Maximizing Precision in Thermal Interface Layers

Simply "Good" is not good enough for TIM as a functional layer

The thermal interface as a crucial building block in power electronics deserves special attention

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Today, modern semiconductors are driven at the edge of their capabilities due to cost pressure in a volatile market. Increased power ratings in given designs are supported using upgraded generations of power modules which lead to increased thermal stress. This in turn shifted the focus in design towards advanced thermal management which became a dominant factor in power electronic devices. Still the combination of power module, heat sink and adequate thermal solution, along with the qualification effort to be done, often leads to second best solutions. As a consequence, 20% of performance respectively lifetime can easily be lost.

Material Science

Searching for a proper material to act as a thermal interface in power electronics is a time consuming work. Minimum requirements were defined and tests conducted to determine the thermal properties and the long-term stability of a given material. The conclusion drawn from a four year project was, that a new, dedicated material had to be developed to really suit the needs of power electronic modules. Figure 1 hints out four steps of the material development conducted to cope with all the requirements.

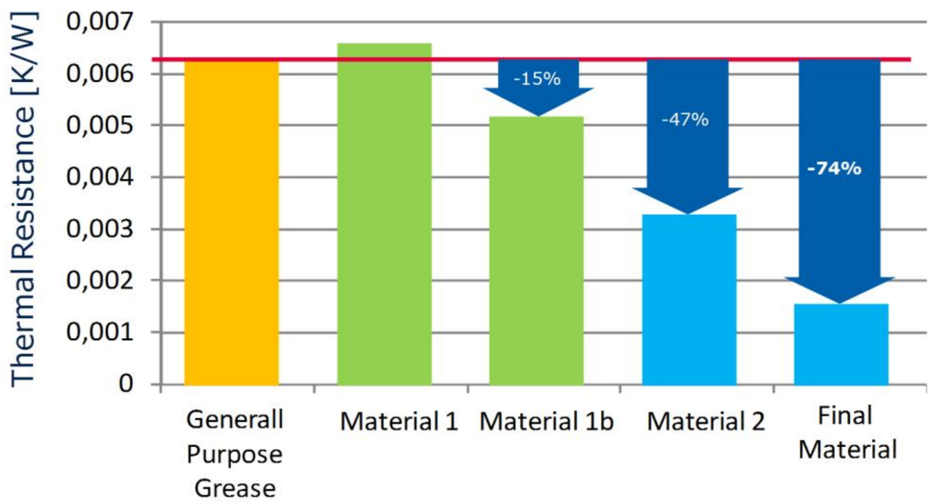

Figure 1: Four steps in developing a new kind of thermal interface compound and the major advancement achieved with the final material. Measurements done acc. to ASTM D-5470

Compared to the general purpose thermal grease widely used in power electronic applications, the first development turned out to fail this benchmark. Changing filler components, blending various filler materials and varying the level and ratios of different fillers used were steps taken during the optimization. Finally, after almost three years of iterative improvements, a material was generated that reduced the thermal resistance, compared to the well established general purpose grease, by 74%. The material, IFX-TIM is customized and exclusively available to Infineon.

Precise local application

Building the perfect thermal interface layer immediately brings up the questions, how much material has to be applied and what kind of distribution to chose. The historic approach of applying a homogenous layer using roller or squeegee cannot be considered the best solution as in general too much material is applied. Additionally, a homogenous layer would prevent the forming of the metal-to-metal contact that is desired.

Applying material using an inhomogeneous pattern is the preferred solution. However a detailed knowledge about the power module geometry is mandatory to determine the area in which to apply the TIM and the volume to be applied. Stencil printing allows controlling both parameters precisely. The distribution can be aligned using the pattern’s shape while the volume can be varied by properly adapting the stencil’s thickness. The drawing in Figure 2 depicts a stencil geometry dedicated to one particular module family.

