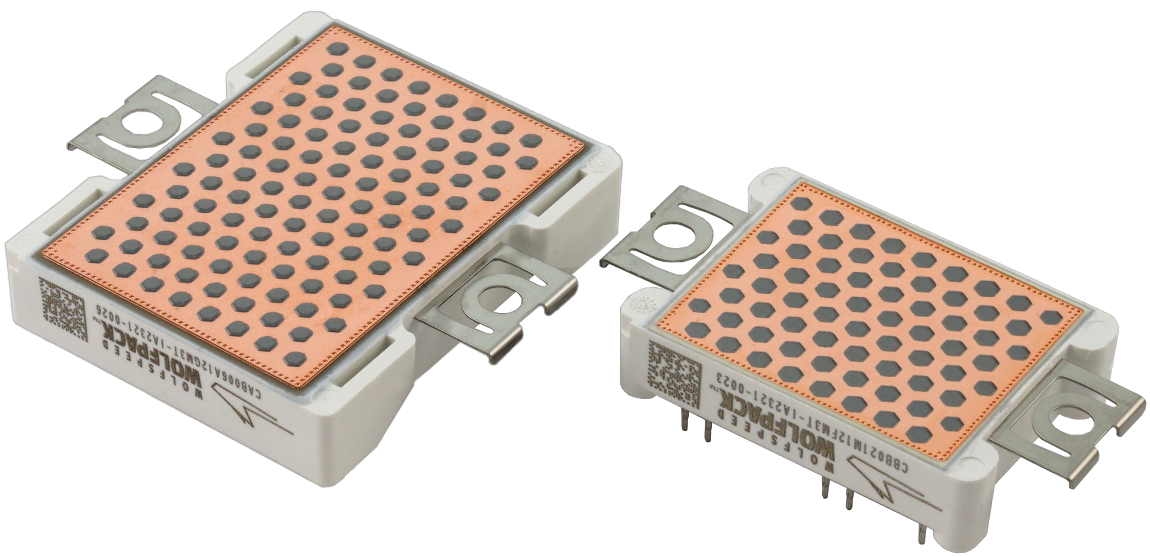
User Guide PRD-07933

Wolfspeed Power Module Thermal Interface Material Application User Guide



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Wolfspeed Power Module Thermal Interface Material Application User Guide

To achieve optimal thermal performance in power modules, it is necessary to mount them onto a heatsink to efficiently dissipate the heat generated by the semiconductor devices and prevent the junction temperature from exceeding safe limits. A Thermal Interface Material (TIM) is commonly used to establish proper contact between the module's baseplate and the heat sink. However, the correct application of thermal grease and the mounting of the power module to the heat sink are crucial for ensuring effective heat transfer between the two components. This application note provides guidance on selecting an appropriate thermal interface material, as well as instructions for applying thermal grease to the module baseplate or heat sink and mounting the power module onto the heat sink. By adhering to these guidelines, optimal thermal performance of power modules can be achieved.

Contents

1. Introduction

To fully take advantage of the benefits of Silicon Carbide (SiC) for higher power applications, advanced packaging formats are required, especially as the application power level and complexity scales. Power modules offer a power dense solution that balances robust electrical performance with effective thermal dissipation. The manufacturing technique in which power modules are assembled results in a layered vertical stack-up. During operation of the power module, heat is generated at the top of the stack by the SiC semiconductors, referred to as the junction in Figure 1. Generally, the point at which heat exits the power module is referred to as the case. The case in modules can generally be classified into two subtypes: baseplate and baseplate-less. In baseplate modules the ceramic direct-bonded copper (DBC) that provides electrical isolation is typically attached to a copper or aluminum baseplate to aid in heat dissipation. Baseplate-less modules only consist of the DBC substrate, resulting in a smaller package without a compromise in thermal performance. The difference between the two is illustrated in Figure 1.

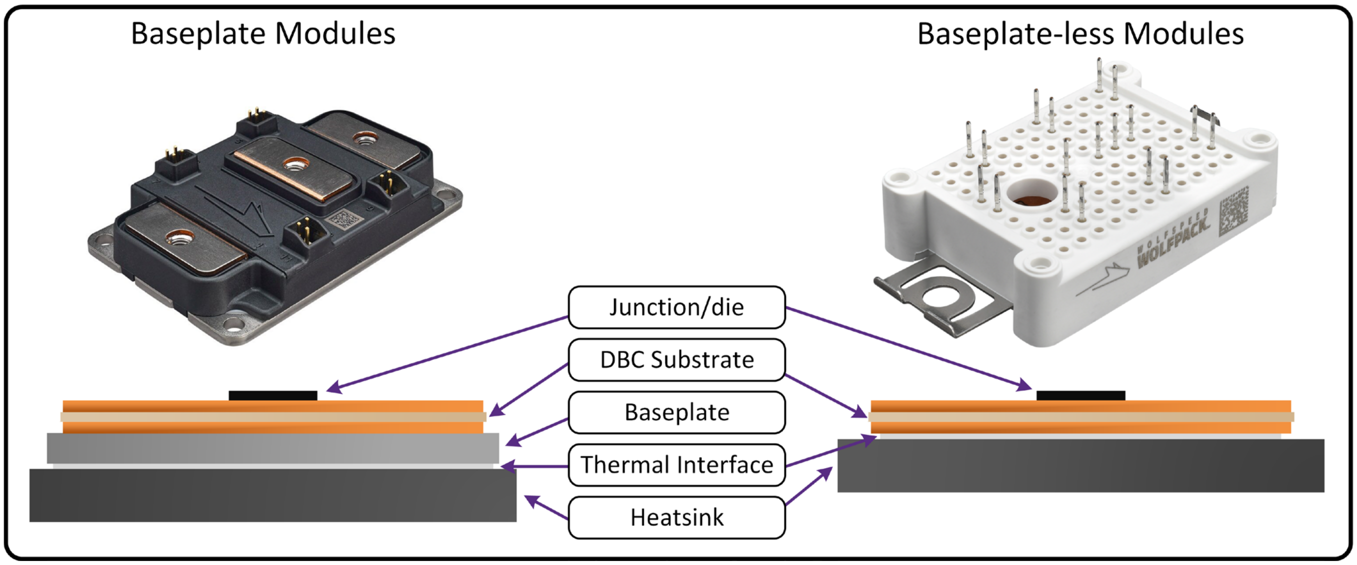


Figure 1: Typical power module stack-up – with baseplate (left), baseplate-less (right)

1.1 Thermal Resistance Background

The thermal resistance, or R_{THJC}, is a system property that describes the steady-state resistance of thermal power dissipation from the device's semiconductor junction to the case with units of K/W (or °C/W). It is an important system characteristic because it is a major factor for determining a module's ampacity. R_{THJC} is given by equation (1):

$$R_{THJC} = \frac{T_J - T_{CASE}}{P_{Loss}} \qquad (1)$$

where T_J, T_{CASE}, and P_{Loss} are the device junction temperature, case temperature, and power dissipation in the module, respectively.

Power modules consist of multiple layers, attaches, conductors and insulators, each of which contributes to the total thermal resistance. Additionally, each of these layers/materials takes time to absorb or dissipate energy prior to a change in temperature. This quantity of energy required to change the material temperature is called the thermal capacitance (C_{THJC}) of the power module, with reference from the device junction to the power module case. Thermal impedance (or Z_{THJC}) therefore describes the transient thermal properties of the system from junction to case. It is not represented as a constant value, but as a plot of the R_{THJC} over time when a known power dissipation is experienced by the system. On a datasheet, Z_{THJC} is represented by multiple plots at different duty cycles.

1.2 Necessity of Thermal Interface Materials

When the power module is placed upon a heat sink, the mated metal surfaces seem flat and perfectly in contact. However, metals have microscopic voids and irregularities that prevent perfect joining of the two surfaces. These imperfections result in small pockets of air being trapped at the thermal interface. The trapped air, in comparison to the metal, is a poor conductor of heat. Therefore, there is a need for a thermal interface material (TIM) to fill in the microscopic air gaps between the module baseplate and heat exchanger as shown in Figure 2.

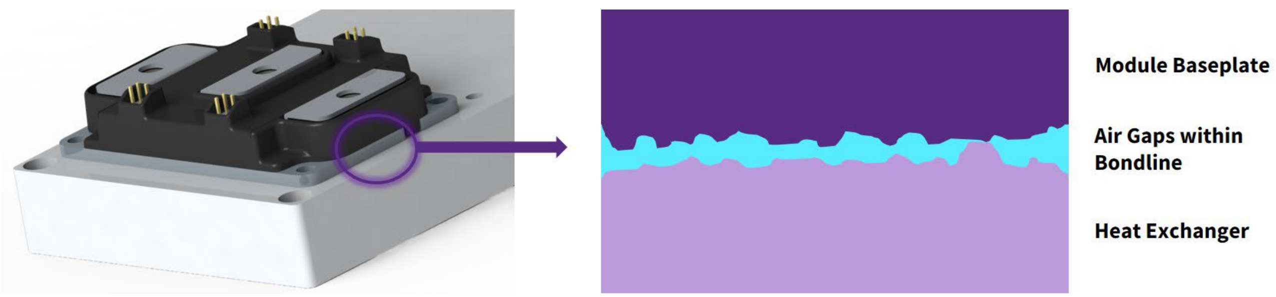


Figure 2: Representation of the voiding between module baseplate/substrate metallization and heat exchanger

Selecting a suitable TIM for your application is crucial in determining the maximum thermal threshold. From observing the thermal stack of a typical module, it was found that the TIM can typically contribute about 60% of the total thermal resistance, as shown in Figure 3. Thus, properly selecting and applying the TIM is critical for maximizing the module performance and ensuring that it can operate at its rated power levels.

