Momentive
Performance
Materials

Fast Cure Thermally Conductive Adhesives

by Jennifer L. David. PhD.

Abstract

As with all electronics packages today, power supply components face increasing challenges. Wattage demands on next generation devices continue to increase, as customers demand higher functionality and faster processing speeds in today's electronic equipment. Continued miniaturization of these devices only compounds the difficulty of rapid transport of large quantities of heat away from sensitive electronics. Of equal importance to thermal management, is the need for long-term reliability and stability of the electronic components. In power converter and power module applications, flowable adhesives can function as potting compounds to fill space between components and rapidly remove heat. In power converter and adaptor applications, where heat sinks are utilized, they can achieve low thermal resistances even at extremely thin bondlines. If these materials have high adhesion strengths, the need for mechanical fasteners or lids to hold packages together can be eliminated. From a manufacturing perspective, cost pressures require the highest levels of productivity on the assembly line. In addition, today's high energy prices are forcing changes in the way that assembly is done, with less tolerance for high temperature long cycle time cures.

A review of the trends driving growth and innovation in the medical electronics industry highlights similar requirements for next generation assembly materials in these markets. One of the most important challenges in medical electronics today is improved heat dissipation. With the increased functionality and faster processing speeds of the next generation of high end diagnostic medical equipment, efficient and rapid transport of large quantities of heat away from sensitive electronics will be of utmost importance. The SilCool LTR3292 material, recently launched by Momentive Performance Materials, has been used with great success in one such medical electronics application; a high speed volume computed tomography scanner. In this application, ability to remove heat effectively from the sensitive imaging electronics is of paramount importance. In other applications, the trend toward in-home and wearable monitoring devices means that the medical electronics of today may no longer be kept under carefully maintained hospital or laboratory conditions. To ensure that assembly materials continue to perform as desired, extensive ageing studies and stress testing must be done as a critical piece of the material selection process.

This paper will review new materials that provide benefits to the packaging engineer in both power supply and medical electronics markets. The new liquid dispense materials to be discussed offer the following benefits: reduction in package stresses, cure temperature of 80°C, cure time of 30 minutes, extremely high adhesion to various substrates, and the capability for room temperature adhesion in a two-part system.

Introduction

This paper is concerned primarily with thermal adhesives for first level high performance electronic packages. Products such as personal computers, servers, gaming machines, medical imaging instruments, and automotive modules, to name just a few, all depend on the proper selection of thermal adhesives in their first level packages in order to function properly. As a prelude to the main discussion of the role of the thermal adhesives and their selection for this type of package, an overview will first be presented to illustrate where first level packages fit in the electronics hierarchy.

The key material requirements of thermal adhesives in first level packages will then be reviewed. Given the demands particular to these applications, several tests specific to the electronics industry are used in conjunction with standard physical property testing throughout the product development process. These tests enable the best prediction of performance in the intended applications.

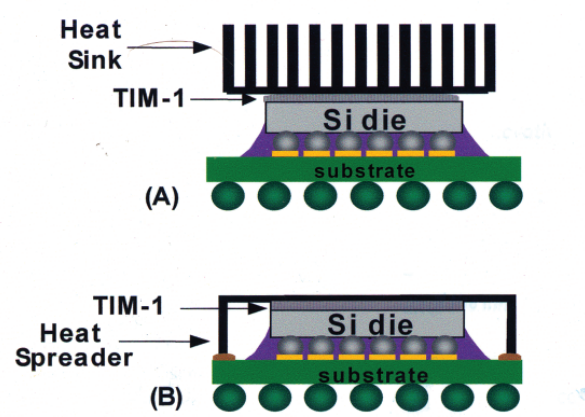
Finally, new development work will be presented which addresses the processing challenges inherent to the power supply and electronics device assembly markets. Customer requests for lower processing temperatures, added design flexibility, and reduced package stresses have driven exploration of these material improvements. In order to better illustrate the productivity and design flexibility improvements made as a result of this work, the discussion will begin with an overview of properties of a typical thermal adhesive. New development work will then be presented to show the improvements made to this baseline formulation in order to reduce cure time and temperature in these new materials.

First Level High Performance Electronic Packages

First level packages include both multi-chip modules as well as single chip modules. These components are attached to printed circuit boards (PCBs) or cards to create the second package level. The third level package, often referred to as a mother board, is comprised of multiple PCBs or cards connected together. The term “high performance”, when applied to integrated circuit (IC) devices, indicates a particular class of packages that have an extremely high number of electrical connections. Flip chip ICs are key examples of first level high performance devices. To achieve the highest performance, the electrical connections in these packages are made using solder “bumps” at the board side of the package. The solder bump process enables the largest number of electrical connections for a given package footprint.[1]

As the technology for integrated circuit design and manufacture has improved over the years, the achievable density of electrical connections in flip chip packages has increased. This improvement has made possible both size reduction as well as increased functionality at all three packaging levels. Electronics products made today are generating more power from smaller areas. The so-called “hot spots” in these products are the first level packages, where the greatest density of electronic signal transmission occurs per unit area.

