Thermally Conductive Adhesive Tapes

A CRITICAL EVALUATION AND COMPARISON

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A well-designed thermal management system involves efficient heat-dissipating components such as heatsinks, air or liquid cooling pipes, and fans. To maximize heat dissipation, choosing the right thermal interface material (TIM) is critical. Thermal resistance of an interface is directly proportional to its thickness, and is inversely proportional to the thermal conductivity of the interface material in the joint. Bulk conductivity is considered in the selection of a TIM, but good wetting is also important. TIMs reduce contact resistance between heat-generating and heatsink components by filling air gaps between contact surfaces. TIMs are designed to conform to surface irregularities, eliminate air gaps, and improve heat flow; and include grease, compounds, gels, pads, phase change materials (PCMs), metallic solders, and tapes.

THE SHORT STORY

Thermally conductive adhesive tapes are used extensively to bond heatsinks to microprocessors and other heat-generating microelectronic components. Critical practical performance factors for tapes include peel strength, lap- and die-shear strength, holding power, and thermal resistance.

Thermally conductive adhesive tapes are considered to be convenient for heatsink attachment with mid-range thermal performance. The double-sided pressure-sensitive adhesive (PSA) films are filled with thermally conductive ceramic or metallic powder, which requires initial contact pressure to conform to irregularities in the mating surfaces. They eliminate the need for external clamps and curing processes. PSAs are mainly acrylics, silicones, rubber, or styrene; the adhesives act like elastomerics on substrates in contact, but show somewhat viscous behaviors under external pressure. Thermal tape choice depends on the substrate and its surface energy. Acrylic PSA adheres to either metallic or ceramic substrates, while silicone PSA is well-suited for plastic components. However, due to improved substrate finish, some qualified acrylic PSAs can be used for various substrates. A thermal tape is usually supported with a carrier film for strength and ease of handling. A metallic carrier, such as aluminum foil, may also provide improved thermal conductivity. Conversely, a polyimide support may provide electrical insulation. Because of the carrier, thermal tapes can be less conformal and conductive than compounds. Thin and loose fiberglass weave mat can be used as a carrier to provide improved conformability.

FIGURE 1. A simplified diagram for the test set-up.

Bond-line thickness and dielectric properties should also be considered. Thick tapes provide good conformability and wetting on substrates, and a thick PSA layer may experience creep behavior induced by the weight of a vertically attached heatsink. Adhesive deformation in bonding — including shear and creep resistance — is related to the viscoelastic response of the PSA upon a given stress.

Experimental Approach

Thermal performance of newly developed acrylic PSA tapes of various thicknesses, consisting of alumina fillers and a glass fabric carrier, were investigated and compared with other thermal tapes using two methods. A non-conductive acrylic transfer tape of 10-mil thickness was also compared.

One method is based on steady heat flux condition. The other was application-oriented, measuring junction temperature difference between two substrates in which a sample was placed (Figure 1). The junction temperatures were measured using the temperature dependence of the diode voltage on the die.

Lap-shear strength was measured using a 25.4- × 25.4-mm adhesive tape sandwiched with two overlapping aluminum substrates. The lap-shear samples were prepared by applying 10 psi

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(69kPa) for 10 seconds. Peel strength measures the force required to remove a thermal tape from a substrate. A 127- × 25.4-mm section of thermal tape was placed on aluminum substrate and pressure was applied. The peel strength was measured with 90° pulling from the substrate. Another critical adhesive strength measurement method for thermal tapes is a holding-power shear-hang test, which hangs a certain weight (typically 1000 g) pulling down on the tape attached on a vertically placed substrate with 25.4- × 25.4-mm bonding area. Hang times on various substrates were measured at ambient or elevated temperatures. The holding-power shear-hang test would be directly related to the prediction on heatsink failures in industry. Unlike lap shear tests, the hang test simulates actual heatsink attachment. High-power semiconductor components require bigger and heavier heatsinks, resulting in severe creep failure on adhesive.

Creep-induced adhesion failure under a constant force was investigated by using a thermal analyzer (TA) device. One disadvantage of the shear-hang test is that the actual bonding area is not a constant during testing. As a hanging weight continues to pull down the adhesive from the substrate, the contact bonding area decreases, and the bonding area is exposed to the increasing hanging load. To prevent this, a TA instrument provides a constant pulling force on the bonding area.