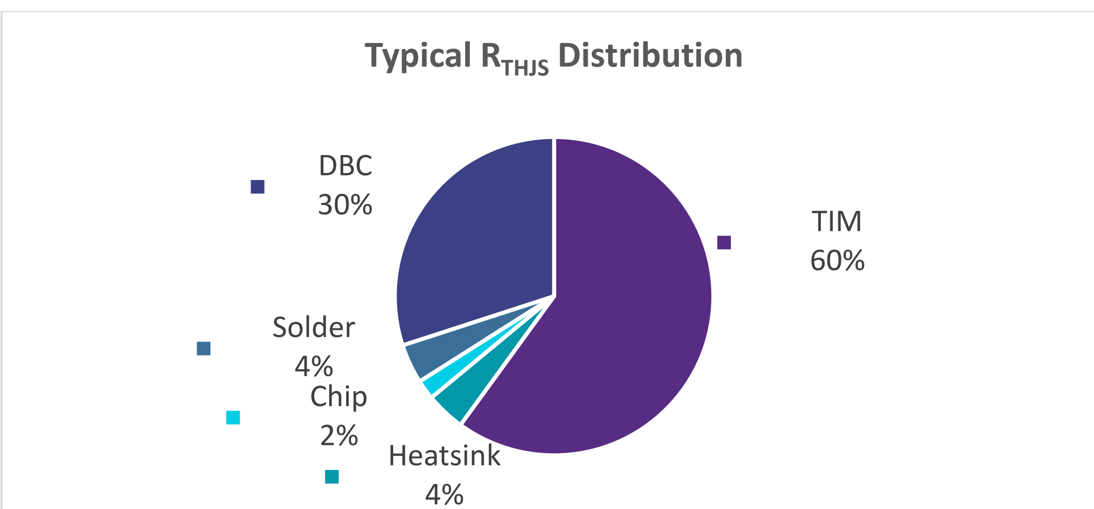


Figure 3: Typical R_{THJS} distribution observed in system application

1.3 TIM Selection

When selecting a TIM, it's important to consider both the immediate thermal performance and the long-time reliability of the interface. There are many solutions available to this problem that vary in price, effectiveness, and ease of implementation. At a high level, the most common technologies for TIMs are thermal pads, phase-change materials, and thermal grease/paste. Each technology has its own tradeoffs, but the recommendation for Wolfspeed modules is to use a suitable thermal paste between the module and the heat sink because of its high thermal conductivity. Of course, even in the subset of thermal paste, their characteristics can vary significantly based on their composition. A summary of the short-term performance and long-term reliability considerations that should be made when selecting a TIM is provided in Figure 4. These considerations are discussed in more detail in this section.

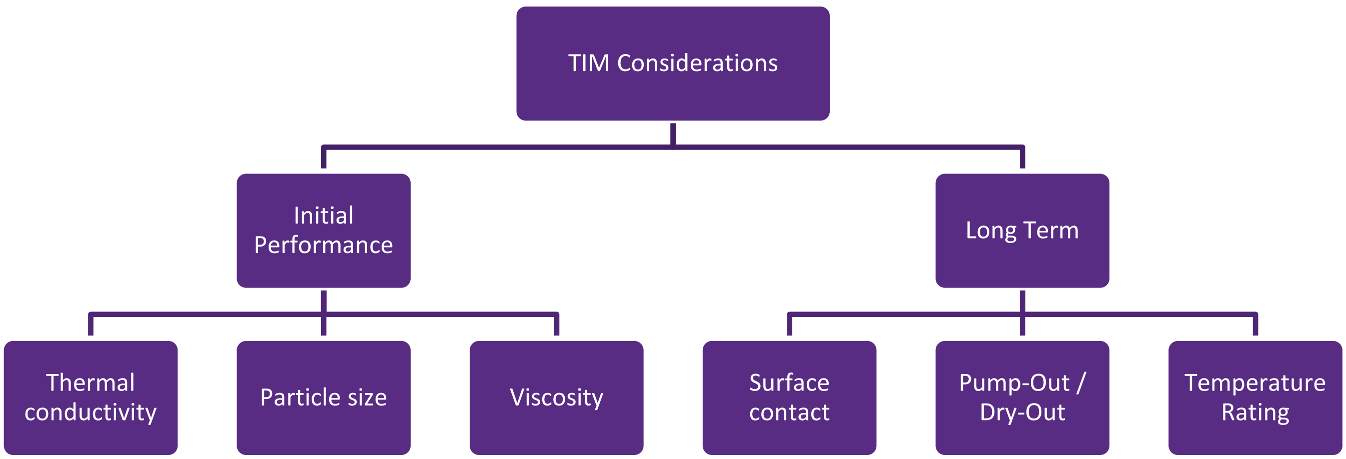


Figure 4: Considerations when selecting a thermal interface material

1.3.1 Maximizing Thermal Conductivity

A thermal paste is a freely flowing, non-curing substance that can flow into the gaps between two metal surfaces. As mentioned previously, the TIM layer is a major contributor to the overall thermal resistance. To minimize this thermal resistance, it is important to consider the TIM's thermal conductivity, particle size, and viscosity.

Thermal pastes are typically comprised of a carrier material mixed with high thermal conductivity filler particles, which can be made from beryllium oxide, aluminum oxide, zinc oxide, aluminum nitride, boron nitride, silicon dioxide, graphite, copper, silver, diamond, or a blend thereof. The carrier materials provide the viscosity needed for the TIM to distribute itself upon the surface between the module and the thermal sink, while the carrier materials conduct the heat through void areas. The effective thermal resistance R_{THeff} of the TIM can be defined as:

$$R_{THeff} = \frac{BLT}{k_{TIM} A} \quad (2)$$

Where BLT is the TIM bond line thickness, k_{TIM} is the thermal conductivity, and A is the material surface area. Balancing these characteristics is critical for minimizing the overall thermal resistance. However, there is no ubiquitous rule that linearly governs the relationship between mixing the carrier and filler concentration to synthesize high thermal conductivity. The physical boundary resistance between the two materials are intricate and highly irregular, and the bulk thermal conductivity is often largely dependent on the size of the filler particle itself.

The first variable to consider is the size and type of the filler particles. Larger particle sizes will yield higher conductivity (k_{TIM} increases), but larger particles may not be able to fill all the voids, preventing the desired metal-to-metal contact and thereby increasing the overall resistance. Thus, it is best to use the largest particles possible that are still small enough to fill the surface voids. This will depend greatly on the metal-metal interface for the application. For Wolfspeed modules, a general recommendation is to use a TIM that has particle sizes of ≤1 µm.

The bond line thickness is dependent on the metal surfaces, the thermal paste being used, and the method of application. The minimum bond line thickness for a TIM is generally provided by the supplier. However, properly applying the TIM can be the most critical consideration for minimizing the BLT. Improperly applying the TIM to the surface (for example, by applying too much material) can increase the BLT significantly. It is generally desired to apply the minimum amount of TIM necessary that can still fill all of the voids in the metal surface because the TIM has a significantly lower thermal conductivity than the metal-on-metal interface. It is recommended to use a stencil application procedure to apply an appropriate and consistent amount of TIM to the modules. The recommended procedure is described in Section 2.

Another consideration for improving performance is the viscosity of the TIM. Ideally, the TIM should cover the entire surface area of the metal interface between the module and the heat exchanger. Portions of the interface without TIM applied will not provide a benefit (A decreases). While a high viscosity TIM provides some advantages in reliability, it is also important to consider its spreading ability across the entire surface. Low-viscosity grease can compress and spread much easier. To demonstrate this phenomenon, two types of TIMs were applied to an XM3 module baseplate using a stencil, and the module was bolted and torqued to a thick sheet of acrylic so the spreading pattern of the TIM could be observed. Figure 5 shows the difference in spreading between the high and low-viscosity TIM. The low-viscosity TIM is shown to coat across the entire surface more evenly.

