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A Thermal Comparison of Power Device Mounting Technologies

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This paper examines different power semiconductor device mounting techniques and compares their thermal performance and power handling capabilities.

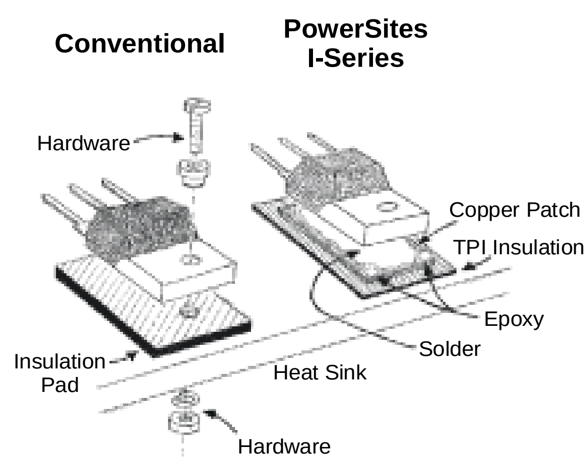
Background

The trend in electronics is toward decreasing size and cost, while increasing speed, performance and reliability. This results in increasing waste heat that must be removed from the operating devices. As heat loads increase, the thermal management to keep junction temperatures within safe operating limits is becoming more and more critical. Power semiconductors have to be attached to heat sinks to control junction temperatures. The drive for improved cooling efficiency requires optimization of not only the heat sink and the interface materials, but also the attachment method.

Power semiconductors have to be attached to heat sinks to remove large quantities of waste heat that is generated as they operate. Traditionally, these devices were attached to heat sinks using mechanical fasteners such as nuts-and-bolts or spring clips, with either greased mica or thermally-enhanced silicone pads providing the required electrical insulation. The assembly method is labor-intensive.

The next mounting method relies on Insulated Metal Substrate (IMS™, Bergquist Company), which allowed the soldering of the power devices. IMS is a laminate of aluminum carrier, a thermally-enhanced epoxy adhesive and a copper foil. In this method, a panel of IMS material would be etched to create copper pads onto which the power devices would be soldered. The assembly would then be attached to a heat sink with mechanical fasteners or an adhesive tape.

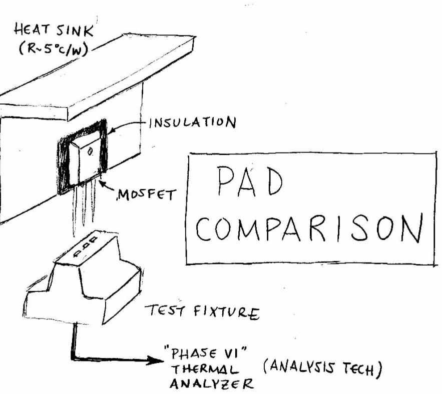
An alternative method of soldering power devices to heat sinks has been developed: laminated copper patches. In this approach, a copper foil patch the size of the device is laminated to a heat sink using a bond film of thermally-enhanced Kapton MT film coated on both sides with thin layers of polyimide adhesive. The devices are soldered to the copper patches. Laminated copper patches can be laminated to a variety of surfaces such as ribbed heat sinks, and as such do not need to be attached to a separate heat sink. Both laminated copper bonding and soldering processes can be automated.



Experimental details

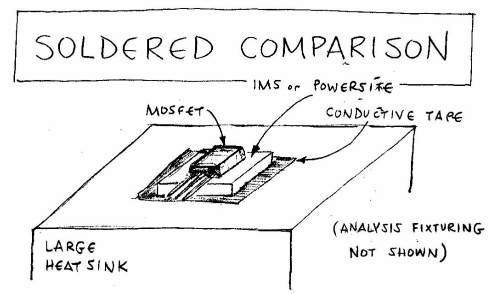
The thermal performance of the different mounting techniques were determined with TO-220 and TO-247 MOSFETS attached to heat sinks. The devices were powered and the junction, case, sink and ambient temperatures were recorded when equilibrium was reached. Devices were operated at constant power dissipation, and also were powered to achieve a junction temperature of 150°C. The effect of forced convection was also examined.

