Thermal Management of

Hybrid Electronic Devices

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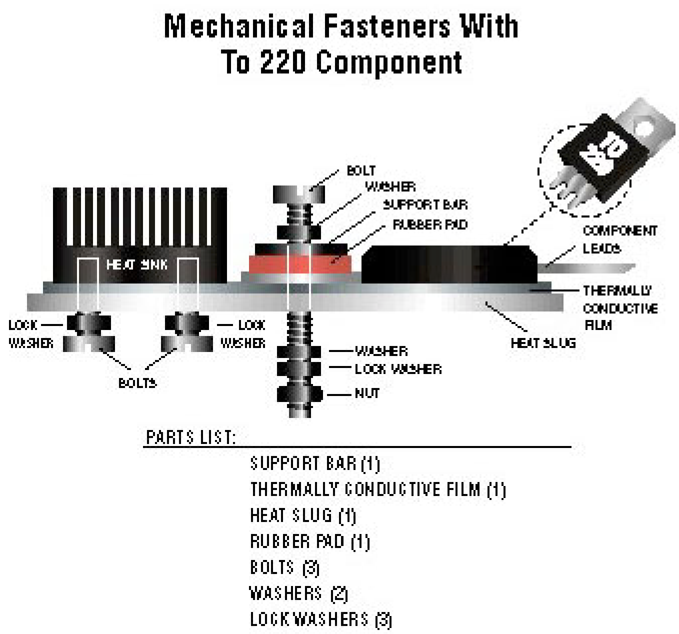
Thermal management is a growing challenge in the electronics industry. As the overall size of electronic devices grows smaller, the enclosed electronic assemblies operate at higher frequencies and generate more heat. Increasing input/output (I/O) counts, which make devices faster in cycles per second, also cause electronic devices such as ASIC and other hybrid devices to generate greater amounts of heat. This heat, which can decrease the effectiveness and shorten the component's overall life, must be quickly and effectively dissipated in order for devices to function effectively.

Electronic device manufacturers rely upon heat sinks attached to integrated circuits (IC's) to diffuse excess heat. These heat sinks are attached using mechanical fasteners, thermally conductive adhesives, greases, tapes, and/or pressure sensitive pads. All of these methods are not equal in their operating effectiveness, their thermal management capabilities, or their ease of application.

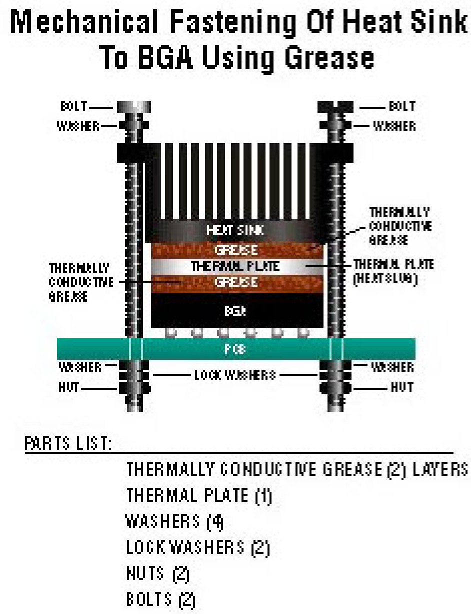
Mechanical Fastening



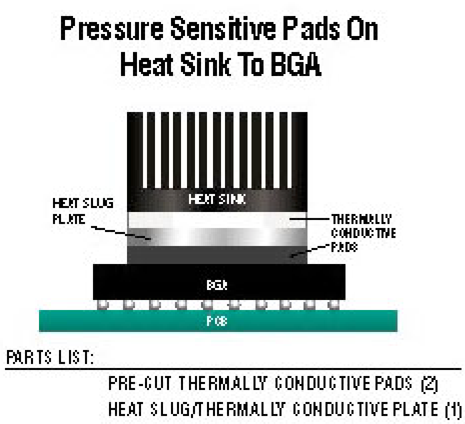
In through-hole and surface mount assembly applications, fasteners, clips and threaded assemblies have been popular methods of attaching heat sinks to components by using the board substrate as the anchor. Although they are fast and simple to install, mechanical fasteners alone provide no electrical isolation and are relatively inefficient thermal managers. Also, as electronic devices and board substrates are becoming smaller, there is frequently insufficient room on the board to accommodate mechanical fastening methods. They also require more individual parts (clips, pins, washers, nuts, screws, lock nuts etc.), which can substantially increase inventory. Mechanical fasteners are known to loosen during higher vibration life cycles, and the shear bulk of the fastened assembly can create stress to solder joints, substrates, and components.

Thermally Conductive Greases

Thermally-conductive silicone greases are frequently used with mechanical fasteners to increase thermal efficiency and minimize electrical conductivity. Thermal greases provide excellent surface wetting capabilities and are the industry standard for thermal conductivity. Because they reduce air voids, thermally-conductive silicone greases minimize the number of hot spots in the heat sink assembly and efficiently transfer heat from a substrate to the heat sink. However, thermally conductive greases are a complicated addition to the heat sink assembly (Figure 1), and can liquefy and migrate when exposed to heat, contaminating other components around the device.



