Mounting Considerations for the SOT-227 Package

Introduction

In order to maximize heat transfer efficiency and long-term reliability, SOT-227 devices must be mounted carefully and consideration must be given to cold plate and mounting hardware as well. Proper mounting ensures optimum mating of a device's base plate to the cold plate surface and minimizes the thermal resistance as well as the mechanical stresses exerted on the device in operation. This application note provides guidelines for mounting the SOT-227 package onto the cold plate.

Thermal Interface Material (TIM) and Contact Resistance

The SOT-227, or sometimes referred to as the ISOTOP® package, as shown in Figure 1, is in widespread use in the power electronics industry primarily because of its thermal capability, built in isolation, rugged terminals and overall power capability.

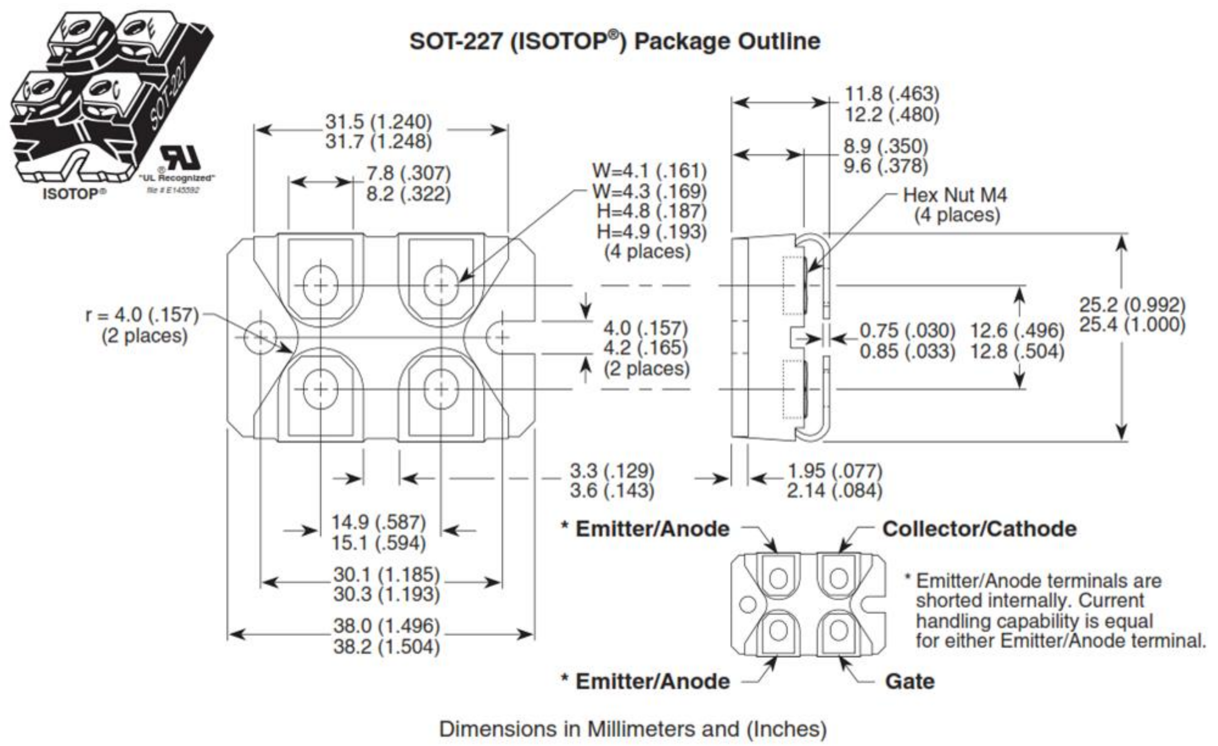

Figure 1 · SOT-227 (ISOTOP®) Package Outline.

To take full advantage of the SOT-227's thermal capability, it needs to be carefully mounted onto the cold plate. Otherwise, the excessive interface thermal resistance, or the so-called contact thermal resistance, between the base plate of the SOT-227 package and the cold plate will greatly reduce the efficiency of heat transfer from the device junction to the coolant flowing through the heat sink. In other words, the contact thermal resistance may become the bottleneck of heat transfer for a poorly mounted device. This can greatly degrade the performance and compromise the long-term reliability of the device, or even prematurely destroy the device.