The power semiconductors were attached to the heat sinks in one of the following ways. For the mechanical method, the device was placed on the appropriate interface pad and torqued to the heat sink with a 4-40 nut and bolt to provide a nominal 300 psi mounting pressure. The heat sink was stamped from 0.125"-thick aluminum with a 32.5 square inch surface area and had a natural convection thermal resistance of 5°C/W at 110°C. The fixture was allowed to relax for one hour before testing.



A device was attached to a 1.5" x 1.5" x 0.060" IMS board as follows. The IMS board was cut to size, and a patch of copper in the center of the board was masked so that the remainder of the copper was etched away. The mask was removed and the appropriate device was soldered to the copper patch with solder paste in a Sikama reflow oven. The copper patches were sized 0.6" x 0.8" for the TO-247 and 0.4" x 0.6" for the TO-220.

The laminated copper patch consisted of a one ounce copper foil (1.4 mil thick) laminated with bond film (based on 1-mil Kapton MT with 0.15 mil of polyimide adhesive on both sides) to the stamped aluminum heat sink at 280°C at 500 psi for 30 seconds.



Junction temperatures were measured using the electrical method with an Analysis Tech Phase 6 thermal analyzer. The forward voltage of the source-drain diode was calibrated against temperature and was used as the temperature-sensitive parameter. Case, sink and ambient temperatures were measured with 36-gauge Type "T" thermocouples. 0.030"-diameter wells were drilled into the surface to be measured, and the thermocouple was potted into the wells with a thermally-conductive silicone potting compound.

The test fixtures were centered in the test section of a 10"-diameter wind tunnel and powered with the Phase 6 thermal analyzer. TO-220s and TO-247s were powered to 8 and 15 watts dissipation, respectively. Tests were performed at natural convention (0 lfm) and forced convention (100 lfm air velocity). Temperature measurements were taken at equilibrium.

Test Results

INSULATING PADS vs LAMINATED COPPER PATCH (Part I)

The conventional insulating pads that were used in the mechanical attachment of devices to heat sinks are described in Table 1.

Table 1.
List of conventional interface materials and their properties

Material Type	Thickness (inches)	Thermal Resistance (°C-in^2/W)
1. Mica / grease	0.003	0.10
2. BN-filled silicone sheet	0.010	0.17
3. Kapton MT / phase change	0.002	0.20
4. Kapton MT / BN-filled silicone	0.006	0.25
5. Alumina-filled silicone sheet	0.010	0.45

These interface materials represent the broad range of materials available for use in mounting power semiconductors. Their thermal performance was compared against the laminated copper patch using a TO-220 and a TO-247 MOSFET.

Two types of tests were performed:
1. Devices dissipated constant power, and the junction temperature was recorded.
2. Devices were powered to a constant junction temperature, and dissipated power was recorded.

TEST #1 -- CONSTANT DISSIPATED POWER

In the first test, the devices dissipated constant power and were cooled at two different air velocities. The TO-220 was powered to dissipate 8 watts, while the TO-247 was set for 15 watts. 0 and 100 LFM air velocities were used. Table 2A shows the thermal advantage in junction temperature for laminated copper patches versus the conventional interface materials. Table 2B shows the corresponding junction temperatures and the junction-to-sink resistances, R_{j-s}, for the five interface materials and for the laminated copper patch.

The data show that the laminated copper patch method provides thermal performance on par with the best interface pad and exceeds most other insulating pads.

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<u>Table 2</u>
Junction temperature and Rj-s for different interface materials
(TO-220, 8 watt; TO-247, 15 watt; 0 and 100 lfm air velocity)

THERMAL PERFORMANCE: Junction Temperature and Thermal Resistance								
	TO-220 (8 watt)				TO-247 (15 watt)			
Interface Material	Tj (°C)		Rj-s (°C/W)		Tj (°C)		Rj-s (°C/W)	
(Air Flow, lfm =>)	0	100	0	100	0	100	0	100
Mica / grease	94.4	74.5	3.53	3.46	112.8	81.4	1.02	0.99
BN-filled silicone sheet	103.5	81.4	4.14	4.05	114.4	84.0	1.16	1.16
Kapton MT / phase change	100.0	79.3	3.87	3.84	112.4	81.8	1.00	0.94
Kapton MT / BN-filled silicone	104.7	93.7	4.46	4.41	116.5	85.1	1.27	1.22
Alumina-filled silicone sheet	107.8	87.0	4.94	4.89	120.8	90.4	1.71	1.67
Laminated copper	90.8	69.5	2.70	2.64	108.4	77.5	0.66	0.68

Interface material #5 -- an alumina-filled silicone sheet -- is widely used in commercial-grade power supplies. The data show that transitioning from this interface material to a laminated copper patch attachment method can reduce the junction temperatures by 12 to 17°C. This can be a significant reduction in operating temperature of a power semiconductor.

