Application Note

AN 18-001

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Prepared by:	Paul Drexhage
Approved by:	Peter Beckedahl

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Thermal Paste Application

1. Introduction

This document describes the application of thermal paste (grease) as a thermal interface material (TIM) between power semiconductor modules and heatsinks. Other TIMs such as phase change materials (PCM), coated foil substrates, or thermal pads are not covered. For information on pre-applied TIM on SEMIKRON products, please refer to [3] and the module-specific Technical Explanations documents. This application note supersedes [6].

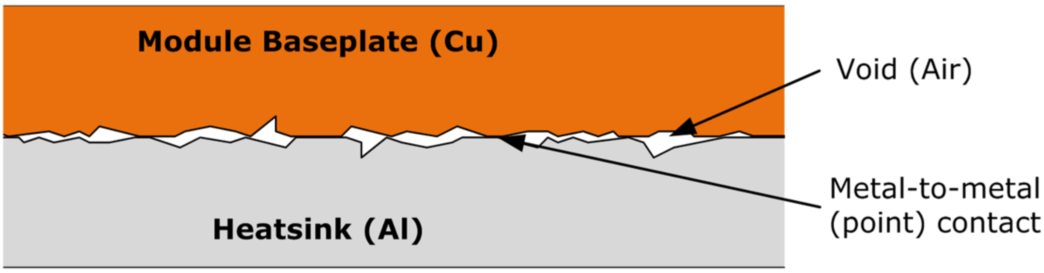
2. Purpose of Thermal Interface Material (TIM)

Heat generated by a semiconductor has to flow through a number of different materials and interfaces before it reaches a coolant (air or liquid) to be carried out of the system. Each of these materials has a property defined by:

> **Thermal conductivity, λ:** A measure of a material's ability to conduct heat as measured in Watts per meter-Kelvin [W/(m·K)]

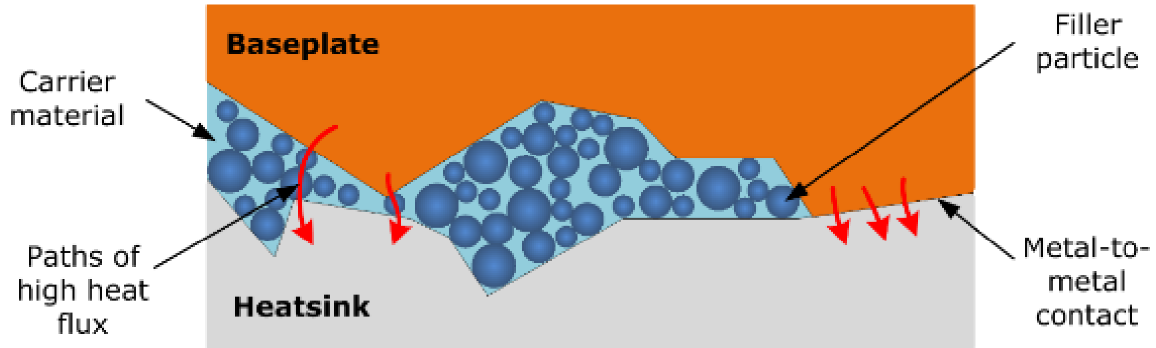
In power semiconductor systems, metals such as copper ($\lambda_{Cu} \approx 390 W/(m \cdot K)$) or aluminum ($\lambda_{Al} \approx 200 W/(m \cdot K)$) have been selected for their high thermal conductivity. In an ideal world, wherever these materials meet would be a uniform surface with complete metal-to-metal contact. In reality, such as where a power semiconductor module is mounted to a heatsink, the interface is non-uniform. As shown in Figure 1, on a microscopic level there are many voids in each of the contacting materials. These voids are filled with air which has relatively poor thermal conductivity ($\lambda_{air} \approx 0.03 W/(m \cdot K)$). The purpose of a thermal interface material is to displace this air with a material with higher thermal conductivity ($\lambda_{paste} \approx 0.5$-$6 W/(m \cdot K)$) while maintaining metal-to-metal contact where possible.

Figure 1: Microscopic cross-sectional view of baseplate-heatsink interface without TIM (exaggerated)



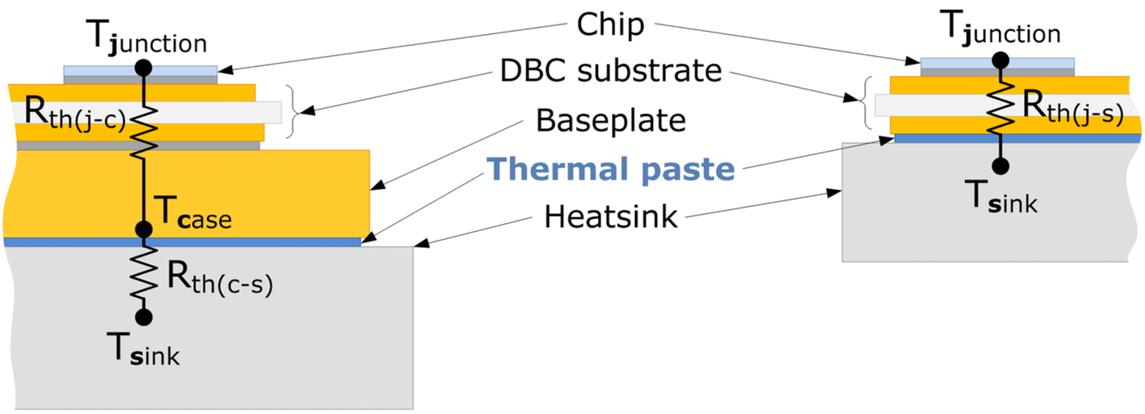
Thermal paste consists of thermally conductive particles suspended in a carrier medium (Figure 2). These particles fill the voids and form a thermal bridge. From this figure, it is clear that the particle size, variation in particle size, and particle distribution all play a large role in how well a paste fills the voids in the interface.

Figure 2: Microscopic view of thermal paste filling voids



While thermal conductivity describes the characteristic of the material, the overall performance of the interface is defined as a thermal resistance (R_{th}) between junction and heatsink. Depending on the module construction (Figure 3), the effect of the thermal paste is included in either the $R_{th(case\text{-}sink)}$ or $R_{th(junction\text{-}sink)}$. For a full discussion of thermal resistance, see [4].

Figure 3: Measure of thermal resistance including thermal paste for modules with baseplate (L) and without (R)



The thermal resistance is determined by more than the thermal conductivity of the paste alone. The following affect the final $R_{th(c\text{-}s)}$ / $R_{th(j\text{-}s)}$ value:

a. Surface finish of heatsink
b. Applied thickness of thermal paste
c. Thermal cycles after mounting
d. Mounting pressure of module on heatsink
e. Design of module (shape of baseplate, layout of chips, baseplate material, etc.)

3. Thermal Paste Selection

3.1 Paste properties

As can be seen from the length of this application note, there are many things to consider when selecting a thermal paste. A summary of the most important characteristics is given in Table 1.