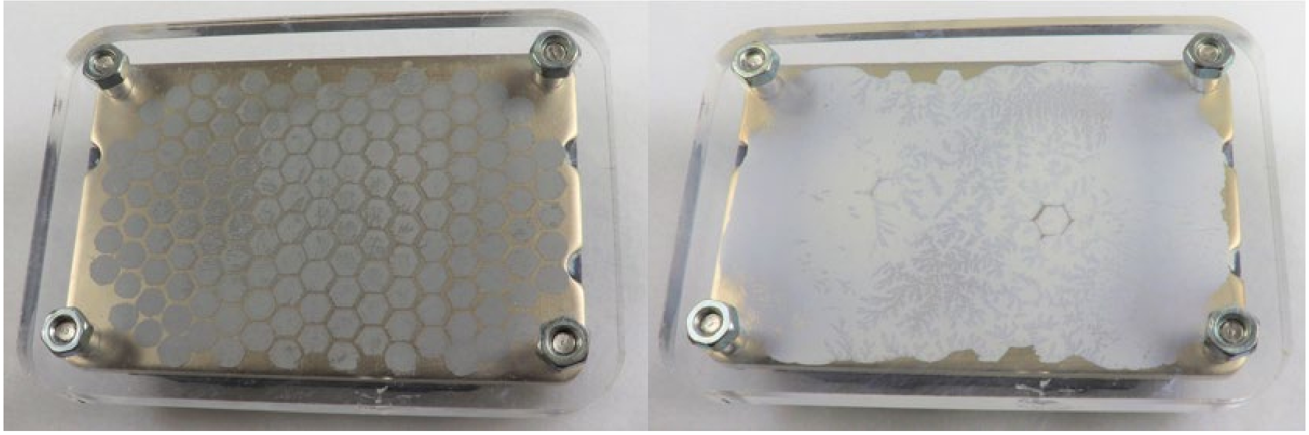


Figure 5: TIM spreading comparison of high viscosity (left) and low viscosity (right)

Finally, it's important to consider that most TIMs are considered thixotropic and require some time in the compressed state before all air escapes and the final bond line thickness is established. In addition, some TIM will need to be exposed to elevated temperatures and undergo thermal cycling before the maximum thermal conductivity is reached. In some instances, this could take up to 200 hours of operation to obtain peak performance.

1.3.2 Maximizing Lifetime and Reliability

A common mechanism of failure for power electronics devices is the degradation of the thermal interfaces caused by long-term heating and cooling cycles of the components. The most common mechanisms of failure are known as "pump-out" and "dry-out". Pump-out is a phenomenon where thermal cycling and CTE mismatch can cause TIM to be squeezed out of the contact area, leaving air pockets. This mechanism is illustrated in Figure 6. As the baseplate and heat sink change temperature, they will expand or contract at different rates. Over time and repeated temperature cycles, this can cause a pumping effect that ejects TIM from the side of the interface, leaving air pockets behind and increasing the thermal resistance of the interface. This can then cause a thermal failure by reducing how much heat can be removed by the heat sink.

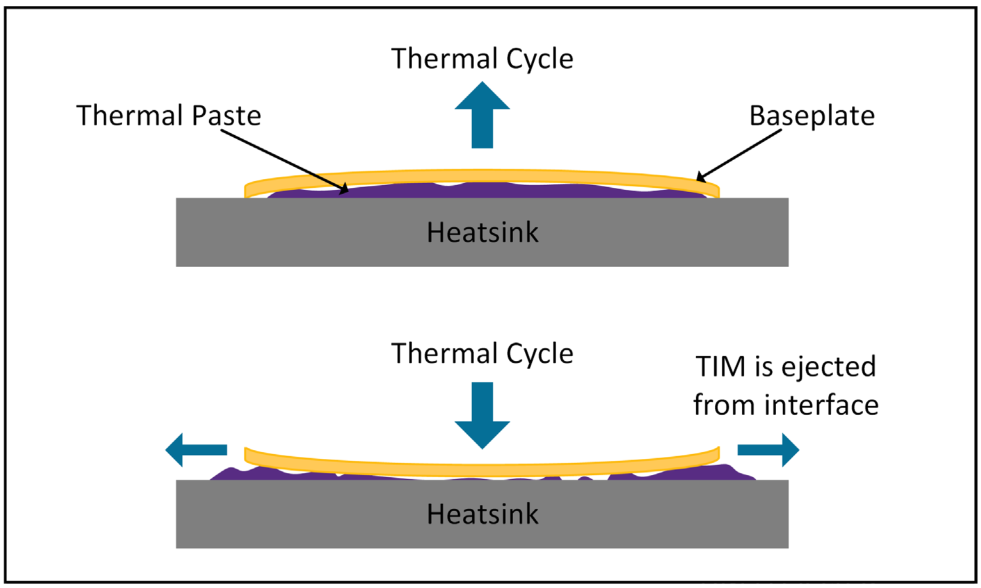


Figure 6: Mechanism for pump-out failure

Dry-out occurs when the thermal paste dries out and loses its ability to act as a filler in the void regions of the metal interface, thus increasing the thermal resistance of the interface. Dry-out is dependent on the temperature and humidity of the operating environment. To maximize device lifetime and reliability, it's important to select TIMs that are resistant to both pump-out and dry-out.

Another consideration when choosing a TIM is its temperature rating. The maximum allowable temperature is often determined by the composition of the suspension oils, grease, or silicones. Organic oils and greases are often unable to withstand the stress of a high-temperature interface. In such cases, a silicone-based TIM should be considered as an alternative. Because of the large surface area that is to be covered, a high-viscosity TIM is not recommended. Additionally, in baseplate-less applications, the TIM can see higher temperatures compared to baseplate applications and as such, a TIM with a temperature rating of >150°C should be selected.

1.4 Alternative TIM Types

If thermal paste does not meet the requirements of the system, there are other TIM types that may be suitable. Some may be in the form of a pre-cut sheet of aluminum, which can be coated with a thermal paste on both sides. Others may be made of either metal alloys or graphite. These TIM types simplify assembly and are less messy, but they add one or more additional layers of thermal resistance to the thermal interface. In general, these TIM types are "non-flowable" and cannot completely fill the voids in the metal surfaces. To maximize the baseplate-to-heat-exchanger contact area, a “flowable” TIM such as thermal paste or grease is recommended. There are many types of TIM available. Thermally conductive adhesives are also available but are not recommended because they greatly complicate any potential re-work.

If the use of a thermal pad is desired, a phase-change material is recommended. These pads can be handled at room temperature but will liquefy at a specified elevated temperature. Some will contain an additional material to help fill large voids. Since the material will remain solid until heated, it may be necessary to perform a burn-in period and then re-torque all bolts attaching the module to the heat exchanger.

Alternatively, the modules and pads could be assembled onto the heat exchanger, torqued, and put into an oven or thermal chamber until the flow temperature has been reached. (The melting temperature is generally within the range of 45° to 70°C.) Then, after a dwell period, the assembly could be removed from the oven, allowed to cool, and the bolts could be re-torqued. This method prevents the need for building, tearing down, and re-building a complex assembly. Also, the use of Bellville or compression washers can assist with keeping the module in constant contact with the heat exchanger during thermal cycling. Compression washers are recommended for power module attachment regardless of which TIM you use.

Phase change materials report performance that can meet or exceed the performance of thermal grease but can also be very expensive due to material and tooling costs. Unfortunately, due to their original thickness, they will often result in a bond line thickness that is greater than what could be achieved with a thermal grease. It should also be noted that since phase change materials will be solid or tacky at room temperature, they can make disassembly quite difficult.

1.5 Surface Flatness

Before applying the TIM, it is important to make certain that the contact surfaces—the cold plate mounting surface and module baseplate—are clean and free from any type of debris. This can be achieved by using an alcohol-based cleaner and a lint free cloth. Another important parameter to consider when selecting a proper cold plate is the roughness of its surface. Any cold plate surface will have imperfections in the surface finish that will cause void regions to develop in the contact region between the module and the cold plate. To ensure the filling of these voids and to minimize the thermal impedance, it is recommended to select a cold plate that meets the requirements listed below and in Figure 7.

- Surface flatness ≤ 25.4 µm per 25.4 mm (DIN EN ISO 1101)
- Surface roughness R_z ≤ 10 µm (DIN EN ISO 4287)
- No steps > 10 µm (DIN EN ISO 4287)

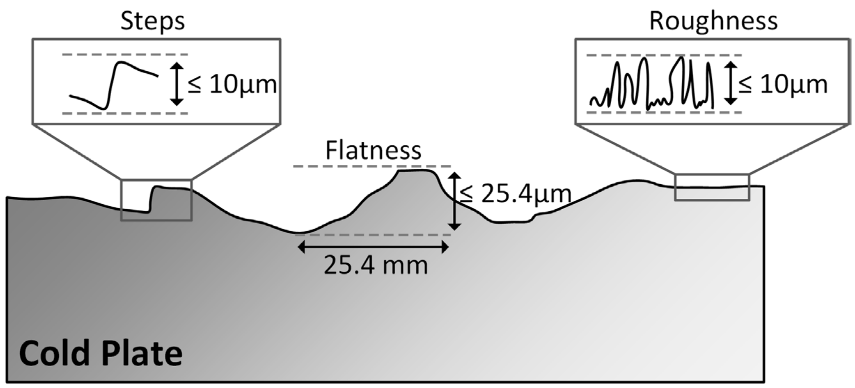


Figure 7: Required cold plate surface tolerances

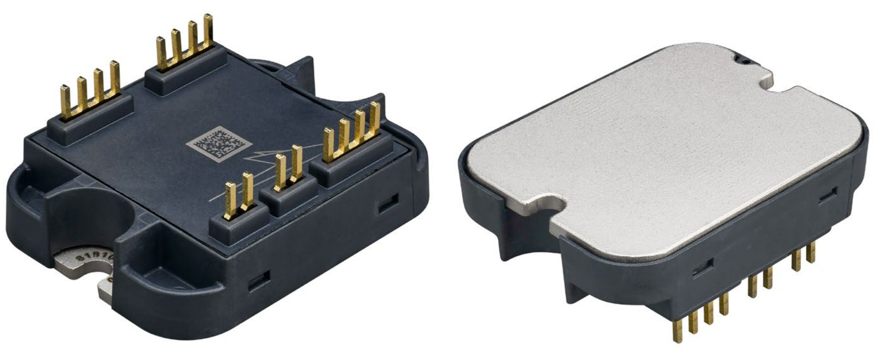
1.6 Pre-Wetting

A few TIM manufacturers recommend that you "pre-wet" the two contact surfaces. This wetting consists of placing a small amount of TIM onto the baseplate and heat exchanger. With a gloved hand or lint-free cloth, the compound is worked into the surfaces at different angles. After that, both surfaces are cleaned, TIM is applied at the desired thickness, and the system is assembled. The purpose of pre-wetting is to help ensure that the particles have been forced into the voids of the metal surfaces. If you plan to compare different types of TIM, keep in mind that once these particles are forced into the voids, it will be nearly impossible to remove them all by any cleaning method. This can skew the results of any subsequent thermal tests.