A representation of a typical flip chip device is shown in the figure below. The silicon die contains the high density electrical connections discussed above and is attached to the electrical connections of the PCB by means of solder bumps. The heat generated at the top surface of the flip chip die must be removed efficiently to prevent overheating and malfunction during use. Heat sinks are used, typically in conjunction with fan cooling systems, to remove the heat. The heat sinks are often fabricated from highly conductive metals such as aluminum or copper. However, a robust thermally conductive connection is needed between the top surface of the die and the base of the heat sik to fully realize the benefit from this approach. The thermally conductive adhesives described in this paper function as the thermal interface material (TIM-1) in this type of configuration. In these applications, the thickness of the thermally conductive layer is typically on the order of 1-2 mil, or 25-50 microns.



Typical Flip Chip Configurations. (A) The thermal interface material (TIM-1) is dispensed between the silicon die top surface and the heat sink. (B) Alternatively, a heat spreader or lid may be used as the top substrate. In this case a second conductive layer (TIM-2) is used to connect the heat spreader to the heat sink. Typically the thermal performance requirements of a TIM-1 material are more stringent than for a TIM-2.

Physical Property Requirements for Thermal Adhesives

Thermal adhesives are just one of a number of material options available to the packaging engineer when faced with the challenges of thermal transport. Other possible thermal management choices include greases, gels, phase change materials, pads, films, and tapes. The choice of which material is best depends upon the specifics of the application.[1]

Benefits of Thermal Adhesives

Thermally conductive greases, gels, and phase change materials can provide improved thermal performance over adhesives, but often at the sacrifice of adhesion and other important physical properties. Greases and phase change materials can flow at package operating temperatures. For this reason, migration can be a concern with these systems. Any loss of conductive material in the device coincides with void formation. Both effects result in a reduction of thermal transport across the device interface. Gels are lightly crosslinked versions of greases. There is less concern that the polymer matrix will migrate from the interface in gels; however, the lower molecular weight components of the formulation are held less tightly in the gel matrices than they are in the highly crosslinked adhesive systems. In contrast to these materials, thermal adhesives are fully cured. There is no danger that the material could leak from the package during use. In addition, the adhesive holds the package together without need for special clips or springs.

Like adhesives, thermal pads are also highly crosslinked. However, thermal pads must be placed onto a heat sink surface and cannot be liquid dispensed. Pads have pressure sensitive adhesive (PSA) layers on their top and bottom surfaces that hold the heat sink in place. Compared with an interface formed by a liquid dispense product, however, the PSA interface does not achieve the same level of intimate contact. As will be described below, poor interfacial contact limits heat transport from the device to the heat sink. For this reason the thermal performance of pads is generally not as good as that of thermal adhesives. To improve the thermal performance of pads, the use of special clips and springs is required.

Table 1: Thermal Material Options

Option	Benefit	Drawback
Grease	Thermal performance, no cure required	Messy, migration issues, no adhesion
Gel	Thermal performance	Potential for migration issues, low strength, low adhesion
Phase Change	Thermal performance, no cure required	Potential for migration issues, no adhesion at use temperature
Adhesive	Good mix of physical and thermal properties	Thermal may not be as good as the no-cure liquid options
Pad	No cure required	Thermal often not as good as adhesives; require clips

As indicated in Table 1, of the options available, thermal adhesives provide an excellent mix of properties. They offer good thermal performance without the need for clips or spring fasteners. They are easy to apply using standard liquid dispense or screen-printing methods. Finally, their strong adhesion to device components and the heat sinks means that no clips or lids are required to hold the package together. Table 2 offers a summary of typical physical property requirements of thermal adhesives. In the next section, each of these performance criteria will be discussed in detail.

Table 2: Typical Physical Property Requirements of Thermal Adhesives

	Test Conditions	Typical Value
Thermal Resistance	Si-TIM-Cr/Al sandwiches	<30 mm^2K/W
Die Shear Adhesion	Si-TIM-Cr/Al sandwiches	>250 psi
Elongation	Cured sheet	>20%
Viscosity	Shear rate 10/s 25°C	10-60 Pa•s

In-Situ Thermal Performance

The primary function of the thermal adhesive is to transmit as much heat as possible away from the device to a location where it can be quickly and safely dissipated. The resistance to heat flow through a material is known as its thermal resistance. It is calculated as the path distance through a material divided by the bulk thermal conductivity of that material. For a given package in which the thickness of a thermal adhesive is fixed, one might assume that the bulk thermal conductivity of the adhesive is its most important defining property. However, this analysis ignores the effect of the interfaces on thermal transport in the device. The path from the silicon die to the heat sink crosses the entire thickness of the thermal adhesive layer, but it also crosses two interfaces. No device surface is perfectly flat, and this fact has significant repercussions in terms of the effectiveness of heat transport. At each interface, the presence of microscopic air voids can dramatically reduce the effectiveness of heat flow in the device.[2]

Physical Property Requirements for Thermal Adhesives (continued)

