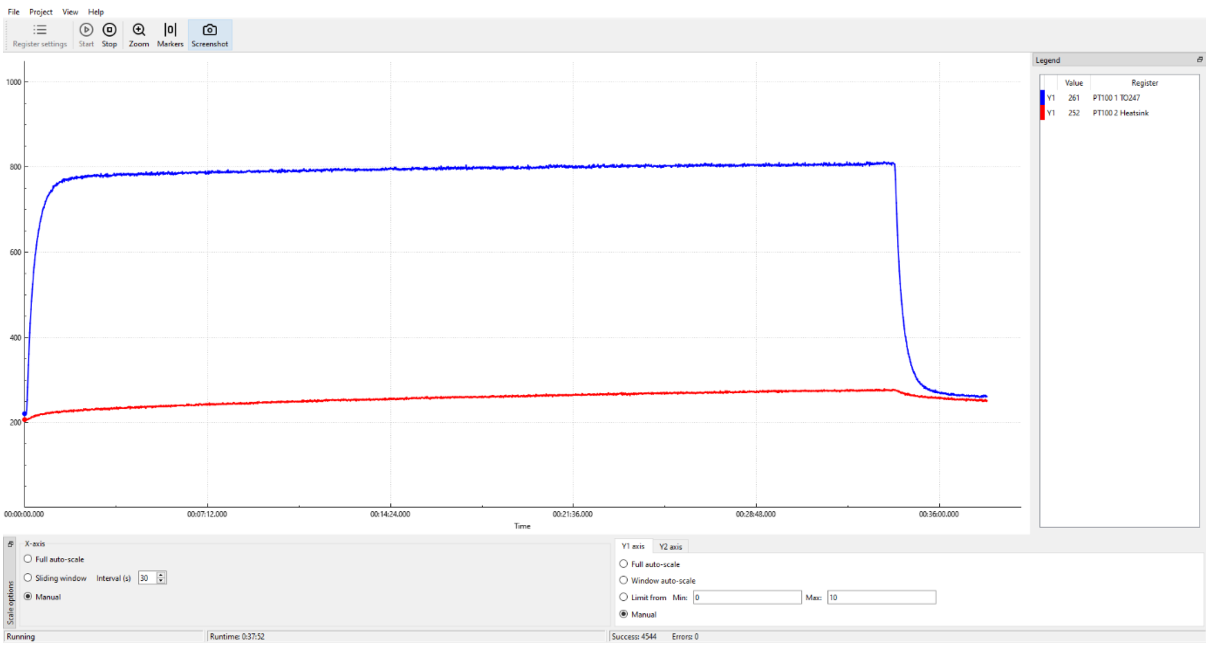
PSU reports 24V 1.76A (42.25W) upon initial stabilisation. After 30 minutes, 24V 1.75A (42.01W).

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



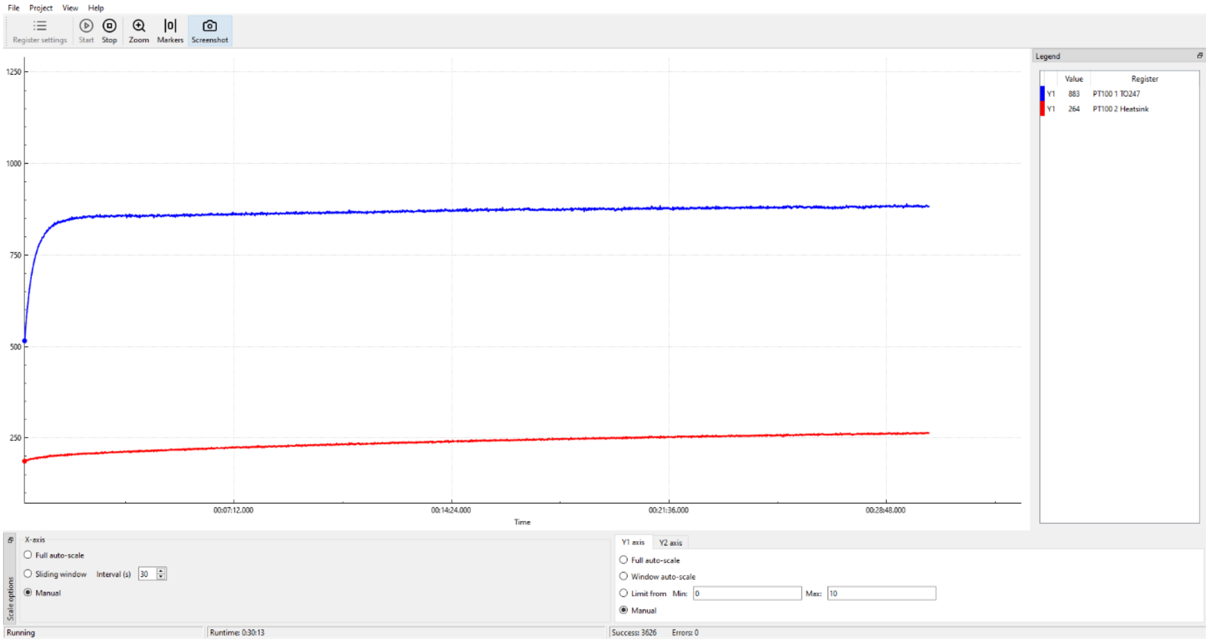
PSU reports 24V 1.85A (44.41W) upon initial stabilisation. After 30 minutes, 24V 1.83A (43.92W).

