EML 4551 Final Report

Team 9 – Phase Change Material Transient Heatsink for Power Semiconductor

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Unison Industries

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1.0 Function Analysis and Performance Specifications

The primary objective of our project was to design a compact heatsink for a power semiconductor contained within an ignition unit of a jet engine. Specifically, our heatsink is required to meet the following performance specifications:

- Be able to keep the semiconductor under 125°C for an indefinite duration while it is generating 1W of thermal energy (referred to later as “steady-state”)
- Be able to keep the semiconductor under 125°C for 5 minutes while it is generating 2W of thermal energy (referred to later as “overdrive”)
- Operate in an ambient temperature of 110°C

To meet these specifications, we designed the heatsink shown in Fig. 1. It is a simple aluminum enclosure, and is filled with an indium-tin solder. During the steady-state period mentioned above, the thermal resistance of the enclosure and the solder was designed to be sufficiently low enough to produce a steady semiconductor temperature below the maximum temperature limit specified above. During the overdrive period, the function of the heatsink is to act as a thermal capacitor: the solder was selected for its melting point (118°C), as melting in this range allows the heatsink to temporarily absorb the additional thermal energy from the semiconductor and convert it into the solder’s latent heat of fusion. In doing so, the heatsink is able to conduct enough heat out of the semiconductor to keep it below its maximum allowable operating temperature.

