Power Modules

How to avoid errors when applying thermal paste

The power electronics sector is continually striving to boost the reliability of power modules. The main focus of research work in this sector is on semiconductor chips, packaging technology and the DBC substrate. The weak point of heat-sink-mounted power modules, however, is the "gap" between the module and the heat sink which results from unevenness on the contact surfaces and which has to be filled with a thermal conductive medium in order to get rid of the air pockets.

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We are working on closing this "gap" on two levels. Firstly, by offering a professional thermal paste application service – Pre-applied Thermal Paste for Power Modules – a service that has already proven rather successful, with over 700,000 power modules having been printed with a thermal paste layer. In addition, Semikron is developing its know-how and expertise in the area of thermal conductive media application and function.

Designated use of thermal conductive media

Thermal conductive media normally consist of a plastic carrier material (e.g. silicon oil) and thermal conductive filler substances such as zinc oxide, graphite or silver. They are available in the form of pastes, adhesives, phase-change materials and foils. Thermal interface materials conduct heat better than air and typically have a specific thermal conductivity (Lambda) of 0.5 - 6 W/m·K. In other words, the thermal conductivity of thermal interface materials is approximately 20 - 200 times better than that of air. To enable the thermal conductivity properties of thermal interface materials to be categorised, Table 1 shows the specific thermal conductivity of materials commonly used in power modules. The thermal paste P12 from the company Wacker has been taken by way of example. The thermal resistance values R(th) shown are based on the module-specific thermal spreading.

If the thermal conductivity of thermal paste is compared with the thermal conductivity of other components in a power module (see Table 1), the thermal paste does not rate particularly well. The extent to which thermal paste contributes to the overall thermal resistance R(thjs) of the module amounts to around 20-65%, depending on the module and the combination with the heat sink. The thermal paste layer therefore has to be as thin as possible but as thick as necessary (see Figure 1).

Material	Spec. thermal conductivity Lambda	Thickness [µm]	Portion R(th) of SKiM modules
Chip	106	120	2,92%
Chip solder	57	70	3,65%
DCB (Copper)	394	300	1,94%
DCB (Al2O3)	24	380	32,91%
DCB (Copper)	394	300	1,31%
Thermal paste (P12 from WACKER)	0,81	30	57,26%

Table 1: Specific thermal conductivity of materials commonly used in a power semiconductor module

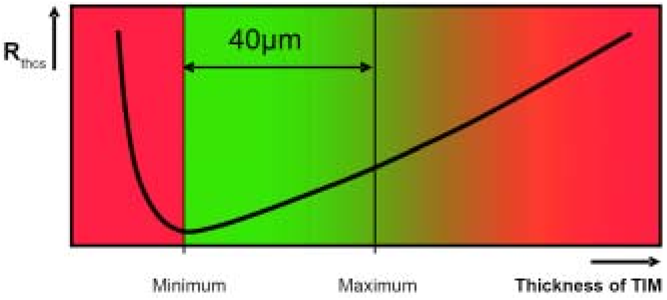


Figure 1: Dependence of thermal resistance on thermal interface material layer thickness

Too thin a thermal paste layer results in air pockets between the underside of the module and the top of the heat sink, causing a high thermal resistance Rth(cs). Once the optimum has been reached, the thermal resistance between the case and the heat sink increases quickly again in line with the increase in thermal paste layer thickness. This happens because the specific thermal conductivity of thermal conductive media is very low compared with other materials in a power semiconductor module. The minimum value is different for every heat-sink-mounted module and has to be defined in appropriate tests.