TEST #2 -- CONSTANT JUNCTION TEMPERATURE

The next test involved increasing the power dissipation to the point where the junction temperature reached 150°C. Table 3A lists the relative thermal dissipation advantage (in increased watts) of laminated copper patches versus the conventional interface systems. Table 3B lists the dissipated power for each interface material and for the laminated copper patch method. Again the data supports the conclusion that the laminated copper offers improved thermal performance versus conventional interface systems.

Table 3B
Maximum power dissipation to reach a junction temperature of 150°C

THERMAL PERFORMANCE: Maximum Power Dissipation to reach Tj = 150 °C				
Interface Material	**TO-220 (watt)**		**TO-247 (watt)**	
(Air Flow, lfm =>)	0	100	0	100
Mica / grease	14.6	18.8	22.7	32.9
BN-filled silicone sheet	13.7	17.6	22.0	31.6
Kapton MT / phase change	14.1	17.9	22.9	33.1
Kapton MT / BN-filled silicone	13.3	16.9	21.8	30.5
Alumina-filled silicone sheet	12.5	15.8	20.4	28.4
Laminated copper	15.9	21.3	24.6	36.4

INSULATED METAL SUBSTRATE vs LAMINATED COPPER PATCH (Part II)

The IMS thermal performance was compared to the laminated copper patch as follows:

- 1.5" x 1.5" IMS substrates and laminated copper patches were prepared with TO-220 and TO-247 sized copper solder sites.
- The devices were soldered onto the patches.
- The test fixtures were attached to a pin-fin heat sink with thermally-conductive tape.
- Thermal tests of the previous section were repeated. (The data is shown in Tables 4 and 5.)
- The thermal resistance from the junction to the aluminum plate of the IMS and the laminated copper patch was measured and reported.
- In addition, the maximum power dissipation to reach a junction temperature of 150°C was established for both technologies.

The data shows that the thermal performance of the IMS and the laminated copper patch is essentially the same.

This, however, does not account for the fact that the IMS has to be attached to a heat sink while the laminated copper patch can be laminated directly to a heat sink….

NOTE: The additional thermal resistance of attaching the IMS plate to a heat sink is a factor that has to be considered.

Table 4
Comparison of junction temperature and Rj-s for solder-attached devices
(TO-220, 8 watt; TO-247, 15 watt; 0 and 100 lfm air velocity)

THERMAL PERFORMANCE: Junction Temperature and Thermal Resistance								
	TO-220 (8 watt)				TO-247 (15 watt)			
Interface Material	Tj (°C)		Rj-s (°C/W)		Tj (°C)		Rj-s (°C/W)	
(Air Flow, lfm =>)	0	100	0	100	0	100	0	100
Insulated metal substrate	88.2	65.3	2.57	2.54	105.3	71.2	0.92	0.88
Laminated copper	87.3	64.5	2.64	2.64	107.9	72.5	1.12	1.09

Table 5
Maximum power dissipation to reach a junction temperature of 150°C

THERMAL PERFORMANCE: Maximum Power Dissipation to reach Tj = 150 °C				
Interface Material	**TO-220 (watt)**		**TO-247 (watt)**	
(Air Flow, lfm =>)	0	100	0	100
Insulated metal substrate	16.6	23.1	25.4	40.1
Laminated copper	16.8	23.7	24.2	38.0

CONCLUSIONS

Laminated copper patches are copper foil laminated directly to heat sinks, allowing soldering. This new technology compares favorably in thermal performance to existing interface pad and insulated metal substrate mounting methods.

This improved thermal performance offers the designer an opportunity to:
- Lower device temperature
- Reduce heat sink size
- Elevate power capacity
- Increase ambient rating.

The work presented only addressed the thermal performance of the device attachment methods. Additional advantages of solder attachment also need to be considered when selecting a power semiconductor mounting method. These include:
- Ability to be automate
- Significant reduction in manual assembly
- Reduced stress on the interface material (dielectric integrity)
- Increased reliability of the assembly.

References

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