Beat *the* Heat

Today's low-power electronic devices can throw off a lot of heat, and engineers must find ways to dissipate it.

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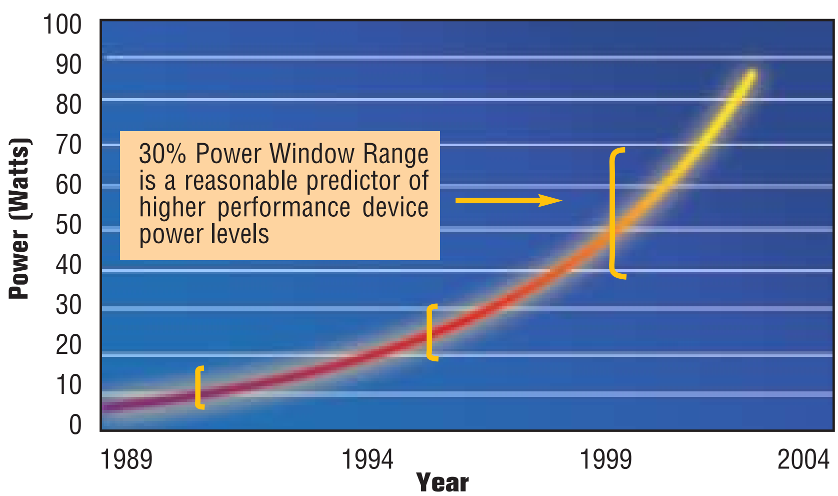
In 1946, Dick Tracy strapped on a two-way wrist radio and modernized crime fighting in the comic pages of America. Some 20 years later, in 1964, Chester Gould's fictional detective upgraded to a two-way wrist TV. Then, in 1986, Tracy began wearing a two-way wrist computer.

Power Requirements Increase With Processor Performance



Chips that once ran at less than 0.25 watt are now running at 20 watts or more. Engineers who once thought that heat was not a problem in their products now have to consider the same issues as engineers responsible for "hot" devices.

Those electronic inventions were science fiction when they were introduced, but they were more prophetic than most readers imagined. Not only did the inventions themselves closely approximate eventual reality, but so too did the pattern of adding more power and more functions in the same or smaller space.

Unfortunately, the comic strip doesn't provide answers that engineers can use to solve technical problems associated with squeezing more power and function into a tight area. One such problem is thermal management. The two-way wrist TV would have been hot to the touch without sufficient thermal management. And even if Tracy had put up with the heat, reliability would have been an issue. The screen could have gone blank just before the crime was solved.

Today, expensive, high-power processors and graphic devices run at a "hot" 20 to 50 watts and above. Some sophisticated microprocessors run at 50 to 100 watts and higher. As these devices add function and speed to shrinking boards, thermal management will be an ongoing challenge with evolving solutions.

There is no reason to buy more thermal conductivity than necessary to meet the specifications of low-power devices.

An Emerging Issue

The increasing speed of expensive processors is forcing less expensive "associated board" devices to keep up. Consequently, thermal management is becoming an issue for application-specific integrated circuits, memory, power resistors, controller chips, LEDs and other traditionally low-power devices that comprise 70 percent to 80 percent of all the components on a circuit board. For example, a controller chip running at 0.25 watt a few years ago may now be as high as 2 watts.

Engineers who once thought that heat was not a problem in their products now have to consider the same issues as engineers responsible for “hot” devices. These include:

- What is the power level of the device and how hot will it get?
- What type of thermal interface material is needed between the package and heat sink?
- What level of thermal impedance is necessary?
- How will the thermal interface material be applied?
- How reliable is the interface material?

These design challenges are not as daunting as they may appear. Devices that consume less than 20 watts of power do not have the same heat dissipation requirements as devices that consume 50 to 100 watts of power. To meet the maximum temperature specifications for high-power applications, engineers may need an interface material with the lowest possible thermal impedance. Such costly materials are rarely necessary for less expensive, low-power devices. As a result, engineers have a greater number of thermal management options for low-power devices.

Thermal Interface Design

Mounted to a ball grid array, a powered silicon chip generates heat that can degrade or destroy its functionality. To prevent that from happening, this heat must be removed from the chip as quickly as possible.