The importance of thermal paste composition

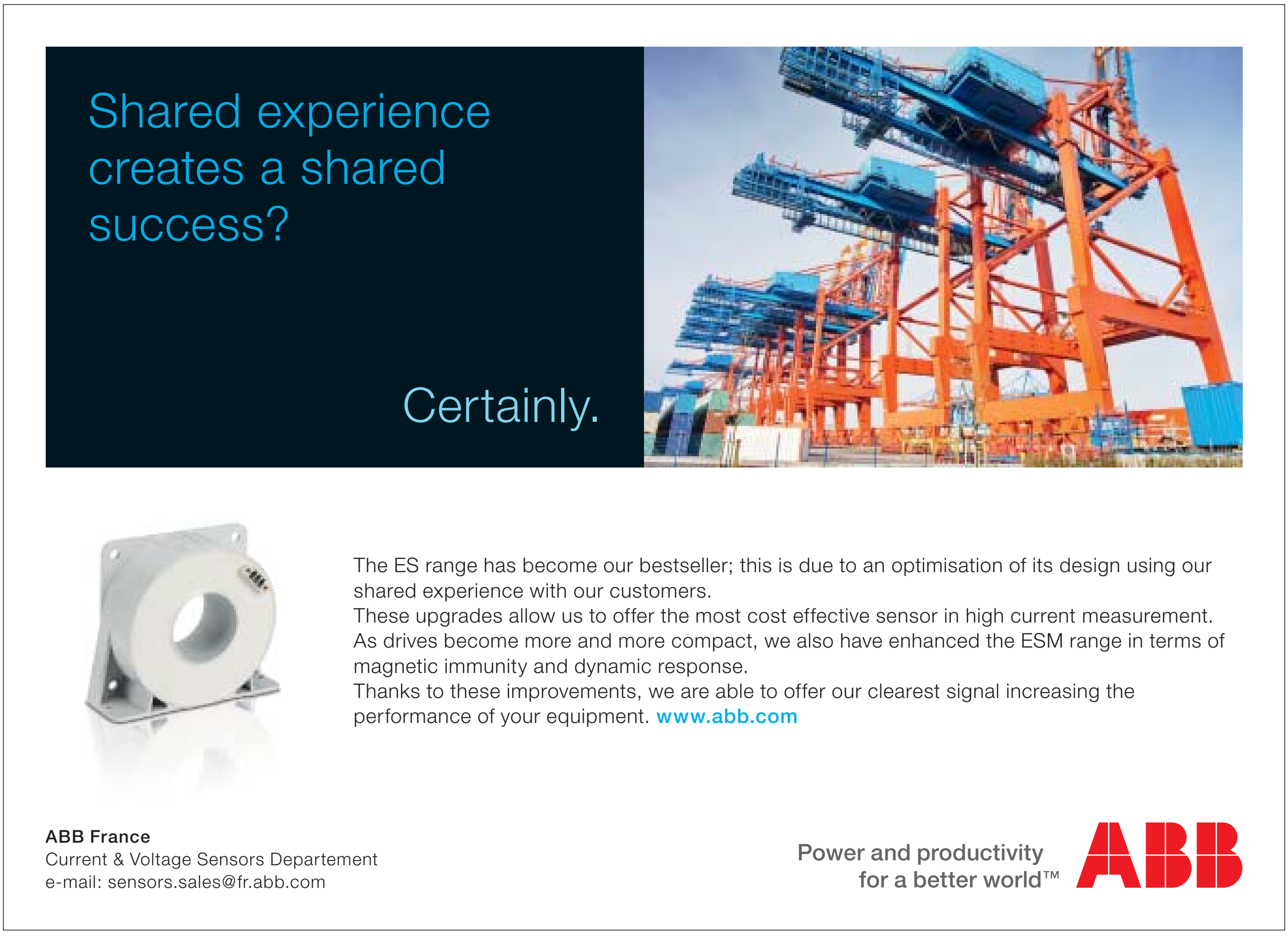
R(th) tests have shown that the thermal conductivity of a thermal paste in actual application does not only depend on its specific thermal conductivity, but also on it its composition. The larger the filler particles in a thermal paste are, the higher the specific thermal conductivity. The particle size of the filler determines the minimum layer thickness. In other words, the thermal paste layer applied cannot be thinner than the largest particles in the paste. After several temperature cycles, a paste with small particles (e.g. P12: particle size 0.04µm - 4µm) allows almost for metal-to-metal contact at points where the pressure is particularly high, resulting in a substantial reduction in R(thcs).

Thermal paste application

Thermal paste can be applied either to the module or to the heat sink. This is done using a roller or in printing processes. In roller application, a rubber roller is normally used, while the most common printing method used is silk screen printing or stencil printing.

Applying thermal paste with a rubber roller can lead to sufficient results, provided this critical step is performed by experienced professional staff with relevant training. This process does, however, have shortcomings such as inhomogeneity, poor reproducibility and the risk of contamination.

In stencil and screen printing, far better results can be achieved than with the roller process, provided automatic printing methods are employed. Manual printing, for its part, can lead to considerable process deviations. The development of a process with an automatic stencil printer featuring continuous process monitoring, as is the case



at SEMIKRON, requires substantial investments, however, which in economic terms only makes sense for large production quantities.

In addition to complying with recommended layer thickness, care should be taken when applying the thermal paste to ensure that the thermal paste layer is spread on the underside of the module or the heat sink surface evenly and homogenously. An inhomogeneous thermal paste layer (extreme case: application of one or more thermal paste blots) can result in DBC ceramic substrate breakage (Figure 2). This applies to modules with and without a base plate alike. In addition to this, thermal paste inhomogeneity can also lead to local overheating resulting from the air pockets between the underside of the module and the upper side of the heat sink surface.