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



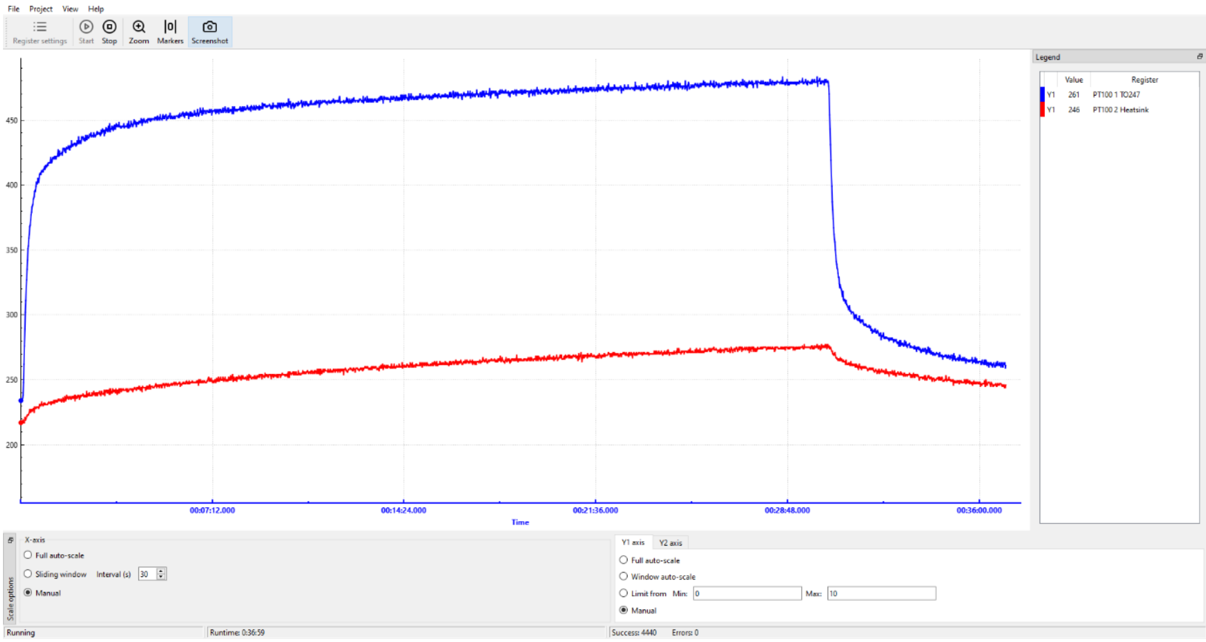
PSU reports 24V 1.91A (45.85W) upon initial stabilisation. After 30 minutes, 24V 1.88A (45.13W).