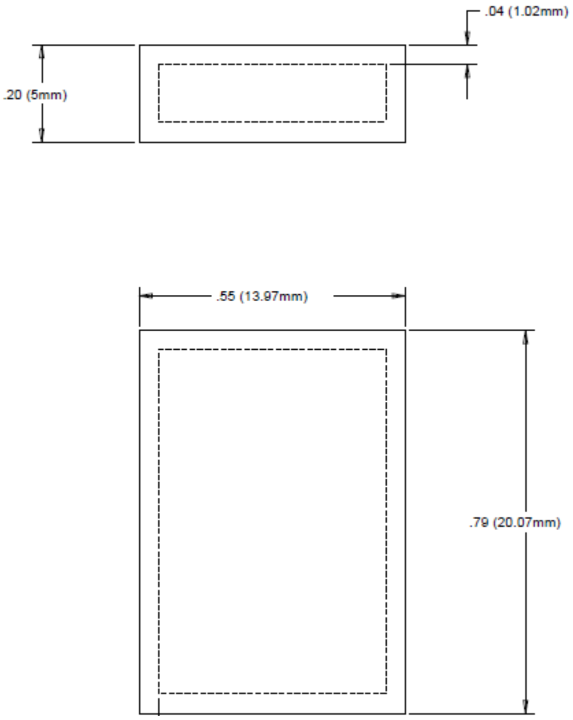
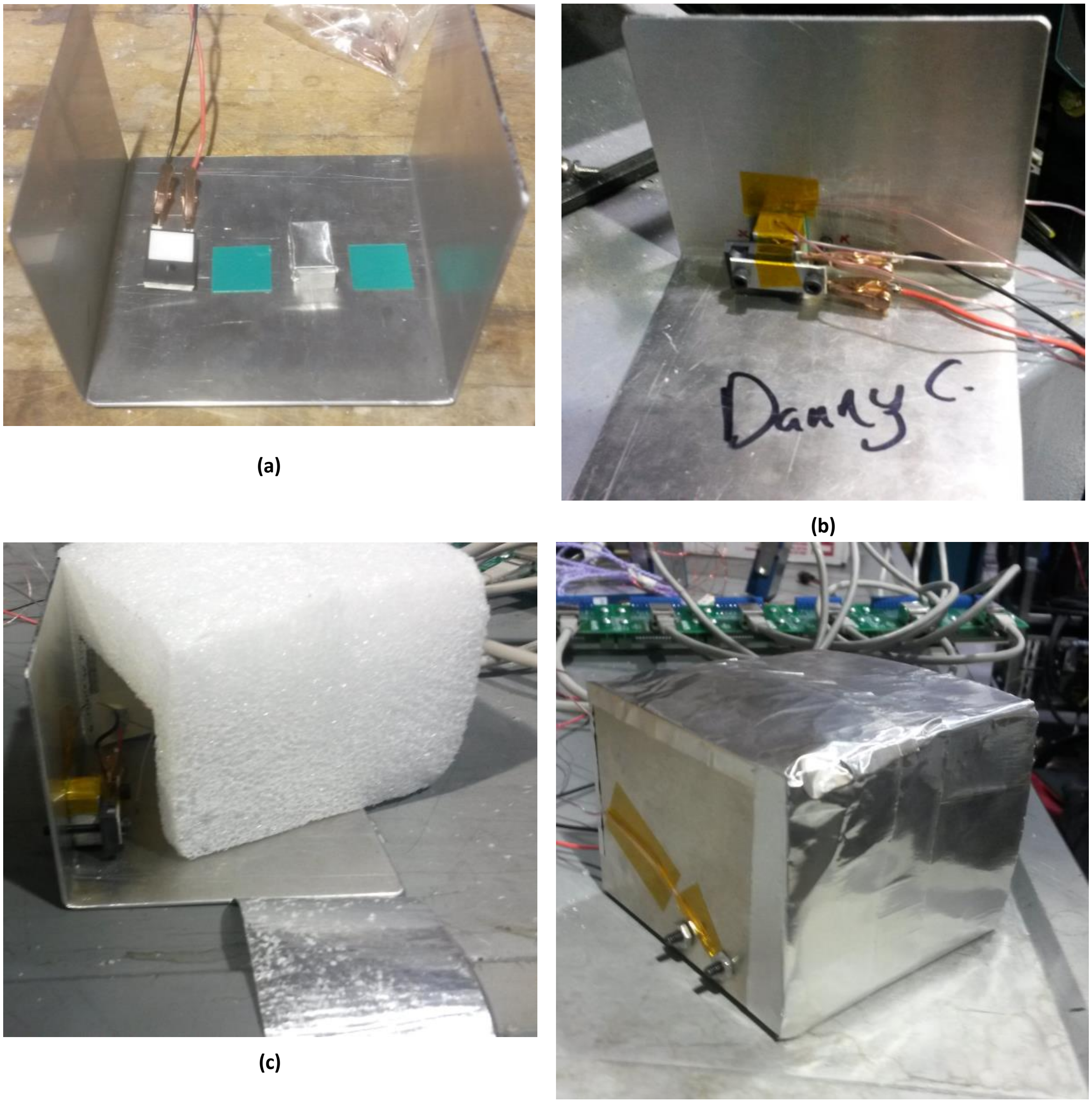


Figure 1. Heatsink geometry.

Besides our prototype itself, our sponsor also tasked us with the design, fabrication, and usage of a test bed to verify our prototype’s capabilities. To that end, we designed and built the test apparatus shown (in various stages of assembly) in Fig. 2. In Fig. 2(a), the black-and-white component attached to electrical leads is a Caddock MP9100 resistor; we used this resistor to simulate the power semiconductor, as the white ceramic surface shown in the figure passes a constant heat flux through Joule heating when driven by a DC supply. The teal material is Berquist Hi-Flow 300P; this material served as a thermal interface material, filling the microscopic gaps in our contact surface to reduce contact resistance. Finally, the small aluminum box between the pieces of Hi-Flow is our heatsink.



(a)

(b)

(c)

(d)

Figure 2. Test bed assembly. (a) is prior to any assembly. (b) is after break-in of thermal interface material, thermocouple mounting, and bracketing. (c) shows Styrofoam used as thermal insulation. (d) shows fully-assembled test bed after application of aluminum tape.

