The Thermal Challenge

Benefits of thermal interface materials (TIM) especially dedicated to power electronics

The enhancements of semiconductors throughout the last decades targeted the improvement of reliability, the increase of efficiency, electrical and mechanical robustness as well as economic aspects. Most of the efforts done by semiconductor manufacturers concentrate on fine-tuning the silicon's abilities along with optimization of interconnection technologies. Recently, more work was done to the interconnection between power module and heat think as with the ongoing increase of power densities the thermal interface becomes a larger challenge.

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Power Density vs. Power Density

Computer processors today can be seen as an application with high power densities. A modern CPU can consume as much as 130W of power on an area of 263mm² representing a rectangle of 16mm in width [1] and a power density of about 0.5W/mm². Thermal grease is needed here too to get good thermal connections between the processor core and the heat sink attached. The vast amount of processors sold is the reason for grease manufacturers to tune grease for this application, especially as processors and larger discrete packages have similar footprint sizes. It is often concluded, that grease works under the condition described by thermal swing regardless of the application. However, the demands in power electronic differ from those in personal computer, notebooks or mobile phones, demanding a dedicated solution.
A brief comparison hints out some of the main discrepancies:

	CPU	PowerElectronic Application
Chip Area [mm²]	263	190
Power Density [W/cm²]	50	100-200
Force applied to heat sink	Several Newton	Several kilo Newton
Thermal Cycling demand	None	Large
Expected Power Cycles	None	>100.000
Expected Lifetime [Years]	<5	10-30
Cost of replacement [US$]	<200	10^3 to 10^6
Ambient Temperature [°C]	20-40	-50 to 65
Case Temperature [°C]	<75	85 to 110

Due to these differences, the thermal interface is far more crucial in power electronics than in any other application. It would be short-sighted to conclude that general purpose materials that perform well on a CPU perform equally well in power electronics as both thermal stress and long term issues cannot be compared. Additionally, thermo-mechanical stress applied to thermal grease becomes a topic in power modules and needs to be examined closely to achieve a thermal interface that features excellent thermal transfer in conjunction with the long-term stability demanded.

Thermal Transfer Capabilities

From technical point of view, the thermal resistance or thermal conductivity of a material defines its thermal transfer characteristics. In detail, this is only true if single materials are observed that are considered to be homogenous. Datasheets of thermal interface materials often include values for the so-called bulk resistance. If experimentally investigated, it turns out that in power electronics there is no relation between measured junction temperature of a chip and the thermal conductivity of the TIM in use. The bars in Figure 1 correlate different TIM to the junction temperature achieved, emphasizing the lack of dependency between the datasheet value for thermal conductivity and the thermal results of the experiment.

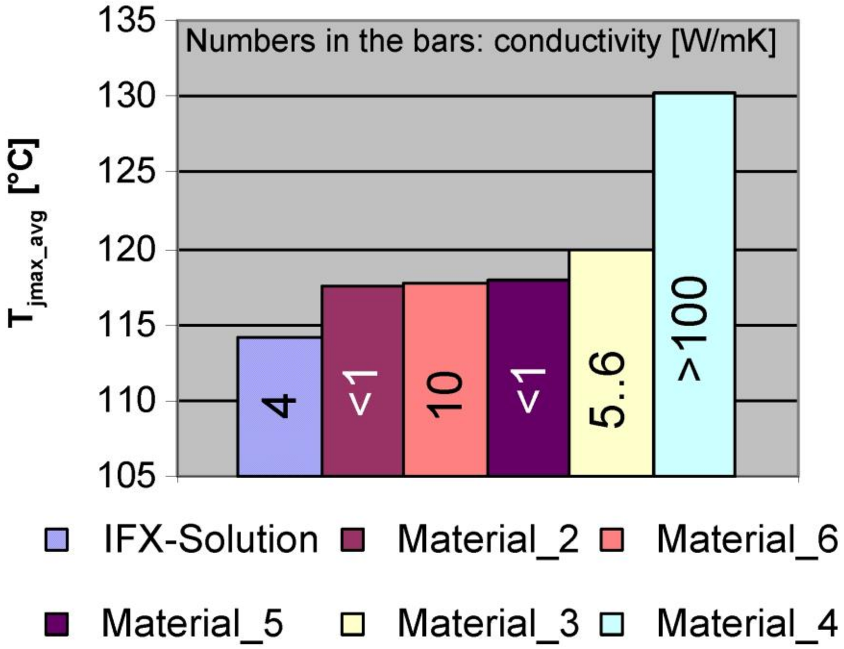

Figure 1: Measured Junction temperatures with different TIM in use; averaged values from a 100k cycle test

The diagram substantiates that this datasheet value is insufficient to compare different products. Particle sizes, particle size distribution and the abilities to wetting surfaces along with forming thinnest possible bond lines are more important, yet partially difficult to quantize in numbers. For an evaluation, extended tests become unavoidable [2].