Two devices accomplish this goal: heat spreaders and heat sinks. Usually made of a copper alloy, the heat spreader is attached directly to the silicon. As its name implies, it transfers heat away from the chip and spreads it out over a large area. The heat sink is attached to the heat spreader. Made of copper or aluminum, the heat sink dissipates heat through multiple fins. To ensure efficient heat transfer, a thermally conductive material must be inserted between the silicon and the heat spreader, and between the heat spreader and the heat sink.

This material can be an adhesive or some other thermally conductive material. If a nonadhesive material is used, a separate mechanical attachment, such as a clip, is necessary to hold the surfaces together. Adhesive holds the surfaces together by a combination of adhesion and cohesion. Adhesion is the force that holds surfaces together through mechanical and molecular attraction. Cohesion is the attraction of particles within the adhesive that holds the mass together.

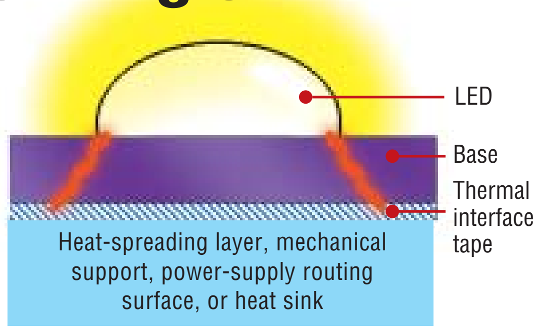
Nonadhesive interface materials are more widely used than adhesives. Nonadhesive materials include thermal greases, phase change materials and gap-filling pads. Adhesives include thermosetting liquids, pressure-sensitive adhesive (PSA) tapes, and thermoplastic or thermosetting bonding films.

With nonadhesive materials, engineers do not need to balance as many properties as they do with adhesives. For example, increasing the density of thermally conductive fillers in liquid adhesives increases their viscosity and can adversely affect application. Fillers are ceramic or metal particles chosen for their dielectric properties, color, cost and overall effect on the mechanical properties of the adhesive, grease or other interface material. Because thermal energy flows by jumping from one conductive particle to the next, thermal conductivity increases with an increase in filler density.

Too much filler in adhesive tape can lessen its conformability and wettability, increasing interfacial impedance. On the other hand, a high filler load in grease simply increases its bulk conductivity.

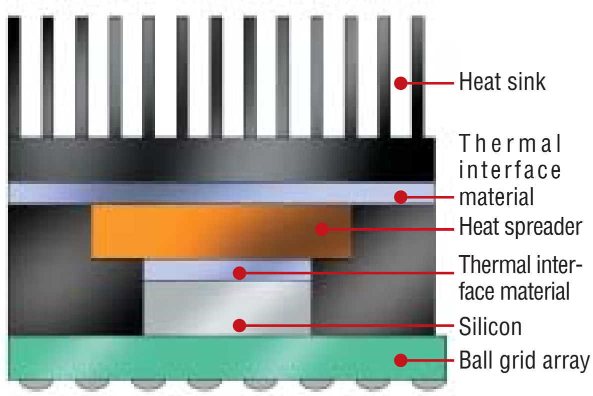
For a better understanding of thermal interface options, adhesive and nonadhesive interface materials can be categorized as “old” and “new.” Old materials include silicone greases, PSAs,

Cooling Off an LED



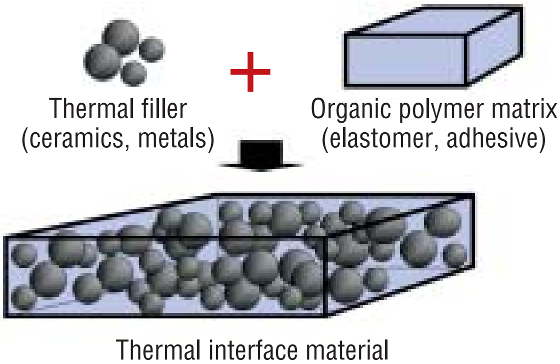
The increasing speed of expensive processors is forcing less expensive “associated board” devices to keep up. Consequently, thermal management is becoming an issue for LEDs, application-specific integrated circuits, and other traditionally low-power devices that comprise most of the components on a circuit board.