Thermally Conductive Pads



Thermally conductive pads are also used with mechanical fasteners to increase thermal efficiency. These pads are typically a composite of silicone, fiberglass mesh, and thermally conductive fillers such as alumina or boron nitride.

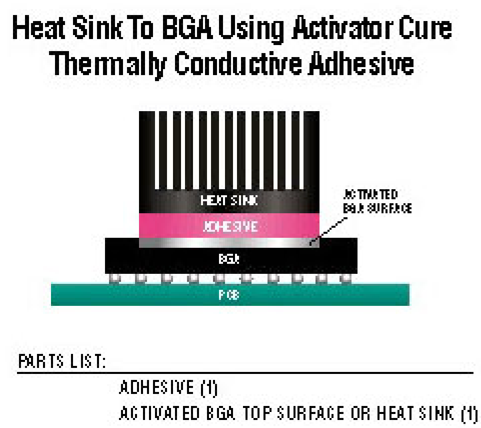
The principal function of these pads, which can be up to 200 mils thick, is to fill large gaps between the PCB and the heat sink. They are typically mounted using pressure sensitive adhesives and/or mechanical fasteners. Thermally conductive pads install quickly, provide good electrical isolation, and are not likely to migrate. However, the manufacturer must inventory a unique pad size, custom cut for each device. Fastener torque is critical for optimum performance; therefore, the compression set or an error in application of the pad can lead to problematic air voids in the heat sink assembly.

Because multiple steps are required to complete an assembly, mechanical fastening methods are difficult to automate, and can cause additional stress to the components and the internal board vias within the substrate during installation.

Tapes

Thermally conductive, double-sided tapes are also a method of bonding a heat sink to a board. While they are fast and easy to install, thermally conductive tapes provide no electrical insulation, are prone to air voids, may loosen over time, and are difficult to automate.

Thermally Conductive Adhesives



Of all the methods of thermal management available, thermally conductive adhesives are the most process friendly. When applied correctly, adhesives produce minimal air voids, resulting in consistent heat diffusion. Adhesives can be used on any shape or size device, and, in addition to providing a permanent bond, will add structural support to the device. Adhesives provide excellent electrical isolation, and will not migrate or loosen during normal application or use. Adhesives are single-component materials that do not require temporary or permanent fixturing with mechanical fasteners; as such, they require little inventory.

Because they are versatile and simple to use, adhesives can be dispensed using a manual process or may be automated with a robotic gantry to pick, place and orientate the pre-activated parts (heat sinks). An added programmable syringe dispenser can apply the set amount/pattern of adhesive to the opposite side (component) of the pre-programmed site or vice versa.

Thicker adhesive bondlines result in improved thermal shock resistance. For consistent performance, it is important to ensure consistent bondline thickness. Adhesive formulators have developed self-shimming adhesives that incorporate tiny, 5 mil (.005"), glass beads into the resin to ensure a minimum 5 mil gap thickness.

Adhesive resins are not thermally conductive by nature. Fillers must be added to the resin base to make the adhesive transport heat more effectively. The most popular thermally conductive filler is currently aluminum oxide, which offers excellent conductivity (70 W/m-K) and low cost. Aluminum nitride and boron nitride offer higher conductivity (150 W/m-K) and higher strength, but are also more expensive.

Other popular fillers include metals such as steel, nickel, aluminum and silver which offer higher thermal conductivity than alumina. Of these, silver has the highest thermal conductivity. However, these metals are also more likely to separate from the resin due to their higher density.

Adhesives are easy to adapt for the specific needs of an application — typical alumina fillers can be easily replaced with a substitute filler that will remove heat faster in more demanding environments. Depending upon the gap thickness that the adhesive must fill and the speed at which the heat must travel between substrates, the percentage of filler in thermally conductive adhesive resins is typically 40 to 60 percent.

Adhesive Chemistries

Thermally conductive adhesives are available in several chemistries appropriate for different applications. In order for an effective and lasting bond to be established, adhesives require solidification or "cure" to take place. Cure times and methods vary depending upon the adhesive chemistry used.

Single-component silicone adhesives are formulated for environments that undergo extreme temperature cycling (below -55° C to above 200° C). By nature, silicones have low cohesive strength and, therefore, are excellent for repair and rework applications. As they are low modulus materials, silicones offer limited adhesion and limited abrasion resistance. Most of these materials require exposure to heat in order to cure, but other available curing mechanisms include room temperature cure, ultra-violet or UV light cure, and activator-induced curing. Depending upon the adhesive formulation and the temperature required, the electronic component can spend several minutes to several hours in an oven for cure to be completed.

Single-component acrylics are general-purpose adhesives that offer good adhesion to many substrates, as well as good cohesive strength. These adhesives can withstand normal operating environments in the -40° C to 125° C range. Acrylics typically require an activator, or a chemical that initiates solidification, to be applied up to 24 hours before the adhesive is applied. Activator-initiated acrylics fixture between 30 seconds to 5 minutes with full ambient cure in 24 hours. Activator cured acrylics are very popular in the electronics industry since many devices cannot withstand the temperatures required for heat cure, and effective light cure is often difficult. Grades of acrylic adhesives are available that can be easily reworked using a thermal parting tool and mild mechanical action.