In-Situ Thermal Performance (continued)

Given the importance of interfacial effects, measurement of the thermal performance of an adhesive is best accomplished using an in-situ measurement technique, such as a laser flash method.(3) To run the test, sample "sandwiches" are prepared using dummy silicon chips and diced heat sink coupons as substrates. The adhesive is dispensed and cured between the substrates. The diffusivity of the test sample is then measured. From the diffusivity of the test sample, along with the heat capacity and the density of each material in the three layers, the thermal resistance of the test sample can be determined in units of mm^2K/W. Experience has shown that this measurement correlates well with thermal measurements performed on actual devices where the thermal adhesive is utilized to transmit heat across a thin bondline to a heatsink. Thermal resistance values of approximately 30 mm^2K/W at bondlines of 1 mil are considered acceptable for many thermal adhesives. The highest power generation packages in specialty applications require even lower thermal resistance values of 5-10 mm^2K/W.

The assembly and cure conditions for packages built with thermal adhesives can have significant effects on thermal performance. The thermal resistance of a package will decrease as the bondline thickness (BLT) of the adhesive layer is reduced. A reduction in bondline thickness is accomplished using both an assembly pressure as well as a cure pressure. Acceptable values for these pressures typically range from 10 to 20 psi.

Die Shear Adhesion

A second material property of importance in the design of thermal adhesives is that of adhesion. Strong adhesion holds the device together. It also prevents delamination as the device undergoes warpage during thermal cycling in use. Just as bulk thermal conductivity testing cannot mimic thin film thermal performance, typical bulk adhesion tests, such as lap shear, are not equivalent to true thin film adhesion values. Since thermal adhesives in these applications are typically applied at layer thicknesses of 1-2 mils, or 25-50 microns, a thin film adhesion test is the best predictor of actual use conditions.

To measure thin film adhesion, dummy silicon chips and large heat sink coupons are used as substrates. The adhesive is dispensed and cured between the substrates. The shear force required to remove the silicon die from the heat sink substrate is measured and the adhesive shear strength in psi is calculated. Typically, die shear adhesion values above 250 psi are required in flip chip packages where the thermal adhesive must hold the heat sink to the silicon surface of a processor chip.

Elongation

One of the few bulk physical properties tested for these types of applications is percent elongation at break, as measured by a standard tensile type test. Elongation is important because of the warpage a package sees during use. As a device powers up and down, the individual components and the PCB expand and contract to different degrees, depending on their coefficients of thermal expansion (CTE). The larger the mismatch in CTE, the more warpage that package will experience. Warpage also increases with package size. However, if the thermal adhesive has sufficient elongation, delamination at the package edges will be prevented. Since any delamination will increase thermal resistance values in those areas, prevention is important. Values above 20% elongation are generally considered acceptable for thermal adhesives.

Viscosity

Certain applications require that the thermal adhesive be dispensed in a bead or a printed pattern; for these assemblies it is important that the material be able to hold its dispensed shape for a certain period of time until the heat sink can be applied. Other applications require that the material self-level after dispense, for potting or prior to the application of the heat sink. Often the viscosities of a thermal adhesive can be adjusted to meet the specific needs of a customer's application. The viscosity of thermal adhesives is often reported as a function of shear rate. These materials are typically shear thinning. This means that their viscosities are lowest at high shear rates of 10/s. For potting type applications, where self-leveling is desirable, a viscosity of approximately 10 Pa·s at a shear rate of 10/s is desirable. For applications where the adhesive has to hold its shape for an extended period of time, a viscosity of approximately 60 Pa·s at a shear rate of 10/s is preferred.

Reliability Testing

As electronics become smaller and more portable, they must be engineered to survive a wide variety of use conditions. To ensure the long-term reliability of high-end electronic products, the components are subjected to rigorous qualification schedules. There are several key tests, summarized in Table 3, that are used to check packages for thermal performance degradation. In one test, the packages are subjected to conditions of 85°C / 85%RH for approximately 250 hours. A second test cycles the packages repeatedly in a thermal shock chamber, where the temperature is varied from -55°C to 125°C for up to 1000 cycles. In a third test, the packages are subjected heat aging at 150°C for 1000 hours. A final test, often requested by customers, is a moisture sensitivity test where packages are subjected to temperature cycling after an initial precondition at 85°C / 85% RH. Depending on the specific application, customers may require evidence that a thermal adhesive can pass one or more of these tests prior to beginning their own formal qualification of the thermal adhesive in an actual device.