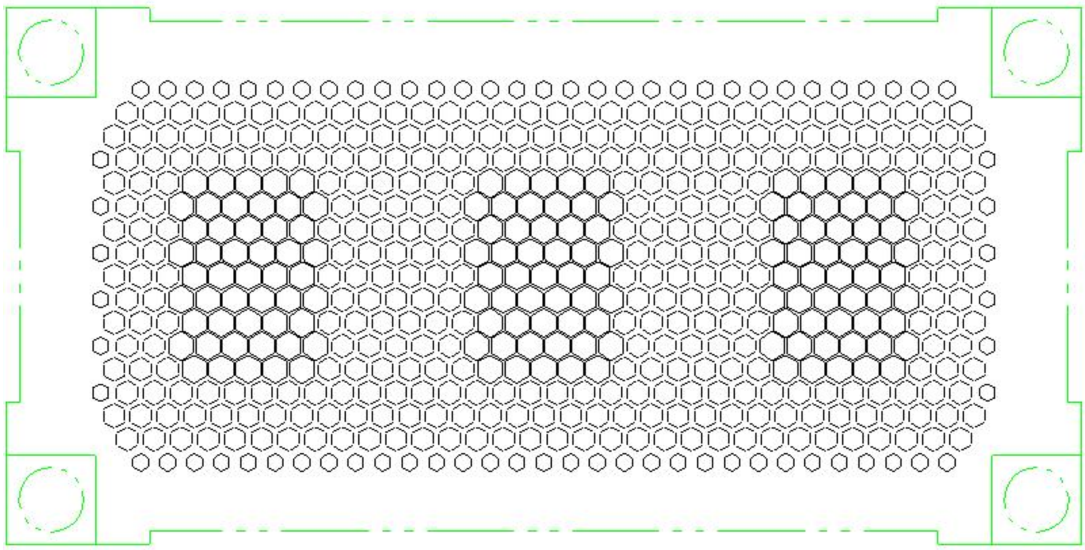

Figure 2: Stencil pattern to define the TIM-distribution on an EconoDUAL3, FF450R12ME4

To apply the material in a reproducible way in mass production, fully automated equipment is unavoidable. A dedicated manufacturing line was build consisting of automated handling systems, inline screen printing and visual inspection machinery. As the Infineon solution consists of a phase changing material, a drying step is necessary. This step is done in an inline oven. Afterwards, controlled cool-down processes ensure that the modules have reached a suitable temperature level for packaging.
Regarding the volume applied, there is a small but reasonable range between too much material applied and too little amount used. In copious examinations, this range was evaluated closely to ensure excellent results, taking slight variations in module geometry and more severe deviations in heat sink qualities into considerations. From the diagram in Figure 3 it can be seen, that a change in stencil thickness from 60µm to 120µm does not lead to noteworthy detrimental effect.