Table 1: Considerations in selecting a thermal paste

Property	**What to Consider**	**Evaluation Method**
Thermal conductivity → thermal resistance	The bulk thermal conductivity of the paste given on the datasheet is not as important as the final effective $R_{th(j-s)}$.	Static thermal testing of power electronics assembly
Viscosity	Higher viscosity pastes can cause substrate cracking in baseplate-less modules and be difficult to screen print.	Assembly testing, Production line qualification
Compatibility with customer requirements	Certain industries restrict the use of certain substances (e.g. silicone).	Inspection of paste datasheet
Pump-out resiliency	Certain pastes and module types (baseplate) are more susceptible to being "pumped out" from beneath the module.	Power cycling
Dry-out resiliency	Certain pastes are more susceptible to drying out over time.	Thermal/environmental cycling

3.2 Carriers and fillers

The carrier material in a paste is generally categorized as a silicone or non-silicone type. In general, SEMIKRON recommends using silicone-based pastes as they are well-established, low-cost, high performing, and very reliable. However, modern manufacturing facilities (particularly those associated with painting or other chemically sensitive processes) require the absence of silicone. Therefore, silicone-free pastes are available where the carrier consists of a blend of synthetic fluids.

The filler material in most pastes is metal oxide (ZnO, BN, Al_2O_3), silver, or graphite. While the filler material is important, equally important are the ratio of filler to carrier and the particle size (as referenced above). High performance pastes often use relatively large particles (e.g. ~50µm) which can limit the minimum paste thickness. Furthermore, pastes with high metallic filler content can be very viscous, which causes problems with baseplate-less modules as the paste is less likely to "flow" when compressed between module and heatsink (see Cracking of ceramic substrate). Some pastes contain a low amount (e.g. 1%) of evaporable solvent to reduce viscosity during the application process. These pastes are more sensitive to storage and handling requirements as the solvent is less stable than the carrier material. Once the solvent evaporates the paste is more difficult to apply and less likely to fill the voids as intended.

4. Thermal Paste Application

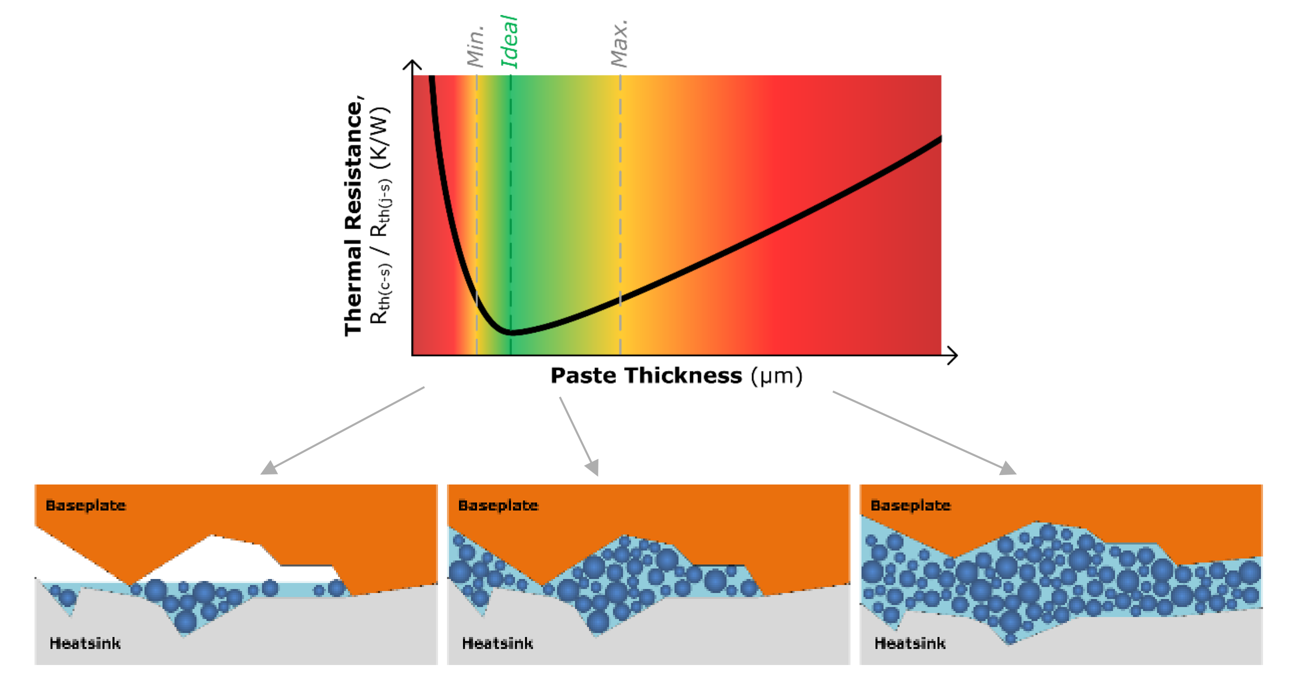
4.1 General

4.1.1 Recommended paste thickness

Given the various parameters that influence thermal resistance, it should be understood that the target paste thickness will vary depending on module type. The manufacturer of the power module should qualify the module with an industry standard thermal paste and then specify a thickness. For SEMIKRON, this paste has traditionally been Wacker P12 and the target thicknesses are given in the respective Technical Explanations/Mounting Instructions for the product line in question (e.g. MiniSKiiP, SEMITOP, etc.). These thicknesses are valid for any thermal paste with similar physical characteristics to Wacker P12 (i.e. silicone paste with oxide carriers and density of ~2.1g/cm^3) and are usually specified over a 5-20µm wide range.

It can be seen from the previous discussion that only enough paste should be applied to fill air-filled voids. Just adding a thin layer of paste will quickly reduce the thermal resistance in the system, but adding additional paste beyond this will slowly raise the thermal resistance since the thermal conductivity of the paste is lower than the two metals in the interface (Figure 4).

Figure 4: Relationship between paste thickness and thermal resistance of system



4.1.2 Heatsink specification

The surface finish of the heatsink is a critical part of the interface. Specifications for roughness (Rz), unevenness over distance, and allowable "steps" are given for different module types (baseplate or baseplate-less). For SEMIKRON product, the heatsink surface finish requirements are given in the respective "Mounting Instructions" document for the product line in question (e.g. SEMiX, SEMITOP, etc.). These specifications must be indicated on the drawing used for machining the heatsink and should be verified on the finished heatsink prior to use. This can be done using optical inspection methods.

4.1.3 Applying to module vs. applying to heatsink

The decision of whether to apply paste first to the module or to the heatsink is based on the mechanical design of the product and the order assembly during the production process. Generally speaking, a screen/stencil is used to apply paste to the heatsink as it physically easier and screens/stencils can support patterns for multiple modules at once. For this reason, the following screen/stencil examples will show application of the paste to the heatsink, though the processes can be adapted for direct module application.

4.1.4 Preparation of paste

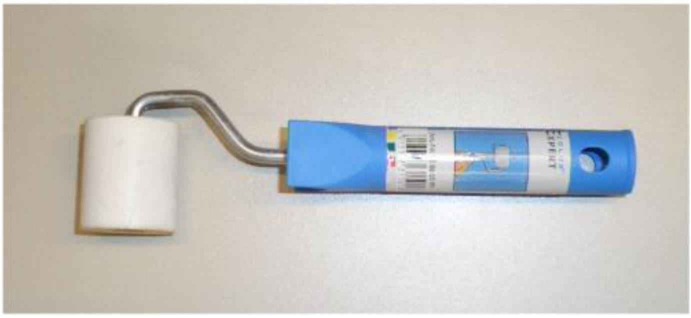
Most pastes benefit from a rudimentary mixing prior to application to check for homogenization of the carrier and filler materials and inform the operator if anything drastic has occurred to the consistency of stored paste. This can be as simple as stirring the paste within its shipping container prior to dispensing on the production line to as complex as running the materials through an automatic mixer as is used in fully automated screen printing. Well-mixed paste should show uniform color and consistency, without any standing carrier material (i.e. oil). Pastes containing a solvent may require mixing per the manufacturer to ensure that the solvent is evenly distributed.