Table 3. Typical Reliability Testing Required for Thermal Interface Adhesives

Reliability Test	Test Conditions	Duration
Moisture Sensitivity Level (MSL-1)	85°C / 85% RH, 3 reflow cycles at 250°C	168 hours
Air to Air Thermal Shock	-50°C to 150°C with a dwell time of 10 minutes at each extreme	1000 cycles
Thermal Aging	150°C	1000 hours
Highly Accelerated Stress Testing (HAST)	130°C / 85% RH at 2 atm	96 hours

Structure-Property Relationships of Thermal Adhesives

Typical thermal adhesives contain thermally conductive fillers and a curable resin matrix. Additionally, adhesion promoters and catalyst inhibitors may be added to increase adhesion strength and prolong shelf life. As with most formulated products, achieving the appropriate balance of these inputs involves physical property trade-offs. To achieve the best thermal performance, high loadings of thermally conductive fillers are employed. However, there is an optimal filler loading level for every system. If this level is exceeded, physical properties such as elongation and die shear adhesion are compromised. In addition, the importance of interfacial wetting on reduction of thermal contact resistance cannot be overemphasized. If loadings are too high, the material will not wet the substrates well and the interface resistance will be very high. At extremely high filler loadings, dispensing becomes too difficult, and target bondline thicknesses cannot be achieved with reasonable assembly pressures. In addition, at high filler loads, the ability of an adhesive to “self-level” is compromised. Finally, the highest purity, highest thermal conductivity fillers come at a price. The cost of incremental improvements in performance must be factored into the equation along with the physical property requirements.

Targeted Improvements for Thermal Adhesives

The thermal adhesives described in this paper may be suitable for use in many different power supply and medical electronics applications. Given the complex manufacturing procedure and multi-component nature of electronic device assemblies, any reduction in cure time is of significant value in terms of productivity and energy savings.

Reduction of the cure temperature of a thermal adhesive is a second area for improvement. Often, cure schedules for package components are coordinated. In this fashion, a single pass through a cure oven cures multiple materials in the device at once. High cure temperatures for thermal adhesives place limitations on the manufacturing process. If certain components cannot tolerate the high cure temperatures of other components, they must be placed and cured in a second process, after the higher temperature cure schedules are completed. By reducing the cure temperature of thermal adhesives, the logistics of the assembly process can be simplified. The development of a room temperature cure thermally conductive adhesive, where no heating is required at all, has still further benefits. Such a material can be used in cases where parts are too large to be placed in an oven, or in instances where no level of heated cure can be tolerated.

Finally, by reducing cure temperatures, parts can be assembled with less “built-in” stress. As an assembly is heated up to cure, the individual components expand. The extent of expansion for each component depends upon its coefficient of thermal expansion (CTE) and the difference between the cure temperature and the ambient temperature (ΔT). At higher cure temperatures, each material in the package undergoes a higher level of expansion, or strain. The components are “locked” in place during cure under these conditions. After cure is complete, the package is cooled to ambient temperature. As the system cools, it undergoes warpage, since the different components are connected together and contract to different extents. The warpage causes internal stresses in the package. The higher the internal package stresses, the more opportunity there will be for delamination and deterioration of the thermal performance of the thermal adhesive. For this reason, thermal adhesives that can cure at low temperatures are desirable.

Properties of a Baseline (“Standard”) Thermal Adhesive

A thermal adhesive was selected for use as a baseline in this development program. The physical properties of the baseline material are given in Table 4. Table 5 contains reliability test data for the baseline formulation. This baseline product has a recommended cure time of one hour at a temperature of 150°C. It is currently in commercial use, most notably as a thermal adhesive bonding heat sinks to processing chips in a high end medical electronics application. The goal of this work was to develop new formulations with reduced cure times and temperatures, while retaining as much of the baseline physical and thermal performance as possible.

Table 4: Typical Physical Properties of the Baseline (“Standard”) Thermal Adhesive[4]

Cure Conditions	1 hour @ 150°C
In-Situ Thermal Resistance (Si-TIM-Al/Cr) 10 psi assembly pressure 10 psi cure pressure	28 mm^{2}K/W (BLT ~1.5 mil)
In-Situ Thermal Resistance (Si-TIM-Al/Cr) 10 psi assembly pressure 0 psi cure pressure	51 mm^{2}K/W (BLT ~2 mil)
Die Shear Adhesion (Si-TIM-Al/Cr) 10 psi assembly pressure 0 psi cure pressure	450 psi
Elongation (pressure cured sheet)	40%
Viscosity (10/s shear rate) 25°C	12 Pa•s

Table 5: Typical Reliability Data for the Baseline (“Standard”) Thermal Adhesive[4]

Test	In-Situ Thermal Resistance Delta
Air to Air Thermal Shock (-55°C to 125°C, 1000 cycles @ 20 min)	-1.7%
Temperature and Humidity Aging (250 hours at 85°C / 85% RH)	-4.8%
Moisture Sensitivity Level 1 Testing (MSL-1) (168 hours at 85°C / 85% RH followed by 3 thermal cycles to 160°C)	+4.8%
Test	Die Shear Adhesion Delta
Air to Air Thermal Shock (-55°C to 125°C, 500 cycles @ 20 min)	-0.8%

Targeted Improvements for Thermal Adhesives (Continued)

Tests to Measure Extent of Cure in Thermal Adhesives

Two of the properties typically used to evaluate extent of cure in thermal adhesives are storage modulus and adhesive strength build as a function of time and temperature. The storage (elastic) modulus, G', scales directly with molecular weight in polymeric systems. As cure begins, the molecular weight increases, and the G' value increases. The plateau temperature is the point at which cure is said to be complete and the slope of the G' curve returns to zero. The crossover point between the storage (G') and loss (G") moduli for a material is a property known as the "gelation point". At this point the material has achieved a sufficient degree of crosslinking that it is said to be an infinite network. The crossover point is recognized as the first point of cure, although full cure requires continued application of heat to reach a plateau value for the storage modulus. For these studies, dynamic mechanical analysis (DMA) testing to measure G' and G" was conducted on a TA Instruments Ares-LS2 DMA instrument with a parallel plate geometry.

