Beyond Thermal Grease:
Enhancing Thermal Performance and Reliability

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Abstract

Power electronics based on silicon devices must operate below 125 C and IGBTs under 150 C. Future SiC devices could extend this to 200 C. Thermal management of power electronics requires interfacing the package to a heat sink using a thermal interface material (TIM). In general this interface is the crucial in terms of the impact on overall thermal impedance and long term reliability. While several greases provide good end of line performance, pump out and separation can degrade thermal performance. Phase change materials as well as gel like, cure-in-place, TIMs can not only match end of line performance of greases, but significantly enhance long term reliability. Finally, significant automation in the case of these TIMs can enhance productivity and manufacturing. In this presentation we will present options for phase change materials – both roll processed as sheets and die-cut parts as well as compounds that can be screened/stenciled by the end user. In addition, new developments in thin bond line, high thermal conductivity, cure-in-place gels for high reliability.

1. IGBT Thermal Challenge

The thermal stack up in an IGBT is a sum of several resistances in series. This is shown in the schematic below. A key compnent of the thermal stack up is the thermal interface material – typically a thermal grease – as shown in Fig.1

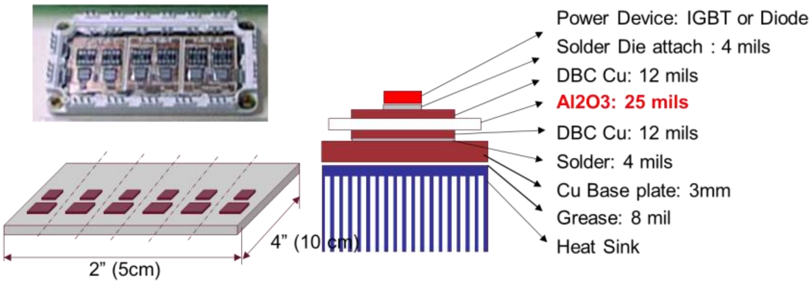

Fig. 1. Typical IGBT device and power assembly using multiple IGBTs

The effective thermal bond line can be quite significant given the size and warpage of the assembly. The thermal resisatnce of the interface material can therefore a significant portion of the total. This is ilustrated below in Fig.2 which shows that the end-of-line thermal resistance of the thermal interface can be 20-40% of the total.

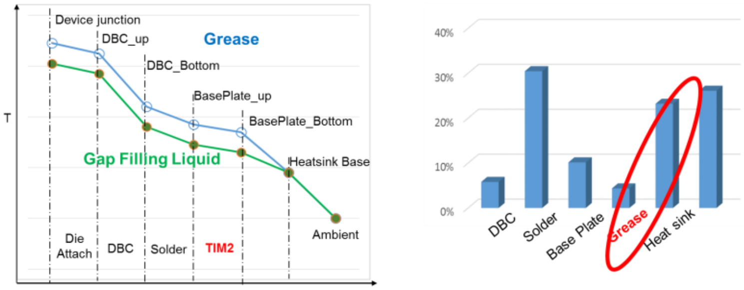

Fig. 2. Thermal simulation of a typical IGBT stack up

The thermal stack up includes materials of several different CTEs and, in addition, there are temperature gradients within the whole assembly. As the assembly goes through power and thermal cycling these can lead to cyclic mechanical load on the interface. The thermal material can pump out of the interface thereby degrading the thermal resistance and consequently the device performance. Therefore the thermal interface material should be chosen carefully to balance and optimize lifetime thermal performance.