Fig. 2(b) shows the testing rig after assembly and bracketing (to ensure sufficient contact pressure between components), as well as after thermocouple mounting. The thermocouples were mounted using thermal contact tape (the translucent yellow tape shown in the figure) to minimize the additional thermal resistance caused by their presence. Fig. 2(c) shows the test rig just before placement of a Styrofoam overlay; this overlay was created to emulate the thermal insulation that would be provided in an actual service setting by a rubber overmold. Finally, Fig. 2(d) shows the test rig after its complete assembly. The only addition between Fig. 2(c) and Fig. 2(d) is aluminum tape, the purpose of which is both to prevent expansion of the Styrofoam during testing, and to provide additional conductive surface area over which heat transfer can occur.

2.0 Standard Operating Procedure

To run tests of our heatsink, we developed the following operating procedure. Note that this procedure assumes that the test bed has already been assembled to the point shown in Fig. 2(b), not including thermocouple mounting. Assembly prior to this point requires a one-time heat treatment process (to melt and break-in the thermal interface material shown in Fig. 2(a)) that we consider to be part of fabrication, rather than operation.

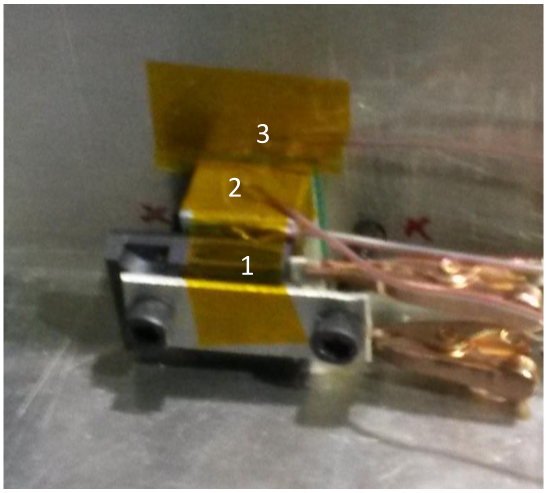


Figure 3. Some selected thermocouple mount locations.

1. Using thermal contact tape, mount thermocouples to these locations: the top edge of the resistor **(1)**, the top-center of the heatsink **(2)**, the inner wall of the test bed enclosure just above the heatsink **(3)**, and the outer wall of the enclosure directly opposite the heatsink. Refer to Fig. 3 for the first three of these locations. Make sure to label thermocouples for later data analysis.
2. Run thermocouple and resistor lead wiring through holes in Styrofoam insulation, then fit insulation over assembly (see Fig. 2(c)) for an image just prior to completion of this step.
3. Adhere aluminum tape to aluminum enclosure and over Styrofoam insulation.
4. Place a concrete block in lab oven, then place test bed atop block (see Fig. 4). Make sure that block and test bed are set sufficiently far back that they will not be struck by the oven’s door when it is closed.
5. Run thermocouple and resistor leads through hole in lab oven door. Connect thermocouples to data acquisition system (DAQ) (see Fig. 5) and resistor leads to DC power supply. Make sure the data acquisition program is set for Type E thermocouples (see Fig. 6).

6. Close and seal lab oven door. Turn on and set lab oven to 135°C, then start data acquisition program in LabView. Monitor thermocouple temperatures until they are around 105°C, then set lab oven to 121°C. Note: the temperatures chosen for the lab oven were determined through trial and error to give efficient preheating and an ambient temperature of 110°C. The set points are far from the desired ambient temperature due to high inaccuracy in the oven's internal thermocouple.
7. Once the thermocouples read 110°C, restart the data acquisition program. At this point, the DC power supply may be used to give any desired power output profile from the resistor. For 1W, set the voltage to 10V; for 2W, set the voltage to 14.1V.
8. Monitor thermocouple outputs for heatsink "failure" condition, defined to be the time at which the resistor's thermocouple reads 125°C.
9. After a run is completed, make sure to stop the data acquisition program to save all data. Turn off lab oven and DC power supply, disconnect thermocouples and resistor leads, and (making sure to wear thermally-insulative gloves) remove test bed from lab oven. Remove aluminum tape from test bed, lift Styrofoam insulation gently (to avoid jerking any mounted thermocouples out of position), and inspect heatsink for leakage.