Applying TIM with a rubber or polyurethane roller is acceptable, but the thickness across the entire surface should be verified with a wet film comb. The target thickness should be 6.0 mil. For consistency and repeatability, a stencil or screen-printed TIM is recommended. While a screen print can allow for uniform TIM thickness, a stencil can provide better control of variable-volume deposit, which is where the final printed thickness of the TIM varies to accommodate uneven surfaces. An optimum TIM layer thickness will displace all air between the module baseplate and heat exchanger without preventing the metal-to-metal contact of the two surfaces. Another advantage of a stencil is that cleanup is much easier. A screen often has many small areas where the TIM cannot be completely removed and may therefore "contaminate" future TIM applications.

2. General TIM Application Procedure

This section describes a general recommended procedure for applying TIM to Wolfspeed power modules. Because the geometry of each module varies, details such as the stencil and fixture design will differ between modules. A picture of the top and bottom views of the DM module is shown in Figure 1. In this demonstration, Grey Ice 4060 non-silicone thermal grease from Timtronics® is applied to the DM power module.



(a) (b)

Figure 8: DM power module platform, (a) DM module top view, (b) DM module bottom view

When handling or applying TIM, follow all of the manufacturer's precautions and guidelines, including personal protective equipment recommendations. To prevent dust or debris from being introduced into the bond line, the TIM must be applied in a clean and ESD-safe workstation. Carefully inspect the equipment during application to ensure it is free of any previously applied TIM or dirt. All handling of the power module will need to be performed while observing ESD-safe rules and practices, which includes a high-impedance grounded conductive mat or table and an ESD wrist strap.

2.1 Designing a Stencil

Start by selecting a pattern consisting of squares, circles, hexagons or a combination thereof. The combination of stencil thickness, pattern spacing, and aperture size will determine the amount of TIM that is deposited onto the module's baseplate. If the apertures are too small, they will not allow the TIM to release. It is good practice to keep the deposit layer away from the bolt holes. The filler particles within the TIM can prevent the desired metal-to-metal contact at the areas where the module is secured. Those particles may also keep the module from fully seating onto the heat exchanger. Furthermore, if TIM gets into the bolt hole threads, it can influence the applied torque. The TIM application stencil for the DM power module is shown in Figure 9. The apertures can be adjusted to allow for variable volume deposit. DXF files of stencils used for all Wolfspeed power module platforms are available upon request.

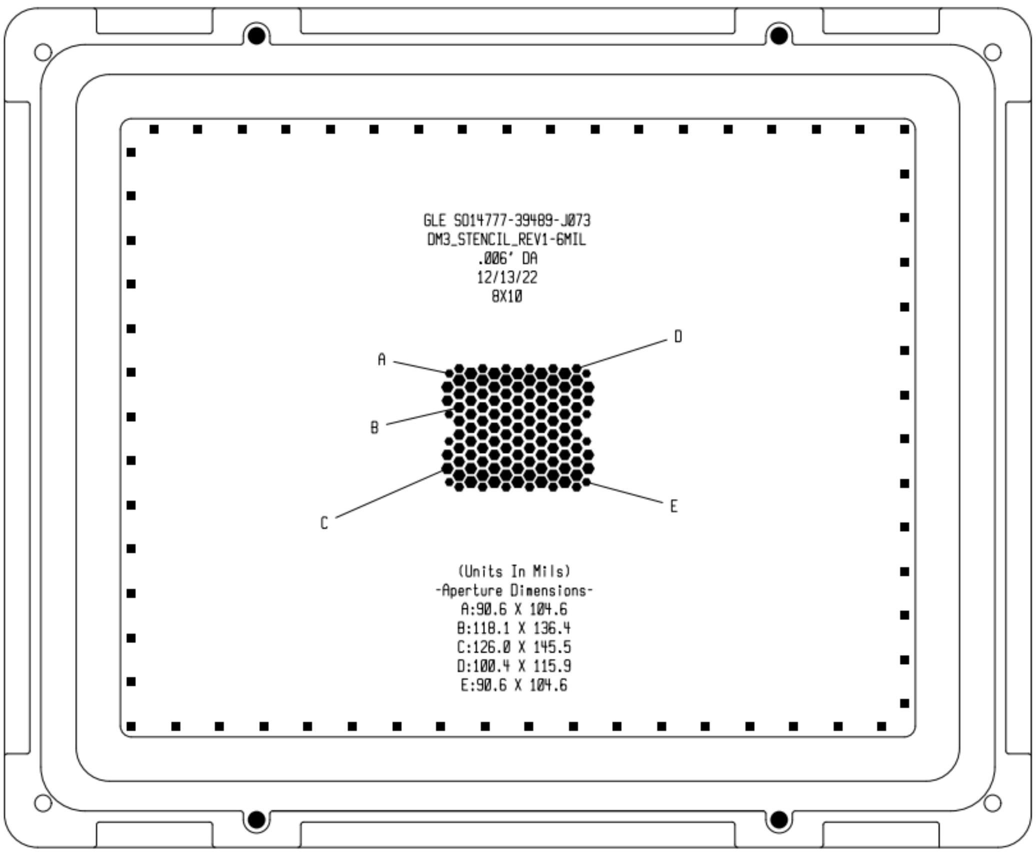


Figure 9: Wolfspeed DM power module TIM application stencil

2.2 Designing a Fixture

A fixture should be used to ensure proper alignment of the stencil and the power module. The stencil will need to be able to lift off the module without causing any distortion to the printed pattern. Higher viscosity TIM may not easily release from the stencil, so it is recommended to secure the module in the fixture so that the module is not lifted when lifting the stencil. An example TIM application fixture used here is shown in Figure 10.

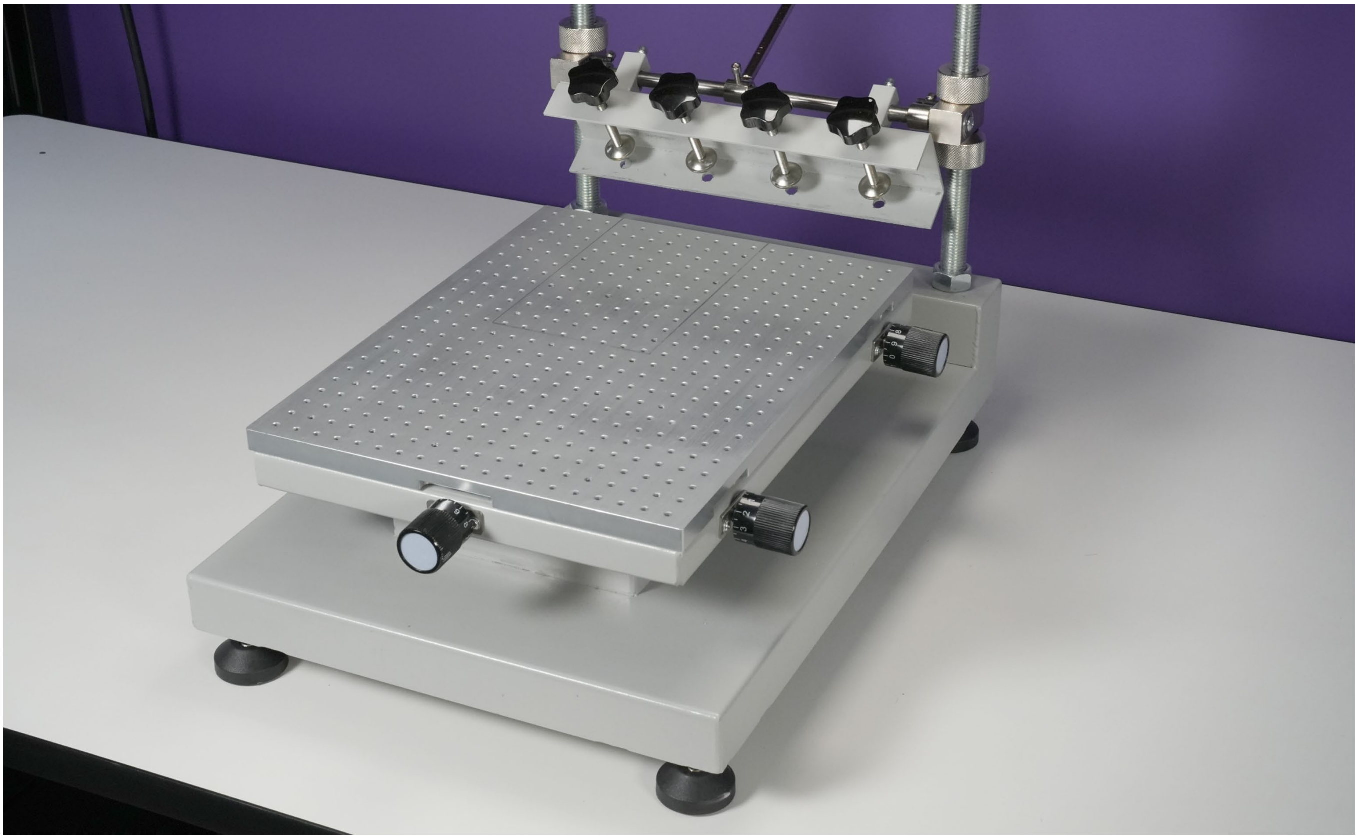


Figure 10: Example TIM application fixture

2.3 Applying the Thermal Interface Material

First, on the power module, ensure the shorting connector is on both gate-source headers. Carefully inspect the surfaces of the power module and heat exchanger to ensure that they are free from contaminants. Prepare these surfaces by cleaning them with isopropyl alcohol and a lint-free towel.