Cooling Off a BGA



The silicon chip inside a ball grid array can generate enough heat to degrade its functionality. Heat spreaders and heat sinks dissipate this heat. To ensure efficient heat transfer, a thermally conductive material must be inserted between the silicon and the heat spreader, and between the heat spreader and the heat sink. This material can be an adhesive or some other thermally conductive material.

Anatomy of a TIM



Most thermal interface materials—including thermal pads, tapes, phase change materials and epoxies—consist of ceramic or metal particles suspended in an organic polymer. Thermal conductivity increases with filler density.

epoxies and acrylic adhesives. New materials include nonsilicone greases, phase change materials, and silicone or elastomer pads. Both old and new materials can be formulated with or without thermally conductive fillers.

Silicone greases are inexpensive. They have the lowest thermal impedance of any interface material because of their good wettability, thinness, and moderate to high bulk conductivity. Grease fills surface irregularities, even grossly uneven areas if enough grease is applied. They are commonly applied between processor chips and heat sinks.

PSA tapes are neat and easy to use. They bond on contact without mechanical fastening, and they provide good wettability for low impedance. They are commonly used to bond heat sinks to controller chips.

Epoxies and acrylic adhesives provide structural-strength bonds with thin bond lines and good wettability for low impedance. The epoxy can be a one-part, heat-curing formulation or a two-part, room-temperature-curing formulation. With an acrylic adhesive, an activator is applied to one surface followed by the base resin. These adhesives are used to bond heat sinks to very high-power components.

Nonsilicone greases do not contain siloxane. Non-silicone grease generally performs well, but it may not have the environmental resistance of silicone greases. Siloxane-free products permit a thin interface, and they have good thermal impedance.

Phase change materials are neater to use than grease. "Phase change" refers to the melting of the binder at the approximate operating temperature of the component to be cooled. The melting binder wets both surfaces to create a thin thermal joint with low impedance. They are commonly used between a central processing unit (CPU) and a heat sink.

Silicone or elastomer pads loaded with thermally enhanced fillers are thick and soft. They conform to fill gaps and achieve a high level of thermal conductivity. They are typically used between the CPU of a portable computer and the heat spreader and chassis.

For the most part, the new materials have improved upon the old ones for thermal impedance, ease of use, and reliability. But both the "old" and "new" have limitations.

Silicone greases are messy and can migrate to contaminate the soldering process or device leads. Because grease has no holding power, the heat sink must be attached mechanically. The adhesive strength of tapes weakens as filler density increases, and tapes are ineffective for devices above 20 watts. Historically, PSAs will not completely wet both surfaces. Epoxies and acrylic adhesives can be messy, and they require fixturing while they cure.

Nonsilicone greases require the heat sink to be mechanically attached. Phase change materials are delicate. They require a heat cycle and mechanical attachment of the heat sink. Their thermal impedance is usually higher than grease. Pads are nontacky or slightly tacky and require mechanical clamping. Woven glass or other scrim may be required to achieve enough mechanical strength for efficient handling.