Experiment Results

Adhesion shear strength is important to determine bonding performance, but the desired adhesion strength cannot be achieved if the adhesive does not have a good initial contact with a substrate. Usually, thermal tapes are not thick enough to provide good conformability. This is a reason for heatsink failure, even if the adhesive is strong and shear-resistant. Though heatsinks and components appear flat, the surfaces are very rough microscopically. The wetting of an adhesive on a substrate determines peel strength. If the tape is thick enough to provide better conformability, the peel strength will be higher. Thermal tapes were prepared with three thicknesses; the thicker tape showed the better peel strength, achieving better wetting on aluminum substrates. Even under the same shearing condition, bulkier adhesive would have higher defect/void concentrations, which may lead to shear failures in a joint (Figure 2).

Lap-shear samples were aged at various temperatures and tested for shear strength and strain. The lap-shear strength of thermal tape continued to increase without indicating any thermal degradation, and the shear strain showed decreased values, indicating that the molecular weight of the aged adhesive increased by further curing, and adhesives became harder and would show higher shear strength as they hardened or toughened. Tape hardening can result in poor mechanical/vibration resistance. Still, the elongation or strain values were higher than many thermal tapes based on an internal comparison study.

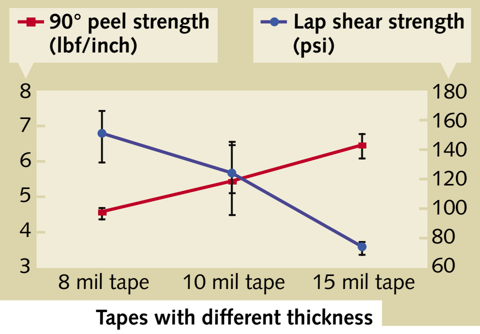

FIGURE 2. Measurement summary with various heating powers when 10 psi (69kPa) of pressure is applied for tape attachment.

Good adhesion performance of thermal tapes means that reliable joints between heatsinks and semiconductor components can be achieved, even with poor surfaces and no mechanical fasteners. However, adhesive strength changes as a function of application temperatures, because of temperature-dependent viscoelastic behavior of PSAs. Bonding pressure is also important for good adhesion. However, if a thermal tape is thick enough, the effect of the bonding pressure would not be significant.

Thermal properties of the tapes are also dependent on thickness. Assuming tapes with different thickness would have similar contact resistance, the bulk resistance is directly related to the thickness. Impedance values are plotted against thickness and the slope is an inverse of thermal conductivity.

On the other hand, when American Society of Test and Materials (ASTM) tests were conducted on aged-tape samples, the trend in thermal impedance values was not clear.

Alternatively, the thermal performance of thermal tapes was evaluated by an application-oriented heatsink attachment method. Several tapes were tested as a TIM between a heatsink and a heat plate. Then the system was screw-tightened to a heating device consisting of a microprocessor chip. Grease was used as TIM1, which refers to the TIM used between the microprocessor chip and the heat spreader. TIM2s, such as the thermal tapes in this study, are designated as those between the heat spreader and heatsink. The temperature difference between heat plate and heatsink would be directly related to the thermal performance of the tape; the smaller the difference, the better the thermal performance (conductivity). The temperature difference was the smallest for grease (used as TIM2) and the largest for the non-thermal tape. The temperature difference seemed to be more dependent on tape thickness than possible thermal conductivity differences. Using a tape thicker than 10 mil seemed to have no merit for thermal performance (Figure 3). For the most part, the quality of the two joining surfaces would determine the amount of contact achieved and the expected thermal performance.

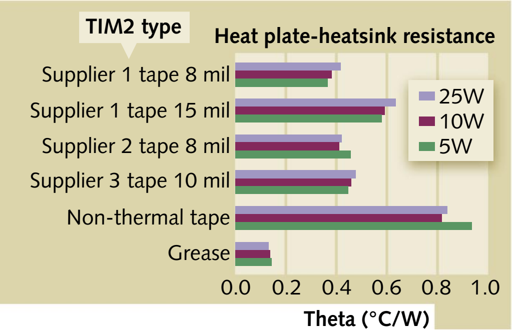

FIGURE 3. Shear strength decreases with thickness.

