Thermal Interface – An Inconvenient Truth

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Increasing the power density along with extended life-time expectation is an omnipresent demand in inverter designs. While chip manufacturers strive to increase the current carrying capabilities of silicon, inverter designers try to reduce the physical volume of the drive. Reduction of the heatsink's volume in combination with increased local power densities leads to higher demands on the thermal interface connecting power electronic components to the heat sink.

The Truth about Datasheet Values

Thermal interface materials (TIM) are used to improve the conduction of heat from a power semiconductor to the heat sink. It is expected that a higher conductivity leads to a better thermal transfer. In power electronic designs, however, this is a misleading conclusion. A paste-like TIM-layer below a module never shows a homogenous thickness. Below the power semiconductor an area with metal to metal contact should remain because the largest portion of heat flows through this area. The TIM's datasheet values describing the conductivity are given for a homogenous layer but solid sheets that provide homogenous thicknesses prevent the metal to metal contact thus eliminating the best portion of the heat transfer path. Additionally, the conductivity of the interface is not a constant parameter. It degrades over time if the material desiccates or separates caused e.g. by capillary effects on surfaces or as a consequence of thermo-mechanical movement.
Figure 1 shows a picture of a tested material applied to a heat sink's surface. In a matter of days the liquid components spread from initially 144mm² to about 850mm² due to capillary effect.

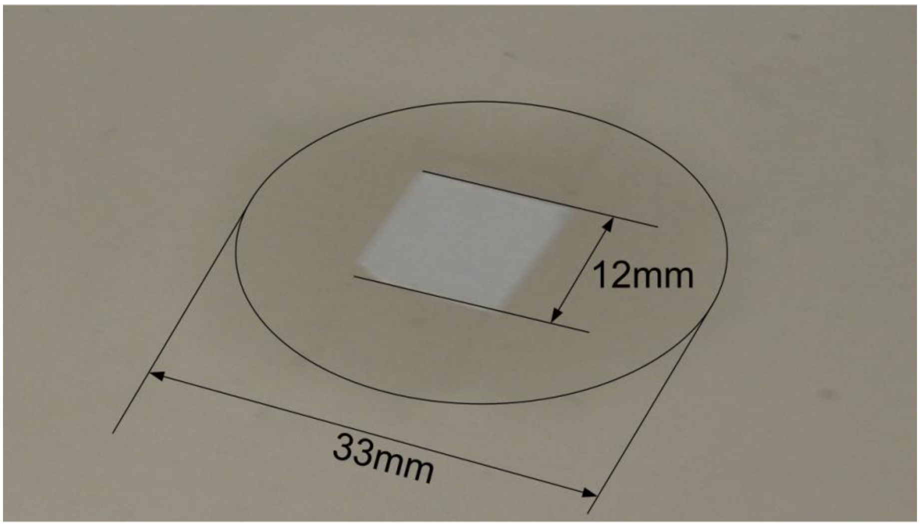

Figure 1: Desiccation and separation of TIM due to capillary effect

Any material used as a thermal interface has to be closely examined regarding the complex interrelations that are often underestimated or even neglected. The datasheet value "Thermal Conductivity" is an indication but not hard evidence.
In combination with good thermal conductivity, the material has to fulfill further requirements. Besides the demand of not being silicone-based, the material has to conform to RoHS and should be easy to apply in production and easy to remove in case of maintenance or replacement. A good adhesive property together with small particle sizes regarding the thermally active materials is mandatory. Ideally, the material should be electrically non-conductive.
The material's reliability over the lifetime of a design can only be validated in long-term experiments. Infineon has done extensive tests of different materials to find a recommendable solution.
Figure 2 depicts the measured results from a power-cycling test that was conducted over a period of eight months.