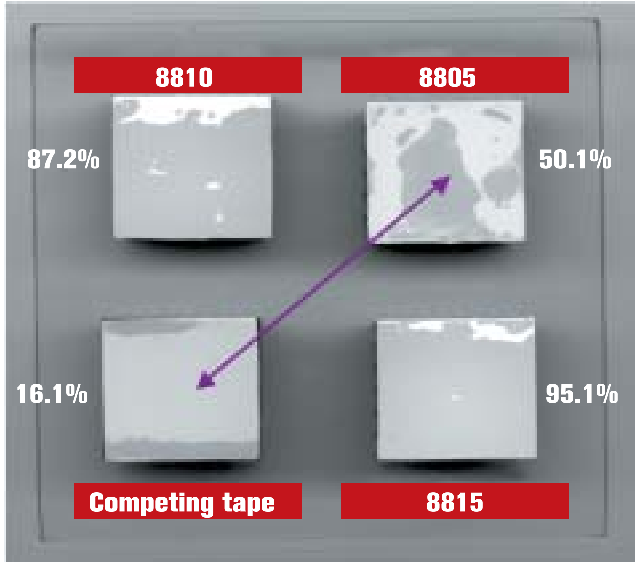
Thermal Interface Options

Technology	Thermal conductivity vs air*	Pro	Con
Grease	20-185x	Thin, low cost. Thin = low impedance. Good wetting.	Messy. No adhesion, so mechanical attachment of heat sink is necessary. Silcone contamination.
Liquids	20-125x	Thin = low impedance. High bond strength Good wetting	Messy. Pot life of epoxy. Needs cure time and fixturing.
Phase change	20-125x	Good wet-out. Less messy than grease. Thin = low impedance.	No adhesion, so mechanical attachment of heat sink is necessary. Initial heat cycle.
Tapes	20-40x	Good wet-out. No mechanical fasteners. Ease of use.	Typically used in applications less than 20 watts.
Pads	35-500x	Greater thicknesses. Very soft, comfortable. Gap filling.	Light adhesion, so mechanical attachment is necessary. Cost due to thickness.
Solder, metal phase change materials	500-1,000x	Thin thickness. High conductivity. Gap filling.	Difficult to apply. Low viscosity when melted. High-cost materials.

* The thermal conductivity of air is 0.02 watts per meter-kelvin.

With the emerging challenge of thermal management for low-power devices, engineers are re-examining older interface materials to see if they can be more cost-effective than the new materials. There is no reason to buy more thermal conductivity than necessary to meet the specifications of these devices.

Comparing Wettability



3M's Series 8800 thermally conductive adhesive transfer tapes have excellent wetting ability. In this test, the tapes were used to bond an aluminum heat sink to a glass slide. All three tapes adhered to significantly more of the slide than a competing tape.

Next-Generation "Older" Technology

3M's Series 8800 thermally conductive adhesive transfer tapes were engineered specifically to meet the cost and performance needs of low-power devices. Each tape consists of a tacky PSA without a carrier, but with high cohesive strength. Spanning the full thickness of the tape, the adhesive is loaded with thermally conductive ceramic fillers that provide a preferential heat-transfer path. The adhesive has good adhesion, wetting and thermal characteristics, and it is soft enough to conform to nonflat surfaces.

In independent testing by Underwriters Laboratories, the four tapes in the series met UL-746C requirements for operating temperature, humidity resistance and dielectric breakdown strength. The tapes also satisfied requirements for thermal impedance stability.

Before applying the tape, the substrates should be wiped with isopropyl alcohol (not denatured alcohol) to remove dust and fingerprints. To remove grease, machine oils and solder flux, a solvent, such as acetone, is necessary.

The tape is applied to only one surface and pressed with a finger or roller to maximize contact. The liner is then peeled off, and the parts are compressed together for good wetting.

Pressure and duration depend on the part design. For example, rigid parts are more difficult to bond without air entrapment, since they are generally not flat. The preferred pressure at room temperature is 5 to 15 psi for 5 seconds. Using thicker tape will help compensate by filling space between irregularities. A twisting motion while assembling rigid parts to rigid parts will also improve wetting.

Heat can be applied after assembly to increase wetting and build room-temperature bond strength.

Engineers have multiple options for thermal management for low-power devices. The optimal choice will balance the cost and performance of the material with the cost and performance of the device. The lowest possible temperature is not necessary for less expensive, low-power devices.

Next-generation thermally conductive tapes should be evaluated for devices operating at 20 watts or less. When the two-way wrist computer/global positioning system/high-definition TV/mini-CD recorder goes into production, easy-to-apply tapes may be at work keeping it cool and reliable.

To discuss thermal conductivity for your low-power device, contact Jeff McCutcheon (651-733-6199 or jwmccutcheon@mmm.com), or Cameron Murray (651-736-9294 or ctmurray1@mmm.com). **A**

Thermal Performance of Thermally Conductive Tapes

Product	Conductivity (watts/meter-kelvin)	Thickness (mils)	Impedance* (degree C-square inch/watt)
8805	0.6	5	0.48
8810	0.6	10	0.88
8815	0.6	15	1.17
8820	0.6	20	1.5

* Impedance is tested between an aluminum panel and power resistor to reflect "real world" surfaces and interfaces.

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