While the storage modulus of a material provides information as to when a material has achieved an optimal level of crosslink density, a second and equally important component of "useful" cure for an adhesive material is the development of sufficient adhesion strength. The mechanisms of the reactions that result in crosslinking and adhesion can be different in adhesive systems, but a sufficient degree of crosslinking and adhesion are both are required if the material is to be considered "cured" to a useful degree. To evaluate adhesion as a function of cure time and temperature for these studies, die shear analysis was performed using a Dage 4000 Die Shear Tester and a 100Kg load cell.

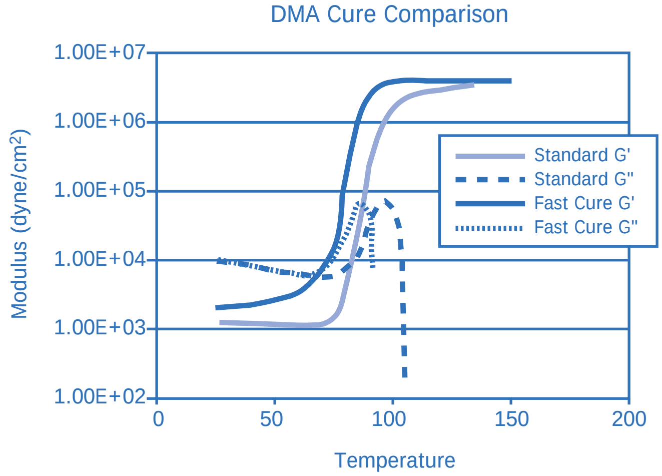
Development of a Low Temperature Cure / Fast Cure 1-Part Thermal Adhesive

The first experiment compared DMA modulus data for the baseline material with data from the improved lower temperature faster cure material (FC-1), as the test temperature increased from 25°C to 150°C at a rate of 2 C/min. As is shown in Table 6 and Figure 1, for FC-1 the increase in G' starts at a much lower temperature than for the baseline material. The slope of the G' line is positive for FC-1, starting at about 30°C. In contrast, the slope of the G' curve for the baseline material remains at zero until approximately 65°C. This difference highlights the fact that FC-1 begins its curing reaction at a much lower temperature than the baseline material. This experiment also shows that FC-1 has a lower gelation temperature than does the baseline formulation. The gelation temperature, the point at which the G' and G" curves cross, is lower by 10°C in the case of FC-1. Finally, the data collected in this experiment shows that FC-1 achieves a plateau in its G' value, an indication of complete cure, about 35°C lower than the baseline material.

Table 6: Comparative Transition Temperatures for Baseline ("Standard") Material vs. FC-1

	Positive G' Slope Temp (°C)	G'G" Crossover Temp (°C)	Plateau Temp (°C)
Fast Cure	30	72	95
Standard	65	82	130

Figure 1: DMA Cure Comparison of Baseline ("Standard") Material vs. FC-1



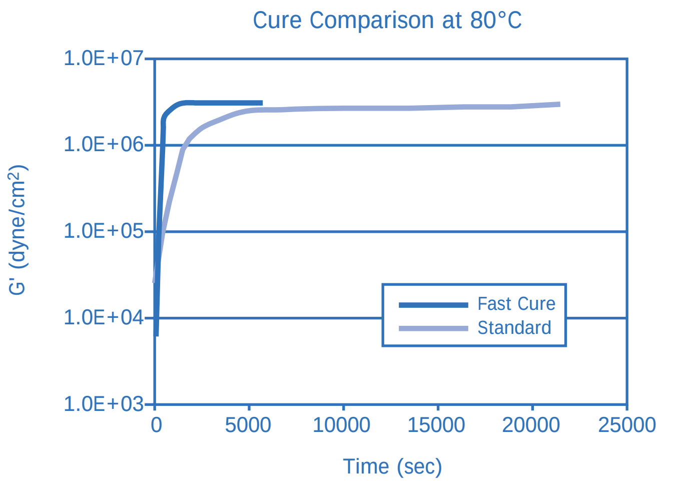
A second experiment, studied the time required to achieve full cure as a function of two different cure temperatures. Table 7 shows that the maximum G' value for FC-1 is reduced by only 8% when the cure temperature is reduced from 150°C to 80°C. This same reduction in cure temperature for the baseline material results in a reduction of 26% in the maximum G' value. A lower plateau value for G' indicates a reduction in crosslink density. The larger the reduction in G', the larger the reduction in crosslink density and the less cured the material is. The fact that the baseline material shows a G' reduction over three times that of FC-1 when cured at 80°C is another indication that the baseline material has a much poorer cure than FC-1 at the low temperature of 80°C. Figure 2 shows the 80°C cure profile comparison of the two formulations.