4.2 Roller

For prototyping and low-quantity production, a roller can be used to apply thermal paste directly to the bottom of the module (Figure 5). While low cost, this method results in inconsistent thicknesses and is messy. It does have the advantage that the thickness of the thermal paste layer can be directly measured prior to mounting the module.

A rubber roller (also known as a "brayer" in the art/print industry) with a medium durometer (Shore hardness 50A to 70A) is recommended. This rubber is hard enough that foreign particles should not become easily embedded. The roller should be compatible with paste cleaning agents and not have mechanical features that would allow old paste or dirt to build up. The width of the roller should be narrow enough to fit the baseplate without overhanging but as wide enough to dispense a consistent layer of paste.

Figure 5: Example roller



4.2.1 Process

1. Paste is dispensed onto a clean, hard, flat surface such as a sheet of glass or hard plastic tray.

2. The roller is run back-and-forth through the paste until a thin layer is spread evenly over the entire roller (Figure 6). This is usually accompanied by high-pitched crackling sound, as the surface tension of the paste is broken as the roller pulls the paste up.

Figure 6: Working the paste onto the roller using a hard plastic tray

3. The roller is applied to the baseplate of the module with light pressure and worked back-and-forth, first in one direction (Figure 7) and then in the perpendicular direction (i.e. both X- and Y-axes) until a thin, even layer is present across the entire baseplate.

Figure 7: Applying paste to a MiniSKiiP module

4. The layer thickness is checked (see Measurement).
5. If too much paste is present on the roller, paste can be removed by running the roller across a "dry" section of the glass sheet.

4.3 Screen printing

Screen printing is a well-established method of printing inks in the fabric and print industries and is well suited for paste application. A fabric mesh is stretched across a frame and a rectangular opening the size of the module baseplate is printed on the mesh using photo-resistive inks. The screen is then pre-wetted with the paste ("flooded"). Finally, the screen is placed a small distance above the heatsink or module and a synthetic rubber scraper ("squeegee") is drawn across the screen with a pre-set angle and pressure. As the screen makes contact with the surface to be printed, the paste is pushed through the mesh and deposited. Since the resulting layer of paste is uniform (without a pattern), the thickness of the paste can be directly measured.

Semi-automated equipment is available that controls the height and position of the screen as well as the pressure applied to the scraper.

4.3.1 Materials

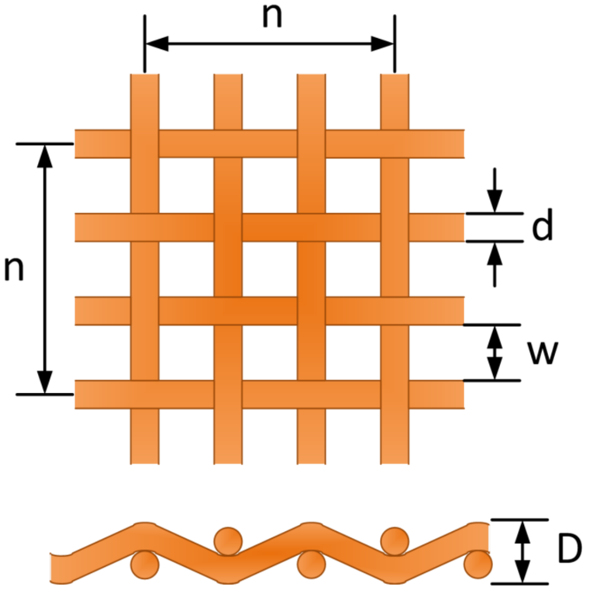
While traditionally known as "silkscreen", modern high-performance screen material is made from plastics such as polyamide yarn ("nylon"), polyethylene terephthalate (PET) or other polyesters and monofilaments. For extra screen longevity, stainless steel mesh is available.

The scraper consists of an extruded aluminum handle to which a medium hard (Shore hardness 60A to 80A) rubber blade has been bolted. Harder rubbers (80A) are used for pastes that are more viscous.

4.3.2 Mesh count and thread size

The most common parameters for defining the mesh are the threads per unit area and the diameter of the thread (Figure 8). The nomenclature varies by measurement unit (cm vs. inches) and material construction (monofilament vs. multifilament) so care must be taken when specifying mesh count depending on the locale (United States vs. Europe). In general, mesh counts for printing thermal paste are much "coarser" than those used for printmaking as the resulting material thickness is greater and less concern is given to feature detail.

Figure 8: Definition of mesh parameters



Percent open area: $a_o = \left(\frac{w}{w+d}\right)^3 \cdot 100\%$

Approximate volume of paste: $V_{paste} = \sim 0.75 \cdot D \cdot \left(\frac{w}{w+d}\right)^2$

SEMIKRON has performed some example tests using PET mesh and Wacker P12 thermal paste (Table 2).

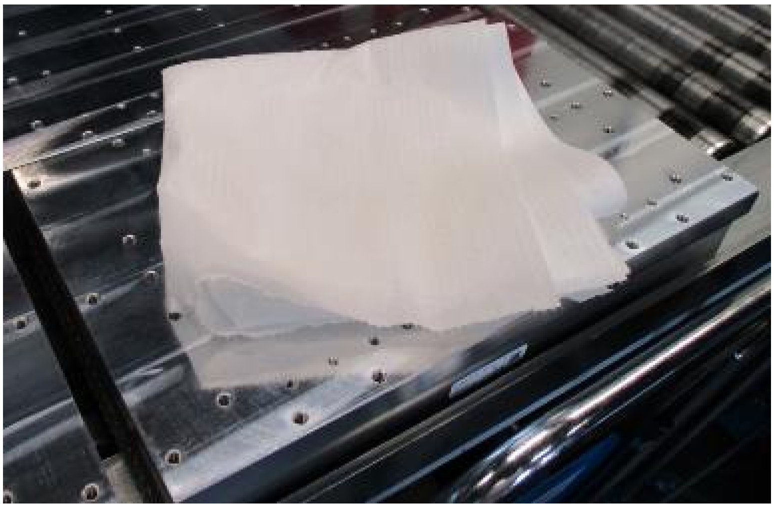
Table 2: Experimental results

Designation (DIN standard)	77-55	43-80	27-140
Mesh count, n	77 threads/cm²	43 threads/cm²	27 threads/cm²
Thread diameter, d	55µm	80µm	140µm
Resulting paste thickness	20-30µm	40-50µm	70-80µm

4.3.3 Process (manual)

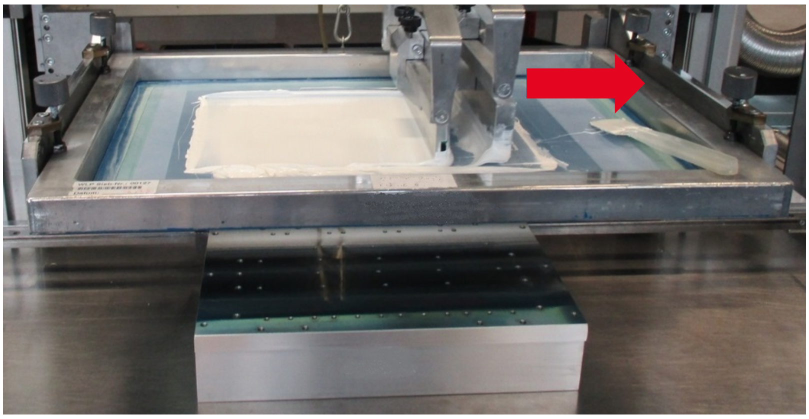
1. A cleaned heatsink is placed into position under the screen. While heatsinks should be degreased as part of the machining process, it is important to use a lint-free rag with a mild solvent such as isopropyl alcohol to remove fingerprints, dust or other residue just prior to the screen printing process.

