High-Temperature TIMs for Power Modules and Devices

The proliferation of the usage of power modules has driven the industry to push for higher performance and more demanding modules. This increase in performance is typically accompanied by higher power densities, hence higher thermal densities that need to be addressed. Significant improvements have been seen in all areas from the Semiconductors to packaging to software to better control the systems. Another area that has made significant progress in addressing these thermal challenges are the Thermal Interface Material (TIM) solutions. **Prashanth Subramanian, Market Development Manager, Advanced Energy Technologies LLC, a subsidiary of Graftech International, Lakewood, Ohio, USA**

TIMs are critical in getting the heat away from the modules into the cold plate / heat sink to quickly and effectively (Figure 1). The primary purpose of the TIM is to provide the path of least resistance (thermally) to enable heat to be moved away from the source and enable the semiconductors to perform to their rated capacity. While traditional silicon based devices would operate in the T_j ~ 100°C, they have significantly increased to well in to the high 100°Cs, it is well established that transistors lose over 10 % efficiency when junction temperatures increase by 50°C, placing greater emphasis on both removing the heat effectively while also operating in significantly elevated temperatures.

Traditionally this solution had been dominated by polymer based solutions like thermal grease, phase change material (PCM) etc which were effective in addressing temperatures in the range of ~120°C. While these materials have seen progress as well, most of them are limited to <150°C in operation, significantly reducing its effectiveness at higher temperatures. There is also a significant challenge to pumping and drying out due to thermal cycling, causing challenges at demanding environments like renewable energy, electric vehicles, locomotives, or inverters. Replacing a "worn-out" TIM is an expensive proposition and can lead to additional costs for maintenance and reliability of the system.

Metal based TIMs has also been around for a while, they tended to serve niche applications, as tend to have increased creep that can affect coverage, hence reliability. Graphite based TIMs traditionally have served the purpose of highly reliable long lasting TIMs (carbon is stable up to 400°C in an oxygen environment and ~3000°C in a non-oxidizing environment), but their usage has been restricted to small surface areas as they are stiff and cannot address large variations in flatness well.

A new generation of compressible graphite based TIM incorporates the compliance of thermal grease while providing the reliability of carbon at high temperatures. The eGRAF® HITHERM™ HT-C3200 Thermal Interface Material is the first of its kind of compressible graphite designed specifically to address the current and future needs of the power electronics market.

Device temperature

The temperature of the device ($T_{Resistor}$ or junction temperature) during the test is regarded as the key criteria to determine performance of the TIM solution. Thermal impedance is defined as the opposition to the flow of heat within an assembly. Figure 2 shows the performance of HT-C3200 in comparison with dry joint (no TIM), eGRAF® Hi-Therm HT-1210, and "Competitive