Shear strength decreases as tape thickness increases, and is also de-

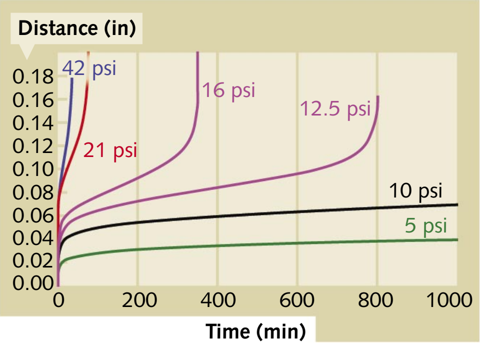

FIGURE 4. Results of the holding-power shear-hang test.

pendent on the substrate type. Aluminum and stainless steel substrates provide relatively strong bonding with the acrylic thermal tape compared to plastic or ceramic substrates. The 10-mil tape survived up to a 10-lb pulling force and showed less than 10% of creep deformation (Figure 4).

Conclusion

This study investigated critical performance of thermal tapes such as lap-shear strength, peel strength, holding power (shear creep resistance), thermal performance, and desirable thickness for balanced tape performance. Shear and creep resistance of a thermal tape can be related to deformation of the adhesive layer. High peel strength and good wetting would provide balanced adhesion properties. Improved conformability resulted in maximum adhesion between less-than-planar package and heatsink surfaces. A good adhesive contact area can minimize thermal resistance values in package systems.

The convenience of thermal tapes does not come without risk. Sometimes the thermal resistance for a thick tape can be only slightly better than a dry joint or air gap. Thermal performance would be carefully evaluated along with shear-creep resistance data of the tapes.

Generally speaking, the tapes' thermal resistance values may not be as critical in selecting the right tape. However, excellent thermal tapes must show good conformability and adhesion properties without losing thermal properties.

Joint reliability including shear and creep resistance should be investigated by TIM manufacturers, end users, and OEMs. The chemical and physical characteristics of thermal tape and the application environment must be considered. While one performance of a thermal tape is not deteriorated by heat aging, performance of other properties is not guaranteed. Achieving product reliability requires an understanding of the adhesion failure mechanisms.

Thermal tapes as a TIM function as a strong attachment between a heatsink and heat-generating component with proper heat conduction. They should be designed to meet the microelectronic packaging industry's strict requirements. **AP**

REFERENCES

Contact the author for a complete list of references.

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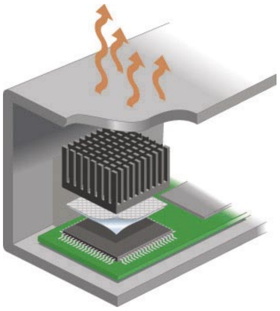

THERMATTACH Tapes

Thermally Conductive Double-Sided Adhesive Tapes

Material	Thickness mm (Inches)	Carrier	Lap Shear Adhesion (ASTM D1002 Al-Al), MPa (psi)	Thermal Impedance (ASTM D5470), °C-cm^2/W (°C-in^2/W)	Flammability Rating (UL94), See UL File E140244 for Details	RoHS Compliant	Comments
T418	0.25 (0.010)	Fiberglass	1.4 (200)	7.7 (1.2)	V-0	Yes	Superior attachment strength, acrylic adhesive
T412	0.23 (0.009)	Expanded Aluminum Mesh	0.48 (70)	1.6 (0.25)	Not Tested	Yes	Highest thermal performance, acrylic adhesive
T411	0.28 (0.011)	Expanded Aluminum Mesh	0.27 (40)	6.5 (1.0)	Not Tested	Yes	**Silicone adhesive**, recommended for plastic components
T404	0.13 (0.005)	Kapton® MT	0.86 (125)	3.9 (0.60)	V-0	Yes*	Electrically insulating acrylic adhesive
T405	0.15 (0.006)	Aluminum	0.93 (135)	3.2 (0.50)	V-0	Yes*	High strength acrylic adhesive
T405-R	0.15 (0.006)	Aluminum	0.93 (135)	3.2 (0.50)	Not Tested	Yes	T405 without brominated flame retardant
T413	0.18 (0.007)	Fiberglass	0.69 (100)	4.2 (0.65)	Not Tested	Yes	Ionically clean, conformable acrylic adhesive
T414	0.13 (0.005)	Kapton® MT	0.69 (100)	3.9 (0.60)	Not Tested	Yes	Low ionic content T404 without brominated flame retardant

*RoHS compliant per exemption October 13, 2005. EU document # C(2005) 3754. Contains an EU acceptable brominated flame retardant.

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