Next, place the module into the fixture (Figure 11) and lower the stencil (Figure 12). The stencil must be coplanar with and come into full contact with the baseplate. If there are any gaps between the two surfaces, excessive TIM will be deposited. To ensure the desired amount of TIM is deposited, the squeegee or trowel must leave the TIM flush with the stencil surface.

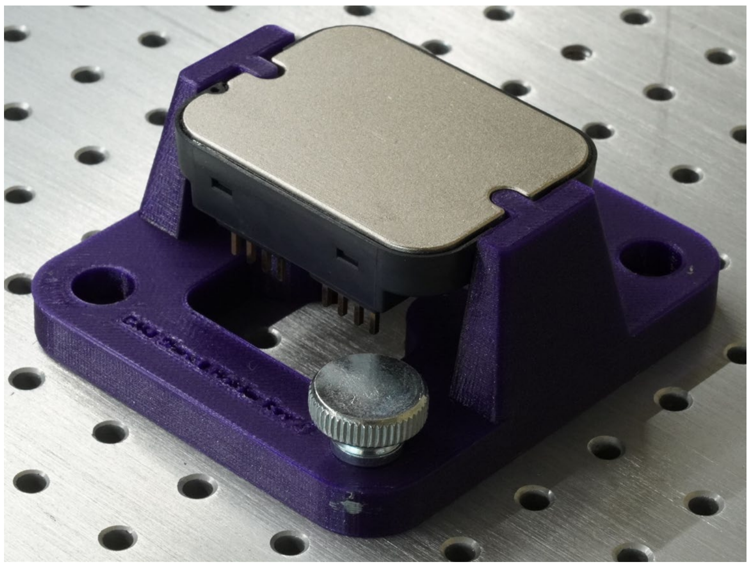


Figure 11: DM Module Placed on TIM Application Fixture

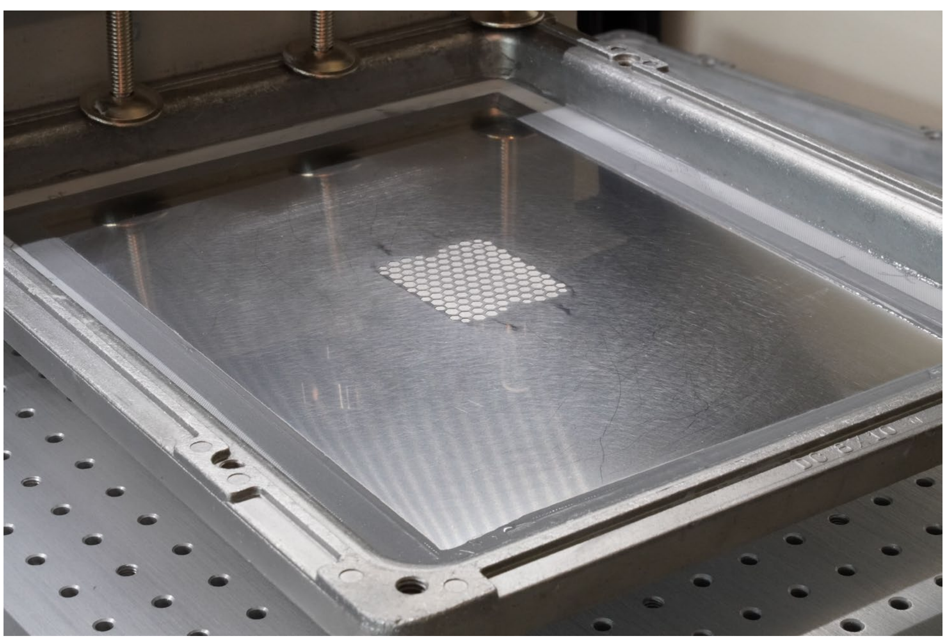


Figure 12: Module in Fixture with Stencil-to-Mounting Surface Full Contact

Dispense some TIM onto the stencil at the edge of the pattern as shown in Figure 13. The amount of TIM applied can be adjusted to limit waste. A metal squeegee, shown in Figure 14, is recommended. The squeegee should be held at a 45° angle during TIM application. Soft-material squeegees may result in “cupping”, where TIM material is removed from the stencil cavities, as shown in Figure 15. A picture of a stencil with visible cupping after applying the TIM layer is shown in Figure 16.