The thermal resistance of a power electronic device has several components and is expressed in a variety of ways depending on the reference location relative to the semiconductor device junction:

$\mathbf{R_{\theta JC}}$ - Thermal resistance of semiconductor device junction to package case;

$\mathbf{R_{\theta JS}}$ - Thermal resistance of semiconductor device junction to heat sink surface;

$\mathbf{R_{\theta JA}}$ - Thermal resistance of semiconductor device junction to ambient;

where $\mathbf{R_{\theta JC}}$ is used as an ambient/system-independent measure of thermal performance of the device; $\mathbf{R_{\theta JS}}$ takes into account the thermal resistance of the mounting interface material and conditions; and $\mathbf{R_{\theta JA}}$ takes into account the cooling from the ambient environment surrounding the package. It is important to note that these thermal resistances are static parameters, i.e., it should be measured based on steady state conditions. (Another important thermal parameter, but unrelated to the current studies, is the transient thermal impedance of a power device, which depends strongly on the thermal mass of the device as well as the pulse conditions of the test signals. The transient thermal impedance is a useful parameter in analyzing the dynamic behaviors of the device.) The thermal resistance is measured by turning on the device under test with fixed voltage and current so that a fixed power is dissipated by the device, which in turn heats up the device junction. The balance between heat generation and removal by coolant thru the heat sink establishes the steady state of the system, when the junction and heat sink temperatures data should be taken.

By definition,

$$\mathbf{R_{\theta JC} = (T_J - T_C) / P_D ,}$$

$$\mathbf{R_{\theta JS} = (T_J - T_S) / P_D ,}$$

$$\mathbf{R_{\theta JA} = (T_J - T_A) / P_D ,}$$

where T_J is the semiconductor junction temperature; T_C is the package case temperature; T_S is the cold plate or heat sink temperature; T_A is the ambient temperature; and P_D is the dissipated power.

Since the SOT-227 device is primarily used in high power applications, where forced cooling is often required, only $\mathbf{R_{\theta JS}}$ will be studied and discussed in this application note. The material stack of the entire SOT-227 package contributes to the overall thermal resistance $\mathbf{R_{\theta JC}}$ including the semiconductor chip, the multiple solder joints, the lead-frame, the isolation substrate, the bonding wires, the plastic encapsulating the device and the base plate of the package. The thermal resistance from junction to cold plate simply is

$$\mathbf{R_{\theta JS} = R_{\theta JC} + R_{TI} ,}$$

where $\mathbf{R_{TI}}$ is the thermal interface resistance, which again, is a function of the thermal properties of the thermal interface material (TIM) as well as the quality of mating between surfaces of the TIM, the device base plate and the cold plate.

The quality of mating between SOT-227, TIM and cold plate depends significantly on surface conditions, the flatness of the base and cold plates and, very importantly, the mounting pressure applied by the two mounting screws used to fasten the SOT-227 onto the cold plate. A test fixture was designed to accurately measure the mounting pressures while simultaneously taking various temperature readings under precise voltage and current conditions to assure a fixed power dissipation by the device. Appendix I provides the details of the experimental setup.

SOT-227 Mounting with Thermal Grease TIM

Thermally conductive paste, or thermal grease, is probably one of the most cost effective and widely used TIM's for mounting SOT-227 device onto a cold plate. In the following experiments, a popular thermal grease is used, namely, OT-201 silicone grease from OMEGA®. It is very important that the thermal grease is applied onto the base plate of SOT-227 ***evenly*** and ***thinly***, preferably, between 1 to 2 mil in thickness. Figure 2 shows the application and spreading of the OT-201 silicone grease onto the base pate of a SOT-227 device by a skilled lab technician, however, in a production environment, screen printing is recommended for consistent layer thickness. It should be emphasized that applying an excessive amount of thermal grease will adversely impact the thermal resistance and thus degrade the performance of the device.

