Selection Criteria for Thermal Interface Materials

By: Thomas Ollila, Thermal Marketing Manager

Introduction

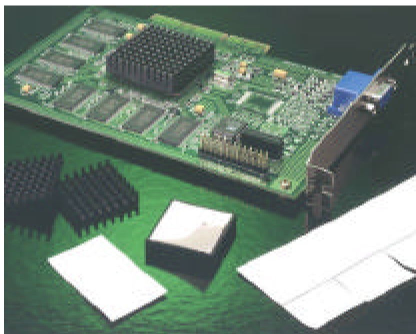
As each new generation of electronic products squeezes more power and performance into ever smaller packages, the relative importance of Thermal Management within the overall product design continues to increase. An integral part of this thermal design process is the selection of the optimal Thermal Interface Material (or "TIM") for a specific product application. This article will describe the general characteristics of the major families of TIMs and examine the trade-offs involved in the selection process. Hopefully, this information will be a valuable tool that electronic packaging engineers can use to help meet the thermal design challenges of the next "hot" product.

Why are Thermal Interface Materials (TIMs) Needed?

Heat generated within a semiconductor component must be removed to the ambient environment to maintain the junction temperature of the component within safe operating limits. Often this heat removal process involves conduction from the component package surface to a heat sink or heat spreader that can more efficiently transfer the heat to the ambient environment. This heat sink/spreader has to be carefully joined to the package to minimize the thermal resistance of this newly formed thermal joint or interface.

Attaching a heat spreader to a semiconductor package surface requires that two commercial grade surfaces be brought into intimate contact. These surfaces are usually characterized by a microscopic surface roughness superimposed on a macroscopic non-planarity that can give the surfaces a concave, convex or twisted shape. When two such surfaces are joined, contact occurs only at the high points. The low points form air-filled voids. Typical contact area can consist of more than 80 percent air voids, which creates a significant resistance to heat flow.

TIMs are used to eliminate these interstitial air gaps from the interface by conforming to the rough and uneven mating surfaces. Since TIMs have significantly greater thermal conductivity than the air they replace, the resistance across the interface decreases, and the component junction temperature will be reduced.



Three-dimensional video graphics boards are an example of an application for thermally conductive adhesive tapes.

Phase-change materials combine grease-like thermal performance with pad-like handling and installation convenience.

Families of TIMs

A variety of TIMs have been developed in response to the changing needs of the electronic packaging market and can be categorized into the following families:

- Elastomeric Pads/Insulators
- Thermally Conductive Adhesive Tapes
- Phase Change Materials
- Thermally Conductive Gap Fillers
- Thermally Conductive “Cure in Place” Compounds
- Thermal Compounds or Greases
- Thermally Conductive Adhesives

Elastomeric Pads/Insulators were developed as a user-friendly alternative to greased mica insulators to be used between discrete power devices and heat sinks. This class of product is characterized by high thermal conductivity, very high dielectric strength and volume resistivity. Pads can conduct very large heat loads from discrete power semiconductors to heat sinks, while providing long term electrical insulation between the live component case and the grounded heat sink. To work effectively thermal pads require very high (greater than 200psi) clamping pressures.

Thermally Conductive Adhesive Tapes are acrylic or silicone pressure-sensitive adhesive tapes designed to securely bond metal heat sinks to power dissipating components. Thermal tapes are used primarily for their mechanical adhesive properties, and to a lesser extent for their thermal properties. The thermal conductivity of these tapes is moderate and their thermal performance in an application is highly dependent on the contact area that can be achieved between the bonding surfaces.

Phase Change Materials provide a combination of grease-like thermal performance with pad-like handling and installation convenience. They are most commonly used between high performance microprocessors and heat sinks. Phase change materials are solid at room temperature but behave like thermal pastes or greases after they reach their phase change or melt temperature. These materials do not undergo a true phase change and turn into a liquid, but their viscosity does diminish rapidly and they flow throughout the thermal joint to fill the air gaps that were initially present. This process requires some compressive force, usually a few psi, to bring the two surfaces together and cause the material to flow. This process continues until the two surfaces come into contact at a minimum of three points, or the joint becomes so thin that the viscosity of the material prevents further flow. These materials do not provide electrical isolation because they may allow the two surfaces to come in contact.

Thermally Conductive Gap Fillers are low modulus (soft), thermally conductive silicone elastomers for applications where heat must be conducted over a large and variant gap between a semiconductor component and a heat dissipating surface. Gap fillers are used to bridge large gaps between hot components and a cold surface. The gaps are not only large, but their tolerances can be +/- 20 % or greater. This means that the gap filler must have sufficient pliancy to fill such spaces without stressing components beyond their safe limits. The thermal conductivity of these materials is in the moderate range and their use is typically limited to moderate to low power dissipation components.

Thermally Conductive “Cure in Place” Compounds are reactive, one or two-part silicone RTVs (room temperature vulcanizing) or similar compounds that can be used to form thermal pathways in applications where the distance between a component and a cold surface is highly variable. A typical application would be a PCB with many different height components which need to be brought into contact with a chassis or heat sink. Once cured these materials have properties similar to the thermally conductive gap fillers described above.