Table 7: Comparison of Maximum G' Storage Modulus for Baseline ("Standard") Material vs. FC-1

	FC-1		Standard	
Cure Temperature (°C)	80	150	80	150
Final G' (dyne/cm^2)	3.25E6	3.46E6	2.85E6	3.86E6
Maximum G' (dyne/cm^2)	3.29E6	3.56E6	2.88E6	3.88E6
Difference of Final G' vs. Max G' (%)	1	3	1	0
Reduction in Maximum G' at 80°C vs. 150°C (%)	8		26	

Targeted Improvements for Thermal Adhesives (continued)

Figure 2: DMA Cure Time Comparison at 80°C



In Table 8, the elapsed time needed (in minutes) for each formulation to achieve 90%, 95%, and 99% of its maximum G' value for the two test temperatures is recorded. The results show that FC-1 is able to achieve 99% of its maximum G' value after only 35 minutes at 80°C. In contrast, the baseline formulation requires over 4.5 hours (278 minutes) to achieve 99% of its maximum G' value at that temperature. This translates to a reduction in cure time of about 87% for FC-1. Furthermore, as shown in Table 7, the maximum G' value for the baseline material cured at 80°C is less than the maximum G' value when cured at 80°C. This means that even after 4.5 hours at 80°C, the baseline material has achieved a lower degree of cure than FC-1 achieves in only 35 minutes at that temperature.

Table 8: Comparison of Time to Achieve Maximum G' Values for Baseline ("Standard") Material vs. FC-1

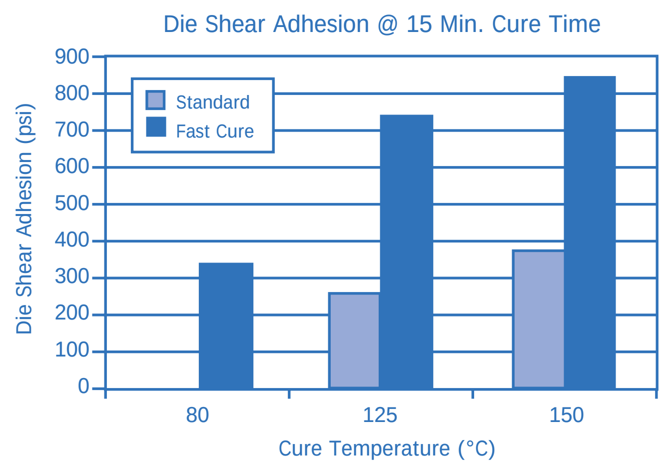
	FC-1		Standard	
Cure Temperature (°C)	80	150	80	150
T-90: Time to Reach 90% of Maximum G' Value (min)	19.3	2.1	128.9	3.2
T-95: Time to Reach 95% of Maximum G' Value (min)	23.4	2.3	183.5	13.7
T-99: Time to Reach 99% of Maximum G' Value (min)	35.4	16.3	278.0	36.8
Reduction in T-99 Cure Time for FC-1 vs. Standard at Cure Temp Indicated (%)	87	55		

A final experiment, documented in Table 9 and Figure 3, illustrates the difference in the adhesive strength for FC-1 and the baseline formulation. Die shear adhesion samples were built with 10 psi assembly pressure in a configuration of Si-TIM-Cr/Al. The results show that FC-1 can achieve a cure of 344 psi after only 15 minutes cure at 80°C, an acceptable value for typical applications. By contrast, the baseline material has not achieved sufficient adhesion or crosslinking after 15 minutes at 80°C when tested in the same manner. At the higher cure temperature of 125°C, FC-1 achieved a die shear adhesion value of over 700 psi after only 15 min cure time. The baseline material does not approach such a high adhesion level, even after curing at the higher temperature of 150°C for 15 minutes.

Table 9. Comparison of Die Shear Adhesion Strength for Baseline ("Standard") Material vs. FC-1

Cure Conditions	15 min @ 80°C	15 min @ 125°C	15 min @ 150°C
Fast Cure (psi) Ave (stdev)	344 (100)	739 (97)	841 (70)
Standard (psi) Ave (stdev)	(no cure)	262 (39)	380 (40)

Figure 3: Adhesion Strength as a Function of Cure Temperature



The above test data show that the cure conditions of the new 1-part formulation, FC-1, were significantly improved over the baseline formulation. The FC-1 material cured faster, at lower temperatures, and yielded higher adhesion than the baseline material. Tables 10 and 11 list the other physical properties tested for FC-1, along with reliability testing data. For ease of comparison with the baseline material, the first column of data in Table 10 contains results for cure conditions of 1 hour at 150°C. A comparison with Table 4 indicates that the physical properties of the FC-1 formulation are comparable to those of the baseline material.