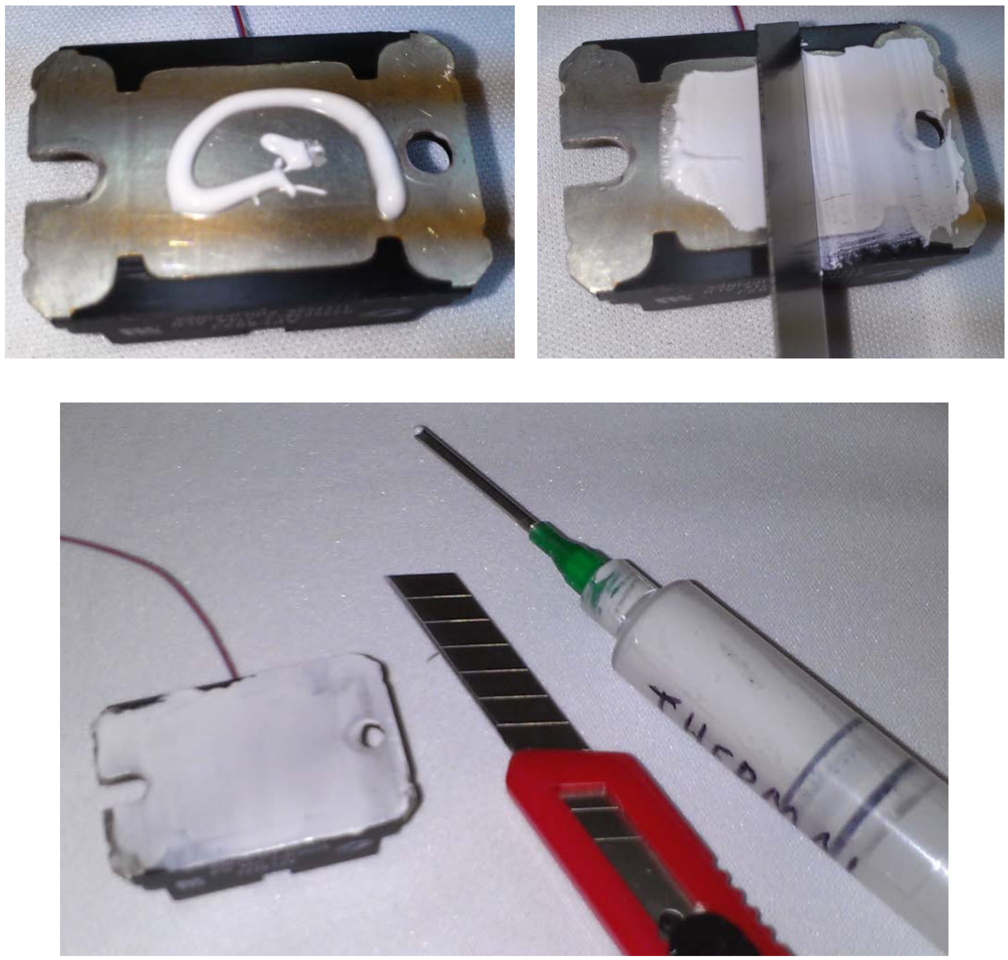

Figure 2 · Example of applying thermal grease onto the base plate of SOT-227.

Figures 3 and 4 show the thermal resistance $\mathbf{R_{\theta JS}}$ versus mounting torque for two SOT-227 devices (APL602J), respectively, with and without surface treatment by lapping. Both devices are inserted multiple times to demonstrate the repeatability of mounting with surfaces thoroughly cleaned before re-application of thermal grease and re-mounting. From Figure 3, it can be seen that not only is the value of $\mathbf{R_{\theta JS}}$ significantly reduced versus the dry mounting case, as shown in Appendix II, but the repeatability is drastically improved for mounting torque above 0.5 in-lbf (0.056 N-m). The repeatability is further improved with both surfaces (base plate and cold plate) lapped, as seen in Figure 4, and additionally, the value of $\mathbf{R_{\theta JS}}$ is further reduced slightly with treated surfaces as well. Finally, there is no further improvement of $\mathbf{R_{\theta JS}}$ above a mounting torque of 1.0 in-lbf (0.113 N-m) for untreated surfaces and above 0.5 in-lbf (0.056 N-m) for the lapped surfaces.

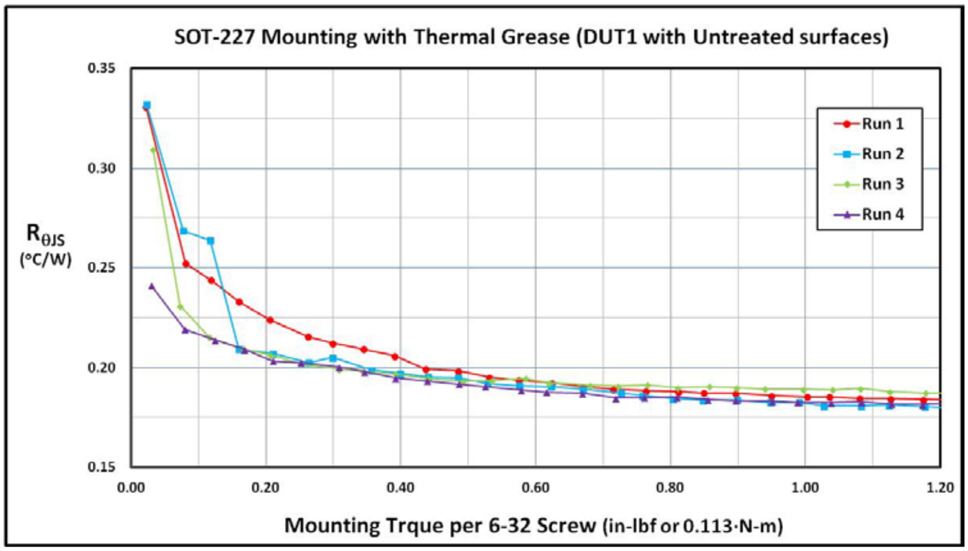

Figure 3 · Thermal resistance vs. mounting torque with Thermal Grease TIM and untreated surfaces (DUT 1).