Figure 9: Degreased heatsink and lint-free rag



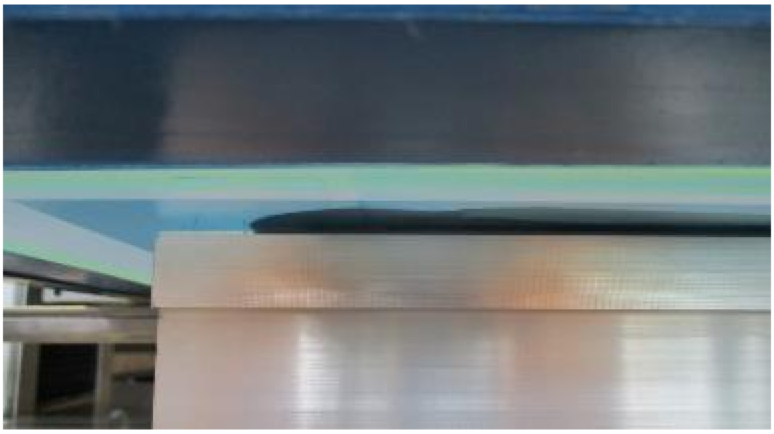
2. A thick line of paste is deposited at the far end of the stencil using a spatula. The screen is "flooded" by drawing the scraper across the screen with light pressure (not making contact with the heatsink).

Figure 10: Flooding of screen (left to right)



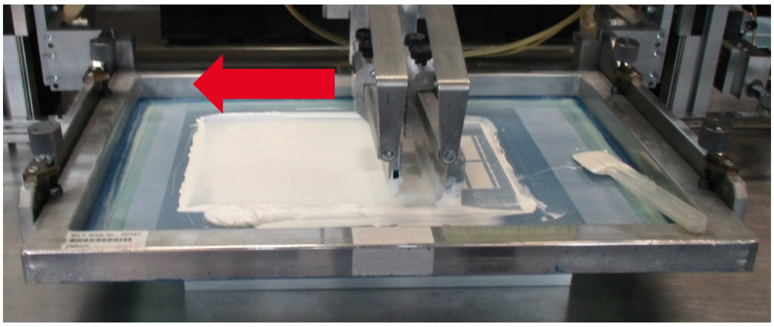
3. The screen is lowered into the final printing position (typ. 4-7mm above the heatsink surface depending on screen tension).

Figure 11: Underside of screen showing gap



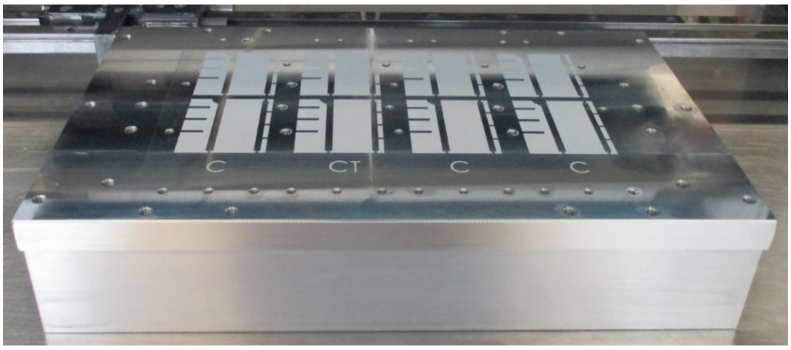
4. The scraper is drawn across the screen once with high pressure, pressing the screen onto the heatsink and depositing a layer of paste.

Figure 12: Application of paste (right to left)



5. The screen is lifted and the heatsink removed and inspected.

Figure 13: Completed paste pattern

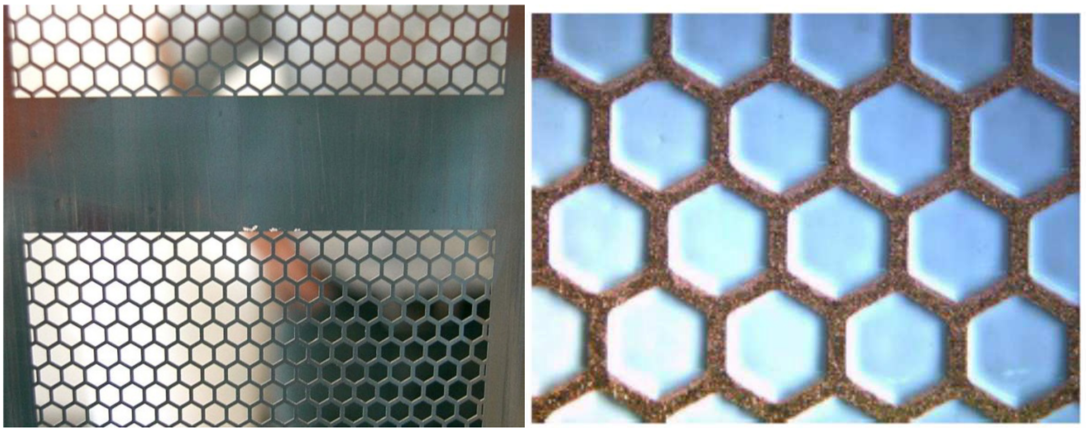


4.4 Stencil printing

The stencil method of paste application is very similar to the screen printing method; however, the fabric screen is replaced with a steel stencil out of which a pattern has been cut (Figure 14). A scraper is used to press the paste into the stencil features, and the use of a pattern ensures that the scraper is parallel to the heatsink at all points. The pattern remains on the surface until the module has been pressed down and temperature cycled, at which point the paste flows to fill voids. The shape, size, and spacing of the holes along with the thickness of the stencil determine how thick the resulting paste is once the module is mounted. Therefore, it is not possible to directly measure the applied thickness of the paste prior to mounting the module. The stencil printing method gives some advantages, including:

a. Ease of design and specification of the stencil for individuals not familiar with the screen printing industry.
b. Allowance for the use of complex thermal paste distributions optimized for chip location and baseplate curvature (typically only performed by the module manufacturer when supplying pre-applied TIM).
c. Equipment longevity as the stencil is typically more wear-resistant than a fabric screen.

Figure 14: Stainless steel stencil and resulting paste pattern on bottom of module

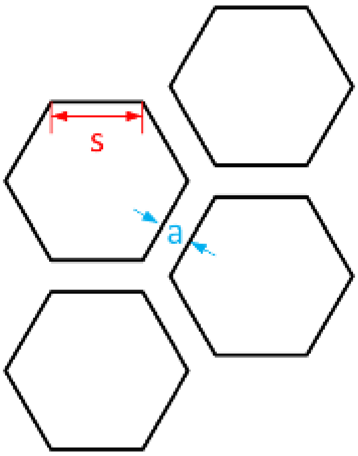


4.4.1 Stencil design

Due to its strength and solvent resistance, stainless steel is usually used for the stencil material. The pattern is cut in the steel using a laser or other process that results in a clean edge on the stencil geometry. Processes such as stamping should be avoided as they can leave a rolled edge or sharp feature that may cause the stencil not to sit flush or cause scratches in the heatsink surface.