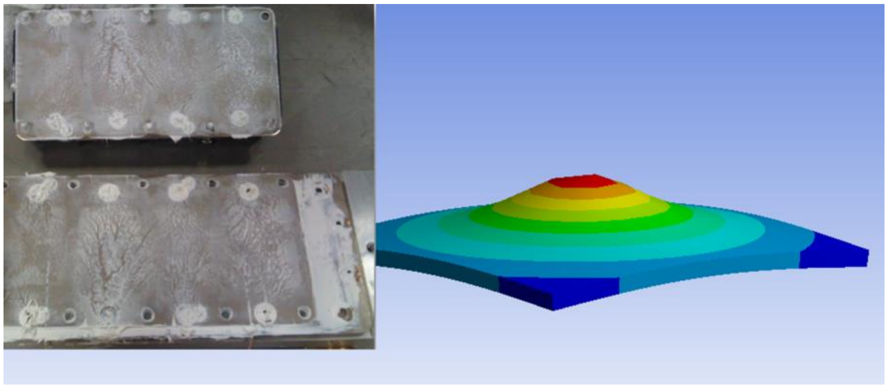

Fig. 3 Simulated warpage during thermal cycling and associated pump out

2. Thermal Interface Material Design

For thermal performance and long term reliability the TIM has to be designed to optimize several interdependent variables. The three main criteria are (1) Thermal conductivity of the TIM, (2) the rheology of the TIM, i.e. the deformation behavior of the material under stress and, (3) response to long term cycling. The interface between surfaces has gaps on two different length scales. The first is small-scale roughness typically O (1 μm) – from which air is eliminated by flow and wetting by the interface material. The second is related to larger gaps - O (100 -1000 μm) - due either to the non-planarity of surfaces and poor co-planarity. The thermal interface material needs to be able to conform to the surfaces, with a low external stress to produce deformation without straining the electronic components.

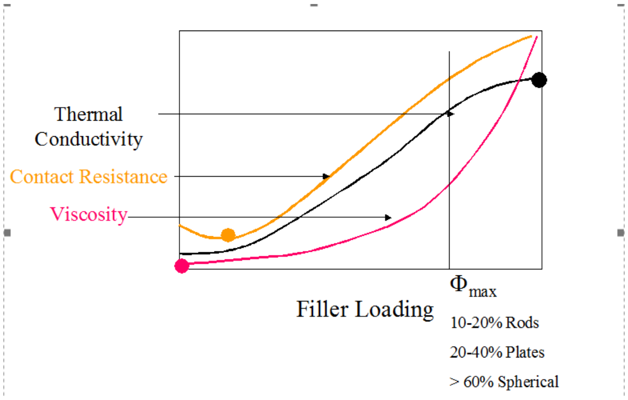

Fig. 4. Balancing thermal interface material properties

The thermal performance and rheology of thermal interface materials depend of both the polymer microstructure as well as the morphology and loading of the filler material. These properties are interdependent and cannot be manipulated in isolation. Since optimal performance depends on a combination of thermal conductivity and rheology one must match the application carefully to formulate the TIM.

3. Application Performance

Thermal interface materials are available in several general categories:

Thermal Greases: These are relatively lower viscosity polymer liquids that have been loaded with thermally conductive particulates. These are thermoplastic, i.e. they will deform continuously under external stresses without limit. They unfortunately are not only difficult and messy in manufacturing but also tend to migrate out of interface due to pump out – creating reliability issues.

Phase Change: These are materials generally solid at room temperature and melt at the phase change temperature. These are available as sheets or rolls and also as screenable or stencilable compounds. They are easier to work with, can be automated and are generally better in terms of pump out resistance. In manufacturing, they may need to be over-torqued or re-torques after phase change.

Curable/Reactive Liquids: These may be either adhesives or form-in-place gap fillers and may be one component (1-k) or two component (2-k). These are thermoset materials that crosslink into a network that does not deform. These perform best – performance like grease but strong pump out resistance. In addition there is little mess and great opportunity for tailoring properties for automated manufacturing.

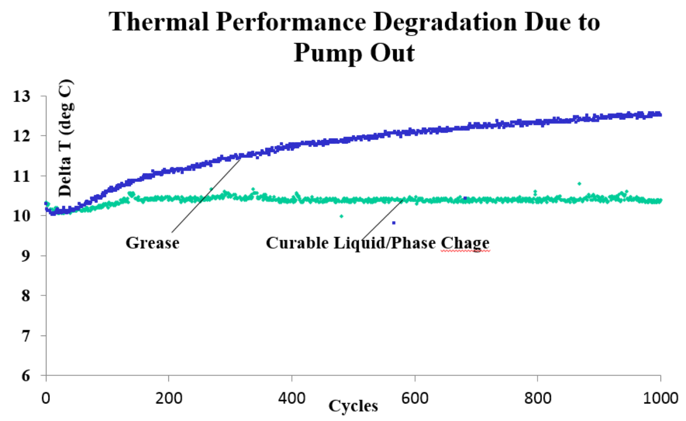

Fig. 5. Effect of pump out on various TIMs

4. Summary

For best thermal performance 1-k and 2-k curable gap filling liquids are the best alternative to greases. Phase change compounds offer an attractive alternative as well from reliability perspective.

5. References

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