Targeted Improvements for Thermal Adhesives (continued)

Table 10: Physical Properties of FC-1

Cure Conditions	1 hour @ 150°C	1 hour @ 80°C
In-Situ Thermal Resistance (Si-TIM-Al/Cr) (10psi assembly, 0psi cure)	54 mm^2K/W (BLT ~2.5 mil)	
In-Situ Thermal Resistance (Si-TIM-Si) (10psi assembly, 10psi cure	35 mm^2K/W (BLT ~1.7 mil)	35 mm^2K/W (BLT ~1.7 mil)
Die Shear Adhesion (Si-TIM-Al/Cr) (10psi assembly, 0psi cure)	900 psi	900 psi
Lap Shear Adhesion Al substrates, ~5 mm thick	115 psi	
Lap Shear Adhesion Al/Cr substrates, ~5mm thick	175 psi	
Tensile Strength	650 psi	
Elongation (pressure cured sheet)	30%	
Viscosity (10/s shear rate), 25°C	15 Pa•s	

Table 11. Reliability Testing of FC-1

Initial Cure Conditions	1 hour @ 150°C		1 hour @ 80°C	
	Initial	After 250 hours at 85°C/85RH	Initial	After 250 hours at 85°C/85RH
In-Situ Thermal Resistance (Si-TIM-Si) (10psi assembly, 10psi cure	36 mm^2K/W	35 mm^2K/W	36 mm^2K/W	36 mm^2K/W
Die Shear Adhesion (Si-TIM-Al/Cr) (10psi assembly, 0psi cure)	915 psi	1530 psi	925 psi	1500 psi

Targeted Improvements for Thermal Adhesives (continued)

Development of a Room Temperature Cure 2-Part Thermal Adhesive

In this series of experiments the baseline material cure performance was compared with that of the new room temperature cure formulation (RT-2). To prepare the RT-2 material for testing, equal weight ratios of parts A and B were mixed together at room temperature. A standard static mixing machine is capable of achieving a proper mix of these two components.

The first study examined the time required to achieve full cure at 25°C. Die shear adhesion samples were built with 10 psi assembly pressure in a configuration of Si-TIM-Cr/Al. As shown in Table 12, RT-2 can achieve an acceptable level of adhesion within 24 hours at 25°C. In contrast, the FC-1 and the baseline formulations do not cure at all, developing no adhesive strength, even after sitting for 3 days at 25°C.

Table 12: Comparison of Die Shear Adhesion Strength for Baseline ("Standard") Material vs. FC-1 and RT-2

Cure conditions	RT-2 Die Shear Adhesion (psi)	FC-1 Die Shear Adhesion (psi)	Baseline Die Shear Adhesion (psi)
25°C, 24 hours	350	(no cure)	(no cure)
25°C, 3 days	342	(no cure)	(no cure)

A second experiment compared DMA modulus values for the RT-2 formulation at cure conditions of 25°C and 50°C. As shown in Figure 4 and Table 13, the gelation time for this material at 25°C is approximately 1 hour. When the cure temperature is doubled to 50°C, the gelation time is reduced to approximately 1 minute.

Figure 4: DMA Cure Profiles for RT-2 at 25°C and 50°C

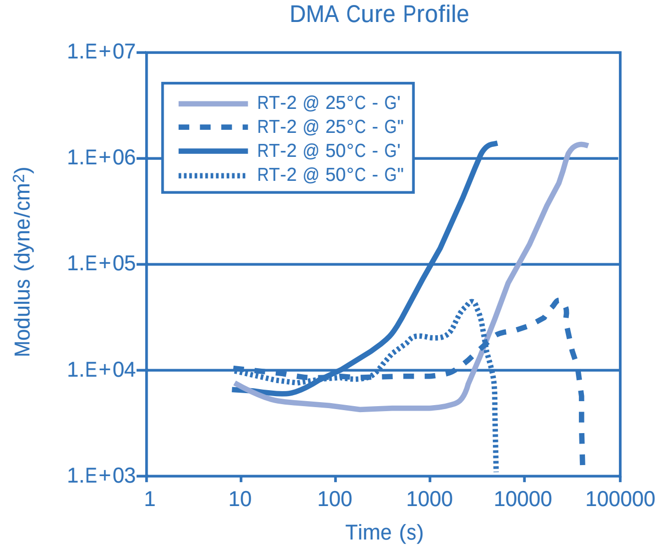


Table 13: Cure Temperature vs. Gelation Time for RT-2

	Cure Temperature (°C)	Time to Reach G'G" Crossover Point (min)
RT-2	25	61.1
RT-2	50	1.2

Targeted Improvements for Thermal Adhesives (continued)

In Table 14, the elapsed time needed for the RT-2 formulation to achieve 75%, 90%, 95%, and 99% of its maximum G' value at the two test temperatures of 25°C and 50°C is compared with cure data for FC-1 and the baseline material. The results show that RT-2 is able to achieve 99% of its maximum G' value in less than 12 hours at 25°C. A cure level of 75% is achieved in less than 8 hours at 25°C. In contrast, neither the FC-1 nor the baseline formulations are able to cure to any extent when held at room temperature for several days at a time.