The feature size of the stencil should be small enough that the straightness of the scraper edge does not influence the thickness of the paste (i.e. wide openings should be avoided). A honeycomb pattern is most common as it gives an even distribution and can easily be specified on a drawing using two dimensions (Figure 15).

Figure 15: Specification of honeycomb pattern



The "correct" honeycomb pattern to achieve a target past thickness varies by stencil thickness, paste type, and module size (Table 3).

Table 3: Example honeycomb parameters for MiniSKiiP modules				
Module Type	**Honeycomb Edge Length, "s" (mm)**	**Honeycomb Pitch, "a" (mm)**	**Stencil Thickness (µm)**	**Nominal Paste Thickness, Wacker P12 (µm)**
MiniSKiiP 1	0.75	0.7	75	30
MiniSKiiP 2	1.1	0.5	100	55
MiniSKiiP 3	0.85	0.55	100	40

4.4.2 Process (manual)

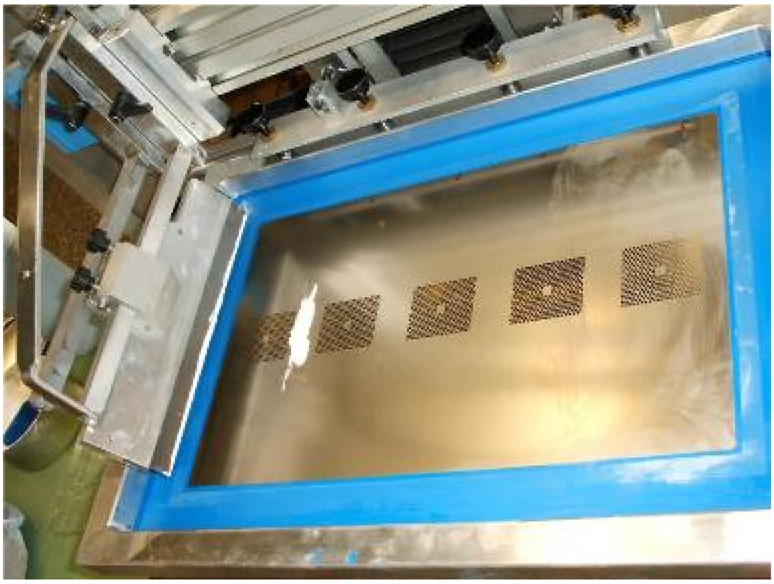
The overall stencil printing process is very similar to the screen printing process with two notable differences:

a. The stencil is placed in contact with the surface to be stenciled.
b. The pattern is printed in one pass with the scraper (no "flooding" of the stencil is required).

The general steps for stencil printing are then:

1. A cleaned heatsink is placed into position under the stencil.
2. The stencil is lowered into position, making contact with the heatsink. A line of paste is applied to one end of the stencil in front of the scrape using a spatula.
3. The scraper is drawn across the stencil once with high pressure, pressing the paste into the stencil features.
4. The stencil is lifted and the heatsink removed and inspected.

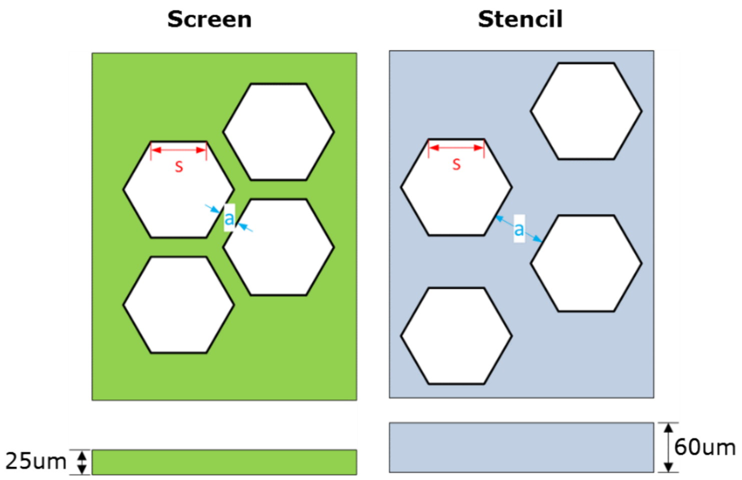
Figure 16: Line of paste deposited prior to drawing scraper across stencil



4.5 Screen vs. stencil application

The question of whether to use a stencil or screen depends on the required thickness of the paste. Metal stencils thinner than 60µm are not common so for thinner paste thicknesses a screen may be more suitable. For example, in order to reach an effective thickness of less than 20µm, the distance "a" between openings needs to be increased in order to reach the same thickness as can be achieved by a thinner screen. This increases the risk of inhomogeneous paste distribution. Figure 17 shows a hypothetical comparison where a honeycomb pattern is applied to a silkscreen and compared with the equivalent pattern on a stencil required to achieve a target thickness. As noted previously, screen printing normally does not require such a pattern.

Figure 17: Hypothetical comparison of required screen and stencil patterns to achieve the same paste thickness



In addition, when the module requires a flexible material in order to print the paste (due to mechanical design) the screen is preferred.

4.6 Screen and stencil wear

Like any other tool, both screens and stencils will wear out over time due to repeated abrasion. As part of a Statistical Process Control (SPC) in a production process, resulting paste thickness should be regularly evaluated and recorded (see Measurement). If it is noticed that the resulting paste thickness is varying or that paste patterns are no longer sharp, the screens/stencils should be examined for wear and replaced if necessary.

4.7 Rework and clean-up

Paste that has been misapplied should be removed completely prior to reapplication. Most pastes are soluble with petroleum-derived solvents (e.g. white spirits, toluene, kerosene, etc.) though the exact recommended solvents are given on the manufacturers' datasheets. However, isopropyl alcohol is commonly used as it is less toxic and leaves little residue. As it is already commonly used in the electronics industry, it is recommended for both cleaning a heatsink prior to installation as well as removing thermal paste.

Use of a lint-free, disposable rag is strongly recommended to avoid introducing any particles that may get between the module and heatsink.

For screens and stencils, automated washing machines are available. If hand cleaning is performed, care must be taken not to bend or distort the patterns. Screens/stencils are often lightly scrubbed with a solvent and cleaned with compressed air.

4.8 Storage and handling of paste

Thermal paste does have a shelf life, after which the filler and carrier materials may become so separated that they are unable to be effectively re-mixed for application. Like any other product, the shelf life is also affected by the storage conditions (e.g. temperature, humidity). Paste manufacturers should be able to provide shelf life (e.g. 5 years for a standard silicone type paste) and storage conditions (i.e. temperature and relative humidity).

Once paste has been introduced to the assembly line, contamination of the paste from foreign objects (dust, dirt, particles) becomes a concern. Therefore it is strongly recommended that a plan be instituted for changing the paste regularly (i.e. per production run or shift) and the tooling thoroughly cleaned using the recommended solvents.