The most accurate insight into the thermal capabilities can be gained by thermographic imaging as depicted in Figure 2.

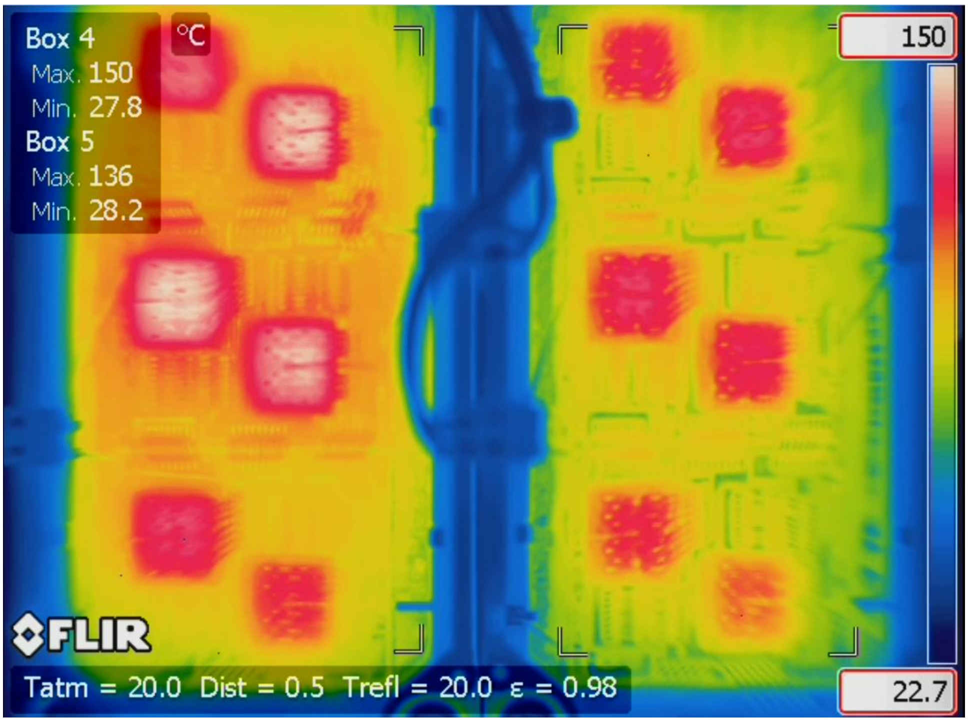

Figure 2: Difference between a common thermal solution to the left and Infineon's TIM dedicated to power electronics to the right, DUT: FF450R12ME4

The picture was taken in a test setup with two modules connected in series. Both were mounted onto a common heat sink carrying the identical current. It can clearly be seen that a solution, especially developed for this application outperforms a standard approach. The thermal situation not only improves for the chips inside. Higher temperatures in the power module also lead to increased stress for the components surrounding the power module [3].

Longevity

As the expected lifetime in power electronics easily exceeds 10 or even 20 years, the thermal interface has to stay intact and operational for the same period. For power modules,

one of the well established reliability tests is High Temperature Storing (HTS) where the module is exposed to 125°C dry heat for 1000 hours.
This test was done for TIM with setups consisting of modules mounted to heat sinks using different thermal solutions. Chip temperatures under given conditions were measured before this test, the measurement was repeated once a week, every 168hours respectively. Six weeks resemble the 1000h test with the results summarized in Figure 3.