Thermal Compounds or Greases are typically made up of a silicone oil with a heavily loaded suspension of a thermally conductive ceramic filler. The actual bulk thermal conductivity of the resulting material is not high, however, since the paste like consistency of the thermal grease allows the final bond line thickness to be very thin, the resulting thermal impedance across the interface can be quite low. Thermal greases were the original TIM, they have a long, proven history and continue to be used in many applications. As a two part suspension, thermal greases can separate and dry out over time. Their paste like nature, while great for thermal performance, can lead to inconsistent and messy application issues.

Thermal Adhesives are one or two part adhesive systems which have been loaded with ceramic fillers to enhance the thermal conductivity of the bulk material. They are typically used to bond small heat sinks to board level components, thus eliminating the need for clips, screws or other mechanical fasteners to hold the heat sink in place. As a structural adhesive thermal adhesives are particularly useful for boding surfaces which are significantly rough or bowed.

1. **Elastomeric Pads/Insulators** are typically supplied as die cut parts for standard component package types
2. 3D Video Graphics Cards are an example of an application for Chomerics' THERMATTACH™ **Thermally Conductive Adhesive Tapes**
3. Chomerics' THERMFLOW™ **Phase Change Material** shown in a typical microprocessor heat sink application.
4. Chomerics' THERM-A-GAP™ **Thermally Conductive Gap Fillers** are often used in flat sheet or molded forms on PCB level applications.
5. For variable gap applications on stress sensitive components, Chomerics THERM-A-FORM™ **Thermally Conductive "Cure in Place" Compounds** provide a reliable thermal connection between component and heat sink.

Typical properties and applications for thermal interface materials

TIM CATEGORY	THICKNESS (in.)	AVAILABLE REINFORCING CARRIERS	DIELECTRIC STRENGTH (Vac)	THERMAL IMPEDANCE ($^{\circ}$C-in.^{2}/W) (Lower value is better)	APPARENT THERMAL CONDUCTIVITY (W/m-K) (Higher value is better)	TYPICAL COST ($/sq in.)	FEATURES
ELASTOMERIC PADS/INSULATORS	0.003 to 0.030 in.	Fiberglass Aluminum Foil Kapton	2,000 to 14,000	0.15 to 0.65	0.7 to 3.0	0.03 to 0.30 0.08 typ	• Often used primarily as electrical insulator. • Silicone binder provides high-temperature stability. • Glass mesh reinforcement or Kapton film provide cut-through resistance. • High mounting pressure required to minimize contact resistance. • U.L. recognized.
THERMALLY CONDUCTIVE ADHESIVE TAPES	0.005 to 0.015 in.	Free Film Fiberglass Aluminum Foil Expanded Aluminum Kapton	0 to 6,000	0.20 to 1.50	0.3 to 1.7	0.06 to 0.30 0.15 typ	• Acrylic-based adhesives for metal or ceramic packages. • Silicone-based adhesives for bonding plastic packages to metal heat sinks. • Ionically pure formulations for use inside component packages and on pc boards. • Limited gap-filling properties since thin tapes typically require reasonable surface flatness.
PHASE-CHANGE MATERIALS	0.002 to 0.012 in. (as supplied) 0.001 to 0.008 in. (final bond line)	Free Film Fiberglass Aluminum Foil Kapton	2,000 to 5,000 (for dielectric carrier versions only)	0.02 to 0.25 0.4 to 0.5 (dielectric versions)	0.5 to 1.9	0.06 to 0.30 0.12 typ	• Solid at room temperature for easy handling and installation. • Softens and flows at operating temperature to minimize bond line thickness. • Excellent surface wetting eliminates contact resistance.
THERMALLY CONDUCTIVE GAP FILLERS	0.020 to 0.300 in.	Molded Parts Internal Fiberglass External Fiberglass Aluminum Foil Polyester	100 to 400 V/mil	0.3 to 4.0	0.7 to 5.0	0.20 to 0.90 0.30 typ	• Soft binders provide low modulus for conformability at low pressures. • Conformable, low modulus allows materials to make up for large-tolerance stack-ups.
THERMALLY CONDUCTIVE CURE-IN-PLACE COMPOUNDS	—	—	100 to 400 V/mil	0.3 to 4.0	0.7 to 3.0	0.12 to 0.45 0.25 typ	• Typically BNi_2- or AlO_2-filled low-modulus resin systems. • Fill gaps ranging from 0.005 to 0.25 in. without stressing components. • Can cure at room temperature. • Localized encapsulating of components.
THERMAL COMPOUNDS OR GREASES	0.0005 to 0.005 in. (final bond line)	—	—	0.02 to 0.20	0.7 to 4.0	0.01 to 0.12 0.02 typ	• Can be used with mica or other dielectric for insulating components. • Excellent thermal performance. • Special handling, process controls required to ensure consistent application. • Can be subject to separation or dry out over time.
THERMALLY CONDUCTIVE ADHESIVES	0.003 to 0.025 in.	—	—	0.08 to 0.40	0.7 to 4.0	0.03 to 0.20 0.08 typ	• Structural adhesives with more thermally conductive fillers. • Tradeoff between high strength and thermal performance. • Can fill relatively large gaps between heat sink and component. • Require special handling and processing steps.