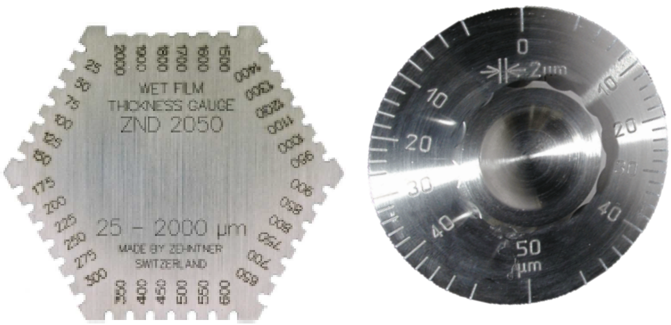
5. Measurement

The recommended thicknesses given in the Technical Explanation documents for SEMIKRON product are valid for a uniform layer of paste sitting on the module or heatsink prior to mounting.

5.1 Wet film thickness gauges

The thickness of thermal paste can be measured directly using a "wet film thickness gauge". The lowest cost, most common gauges are two handheld types: roller and comb.

Figure 18: Comb (L) and roller (R) type wet film thickness gauges



5.1.1 Comb type

The comb type gauge consists of a metal or plastic plate into which measurement tines of varying lengths have been cut. The tines are a fixed distance away from the surface of the heatsink. The gauge is placed perpendicular to the measurement surface and moved through the paste (Figure 19). The paste is at least as thick as whichever tines touch the paste.

Figure 19: Comb gauge operation (side view)

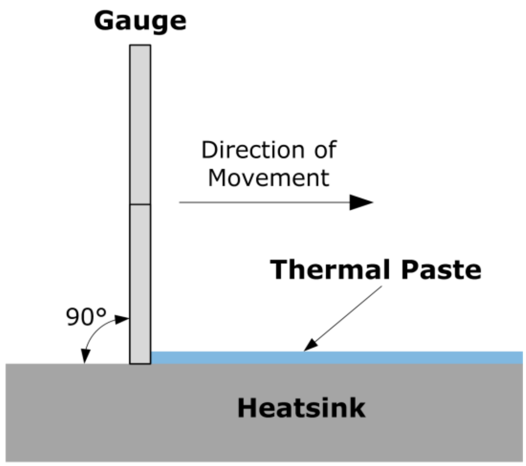
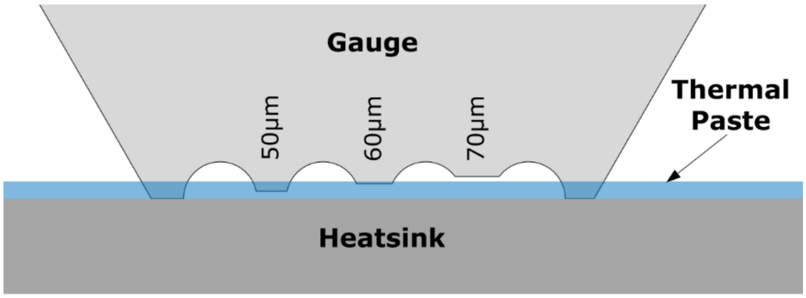


Figure 20: Example of using a comb type gauge. In this figure, the paste is somewhere between 60 and 70µm thick (assuming uniform paste thickness)



While low in cost, the comb gauge has the following disadvantages:

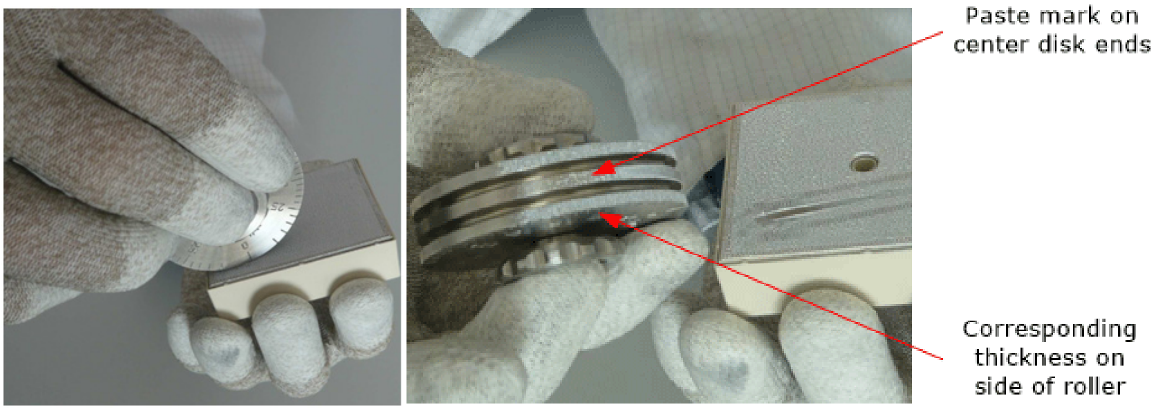
a. Comb must be kept exactly 90° (perpendicular) to the surface.
b. The paste is assumed to be of uniform thickness, therefore any high or low spots in the paste can distort the measurement.

Because of these disadvantages, it is not recommended to use the comb type gauge in applications where the paste thickness must fall within a narrow range (such as with baseplate-less modules).

5.1.2 Roller type

The roller type gauge consists of two disks of identical diameter between which an eccentric disc of gradually reducing radius has been affixed. The discs rotate about an axle that is held between thumb and forefinger. The gauge is rolled once through a uniform layer of paste and examined. The point on the center disk where the paste mark ends corresponds to the measured thickness. As with the measurement comb, non-uniformity in the paste thickness can distort the measurement. Generally, the roller gauge is still more accurate than the comb as the two outside wheels keep the measurement edge perpendicular to the measurement surface.

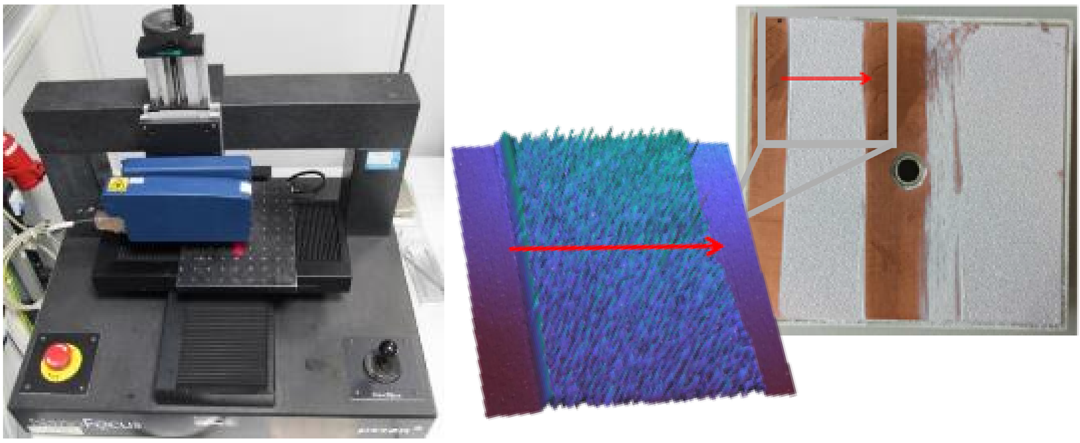
Figure 21: Using a roller gauge to measure the thickness of paste on a MiniSKiiP module



5.2 Optical inspection

Optical 3D profilometry offers the most advanced method of evaluating film thickness. Once a sample has paste applied, a portion of the paste is remove to give a reference point for the scanning machine. The sample is placed in the machine and a laser incrementally moves over the sample measuring the profile of the surface (Figure 22). The result is a detailed profile of the paste surface from which the average paste thickness can be deduced. As a time-intensive full-3D scan is required to evaluate the entire paste surface, this method is generally reserved for qualification and academic studies.