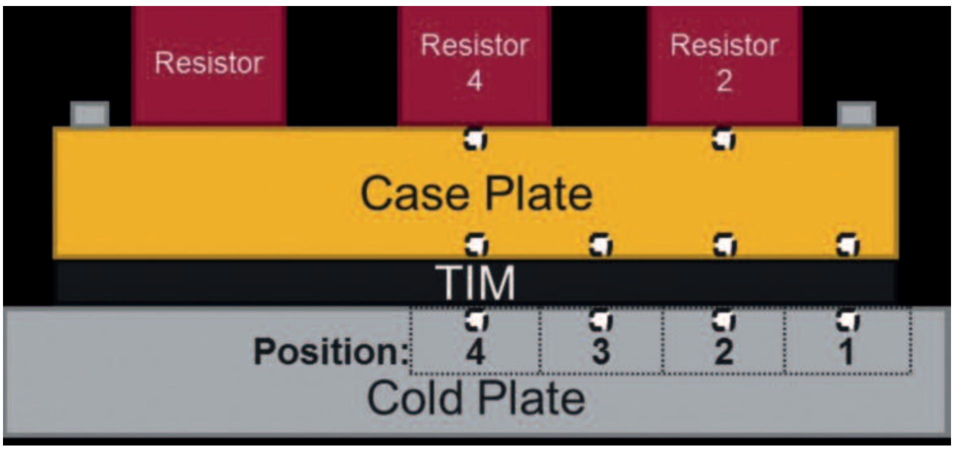

Figure 1: Schematic and temperature measurement locations in the assembly

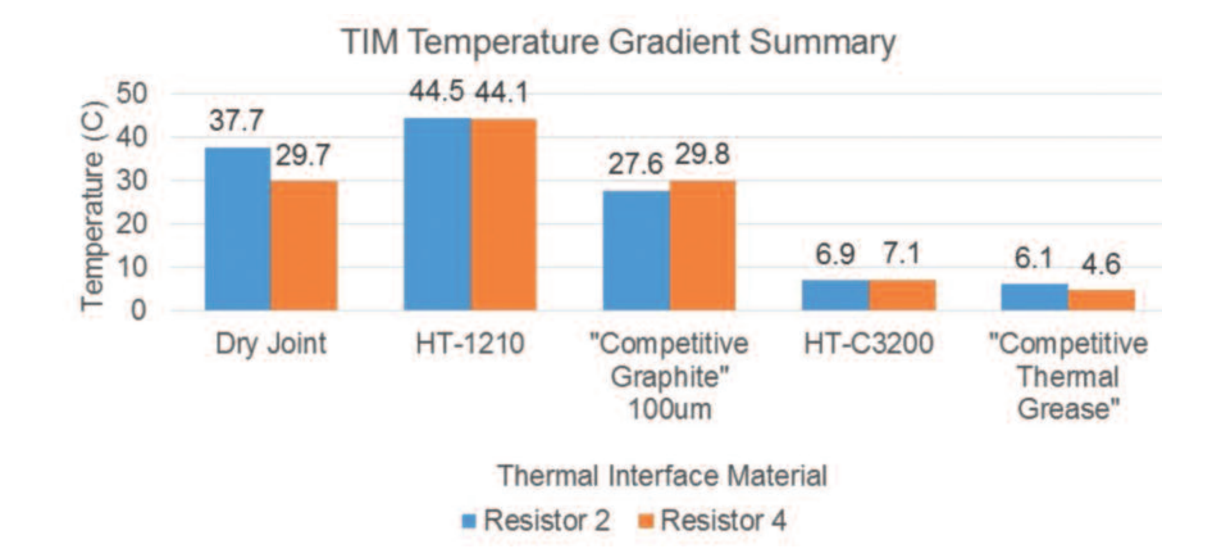

Figure 2: TIM temperature gradient through the thermal path

Graphite" - a commercially available 100 ?m thick graphite solution and "Competitive Grease" is a commercially available and popular silicone based solution and is widely used in the power electronics industry. The HT-C3200 shows comparable performance to grease while clearly outperforming both the HT-1210 and the dry joint. The temperature delta across the TIM shows the effectiveness of the heat transfer between the case plate and the cold plate and in turn the performance of the TIM. Temperatures were measured at four locations as described below in Figure 1.

Compressibility

One of the key advantages of using a grease like solution over a non-compressible foil like solution is the increased effective wetting aided by the ability of the material to flow and adjust to the flatness variations of the metal surfaces. Most rigid foil based solutions (including some graphite and metals) typically have less than 10 % compressibility and followability limiting their effectiveness in contacting both mating surfaces, hence allowing for air gaps that act as insulators.

For the foil based solutions to work more effectively, they must be able to effectively fill the variations in the bond lines between the mating surfaces. The HT-C3200 is an engineered graphite foil that can be compressed to about 70 % of its initial thickness under pressure (see **www.graftech.com/wp-content/uploads/2015/03/TDS319-HITHERM-HT-C3200.pdf**). This compressibility helps mimic the followability of the grease like substance while maintaining its ability to not pump-out under pressure. This purely graphite based solution does not pump out or dry out during thermal cycling or while applying pressure. This significantly improves the life of the material both during storage and during operation. Figure 3 shows the thickness of the material under compression. The difference in pressures between the edges and the center of the cold plate and case plate creates a bond line variation that can be between 50 and 100 μm based on the flatness of the metal surfaces, the torque applied and the thickness of the metal plates. The thickness was measured using a vacuum controlled thickness gauge.

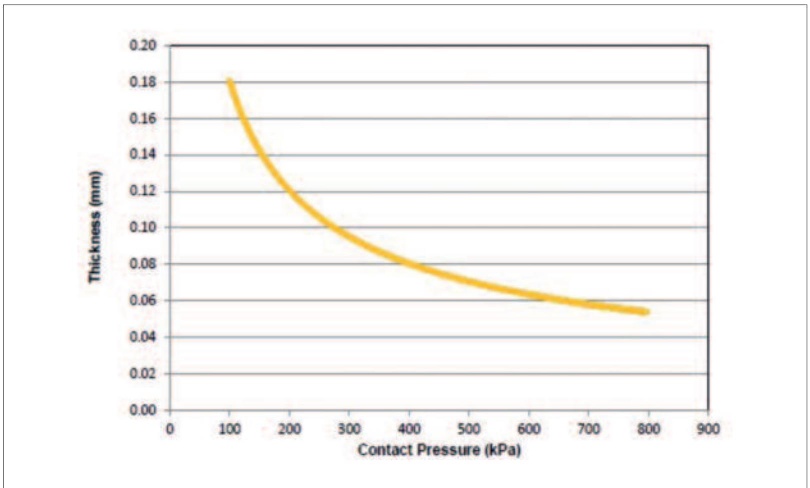

Figure 3: Thickness vs. pressure of TIM HT-C3200

Operating temperature

Most grease or Phase Change Material based TIMs have effective operating temperatures <150°C, the higher temperatures cause the material to dry out and lose its performance significantly. With the gradual but definite proliferation of Wide Band Gap material such as SiC and GaN based devices, the devices can operate comfortably in the 180°C to 220°C range, rending the current grease like solution inadequate. The HT-C3200 can operate in temperatures up to 400°C with no noticeable difference in performance. This graphite solution does not have the challenges like grease to pump out or dry out either during assembly or during operation.

Conclusions

The HT-C3200 is a highly engineered compressible graphite based TIM that provides both the surface wettability like grease while not having the same challenges with pump out and dry out that plague the long term performance of these paste like materials including Phase Change Materials. The HT-C3200 also does not require any dispensing equipment and is not messy in its application unlike the paste like