Table 14: Comparison of Time to Achieve Maximum G' for Baseline ("Standard") Material vs. FC-1 and RT-2 Formulations

	RT-2		FC-1	Baseline
Cure Temp (°C)	25	50	25	25
T-75: Time to Reach 75% of Maximum G' Value (hours)	7.9	0.9	No cure	No cure
T-90: Time to Reach 90% of Maximum G' Value (hours)	9.0	1.0	No cure	No cure
T-95: Time to Reach 95% of Maximum G' Value (hours)	9.6	1.1	No cure	No cure
T-99: Time to Reach 99% of Maximum G' Value (hours)	11.2	1.3	No cure	No cure

The above test data show that the new 2-part formulation, RT-2, cured and developed acceptable adhesion at room temperature, something that neither the FC-1 nor the baseline material could achieve over the course of several days. Table 15 lists the other physical properties tested for RT-2 to date. A comparison with Table 4 indicates that the physical properties of the RT-2 formulation are comparable to those of the baseline material.

Table 15: Physical Properties of RT-2

Cure Conditions	24 hours @ 25°C
Die Shear Adhesion (Si-TIM-Al/Cr) (10psi assembly, 0psi cure)	350 psi
Elongation (pressure cured sheet)	31%
Part A Viscosity (10/s shear rate), 25°C	75 Pa•s
Part B Viscosity (10/s shear rate), 25°C	152 Pa•s

Conclusions

This paper has reviewed the requirements of thermal adhesives for use power supply and medical electronics applications. The key physical properties requirements of thermal adhesives have been described and include: in-situ thermal resistance, die shear adhesion, elongation, viscosity, and reliability. The testing data for a baseline thermal product that meets the outlined performance requirements was presented.

Next, the customer benefits of certain material improvements such as lower cure temperatures, faster cure times, and room temperature cures were explained. Finally, data was presented for two new developmental grades that have been specifically formulated as improvements to the baseline grade. These two formulations offer reduced cure temperature, reduced cure time, design flexibility and lower package stress.

References

[1] Gowda, A., Tonapi, S., Reitz, B., and Gensler, G., "Choosing the Right Thermal Interface Material," Advanced Packaging, March 2005.

[2] Marotta, E., Mazzuca, S., and Norley, J., "Thermal Joint Conductance for Graphite Materials", Electronics Cooling, Vol. 8, No. 3, 2002, pp. 16-22.

[3] Campbell, R. C., and Smith, S. E., "Flash Diffusivity Method: a Survey of Capabilities", Electronics Cooling, Vol. 8, No. 2, 2002, pp. 34-41.

[4] The baseline thermal adhesive described in this paper is the Momentive Performance Materials commercial product SilCool LTR3292.

Principal Locations

Regional Information	Phone	Fax
North America World Headquarters 187 Danbury Road Wilton, CT 06897, USA	800.295.2392	607.754.7517
Latin America Rodovia Eng. Constâncio Cintra, Km 78,5 Itatiba, SP – 13255-700 Brazil	+ 55.11.4534.9650	+ 55.11.4534.9660
Europe, Middle East, Africa and India Leverkusen Germany	00.800.4321.1000 + 31.164.293.276	+ 31.164.241750
Pacific Akasaka Park Building 5-2-20 Akasaka Minato-ku, Tokyo 107-6112 Japan	+ 81.3.5544.3100	+ 81.3.5544.3101

Customer Service Centers

North America
Charleston, WV 25314, USA
E-mail: cs-na.silicones@momentive.com

	Phone	Fax
Specialty Fluids	800.523.5862	304.746.1654
UA, Silanes, Resins, and Specialties	800.334.4674	304.746.1623
RTV Products-Elastomers	800.332.3390	304.746.1623
Sealants and Adhesives and Construction	877.943.7325	304.746.1654

	Phone	Fax
Latin America		
Argentina and Chile	+ 54.11.4862.9544	+ 54.11.4862.9544
Brazil	+ 55.11.4534.9650	+ 55.11.4534.9660
Mexico and Central America	+ 52.55.5899.5135	+ 52.55.5899.5138
Venezuela, Ecuador, Peru, Colombia, and Caribbean	+ 58.212.285.2149	+ 58.212.285.2149
E-mail: cs-la.silicones@momentive.com		
Europe, Middle East, Africa and India		
E-mail: cs-eur.silicones@momentive.com	00.800.4321.1000 +31.164.293.276	+ 31.164.241750
Pacific		
E-mail: cs-ap.silicones@momentive.com		
Japan	+ 81.276.20.6182	
China	+ 86.21.5050.4666 (ext. 1523)	
Korea	+ 82.2.6201.4600	
Singapore	+ 65.6220.7022	

Worldwide Hotline	**800.295.2392**	**+607.786.8131**	**+ 607.786.8309**
Worldwide Web		**www.momentive.com**	

140-009-00E-GL
3/07