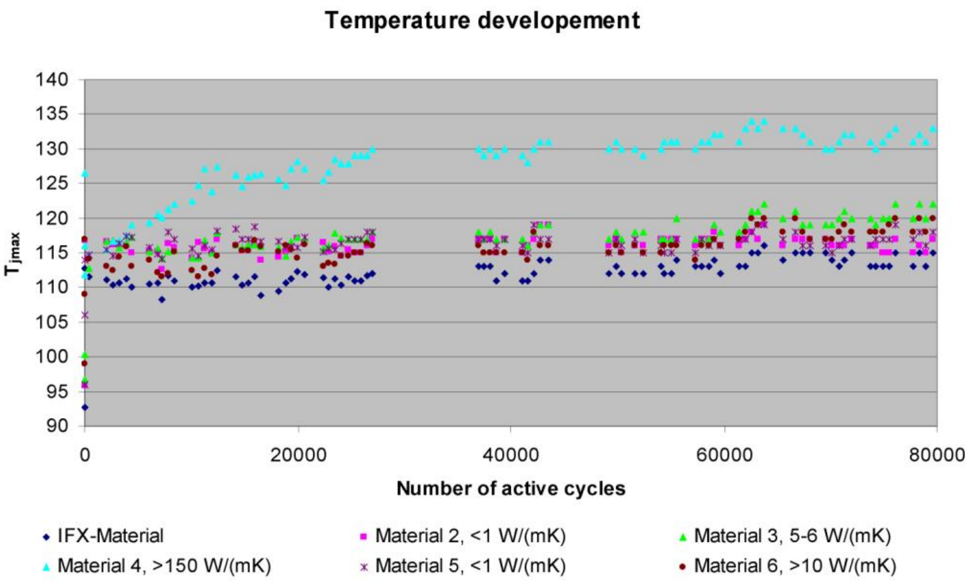

Figure 2: Chip-temperature development during Power-cycling Test,
DUT: FF450R12ME4 @ 180A; T_{on}=1 min, T_{off}=2 min, 80.000 Cycles done

Six modules with TIM applied were mounted to heat sinks and active heating cycles were done under identical conditions. Figure 2 shows a noteworthy difference regarding the temperature development caused by the different TIMs in use. It can also be concluded that there is no obvious correlation between the thermal conductivity stated in the datasheets and the temperature development inside the power electronic module.

The Truth about Imprints
It is a common habit to apply TIM to a module, mount the module to a heat sink and disassemble the setup after a certain time or a certain number of thermal stress cycles to determine the quality of the thermal interface. As an example Figure 3 shows the result of a test done this way:

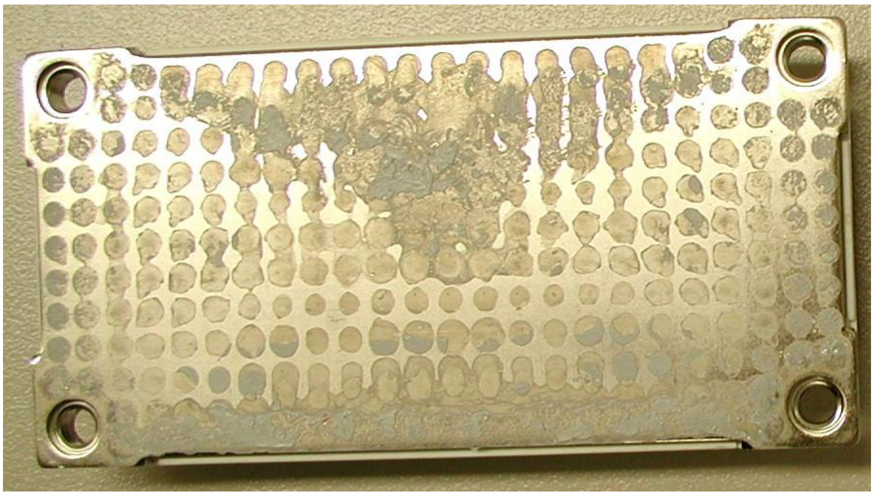

Figure 3: Imprint of TIM showing almost no spreading

From the optical inspection the conclusion was simple: This particular material was obviously insufficient as it did not spread to cover the whole baseplate of the module. In spite of this impression, actual measurement of the junction temperature during the active cycling revealed an excellent thermal connection. This observation led to the conclusion, that interpreting imprints is of very low significance regarding thermal aspects. It only allows a statement towards the mechanical spreading of TIM.
An alternative often used is to mount the module to a glass plate and watch the TIM spreading. As a glass plate does not allow thermal stress, the results gathered here are just as misleading.
The limiting factors in power electronic designs are junction temperature along with temperature swing. The only trustworthy information is gathered by observing the chip's temperature during operation. This can be achieved by K-type thermo elements mounted to the chips surface. Due to a temperature gradient across the chip, however, this does not necessarily give the highest temperature. Using a thermographic camera allows an exact determination of the highest chip temperature in a given area. This can be seen from Figure 4.