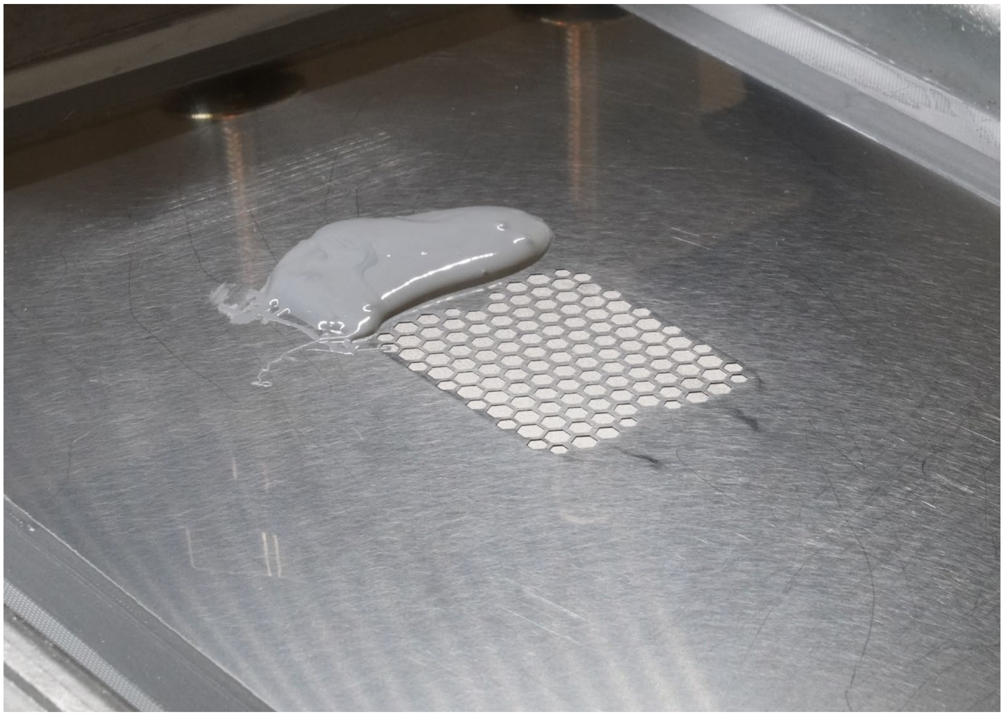


Figure 13: TIM Application Amount

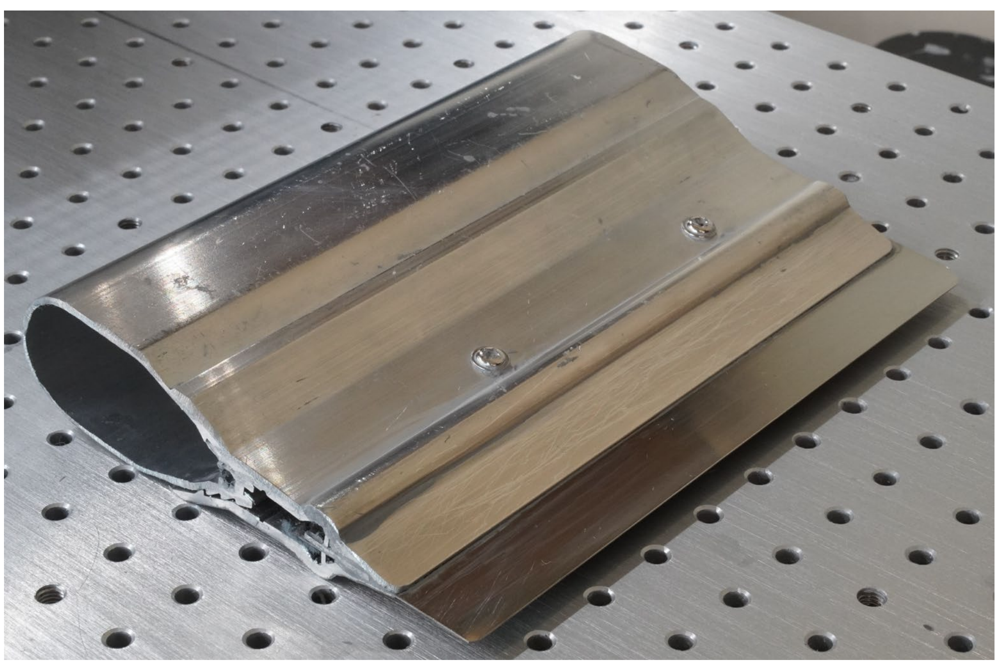


Figure 14: Metal squeegee for TIM application

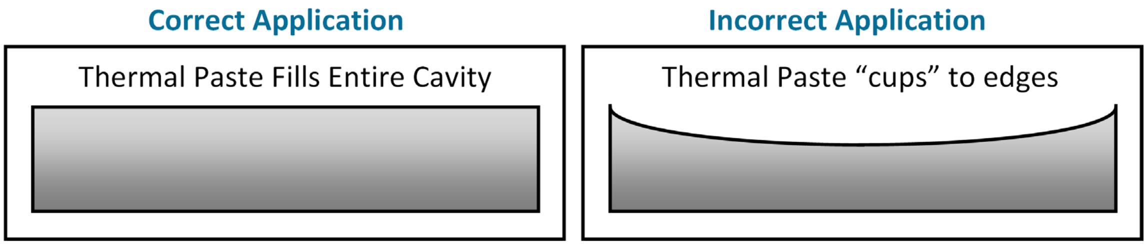


Figure 15: Cupping description diagram

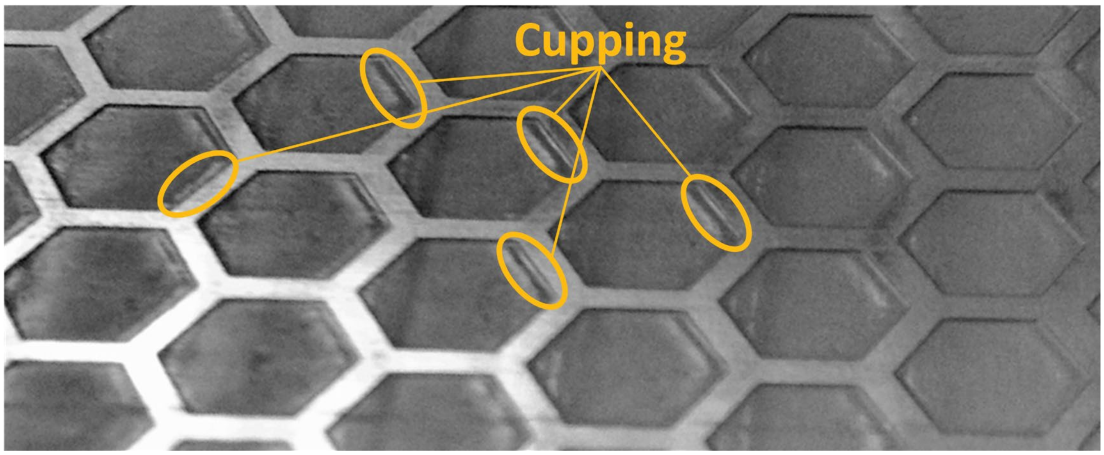


Figure 16: Picture of cupping occurring on a stencil after TIM application

Drag the squeegee across the pattern, applying only enough downward force so that the stencil surface is free of TIM after the squeegee passes. Inspect all apertures to ensure they are completely filled and that there is no cupping. Once verified, remove the module from the fixture and inspect the pattern. There should be no bridges of TIM between the apertures. Figure 18 shows the baseplate of the DM module after the TIM has been applied by this process.

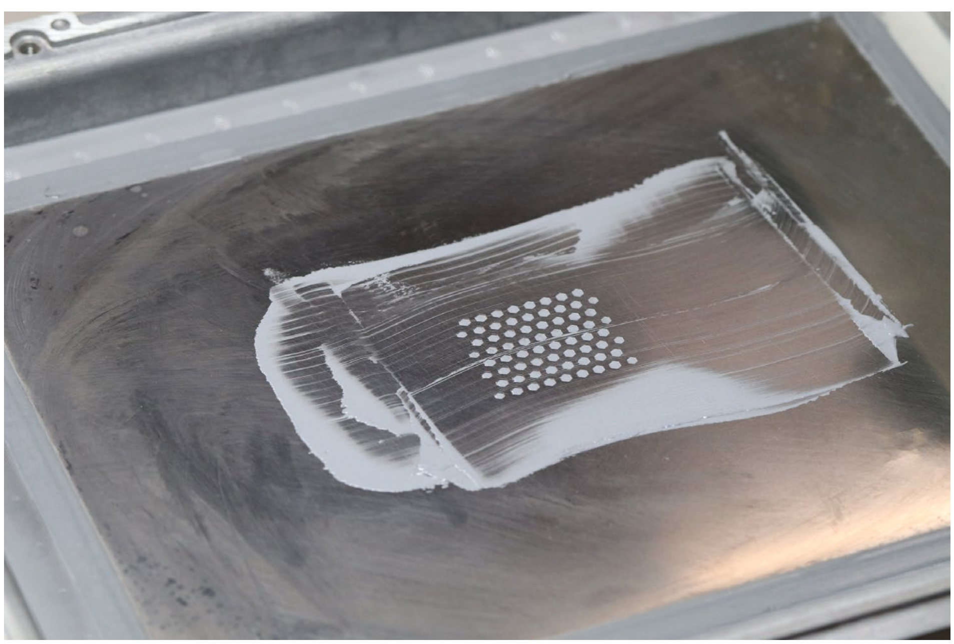


Figure 17: Correct application of TIM to stencil

Figure 18: Correct application of TIM to DM power module

2.4 Verification

To verify that the correct amount of TIM has been used, it is highly recommended that the module be removed from the heat exchanger and the TIM layer be inspected. If the module is removed immediately after assembly, the TIM layer may not have had time to fully spread and push out the air - therefore it is recommended that the module be torqued and allowed to rest for at least two hours. In the case of high-viscosity TIM, consult the TIM manufacturer for their recommended rest time.

Extreme care must be taken when the module is removed so the spreading pattern is not disturbed and that the surfaces are not scratched. This can be difficult, but using a non-marring tool such as a plastic chisel should help to remove the module in this manner.

Alternatively, a thick transparent material like acrylic can be used to mount the module with TIM applied on it and inspect the TIM spreading without removing the module from the acrylic. If an insufficient amount of thermal grease is applied to the module baseplate, the thermal grease will not fully spread across the surface of the module baseplate (see Figure 19). The optimal thermal grease application will fully wet the module baseplate surface (see Figure 20) but will not be so thick as to prevent metal-to-metal contact. If an excessive amount of thermal grease is applied to the module baseplate, the thermal grease will look very dense (thick) on the surface of the module baseplate (see Figure 21).

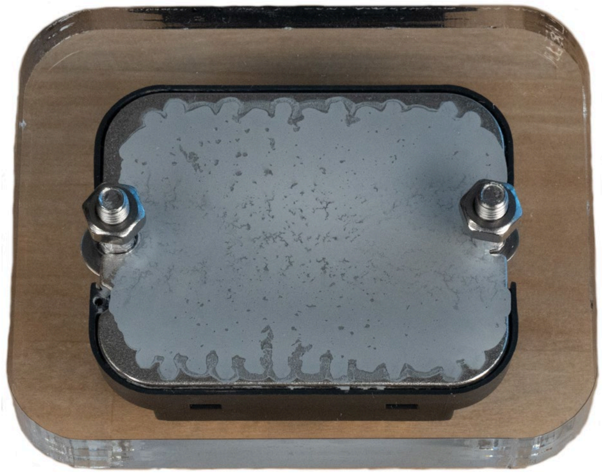


Figure 19: Thermal grease applied with a 4 mil stencil: module baseplate surface not fully wetted indicating insufficient thermal grease application

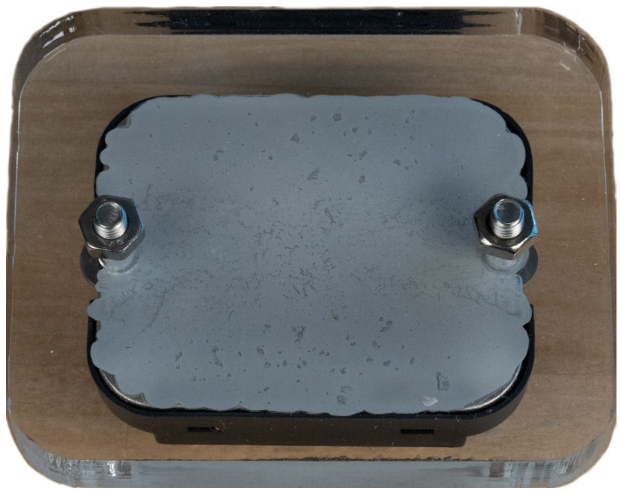


Figure 20: Thermal grease applied with a 6 mil stencil: module baseplate surface fully wetted and thermal grease not very dense indicating optimal thermal grease application