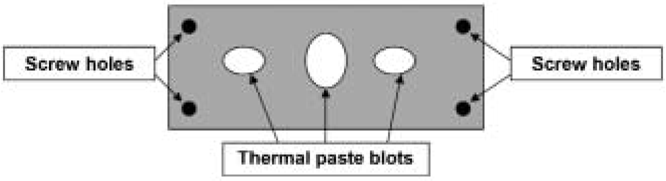


Figure 2: Module underside showing problematic thermal paste layer application

Measuring the thickness of thermal paste layer
The thickness of a thermal paste layer can be measured directly or indirectly. An indirect way of measuring the thickness is, for example, to weigh the thermal paste by performing a Tara weight measurement using suitable scales. An example of a direct contact-free measurement of the thermal paste layer is a measurement using an optical profilometer such as the µSCAN from Nano Focus. Other measurement equipment that could be used to measure the thermal paste layer directly includes, for example, thickness gauges such as wet film combs (e.g. from Zehntner (ZND 2051) or Elcometer Instruments or BYK Gardner (PG-3504)) or wet film wheels (e.g. from Zehntner (ZWW 2100-2102) or BYK Gardner). The downside of these, however, is that they may cause damage to the layer in places.

Determining the optimum thickness for thermal paste layer
The optimum minimum thickness for a specific thermal paste in combination with a specific heat sink surface can be determined in a defined process which starts at a minimum thickness of around 10µm and is increased in 10µm steps (another option would be to alternate the steps). Here, the thermal paste is applied to the module or the heat sink or to an aluminium plate in accordance with the specifications of the module manufacturer. When tightening the mounting screws, the tightening torques specified by the module manufacturer must be observed. To achieve a relaxed system state the mounted and secured module should undergo three thermal cycles (20°C/100°C/1h).

After thermal cycling, a module with no base plate can not be easily removed without causing destruction, since the module is pressed onto the heat sink/aluminium plate and the sticky thermal paste is distributed in the space between, producing an enormous adhesive force. To ensure non-destructive removal, the module should therefore be left untouched at room temperature for 12 hours after the screw has been loosened or should undergo 1-2 thermal cycles.

Once the module has been unscrewed, the imprint pattern on the underside of the module gives an indication of whether the thermal paste layer provides optimum contact between module and heat sink. Figure 3 (left) shows the underside of a power module containing large areas with untouched thermal paste. This indicates that the thermal paste layer is in fact too thin (approx. 30µm). By way of comparison, Figure 3 (right) shows the underside of a module that is covered entirely with thermal paste, with the exception of certain high-pressure points where metal-to-metal contact is achieved. This is indicative of optimum thermal paste application (approx. 50µm).

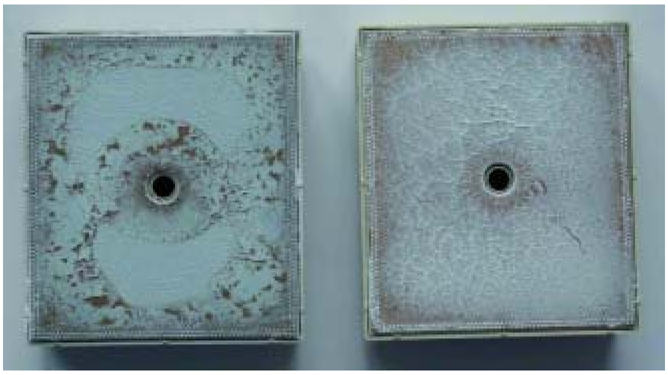


Figure 3: Module showing poor (left) and optimum (right) thermal paste application

By optimising the thermal paste layer thickness for the individual heat-sink-mounted module and using automated application processes to guarantee quality standards, the shortcomings of thermal conductive media can be compensated for to a certain extent. The problem with the “gap” that emerges between the power module and the heat sink, however, still bears the biggest potential for improvement.

Thermal paste application service
The thermal paste application service provided by Semikron simplifies the module assembly onto the heat sink. Customers no longer have to include this production step and can therefore reduce costs. The production staff’s gloves are not at risk of contamination from the thermal paste and the thermal paste cannot accidentally find its way into production. The optimised module-specific thermal paste layer thickness reduces the overall thermal resistance and the risk of DBC breakage. The thermal paste is applied in an automated printing process, and the module-specific thermal paste layer boasts an accuracy of +/-10 µm. The application process is monitored using SixSigma quality control methods. The modules with thermal paste layer are transported to the customer in purpose-developed, patent-protected packaging that ensures contact-free transportation of finished modules containing a thermal paste layer. Modules containing a thermal paste layer can be stored in this packaging for up to 18 months. The thermal paste application service is available for SKiM 63 and 93, SEMIPACK 2, SEMITRANS 2, and MiniSKiiP modules.

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