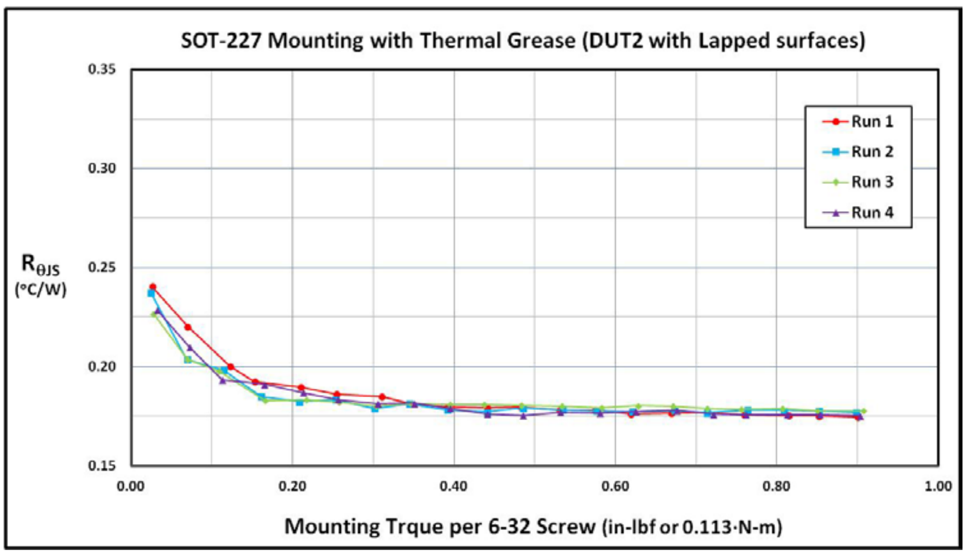

Figure 4 · Thermal resistance vs. mounting torque with Thermal Grease TIM and treated surfaces (DUT 2).

SOT-227 Mounting with Advanced TIM

The thermally conductive paste used in this study, OT-201 from OMEGA®, has a relatively high thermal conductivity of 2.3 W/(m-K) with a medium price tag. Costly, high performance conductive pastes, are also available, e.g., TC-5022 from Dow Corning®, with a thermal conductivity of 4.0 W/(m-K) which is 74% higher than OT-201. While thermal grease drastically improves the thermal interface performance, it does present some challenges, although not insurmountable, in the assembly of SOT-227 devices. More specifically, it can be difficult to control the application of thermal grease in production to consistently achieve an even and thin layer of thermal grease. It should be mentioned that the thermal grease in this study was applied by a highly skilled lab technician, who understands the requirements for and importance of thermal grease for the optimal thermal performance. In a production environment, extensive and continued training of operators is often required.

In addition to these challenges in production process control, it is also widely known that thermal grease may be "pumped" out over time under normal operation of the SOT-227 devices due to expansion and contraction of the base plate of SOT-227 and the cold plate during power cycling of the devices. This pumping of thermal grease can gradually compromise the long term reliability of the SOT-227 device. Based on these issues, thermally conductive paste is by no means a perfect TIM, and therefore, a seemingly unending quest for better TIMs continues. Recent development and adoption of Indium foils for use as TIMs shows great promise to further improve thermal interface performance for high power electronics.

Indium is a chemically stable and malleable, pure metal with a melting point of 156.6°C. It is not a rare earth element. Indium is also nontoxic, and requires no special handling. Most importantly, Indium has a thermal conductivity of 81.8 W/(m-K), which is more than 20 times better than the best thermally conductive paste (TC-5022 from Dow Corning®) on the market today. In cooperation with the manufacturer of indium TIMs, Microsemi Power Products Group is pioneering the development and adoption of indium foils along with its various alloys as advanced TIM's for power electronic applications.

Figure 5 shows the thermal resistance from device junction to cold plate of a SOT-227 device (APL602J) mounted onto the cold plate using a 3-mil Indium heat-spring foil from Indium Corporation (the surfaces of the base plate and cold plate were untreated). As can be seen, $\mathbf{R_{\theta JS}}$ improved to 0.15°C/W with Indium TIM from 0.18°C/W with thermally conductive paste – This is a significant 20% reduction of $\mathbf{R_{\theta JS}}$ using advanced TIM Indium. It is also worthwhile to notice that $\mathbf{R_{\theta JS}}$ under extremely light mounting pressure is much higher than that of thermal grease, reflecting the difference between the nature of a non-Newtonian fluid (thermal grease) and a soft metal. The data in Figure 5 were recorded when the steady-state temperatures were reached at a given mounting pressure, however, it should be noted that it takes at least 24 to 48 hours for indium to settle, (i.e., filling all macro- and microscopic voids in the interface, for a fixed mounting pressure) before the optimal $\mathbf{R_{\theta JS}}$ can be obtained. Although not studied, we expect the mounting repeatability can be improved with surface treatment by lapping as well.