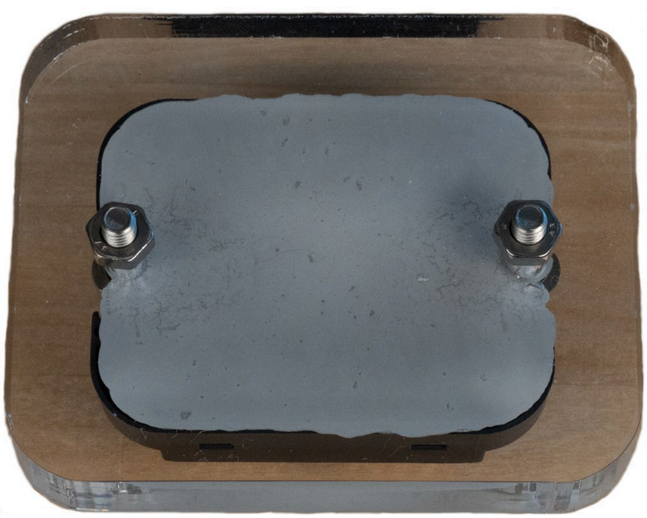


Figure 21: thermal grease applied with an 8 mil stencil: very dense thermal grease indicating excessive thermal grease application

It is also necessary to inspect the quantity of thermal grease that appears around the side of the power module. The quantity of thermal grease is correct when a small amount of grease appears around the power module (see Figure 22). If no or a very small amount of thermal grease appears around the side of the power module (see Figure 23), an insufficient amount of thermal grease has been applied to the module baseplate. On the other hand, if a large amount of thermal grease appears around the side of the power module (see Figure 24), an excessive amount of thermal grease has been applied to the surface of the power module baseplate.

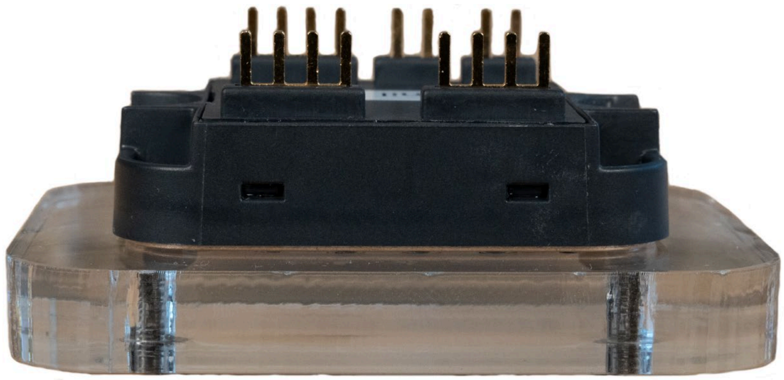


Figure 22: Thermal grease applied with a 4 mil Stencil: no thermal grease appearing around the side of the module, indicating insufficient thermal grease application

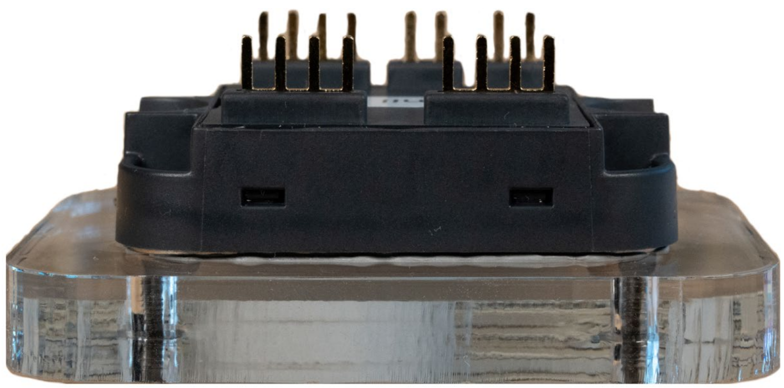


Figure 23: Thermal grease applied with a 6 mil stencil: small amount of thermal grease appearing around the side of the module, indicating optimal thermal grease application

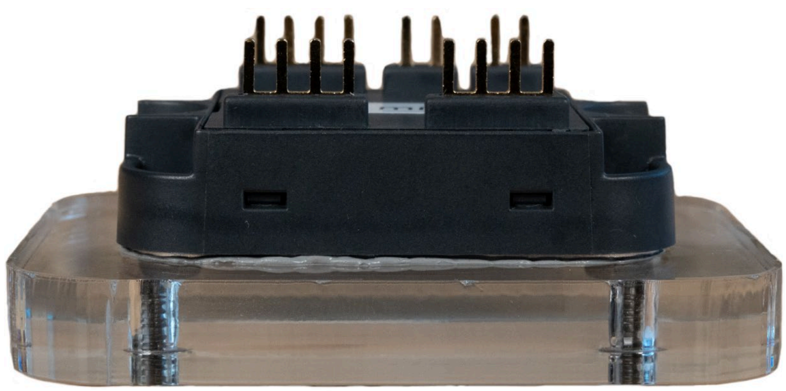


Figure 24: Thermal grease applied with an 8 mil stencil: large amount of thermal grease appearing around the side of the module, indicating excessive thermal grease application

2.5 Assembly

Once the TIM has been applied, the module should then be properly mounted to the heat sink and other system components (such as the PCB or bus work). Improper mounting of the module and the heat sink may cause the TIM to spread unevenly, be pushed out of the interface, or leave air in the interface. Documents describing the correct mounting procedure are provided for the following Wolfspeed power modules: XM module platform, 62 mm module platform, DM module platform, WolfPACK module platform (F and G).

3. Modules with Pre-Applied Thermal Interface Material

Currently, all WolfPACK™ F and G modules and all 62 mm platforms, including the B and H module portfolios, can be purchased with a Pre-Applied TIM (PATIM) option. The pre-applied TIM modules include a **T** suffix in the part number (ex: CAB006M12GM3**T**). This eliminates the need for custom application techniques and ensures that the module will be installed properly. Pictures of F and G power modules with PATIM are provided in Figure 25.

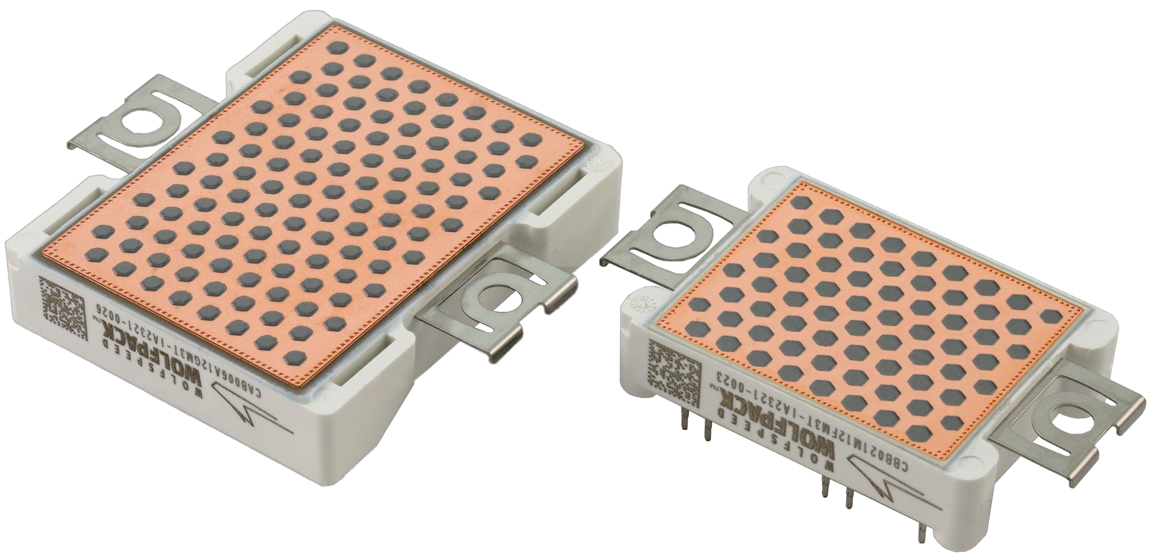


Figure 25. F module (left) and G module (right) with pre-applied TIM

3.1 Features and properties

Wolfspeed Pre-Applied TIM Modules use Honeywell PTM6000HV paste as the thermal interface material. It is designed to minimize thermal resistance at interfaces and maintain extremely stable performance across thermal cycling. Based on a robust polymer PCM structure, this material exhibits excellent wetting properties during typical operating temperature ranges, resulting in very low surface contact resistance.

During mounting, the TIM must be subjected to a temperature greater than or equal to 60°C for at least 30 minutes for the phase transition process. This process ensures that the TIM layer melts, wets the surface, and spreads into the gaps between the surfaces. A clean heat sink surface is particularly important for a uniformly spread TIM layer.

The pre-applied TIM pattern dimensions of the F, G, and B/H module platforms are illustrated in Figure 26, Figure 27, and Figure 28 respectively. The patterns have a typical post-cure thickness of 85 µm (B, H), 130 µm (F), or 190 µm (G) depending on module type.