Acrylics can also be formulated to achieve partial cure or fixturing on exposure to UV light. Because electronic devices seldom incorporate one transparent substrate capable of transmitting light, UV-fixturing acrylic adhesives are formulated with a secondary heat cure mechanism that will complete the cure process in shadowed areas.

Epoxies are highly durable adhesives that offer good thermal and chemical resistance, good cohesive strength, and high adhesion to a wide variety of substrates. Available as single and two-component systems, epoxies will withstand operating temperatures slightly higher than 125° C, and cure upon exposure to heat or a two part catalyzed reaction. Rework is extremely difficult and sometimes impossible due to the structure of the epoxy. Techniques used to get the epoxy to revert to a reworkable state will usually destroy the board or the component which are usually also made from epoxy material.

Additional available adhesive chemistries include urethane, polyester, and other thermoset elastomeric systems.

Thermally Conductive Applications

Thermally conductive adhesives can be used effectively on any electronic device that requires a heat sink to be bonded to a chip, microprocessor or transistor. Typical applications include ASIC devices, TO220 power transistors, ball grid arrays (BGAs), pin grid arrays (PGAs), multi-chip modules (MCMs), and some dual in-line package (DIP) devices. The more of these devices that are designed into printed circuit boards, the more heat sink attachments will be required.

Descriptions of real world applications will better illustrate the use of thermally conductive adhesives:

Application: Designing a High-Speed Production Line

A manufacturer of controllers for industrial farm equipment was designing a new device that required a large quantity of transistors to utilize the controller’s steel housing as a heat sink. The manufacturer evaluated thermally conductive greases, pressure sensitive tapes, and adhesives for their thermal management capabilities. Because the manufacturing process required automated, high-speed production with on-line quality testing, the manufacturer selected adhesives over the other two methods of thermal management. While all three methods provided adequate thermal transfer, the grease required mechanical fasteners which increased material and inventory costs and sometimes migrated during on-line testing, and the tapes were difficult to automate as they required prohibitively expensive equipment.

A one-part, UV/heat cured thermally conductive acrylic adhesive offered rapid fixturing, and the on-line thermal testing actually provided enough heat to complete the adhesive’s secondary cure. Since the adhesive naturally added structural integrity to the assembly, no mechanical fasteners were required. This provided a fully automated, flexible, high speed manufacturing process with improved quality, faster throughput, and reduced labor costs.

Application: Replacing Clips with a Pre-Assembled Sub-Component

A manufacturer of automotive engine controllers was using clips to fasten heat sinks to TO-220 transistors. However, the clips did not eliminate the air interference between the transistor and the heat sink causing poor thermal transfer, and required excess materials inventory and a costly manual assembly process. To eliminate these limitations, the manufacturer opted to manufacture the heat sink/transistor assembly off-line as a sub-component.

The transistors were bonded to the heat sink in an automated production process using a two-part, no mix, thermally conductive acrylic adhesive. The adhesive fixtured rapidly in 30 to 60 seconds to minimize work-in-progress, eliminated the air interference improving thermal transfer, and added structural integrity to the assembly. The pre-assembled sub-component could then be quickly and easily placed into the on-line assembly process.

Application: Electrical Isolation and Thermal Cycling Resistance

A manufacturer of automotive anti-lock break modules was bonding transistors to a heat rail using a two-part, no mix, thermally conductive adhesive, and was experiencing sporadic failures associated with an inconsistent surface finish of the heat rails. Burrs located along the heat rails were causing shorts. In order to improve the thermal cycling resistance of the assembly, the manufacturer evaluated the effectiveness of a thermally conductive silicone which contained 0.005" diameter spacer beads.

The lower modulus and higher thermal resistance of the silicone addressed the thermal cycling requirements of the application. The 5 mil glass spacer beads induced a 0.005 to 0.006" gap to ensure electrical isolation even in the presence of relatively large surface imperfections. The induced gap also improved the thermal cycling resistance by allowing more stress to be distributed in the polymeric matrix of the adhesive when the assembly experienced thermal excursions.

The Future

Adhesive formulators are experimenting with several filler materials to enhance the thermal performance of their adhesives. Fillers currently under consideration include boron nitride, aluminum nitride, diamond graphite, certain precious metals, and silica coated aluminum nitride. Of these, diamond graphite has the highest thermal conductivity. Some of these fillers can reduce overall adhesive costs and increase the thermal conductivity of the formulation. Generally, these fillers are expensive compared to today’s more popular filler materials.

Phase change technology is the latest development in thermally conductive materials. These materials are generally high melting waxes that contain conductive fillers. They offer most of the advantages of thermal greases as far as wetting, bond filling, and conductivity, but will not migrate. These materials are typically pre-applied on the heat sink. When the entire apparatus is heated during the manufacturing process, the phase change material melts and provides void free gap filling. Over the next five years, adoption of phase change technology into the assembly process is expected to grow by 40 percent per year, in large part due to their excellent thermal conductivity, ease of application, low cost, and ability to be repaired and reworked.