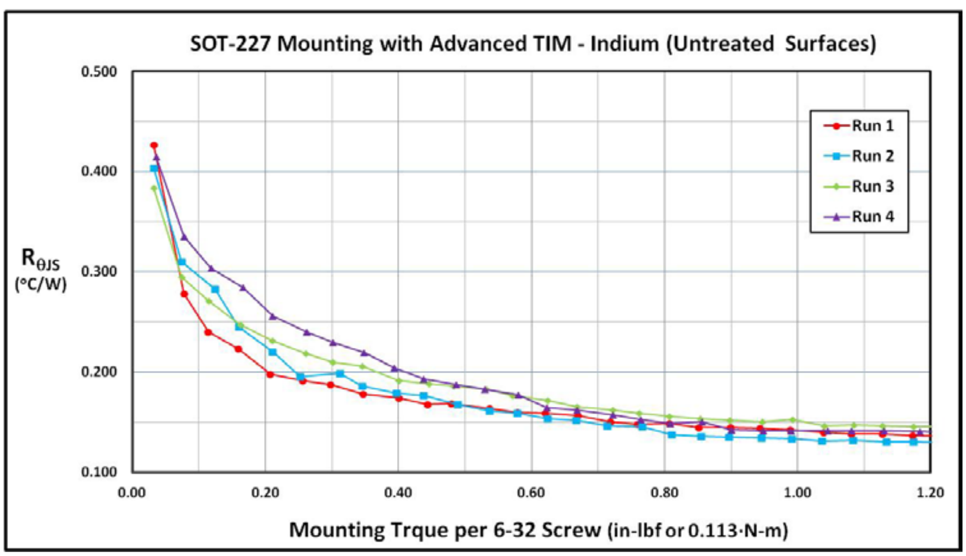

Figure 5 · Thermal resistance vs. mounting torque with advanced TIM - Indium and untreated surfaces.

Conclusions

The relationships between the thermal resistance of the SOT-227 package vs. mounting conditions and pressures were carefully studied. For the optimal performance of the SOT-227 devices, it is concluded that:

1) SOT-227 devices need to be mounted with TIM;
2) Thermally conductive pastes are a reasonably good TIM for mounting SOT-227 devices;
3) $\mathbf{R_{\theta JS}}$ with thermal grease TIM reaches its optimal value at a mounting torque above 1.0 in-lbf (0.113 N-m) with untreated surfaces of the base plate of SOT-227 and the cold plate;
4) $\mathbf{R_{\theta JS}}$ with thermal grease TIM reaches its optimal value at a mounting torque above 0.5 in-lbf (0.056 N-m) with surface treatment by lapping the base plate of SOT-227 and the cold plate;
5) Surface treatment by lapping the base plate of SOT-227 and the cold plate improves the repeatability of mounting the SOT-227 devices;
6) Surface treatment by lapping the base plate of SOT-227 and the cold plate incrementally improves the value of $\mathbf{R_{\theta JS}}$ using a TIM;
7) Use of an advanced TIM such as Indium heat spring foils and its alloys may further improve the thermal performance by about 20% for the SOT-227 package;
8) Indium heat spring foils take about 24 to 48 hours to settle into its optimal performance under a fixed pressure.

Although not studied, the upper pressure limit of mounting the SOT-227 package is mostly determined by the mechanical integrity of the SOT-227 package itself as well as the environmental considerations such as immunity to vibration in the application, alleviation of pumping thermal grease**,** and the mechanical integrity of the mounting screws. In general, the SOT-227 package can easily withstand a mounting torque up to 10 to 15 in-lbf (1.13 to 1.69 N-m) per 6-32 screw, however, mounting torques from 2 to 5 in-lbf (0.226 to 0.565 N-m) per 6-32 screw should be adequate for SOT-227 package in most applications.

Step-by-step instructions are also recommended and provided in Appendix III for mounting the SOT-227 device onto the cold plate and mounting the electrical connections. Finally, the base plate of a freshly assembled SOT-227 device typically has a surface flatness within 5 mil (0.12 mm). Care must be taken when handling these devices to prevent any scratch and damage to the surface of the base plate. With enough mounting pressure, lapping the device before mounting is not necessary; however, the thermal performance as well as mounting consistency can be improved slightly by lapping both surfaces of the base plate of the SOT-227 device and the cold plate.