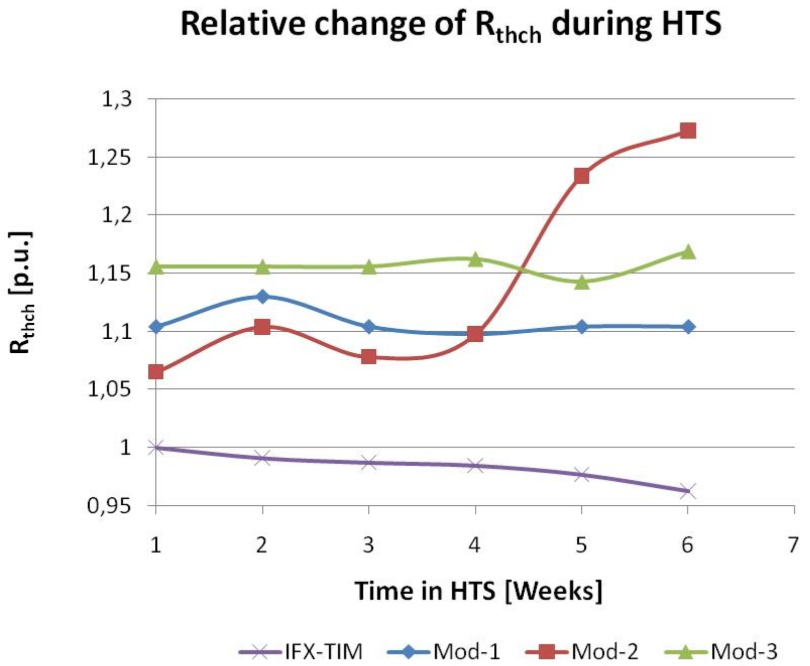

Figure 3: Relative changes of thermal resistances during HTS-Test referenced to IFX-TIM

Multiple conclusions can be drawn from the data gathered:

1) As expected, a specially tuned material dedicated to the particular application outperforms those considered general purpose components
2) The composition chosen for Infineon's new material achieves the best initial condition. Due to excellent wetting abilities and optimized particle content the bond-lines decrease over time, thus further reducing the thermal resistance
3) Though materials like Mod-1 or Mod-3 behave stable, they do not show the best thermal performance
4) With Mod-2 it is obvious that a reliable statement regarding longevity cannot be give within days or simple tests; the material performed well for the first four weeks.

One detrimental effect often observed with TIM is pump-out. Here the material gets shifted away from its position by movements of the base plate as a consequence of thermal expansion. To best counteract this effect, a phase-changing base material was chosen at Infineon that changes to a thixotropic state at elevated temperatures. Thus, the TIM's viscosity stays in a range that prevents the material from being pumped out.
Besides the thermal investigation it was also verified that neither retightening of screws nor burn-in for settling was necessary; these are an often observed drawbacks in common phase-changing materials.

Applying TIM

As implied, thermal performance depends on forming the thinnest possible bond lines between the power electronic component and its heat sink. Thus, the amount of material applied becomes a crucial parameter and manually handling of thermal interface material is no longer a preferred option. While manual stencil printing already is a step in the right direction, only automated processes allow for a reliable and reproducible procedure. A stencil-printer to apply TIM is set up to first flood the stencil and removes the excess material in a second step. The two sequential steps can be seen in Figure 4.

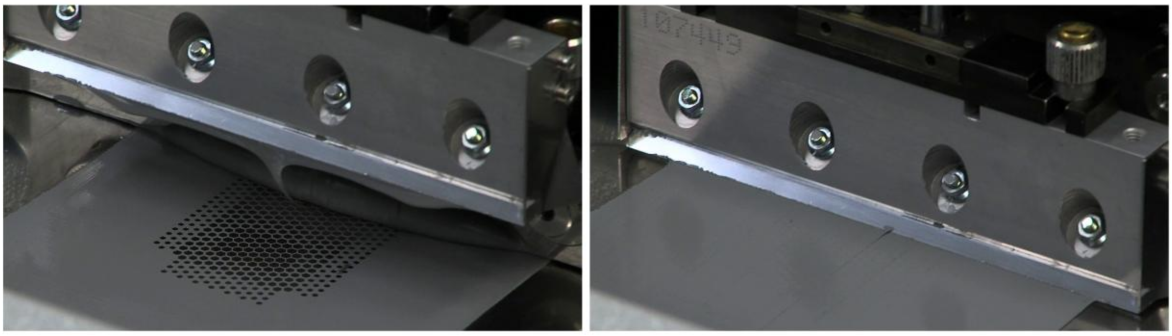

Figure 4: Flooding the stencil and removing the excess material afterwards to achieve the best possible printing results

A further step in applying Infineon’s new solution is a thermal treatment, transferring the paste-like material into its final phase changing status with a solid appearance at room temperature. This way, the material can safely be handled and transported.
The final step consists of an inspection verifying that every dot of the printed pattern is done properly and the correct amount of TIM has been applied.

Conclusions

As the complete process of design, qualification and application of thermal grease is of complex nature, Infineon has decided to offer power electronic modules with pre-applied thermal interface material to the market. This will improve the thermal behavior, release the customer of the often unwanted process of applying thermal grease and therefore contribute to managing the thermal challenge in power electronics.

References:

[1] Intel Core i7, Product Specifications from http://ark.intel.com
[2] The Challenging Task of Thermal Management, Martin Schulz, PCIM 2011
[3] IGBT with Higher Operation Temperature – Power Density, Lifetime and Impact on Inverter Design, Klaus Vogel et. al. PCIM 2011