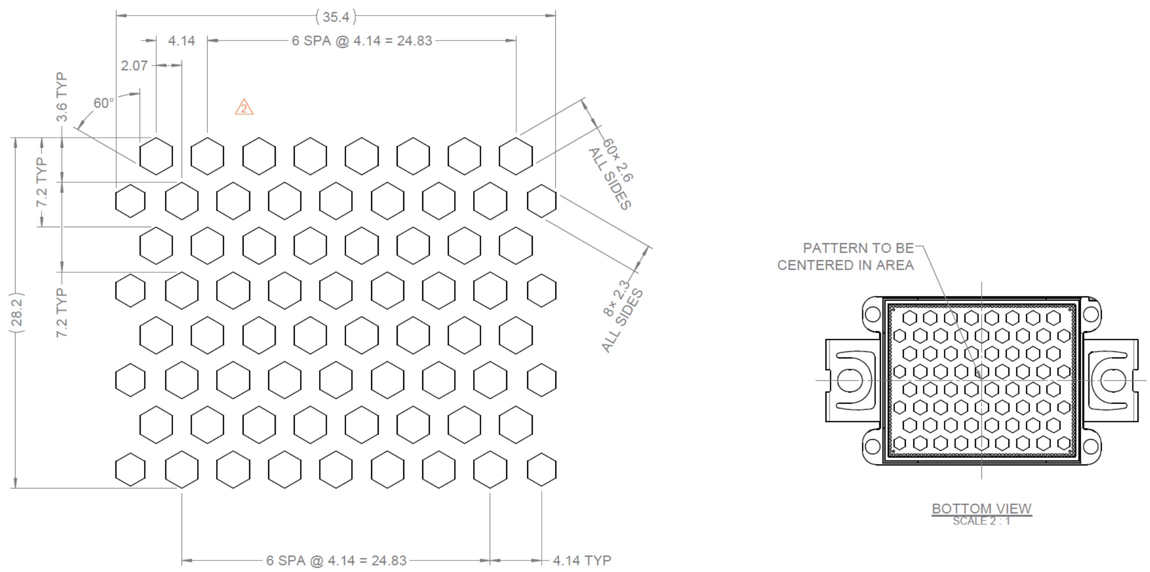


Figure 26. TIM pattern for the F module platform

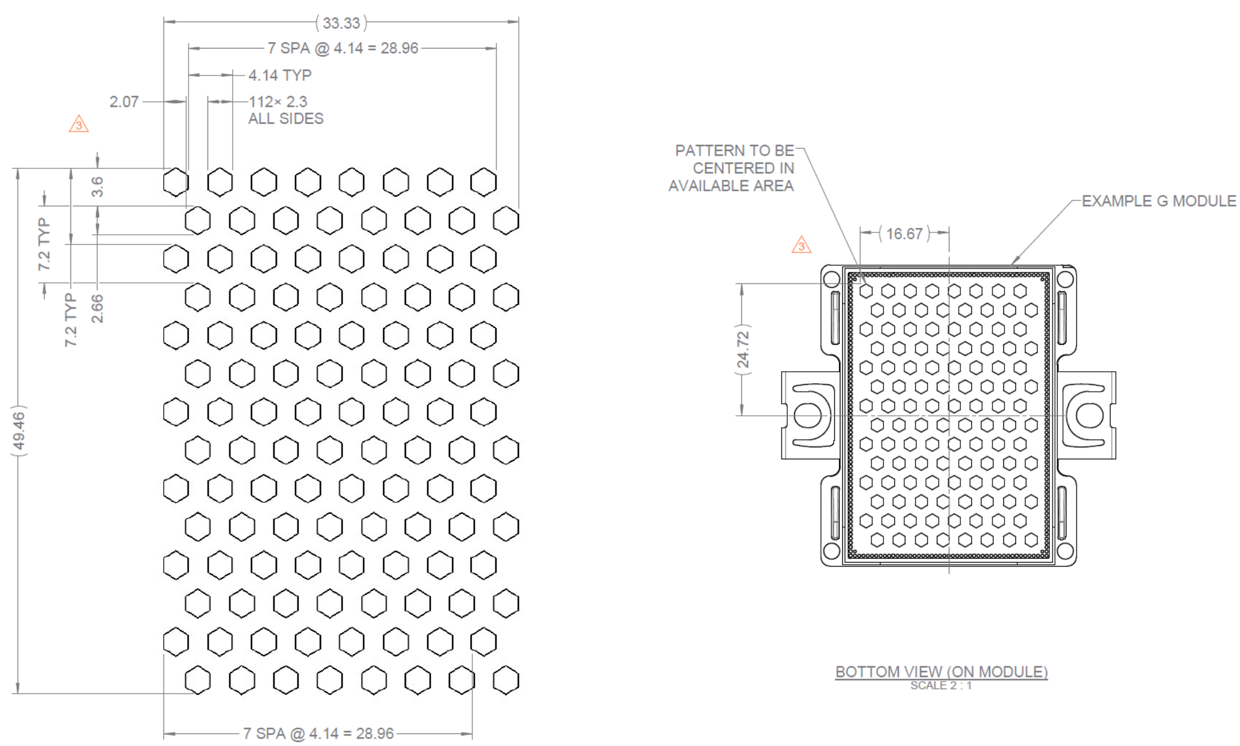


Figure 27. TIM pattern for the G module platform

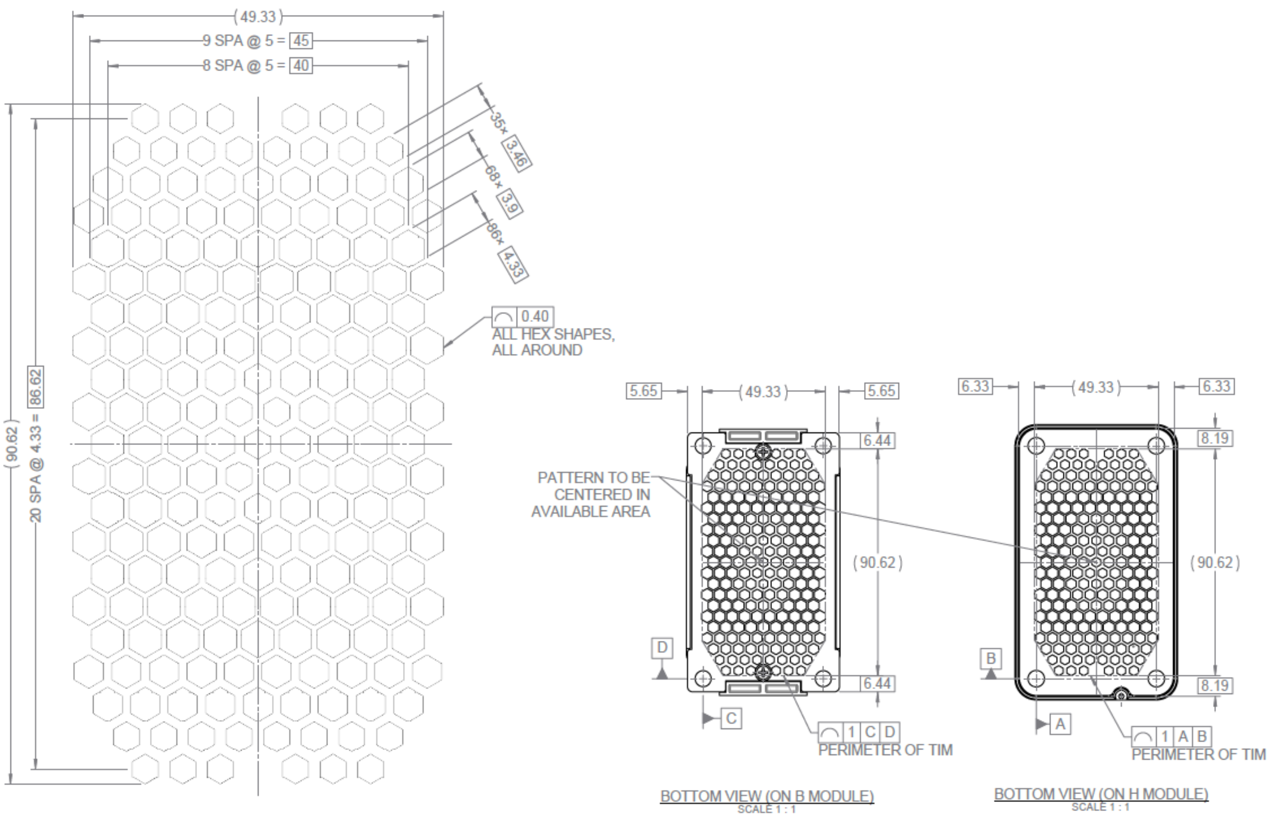


Figure 28. TIM patterns for B and H module platforms

3.2 STORAGE

PATIM modules should be stored in their original packaging only. It is also essential to ensure that the TIM layer is NOT contaminated in any way during storage. The recommended environment and storage durations are elaborated in Table 1 below. Violation of these conditions can lead to reduced performance and even malfunctioning of the modules.

Table 1. Storage Conditions

Parameter	Value
Temperature	10-30°C
Rel. Humidity	< 65%
Duration	12 months

Revision History

Date	Revision	Changes
January 2024	1	Initial Release
March 2025	2	Updated Pre-Applied TIM Patterns