Appendix I - Thermal Resistance Measurement Setup

Figure 6 shows the test fixture designed for measuring the thermal resistance of the SOT-227 devices at precisely controlled mounting pressures. The press plate transfers the mounting force, either from tightening the screws--Figure 6(B) or by placing weights--Figure 6(C), through a point contact with a roller to a downward force on the shaft guided by two sleeve bearings through two alignment plates. This downward force is then applied to the SOT-227 device mounted onto the heat sink via a press chuck. The heat sink assembly is in turn mounted onto the load balance plate, which is sitting on top of three load cells for the precise measurement of the mounting force as shown in Figure 7.

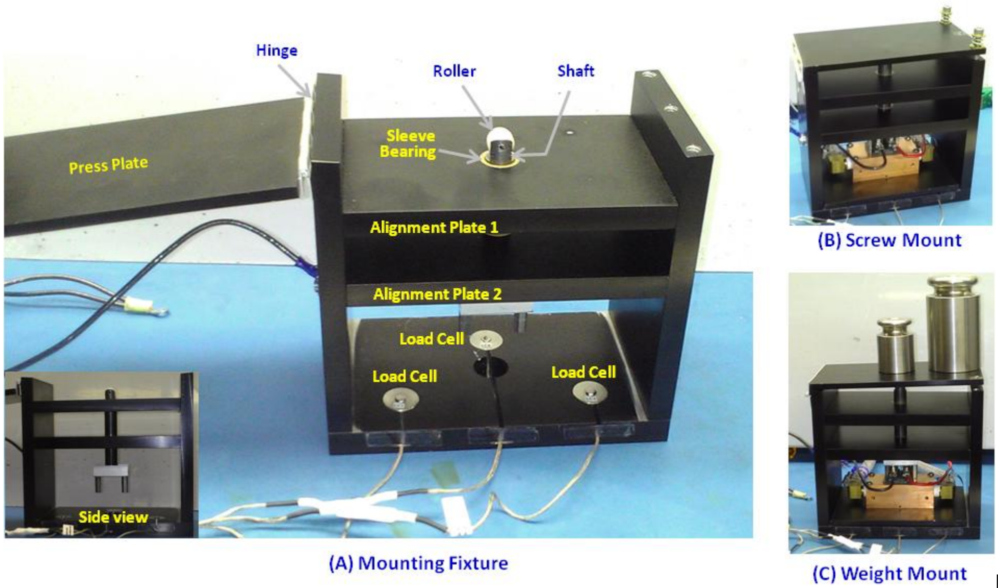

Figure 6 · Test fixture for thermal resistance vs. mounting pressure measurement: (A) Mounting fixture assembly, (B) Mounting force controlled by screws, and (C) Mounting force controlled by weights.

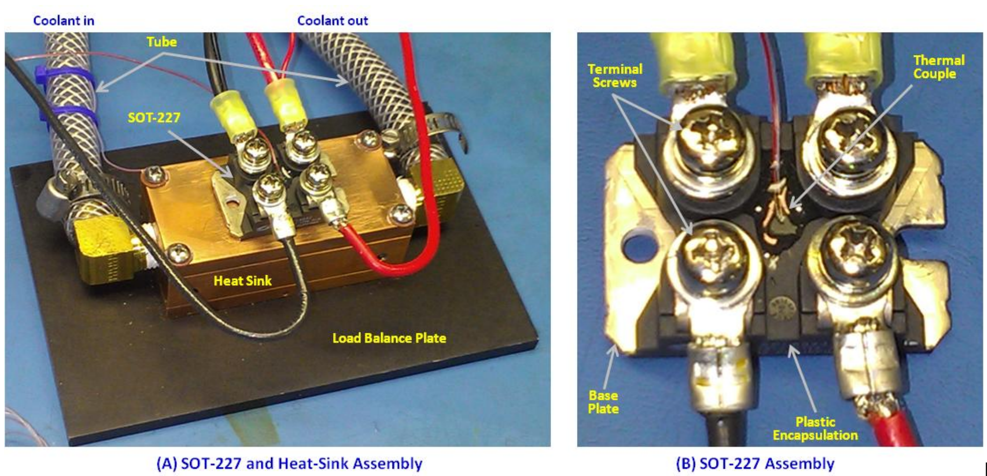

Figure 7 · Heat sink and SOT-227 assemblies of the thermal resistance vs. mounting pressure measurement.