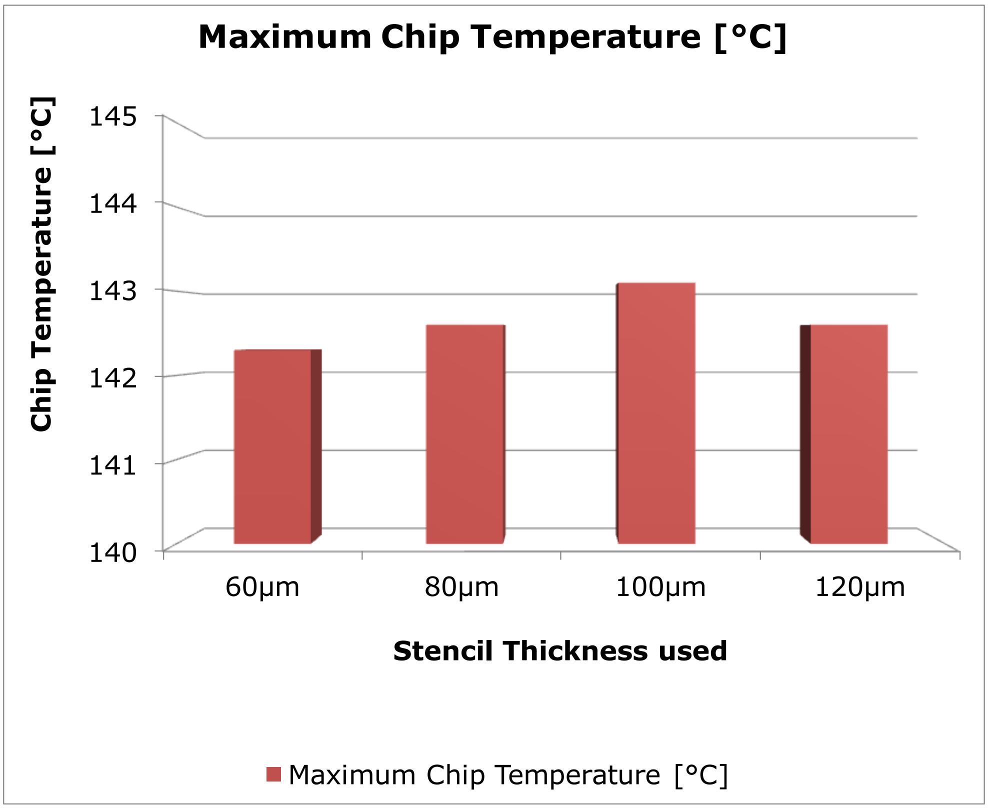

Figure 3: Thermal results from various screen thicknesses. DUT: FS450R17OE4P

Of utmost interest is the hottest spot inside the module. As a consequence of the unique TIM-properties, the influence of the screen thickness is very small in the range targeted. The tiny variations are all within the +/- 1K resolution accuracy of the equipment in use.

A stencil thickness was finally chosen that takes a worst case scenarios of combining borderline materials in both, heat sink and module geometry under considerations.

Accurately controlling the process

If 100µm is targeted but 60µm could be a risky limit, meticulous monitoring of the process is mandatory. The deviation allowed is less than 40µm, about half the thickness of a human hair.

To prevent getting close to the limit, a very accurate measurement strategy for verification is implemented.

This extraordinary level of precision can only be achieved using fully automated, cutting edge optical inspection systems. The system accurately checks the alignment of the printed pattern in respect to the module regarding translational and rotational deviation. Every single dot is measured in position, size and height allowing the calculation of the volume applied dot by dot.

High-speed 3D pattern recognition is the key to perform this 100%-test in a timely manner.

As a result, even tiniest deviations are recognized as for example bridges forming between two honeycombs as shown in Figure 4. For comparison, the screenshot in Figure 5 displays a pad with the demanded high quality printing result.

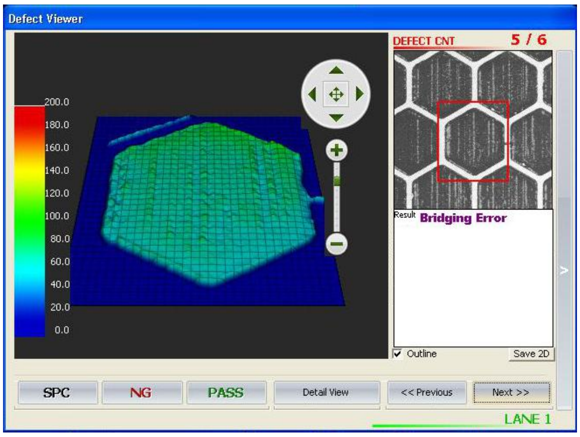

Figure 4: 3D-Pattern of pad 146 out of 3078 revealing an unwanted bridge

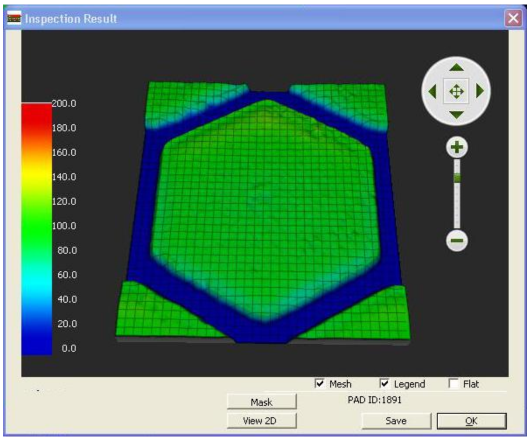

Figure 5: 3D-Pattern of pad 1891 out of 3078 showing the desired printing result

For traceability reasons and quality management, a proper set of data of all modules considered ok is stored.