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



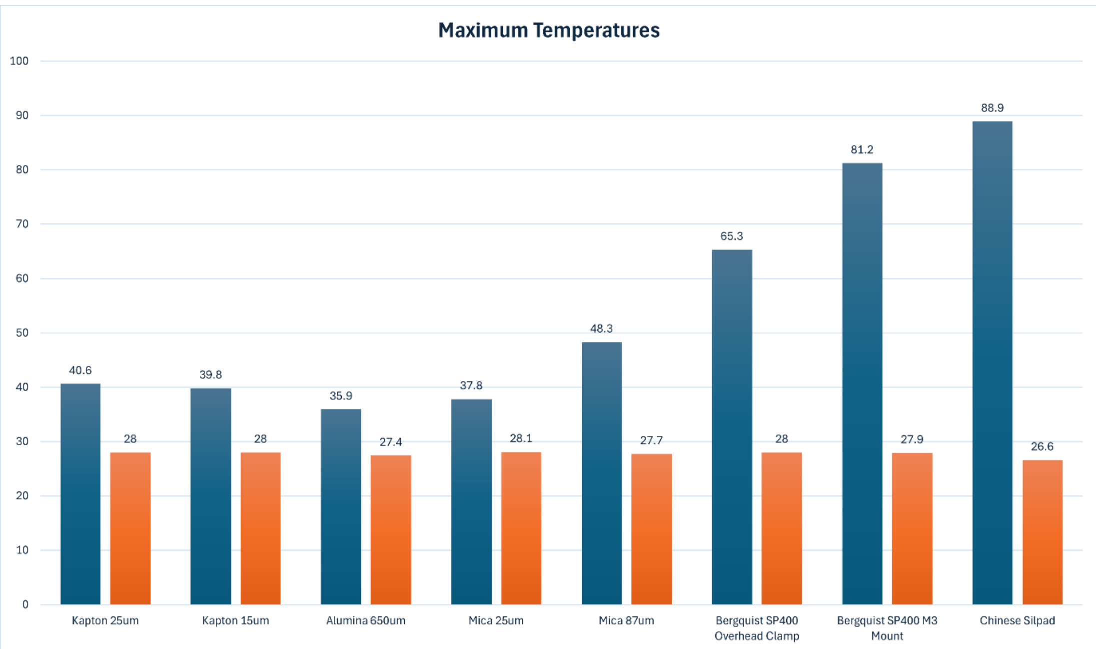
PSU reports 24V 1.68A (40.33W) upon initial stabilisation. After 30 minutes, 24V 1.67A (40.08W).

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

Standard as supplied NOS mica washers.

Results Comparison

Blue is maximum temperature (°C) read from TO247 probe. Orange is maximum temperature from Heatsink probe.



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.

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.

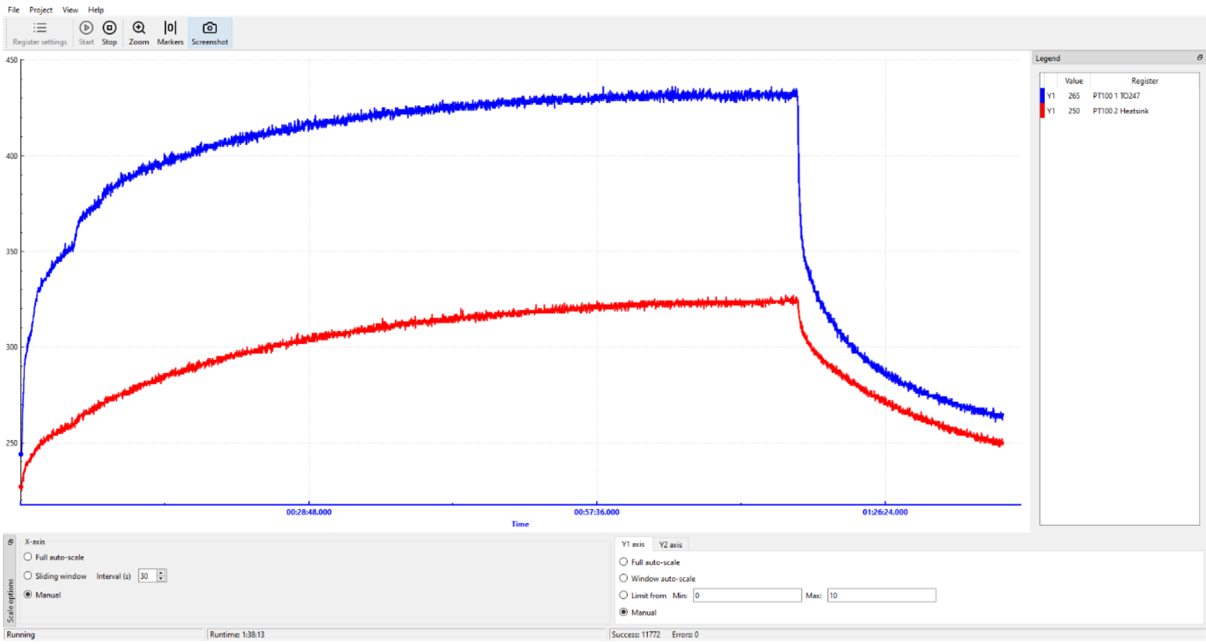
Interesting to note that DIY Audio forum sell Kerafol Keratherm silicone/ceramic/glass fibre composite pads. https://diyaudiostore.com/products/keratherm-transistor-insulators
datasheet: https://cdn.shopify.com/s/files/1/1006/5046/files/kerafol_keratherm_red.pdf.
Reported thermal conductivity 6.5W m-1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

9. Biasing Mofo using Alumina Pads.

Using overhead clamp and thermal grease.

24V 2.5A 60W dissipation.



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

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.

Misty Blue 25/11/2024

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