Figure 22: Benchtop profilometer system (L) and resulting scan on MiniSKiiP module (R)



5.3 Weight

In the case of a paste pattern, the effective thickness cannot be measured directly. However, measuring the weight of the paste gives an indication if the correct amount has been applied. Smaller modules are placed on a digital scale and zeroed out (Figure 23L). The paste is applied and the module re-weighed (Figure 23R). The effective thickness of the paste (assuming equal distribution) can be estimated by:

$$Effective\ Paste\ Thickness = \frac{(Weight\ of\ paste)}{(Density\ of\ paste)\cdot(Printed\ Area)}$$

Figure 23: Measurement of module weight before (L) and after (R) paste application

6. Evaluation

6.1 Checking for cracked substrates

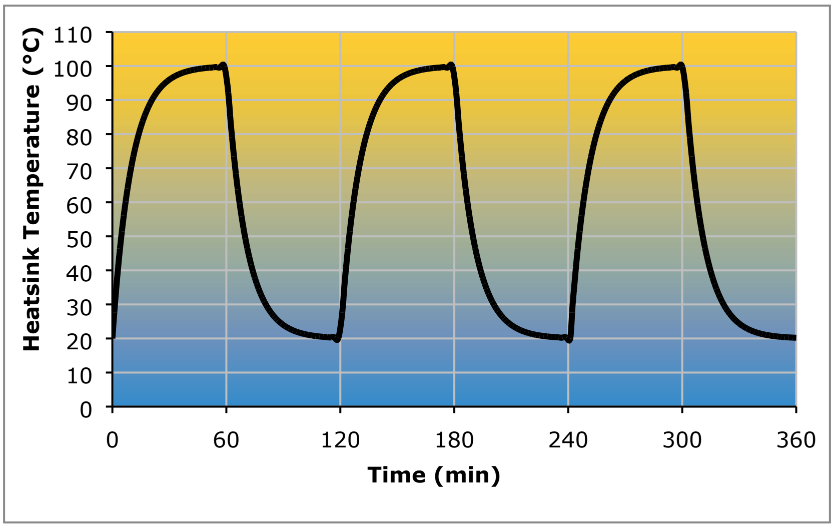
For modules sensitive to improper mounting, the voltage withstand test is used to determine whether the ceramic in the Direct Bonded Copper (DBC) substrate was cracked as the result of too much paste (or other issues in mounting process). By applying high voltage between the power terminals and the heatsink, it can be determined whether small cracks have formed that would allow current to flow from the top side of the DBC substrate to the heatsink. This high voltage test is usually required as part of production tests for products adhering to an agency standard (e.g. UL). Refer to the "routine test" described in [5].

6.2 Thermal cycling

Thermal paste does not reach its optimum distribution (and hence performance) immediately after mounting. Heating and cooling cause expansion and contraction in the heatsink and baseplate metals that result in migration of the paste beneath the module. Therefore, once a module has been mounted it must be thermally cycled before checking the paste distribution and thermal performance.

Thermal cycling involves raising the heatsink temperature from room temperature (~20°C) to approximately 100°C and back to room temperature three times. Heating/cooling time is typically one hour to allow the system time to come to thermal equilibrium.

Figure 24: Heatsink temperature profile for thermal cycling (3 cycles)



6.3 R_{th} measurement

As implied by Figure 3, the most direct evaluation of the effectiveness of a thermal paste is its contribution to thermal resistance. On a module with a baseplate, this can involve a standard module on a prepared heatsink where the case (baseplate) temperature can be measured along with the appropriate reference point on the heatsink. For a known power dissipation, the $R_{th(c-s)}$ / $R_{th(j-s)}$ can then be calculated and compared with simulated results or between various pastes.

In the case of a baseplate-less module, this becomes more involved as a reference point inside the module (junction or thermistor) must be known. This involves a module equipped with a thermistor and a known R_{th} from the sensor to a reference point, or a specially prepared module with thermocouples on the chips or access for an infrared camera (e.g. FLIR). The appropriate reference points for both module types are described in [4].

6.4 Visual inspection

After a module has been thermally cycled, the module can be removed to check for proper distribution of paste. As opposed to the situation where the module needs to be re-used or electrically evaluated, in this case it is allowed to pry the module straight up in order to preserve the paste pattern. For this process, a sharp plastic spatula is recommended. The spatula is inserted just slightly under the edge of the module and a small amount of force applied. Time must be taken to allow the surface tension of the grease to break, at which point the spatula can be twisted to lift the module straight up off the surface of the heatsink.

Proper distribution is indicated by an even paste color in the main field of the module and the absence of any voids (Figure 25L). Paste near mounting holes or around module edges is usually thinner. Improper distribution yields voids or distinctive patterns with higher concentrations of paste (Figure 25R). Excess paste may also be present around the edge of the module or squeezed into mounting holes. For additional photos of acceptable and non-acceptable paste patterns, please refer to [3].

Figure 25: Correct distribution of paste (L) and too much paste (R)

7. Lifetime

7.1 Pump-out

The same heating and cooling that causes paste to settle can also result in a pumping action that forces the thermal paste out from beneath the module. Temperature-induced expansion of the baseplate metal results in an up/down motion (simplified diagram shown in Figure 26). The effect is more prominent in modules with baseplates as the movement of the baseplate is larger during temperature cycles than in modules without a baseplate. It is also mainly associated with high load cycles of long enough duration that the baseplate heats and cools with a significant change in temperature (ΔT).

Figure 26: Exaggerated diagram of thermally induced baseplate movement causing pump-out

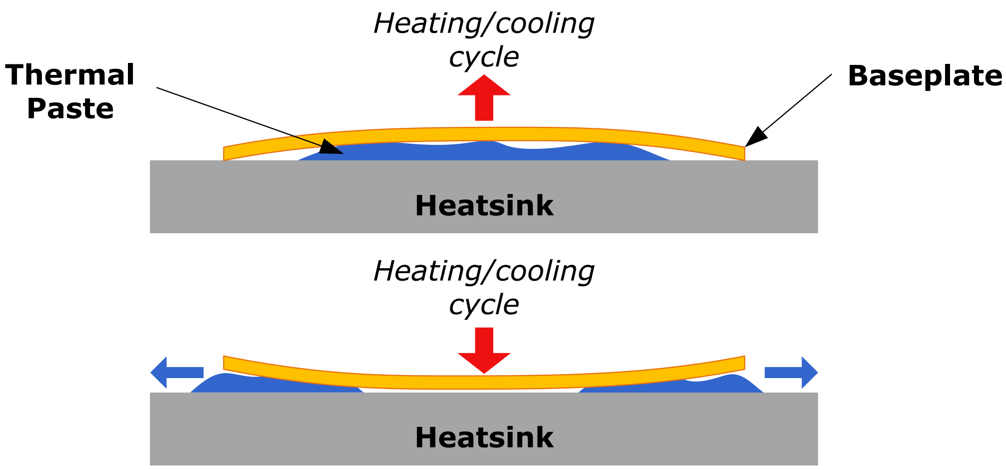


Figure 27: Mounting position of SEMITRANS module showing signs of pump-out after repeated thermal cycling

Related to pump-out is a phenomenon where the carrier and filler material in a paste separate. Within the paste, the individual filler particles are encased in a coating material that allows them to stay bound to the carrier oil. High heat and humidity can break down this coating and allow the filler and carrier to separate. The pump-out process described above then causes the filler to migrate. In Figure 28, the sheen on the underside of the module is the silicone oil carrier left on the bottom of the module after the filler has separated and moved to the outside of the module. Certain paste compositions seem more susceptible to this effect than others are; long-term power-cycling testing is the only way to evaluate performance.