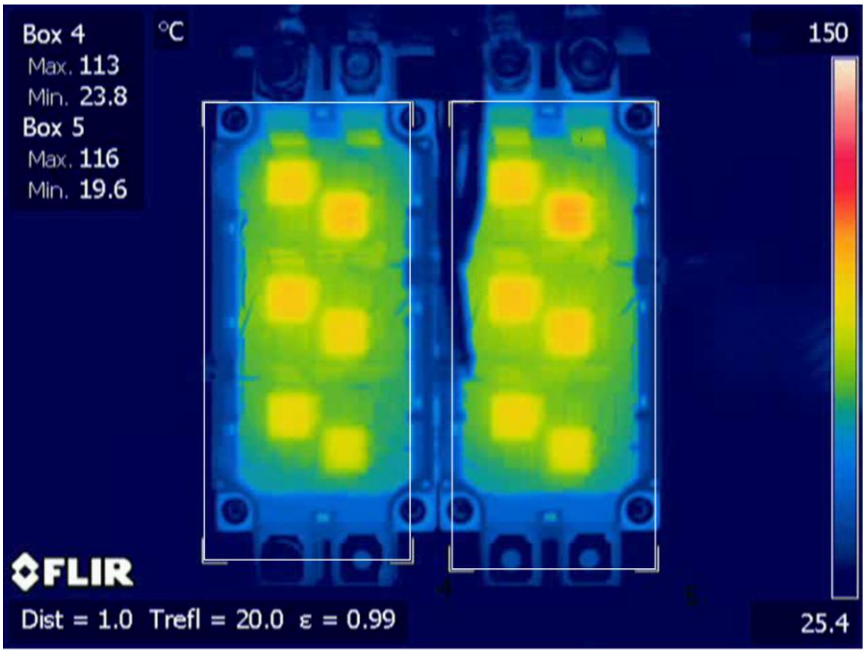

Figure 4: Thermographic analysis of the junction temperature

The truth about mounting
Applying thermal grease often is considered a simple process. Just apply some TIM to a module and tighten the screws. The module will close the gaps mechanically and presses out the material that is not needed so the rest can form the thermal interface. This often heard statement is far from being true. "The more, the better" may apply for a lot of things but definitely not for thermal grease. Care has to be taken to apply the correct amount of grease to the place where it is needed. Even with the same material in use, large differences regarding the thermal properties can occur depending on the process of application. The preferred way to apply thermal grease is an automated stencil printing as it constitutes a procedure that can closely be monitored and reproduced. Adapting the stencil's geometry allows to fine tune it to a given module family. This way, amount and alignment of the thermally active component are defined by the stencil printing process.

Some Facts about Phase Change Materials (PCM)
Phase change materials have been around for quite some time but have not, for good reasons widely penetrated the power electronic market. PCM-Foils, for the reasons explained earlier, have proven not to form the perfect thermal interface. Most PCM loose in volume when going to the liquid state. If additionally material from foils gets pressed out from below the modules during the first heat up, re-torqueing of the screws holding the power module needs to be done. Both, burn in and re-torquing are processes highly unwanted in assembly lines.
Still PCM holds some advantages but only if not applied as a solid sheet. If properly applied to the module, PCM can be designed to be mechanically more robust than usual greases achieving convenient methods for transport and handling. Choosing highly conductive filler materials results in excellent thermal conductivity. The grain size can be reduced to achieve large contact areas and the thinnest possible layers between module and heat sink. A special PCM was designed according to IFX specification to overcome the disadvantages known from common materials. It is applied to the module in similar ways as usual grease but offered to the customer as a solid, ready to mount TIM as shown in figure 5.

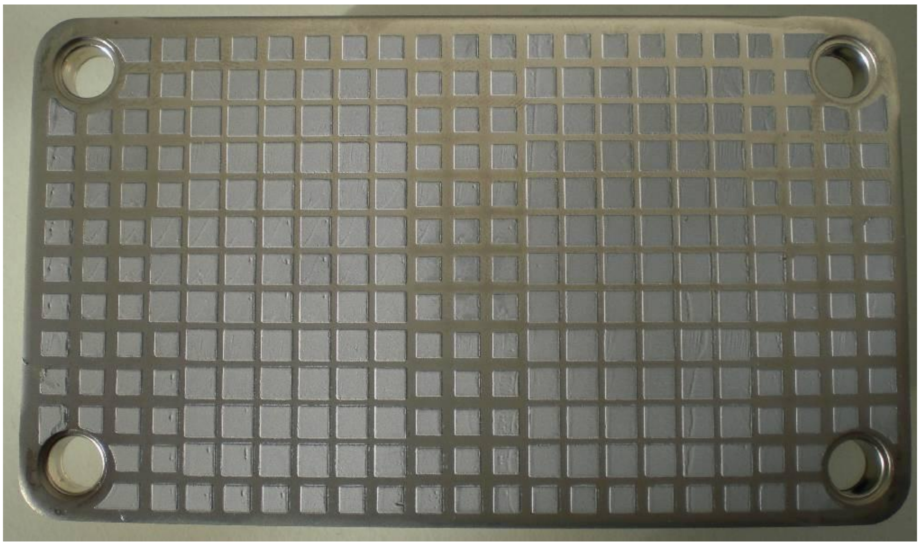

Figure 5: An Infineon 62mm-Module with PCM-based TIM ready to use

In addition to the excellent thermal and mechanical properties, the material does not suffer from drying effects and is resistant to capillary influences. Either is mandatory to achieve the desired long term stability.

Future Prospect
During the process of finding a recommendable material to build an adequate thermal interface for power electronic modules it became obvious that simply having access to a qualified material is necessary but not sufficient. The process of applying the material and the control of the process itself are sources of negative influences that can only be avoided if TIM and module are considered as a combined unit. To support thermal design Infineon offers stencil geometries for all IGBT modules. Furthermore, Infineon is currently evaluating methods to offer power electronic modules that feature a base plate with thermal interface material applied.