Going 'Off The Curve' With Polymers For Thermal Interface Materials

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Smaller and faster silicon devices have made heat dissipation at the die package level a critical issue in some applications, with the cooling capabilities of package designs still limiting device performance. In order to improve heat dissipation from these new packages, higher thermal conductivity Thermal Interface Materials (TIMs) are necessary. Increasing thermal conductivity in TIMs typically requires making trade-offs in other areas, such as viscosity or rework-ability. New technical developments have made it possible to go 'off the curve' of traditional tradeoffs to design highly thermally conductive TIMs. These new TIMs have high thermal diffusivity, as well as low modulus and high adhesion, which are required for newer, smaller form factor, higher power packages in current and future automotive and microelectronics applications.

Advances in the manufacture of silicon devices for the automotive industry have resulted in electronics with reduced feature size and higher operating speeds. Reducing the size of power electronics essentially means reducing the package footprints of Metal Oxide Semiconductor Field-Effect Transistors (MOSFET) and Insulated Gate Bipolar Transistors (IGBTs). While these changes are beneficial, the reduction in footprint results in higher power densities on both the die as well as the module. Heat dissipation in particular is critical at the die level for IGBTs with increased switching frequencies and voltage ratings. Despite improvements resulting from advances in the chip design, the cooling capabilities of these package designs still limit device performance. In order to improve heat dissipation from these new packages, higher thermal conductivity Thermal Interface Materials (TIMs) are necessary. Increasing thermal conductivity in TIMs typically requires making trade-offs in other areas, such as viscosity or rework-ability. New technical developments have made it possible to go 'off the curve' of traditional tradeoffs to design highly thermally conductive TIMs.

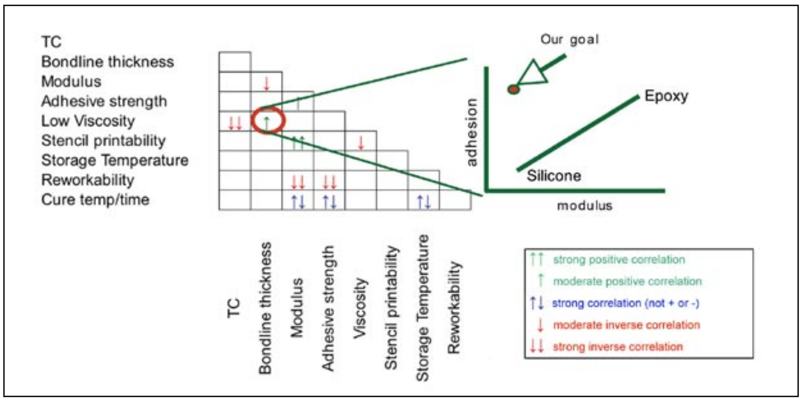
Material tradeoffs

Thermal (and other) materials development always involves performance tradeoffs (Figure 1). Deciding which property tradeoffs are possible involves making decisions about which properties are critical vs. nice-to-have; these choices are an important part of new material development. Formulation of new thermal materials requires a blending of many dissimilar, complex, and sometimes incompatible components into one formulation. As can be seen in Figure 1, varying one performance parameter may have direct effects on other properties.

For example, increasing filler loading typically increases viscosity. Often industry requests for high thermal conductivity (TC) are coupled with the requirement for low viscosity for ease of material dispensing. Increasing TC, however, is achieved by increasing filler loading, which, as stated above, increase viscosity. As with all TIM development, it is important to ascertain how to achieve high TC materials, while retaining low viscosity.

An example of how to deal with these complex tradeoffs is a practical filler packing system, as developed by Lord - a leading supplier of thermal management materials, adhesives, coatings and encapsulants to the electronics industry – which can achieve high TC TIMs while retaining low viscosity. Described below is a second example of methods to develop materials that have seemingly contradictory properties.

Figure 1 – Understanding tradeoffs between material properties is an important part of new material development. The tradeoffs required between adhesion and modulus is circled in red. The plot schematic shows the need for new TIMs to have low modulus while retaining high adhesion, thus requiring materials that are 'off the curve' of traditional epoxy and silicone materials



Property	MT 431	MT-410
Filler size (max, micron)	d90 = 15 µm	d90 = 15 µm
Viscosity (cP, 5/sec)	131,000	60,000
Specific Gravity (g/cm3)	3.85	2.35
Tg (ºC)	-10	-10
Modulus (MPa)	170	43
Die Shear Adhesion (psi)	2500 (175 Kg/cm2)	3200 (220 Kg/cm2)
TC (W/mK)	3.1	1.1
CTE $\alpha 2$ (ppm/ºC)	208	208
Cure condition (ºC/hrs)	150/1	150/1
Filler	ceramic/metallic	ceramic/metallic