Figure 28: Underside of SEMITRANS module showing separation of carrier oil and filler after high temperature operation in the field

7.2 Heatsink discoloration

The repeated mechanical motion resulting from thermal cycling also causes rubbing of the metal-to-metal contact points between heatsink and module. In the case of an aluminum heatsink, this very often results in the formation of black marks or particles with the color of soot. Figure 29 shows the formation of such marks around the four corner mounting holes of a SEMITRANS module. These locations are where the metal-to-metal contact is strongest due to the mounting force of the screws. While not inherently bad, the presence of such marks may indicate heavy thermal cycling.

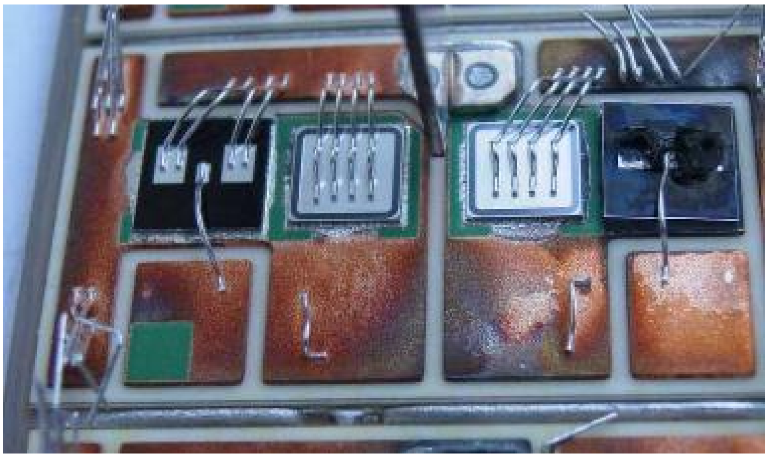
Figure 29: Black marks on heatsink resulting from heavy thermal cycling

8. Failure Modes

8.1 Heating

If the thermal interface material is misapplied, the most common symptom outside of outright mechanical damage is that the module overheats. Modules with built in temperature sensors may be able to warn of this during operation, but oftentimes it is not until a semiconductor chip has failed that the signs of heating are seen. Once a failed module has been disassembled, prolonged overheating can be seen in the form of discolored copper (Figure 30) and even solder that has partially melted and solidified ("reflowed").

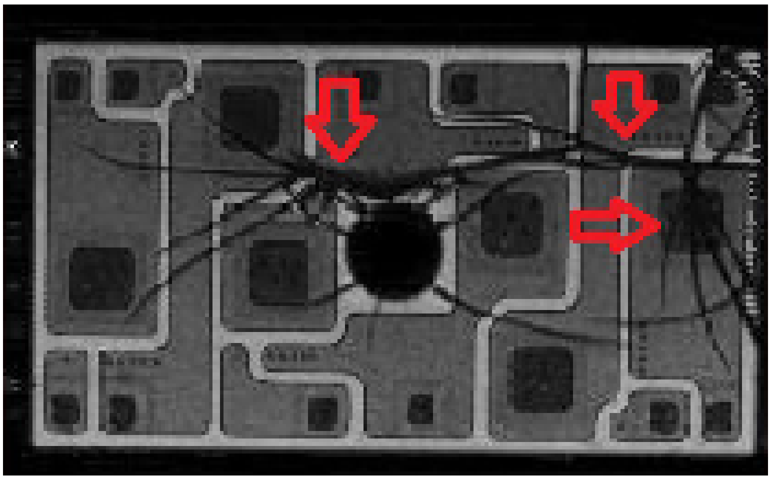
Figure 30: Discoloration of copper on DBC substrate due to prolonged overheating



8.2 Cracking of ceramic substrate

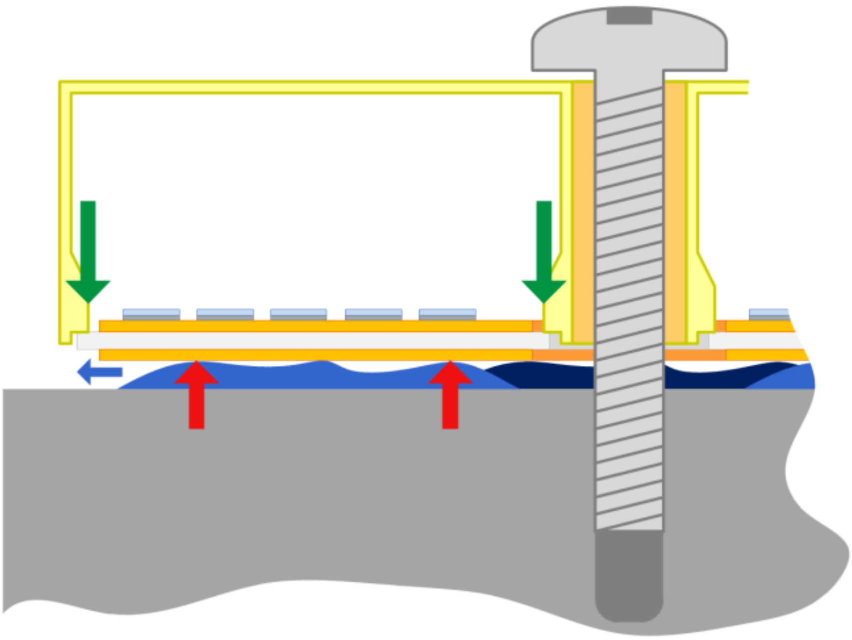
In addition to impeding thermal performance, too much paste can also cause physical damage to power modules. The force required to "squeeze out" the paste is often greater than the proper mounting force for which the module was designed. Figure 31 shows the result of too much thermal paste applied to the heatsink prior to module mounting. Excess paste, if not able to escape from underneath the module, can build up tremendous pressure since it is relatively incompressible. The same is true of air pockets that might form in thick, poorly distributed paste.

Figure 31: Scanning Acoustic Microscopy (SAM) image of SEMITOP 3 module showing cracks in ceramic substrate resulting from excessive thermal paste and unregulated screwing process.



The viscosity of the paste, coupled with the speed of module as it is screwed down, influences how much stress is placed on the module substrate. A thick paste (poorly mixed or with high filler content) will not move under compression as quickly as a paste with lower viscosity. Therefore, care should be taken when considering supposed "high performance" pastes with high filler content. Additionally, the rules for automatic screwdriver speed (given in the module Mounting Instructions) should be followed. Higher screwdriver speeds reduce the time that the paste is allowed to flow, increasing stresses in the module (Figure 32).

Figure 32: Stress points (red arrows) in a baseplate-less module resulting from too thick/too viscous paste



Symbols and Terms

Letter Symbol	Term
λ	Thermal conductivity
$R_{th(x-y)}$	Thermal resistance, measured from point x to point y

A detailed explanation of the terms and symbols can be found in the "Application Manual Power Semiconductors" [2]

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IMPORTANT INFORMATION AND WARNINGS

SEMIKRON INTERNATIONAL GmbH
Sigmundstrasse 200, 90431 Nuremberg, Germany
Tel: +49 911 6559 6663, Fax: +49 911 6559 262
sales@semikron.com, www.semikron.com