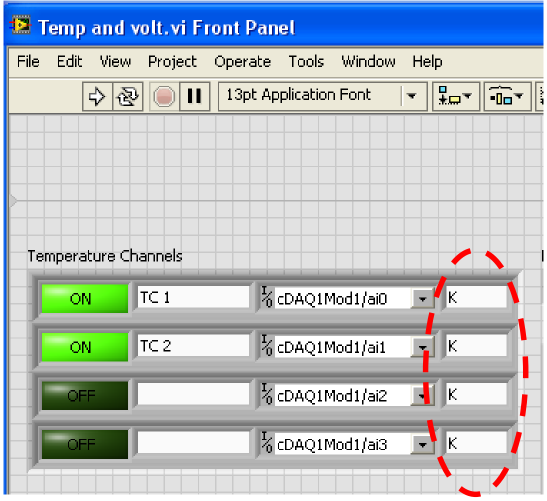
3.0 Troubleshooting

Below is a list of potential problems and associated solutions for our prototype and test bed.

1. Thermocouple(s) is/are outputting temperatures far outside of expected range.
    a. Check program to make sure it is set for Type E thermocouples.
    b. Check that thermocouples are firmly mounted within test bed and DAQ.
2. Thermal runaway (i.e., semiconductor

Figure 4. Test bed placement within oven.

Figure 5. Thermocouple leads inserted into DAQ.



Temperature Channels

ON	TC 1	cDAQ1Mod1/ai0	K
ON	TC 2	cDAQ1Mod1/ai1	K
OFF		cDAQ1Mod1/ai2	K
OFF		cDAQ1Mod1/ai3	K

Figure 6. Close up of DAQ user interface. Drop down menu for thermocouple selection is circled.

temperature exceeds 125°C) occurs far before expected time during overdrive period.
    a. Check power supply to ensure correct voltage has been set (should be set to 14.1V for 2W overdrive at resistor).
    b. Check that thermocouple at outer wall is near 110°C (should not exceed 113°C if ambient temperature is 110°C).
    c. After shutting down oven, power supply, and DAQ, remove and open the test bed. Ensure that the solder has not leaked out of the heatsink. Also make sure that the resistor, heatsink, and test bed wall are firmly bracketed together.
3. Test bed temperature does not rise (or only resistor temperature rises) after supplying power to the resistor.
    a. Check that resistor leads are firmly secured at resistor and at power supply.
    b. Check that the resistor is firmly attached to the rest of the test bed assembly.

4.0 Maintenance, Repair, and Replacement

In its final packaging, our heatsink would be completely sealed with the semiconductor in a rubber overmold. This overmold would serve to thermally, mechanically, and hermetically insulate the assembly, but would also make maintenance or replacement of the heatsink alone infeasible. In essence, if our heatsink needed to be replaced, it would necessitate the replacement of the entire ignition unit of which it is a part. As such, we designed our heatsink with the intent that it last for the entire useful life of the ignition unit.

In a prototyping setting, however, replacement of our heatsink is possible:

1. Remove the bolts and aluminum bracket that are clamping the resistor and heatsink together (see Fig. 2(b)).
2. Carefully peel the resistor, heatsink, and enclosure wall apart (they will be adhered to each other due to the thermal interface material).
3. Using a razor blade, carefully scrape any residual thermal interface material from the surfaces of the resistor and the enclosure wall.
4. Cut out new pieces of thermal interface material to fit the contact surfaces between the resistor and the heatsink, and between the heatsink and the enclosure wall.
5. Bracket the test bed assembly together (as shown in Fig. 2(b)), but do not mount thermocouples or resistor leads.
6. Preheat lab oven to 60°C. Place partially assembled test bed into oven and let sit for 10 minutes to break-in thermal interface material. Once test bed cools, it is ready for further assembly and testing.