Table 1 – Material properties for MT-431 and MT-410

Recent changes in (micro) electronic package conformations, such as the development of lidless packages, have precipitated the need for new thermal materials that have both high adhesion and low modulus. Another major change is the smaller and smaller form factors, which result in greater power densities. As packaging engineers try to force more and more components onto a package, the keep-out-zone (KOZ) between adjacent components shrinks. This results in the need to develop new improved materials to remove heat from the package. The two most commonly used polymers in thermal management are silicones and epoxies. Silicones generally have lower modulus, and are therefore softer than epoxies. Silicones also have relatively low adhesion as compared to epoxy materials, which typically have quite high adhesion. For applications such as lidless packages or thermal die lid attach materials (Figure 1) where the thermal materials require both high adhesion and lower modulus, there are few materials that can meet these requirements.

The seemingly contradictory requirements are another example of tradeoffs that need to be addressed. Traditional thermal interface materials are usually silicone based, and thus have relatively poor adhesion, whereas highly adhesive epoxy materials have a modulus that is too high. For example, Lord MT-315 – an epoxy TIM – has high adhesion but the modulus is in the GPa range. By contrast, Lord Gelease MG-121 – a silicone gel TIM – is quite soft with a modulus in the KPa range, but has very low adhesion.

As traditional silicone and epoxy chemistries are unable to meet the new requirements for thermal materials, a new polymer technology was recently developed to achieve both high adhesion and lower modulus (2-3 orders of magnitude lower than epoxy). Applications that require differentiating material properties, such as high adhesion and low modulus, clearly demonstrate the need for creative material solutions to minimise material tradeoffs. This new technology enables opportunities for materials developers and packaging engineers to together create the future generation of smaller more powerful electronic assemblies.

New polymer for thermal materials

Recognising the effects of tradeoffs, how is it possible to solve these seemingly 'unsolvable' material conflicts? It requires going 'off the curve.' The development of new technology to meet normally contradictory property requirements of new thermal materials has proven to be the optimal solution. By clearly understanding the required properties, Lord is able to invent new technology that is not within the usual material set. New polymer technologies were explored that were purposely very different from the polymers commonly used in thermal management (i.e. silicone and epoxy) for these applications.

The new, proprietary polymeric material technology is a functionalised olefinic (non-silicone) polymer. It has been formulated into two new thermal products that have immediate applications in both the automotive and microelectronics industries. This new

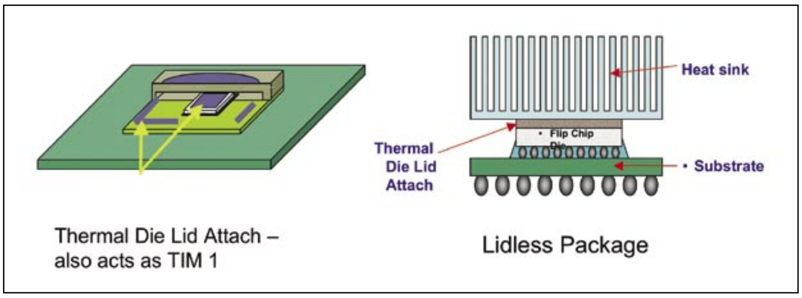
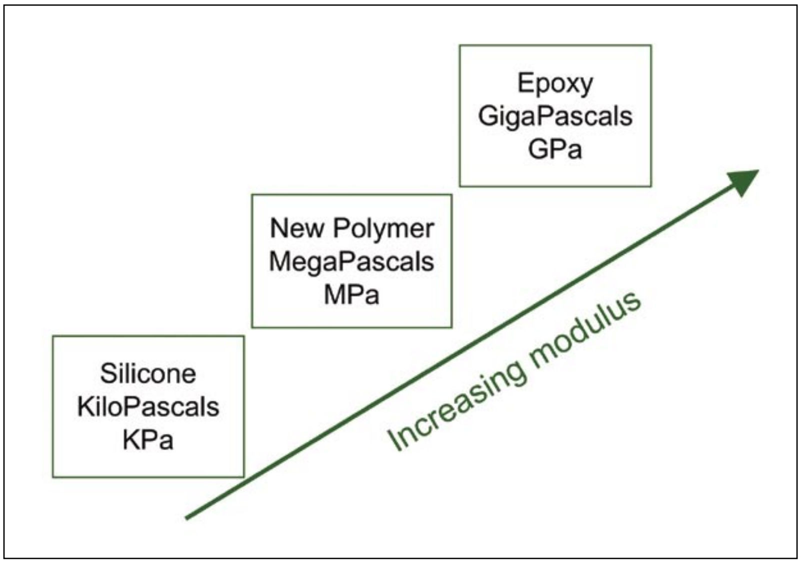