A thermal couple is glued onto the top of the SOT-227 device by thermally conductive epoxy for (approximate) device junction temperature measurement as shown in Figure 7(B). A second thermal couple is placed directly underneath the SOT-227 device in the heat sink for the heat-sink temperature measurement. For the thermal resistance measurement, the SOT-227 device is powered up, and its power dissipation is monitored by the precise measurements of the voltage drop across its active terminals as well as the current flowing through them. Finally, the load cell transducers are calibrated before the measurement, and the mounting pressure is varied and recorded during the thermal resistance measurement.

Appendix II - SOT-227 Dry Mounting without TIM

Although not recommended, mounting the SOT-227 device without any TIM (dry mount) can be very informative. Figure 8 shows the $\mathbf{R_{\theta JS}}$ versus mounting torque for a SOT-227 device (APL602J) without any TIM. The four curves in Figure 8 were obtained by inserting the same device four different times. As can be seen, the repeatability in this dry-mount case was poor. Secondly, the thermal resistance, $\mathbf{R_{\theta JS}}$**,** only starts converging to a constant value around the highest pressure setting in the experiment.

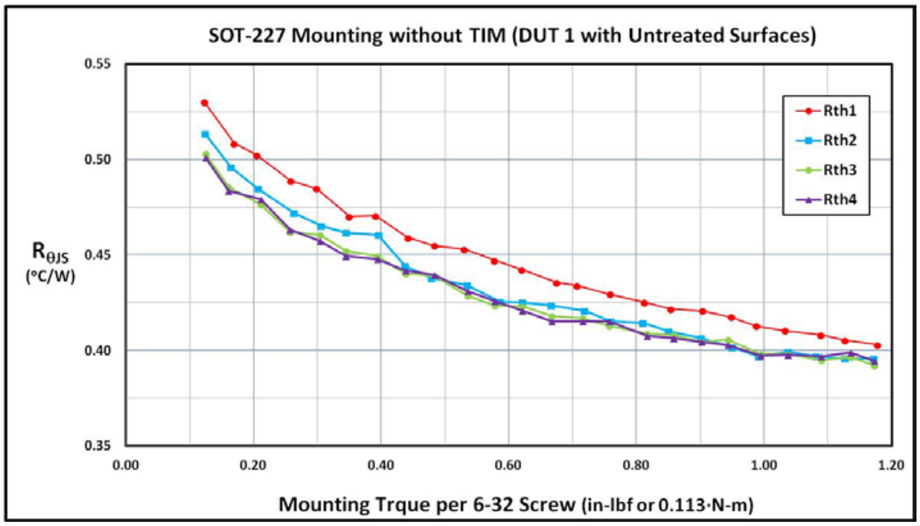

Figure 8 · Thermal resistance vs. mounting torque without TIM and untreated surfaces.

By lapping the surfaces of the SOT-227 base plate and the cold plate, the surface conditions and therefore the intimate contact between them should be improved. This is indeed the case as shown in Figure 9, where the same SOT-227 device (with base plate surface lapped) was inserted four different times onto the cold plate (with lapped surface as well). Again, the repeatability is not very good typical of dry mounting conditions. Interestingly, the thermal resistance reaches a minimum at a relatively low mounting torque, around 0.4 in-lbf (0.045 N-m), and increases towards higher mounting torque. This indicates that excessive mounting pressure tends to deform the plates causing slight deterioration of the mating quality between these surfaces.

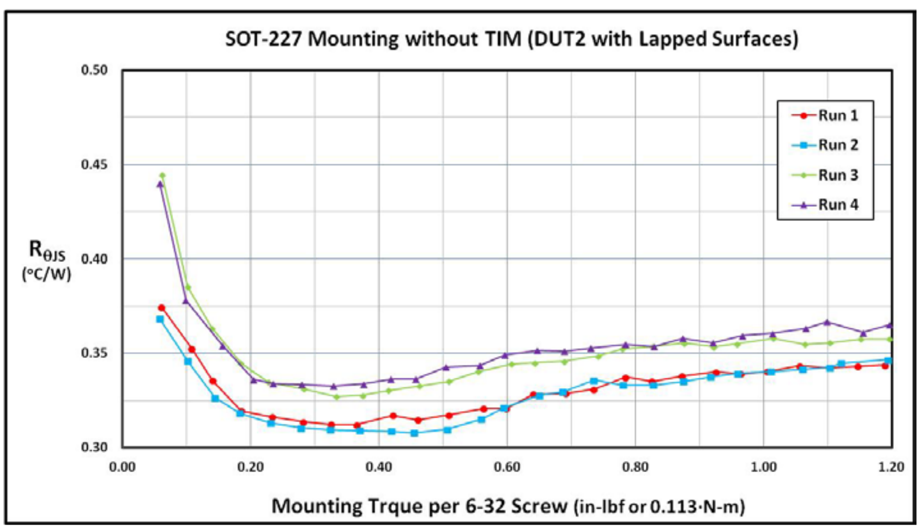

Figure 9 · Thermal resistance vs. mounting torque without TIM and treated surfaces.