Customer Benefit

Screen printing is a common process in industrial applications, though it is rarely controlled down to the µm scale and taking place in clean-room environment. Having the thermal interface material applied to the module releases the customer’s assembly line from this often unwanted process and reduces assembly times. It also eases work in case of maintenance. This however is of minor importance. The major benefit for the customer is the change in paradigm and the committed improvement regarding the thermal quality of a power semiconductor.
Comparing the datasheet of a FS450R17OE4, a module without IFX-TIM applied, and the TIMed version FS450R17OE4P, the change in thermal qualities can easily be found within the thermal resistance Case-To-Heat-Sink R_{thch}. The excerpt taken from the according datasheets is given in Figure 6 revealing two changes.

Charakteristische Werte / Characteristic Values			min.	typ.	max.	
FS450R17OE4P						
Wärmewiderstand, Gehäuse bis Kühlkörper Thermal resistance, case to heatsink	pro IGBT / per IGBT valid with IFX pre-applied thermal interface material	R_{thCH}			0,037	K/W

Figure 6: Committed to excellence. The datasheet clearly states the superior performance of modules equipped with Infineon’s new thermal solution

- The thermal resistance is no longer listed as a typical value but qualifies as a maximum value. Designers of power electronic equipment now can rely on this parameter to be a guaranteed value that remains correct throughout the lifetime of the design. The effort of qualification in respect to “how typical is my design” is eliminated.
- Compared to the 41K/kW for the typical value stated for the standard module, the value for the module with TIM applied additionally is reduced by about 20% down to 37K/kW.

With this, it remains customer’s choice to either increase the output power staying at a given temperature level or keep the output power and benefit from decreased temperature levels. This in turn will extend the design’s lifetime.

EconoPACK+ in the new D-Series design is the first module available with TIM applied. Mass production has started in November 2012. Several projects are currently ongoing to serve the market with further module families featuring Infineon TIM. Figure 7 shows the portfolio that will be available in the near future.

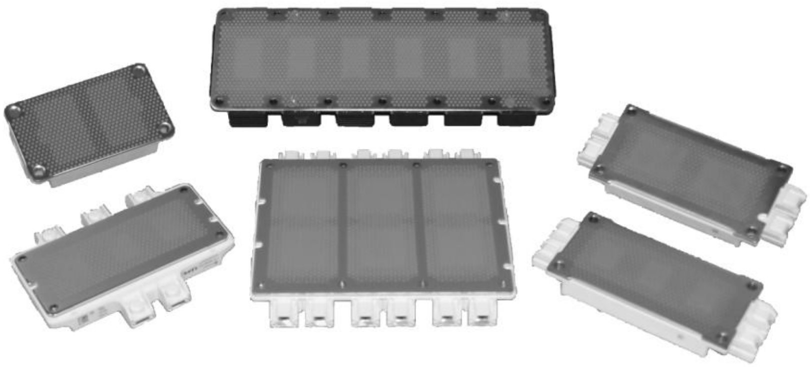

Figure 7: Module families that will be available with TIM in 2013, including 62mm, PrimePACK, EconoPACK4 and EconoDUAL3

Conclusions

With the ongoing developments in IGBT module technology, power electronics and the increased power densities today, thermal interface materials become a more crucial aspect in the field of thermal management. To achieve outstanding results, in-depth knowledge of the power module is necessary and a dedicated material is the most wanted solution. After several years of testing, refining and qualifying, Infineon Technologies now offers modules with TIM applied. In doing so customers are supported in building a high performance, reliable, long-term stable thermal interface to cope with the demanding conditions seen in power electronics.