Figure 2 – Die lid attach material application (a) and lidless package (b)

Figure 3 – Comparison of modulus of tradition polymers, silicone and epoxy, with new polymer developed for thermal materials



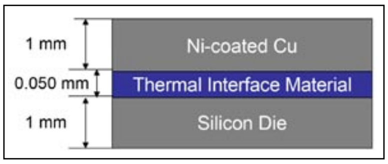


Figure 4 – Image of sandwich testing

polymer is the basis for the development new TIMs with low modulus and high adhesion (Figure 2). One application of this new polymer in TIMs is as a thermal die lid attach (TDLA) material. The TDLA can act as a replacement for both the thermal interface material and the lid attach in traditional package types. By replacing two materials with one, the overall process time and cost can be reduced as the number of dispense and cure steps are reduced. Additionally, the coefficient of thermal expansion (CTE) mismatch between the TIM and lid seal can be a problem for package reliability. By having the same material, this problem can be dramatically reduced. The TDLA can also be applied to lidless package applications as well.

The new TDLA material, named MT-431, has been extensively tested by both Lord and its customers, and shows excellent reliability, wetting, dispensability, stencil printability and TC. Thermal cycling (-50 to +150°C, 1000 cycles), thermal aging (150°C for 150 hr) and humidity testing (85°C/85%RH), as well as studies of surface wetting by making TIM sandwiches, have also been successfully completed. In all testing, little or no change in thermal properties (Table 1) was observed based on Lord's internal testing method. The testing method, which involved the use of Si-TIM-Si and Si-TIM-Ni/Cu sandwiches (Figure 3), allowed the ability to mimic in-package properties including surface interactions and package warpage. For thermal cycling using air to air thermal shock (AATS), MT-431 TIM sandwiches at a thickness of approximately 50 microns between two Si die, after 1000 cycles from -50 to +150°C, showed a less than 5 percent change in TC. This validated that the polymer itself was quite robust to thermal changes. When placed between Si and nickel coated copper (Ni/Cu), the MT-431 showed excellent reliability as well.

A second product that was developed using this new polymer technology was a new thermal lid attach (TLA) material (Figure 4). Not only are smaller form factors making heat removal from the active chip difficult, the reduction in keep out zone (KOZ) has reduced the overall space in which heat can dissipate from the entire package. In the past, lid attach (lid seal) materials were typically an unfilled polymer with a TC generally in the range of 0.1 W/mK. By increasing the thermal conductivity of the lid attach polymer, the ability of the heat to be moved out of the package dramatically increases. New Lord TLA materials have thermal conductivities ranging from 0.6-1.4 W/mK. They are easy to dispense, and have excellent adhesion. The company's MT-410 lid attach material shows a thermal conductivity of 1.1 W/mK and die shear adhesion of over 200 Kg/cm^2. This material has shown excellent reliability in humidity testing, high temperature aging, and thermal cycling. The material can be used to replace any lid attach polymer as it also has excellent dispensability and surface coverage.

The future of thermal interface materials

As package sizes shrink and power output increases, developing new types of TIMs to meet these new packaging challenges is a key to advancing the field. By 'going off the curve' and choosing a new type of polymer matrix for thermal materials, novel TIMs have been developed that solve these complex design compromises. These new TIMs have high thermal diffusivity, as well as low modulus and high adhesion, which are required for newer, smaller form factor, higher power packages in current and future automotive and microelectronics applications.

By approaching material trade off issues from the perspective of the required material compromises, new design space can be developed that expands the potential options for new technology beyond the traditional choices, ie the ability to 'go off the curve' to enter new design space. These new technologies will drive product formulation to new highs for current and future applications through the introduction of customised and proprietary polymer resins, nano fillers, filler compositions, and specialised additives.

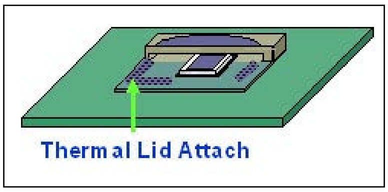


Figure 5 – Thermal lid attach material application

Figure 6 – New TDLA and TLA TIMs show 'off the curve' properties compared to traditional silicone and epoxy TIMs