Appendix III - SOT-227 Device Mounting Guides

SOT-227 devices are provided with two mounting holes/slots in the base plate designed to accommodate M4 mounting screws that are used to clamp the SOT-227 copper base plate onto the cold plate. Each SOT-227 device also has four terminals with captive nuts for electrical connections (Gate – Source (2) – Drain). These terminal connections are also designed to accommodate M4 screws.

Mounting the SOT-227 device onto the cold plate

1. The spacing of the screw holes in the customer's cold plate should be designed to provide sufficient distance between the barrels of the mounting screws to allow the copper base plate of the SOT-227 device to expand freely as needed to accommodate expansion due to increasing temperature during operation.
2. The distance between mounting holes should also be sufficient to accommodate the radius of the screw heads versus the dimension of the plastic body of the device in relation to the mounting holes in order to avoid transfer of stress from the screw heads to the plastic body of the device.
3. It is recommended to use a spring-loaded (Belleville or other) type of washer between the mounting screw head and the top of the base plate so as to promote un-restricted expansion/contraction of the base plate during temperature cycles.
4. Just prior to mounting, make sure the base plate of the part and the cold plate mounting surface are clean and free of large particles, foreign materials or burrs that could prevent optimum contact between base plate and cold plate.
5. An even and thin layer of thermal grease should be applied to the bottom of the base plate or the cold plate before the device is mounted. The thickness of the thermal grease layer should be the minimum practical amount that is necessary to achieve a void-free layer between the base plate and the cold plate.
   a. Only a small amount of grease should squeeze out from under the edges of the base plate when the part is fully mounted down.
   b. Solid thermal interface materials (such as Silpad or Grafoil) are not recommended.
   c. In order to assure a uniform and controlled layer of thermal grease, the use of a roller, spatula or screen printing technique is recommended.
6. The mounting screws should be tightened in several increments alternating end-for-end. For example: first just barely "finger tight" at each end, then incrementally on each end to the final specified torque at each end.
   a. The goal is to settle the device down evenly onto the cold plate and avoid a rocker effect. This will help minimize bending stress on the base plate.
   b. This procedure should also allow the middle portion of the device (where the die are located) to come into very close contact with the cold plate while at the same time allowing the thermal grease to flow outwards to fill any gaps.
   c. If possible, it can be a good idea to allow the devices to "rest" for a few hours after initial mounting to allow for relaxation of the device and re-distribution of the thermal grease. After this rest, re-torque the mounting screws to the final torque setting. Often, this re-torque will result in additional settling of the device onto the cold plate.

Mounting Electrical Connections:

7. The PC board or buss bar electrical connection screw holes should be located so as to avoid putting any bending stress on the terminal connectors to avoid stress on the body of the device. The terminals of the SOT-227 package are designed with a U-bend for stress relief and the mounting holes are oblong. These features are intended to help avoid excessive transfer of stress to the body of the device due to variations in the connection to the customer's circuit.
8. Care should be taken to avoid cross threading during the initial insertion of the connector screws into the captive nuts. This is best accomplished with a manual screwdriver rather than the use of power screwdrivers. To minimize cross threading, it is preferable to choose a screw which has a beveled leading end (see Figure 10 below.)

Figure 10 · Screws with preferred beveled design on the right to avoid cross threading.

9. The optimum length of the barrel of the screw used by the customer for the four electrical connections will depend on the configuration of the electrical connectors/PCB used by the customer. The screw barrel length should not exceed the cumulative thickness of the stack of connectors/PCBs plus the distance between the top of the terminal to the bottom of the nut cavity. When the screw is fully inserted and tightened down, it should not be forced into contact with the bottom of the nut cavity (thus avoiding upwards bending force on the terminal).

Acknowledgements

This application note is a collective work from many highly competent application, product and quality engineers and technicians within Microsemi Corporation. Among them, ***Mark Gabler*** and ***Brian Wilkinson*** provided the original framework; ***James Varner*** designed and assembled the test fixture and measurement system as well as performed the entire thermal resistance measurements; ***Russell Crecraft***, ***Mark Gabler***, **Serge *Bontemps***, Brian ***Wilkinson***, ***Frans Hager*** and ***Charlie Christman*** also provided valuable inputs with their in-depth knowledge of the SOT-227 device's construction, application and long-term reliability. Without their expert contribution, this work simply is not possible.

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