Thermal Interface Materials

Thermal Interface Materials (TIMs) are used to efficiently transmit heat from an area of high thermal energy to an area of lower thermal energy. These materials are often used to conduct heat away from a temperature sensitive device, or to transmit thermal energy to a device that is being thermally tested. More efficient materials enable the cooling of higher power devices. In portable applications, better TIMs are required for reducing thermal resistance and miniaturizing forced cooling systems, which will in turn lead to increased battery life.

Key Properties and Terms

TIMs come in a variety of forms and each form has its advantages and drawbacks. (Please refer to *What is a Thermal Interface?* application note.) There are many considerations to take into account when choosing a TIM for your project. Among the possibilities are greases, gels, dispensable adhesives, thermal tapes, pads, phase change materials, and solders. Ideally, the material used has high thermal conductivity; it forms intimate contact with the device and the heat sink surfaces, and it has the compliance to accommodate the difference in thermal expansion between the two surfaces. Further, the material cannot degrade over the life of the assembly.

To be effective a TIM combines properties to minimize the total interface resistance. High conductivity (200-420 W/m°C) materials, like copper, silver, aluminum and gold, maximize thermal conductivity, but do not flow into intimate contact because of the relative lack of compliance so the interface resistances are very high and the overall performance is poor. In contrast, lubricants and wetting agents provide intimate contact with the device surfaces, but fail in TIM applications due to poor thermal conductivity and instability during the operation life cycle.

Grease

Thermally conductive greases are commonly used to attach heat sinks to CPUs in personal computers. These greases are designed to flow into the surface imperfections, minimizing the interface resistance. Thermal greases are emulsions of ceramic (e.g., alumina, boron nitride) or metal particles (e.g., aluminum, silver) in an organic or silicon fluid. The emulsion particles increase the thermal capacity and provide body to minimize flow out of the interface. Despite the improvements, the bulk thermal conductivities of the greases are very low (1-4 W/m°C) so the contact layer must be very thin. Grease TIM is relatively less expensive than other alternatives. Unfortunately, in service with high temperatures or extensive thermal cycling, the thermal greases have suffered from drying out or voiding from pumping out of the interface.

Gels

Gels are similar to thermal grease with a few differences. The gel material is cured to form cross-linked polymer chains, this provides lateral stability to minimize the problem associated with liquid TIM materials. Gels are reusable, although they generally have a slightly lower thermal conductivity than thermal grease.

Adhesives, Tapes, and Pads

Thermal interface pads are pre-formed materials that can be compressed between the heat generator and the heat receiver. Pads are either electrically conductive or non-conductive, based on application. They may also be supplied with adhesive, although an adhesive layer often complicates future disassembly of the thermal package.

Tapes and adhesives are used to provide a better thermal interface while also securing the component and heat sink. This bond can be unreliable though, and may also need to be supplemented by mechanical attachment. Pads are generally thicker than tapes and adhesives because the added thickness helps to fill larger gaps.

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Phase change materials are applied as a thermally conductive pad. The phase change materials have compositions that transform from a solid at room temperature to a mixture of solid and liquid phases at various operating temperatures. The liquid from the mixture makes intimate contact with the surfaces of the device and heat sink while the solid retains the integrity of the gap. At this temperature the phase change material is able to act like a thermal grease, allowing it to form a thinner bond-line. Excess liquid should then flow to the perimeter of the interface and solidify so it remains away from other components.

Solder

Thermal solders are very attractive because they have high thermal conductivities (30-86 W/m-°C). Various metal alloys can be ideal for use as a thermal junction, although each will offer different mechanical and thermal properties. The key to using solder TIMs is to reduce voiding during reflow, which may be an iterative process. Unlike other materials used for thermal interfacing, solder voids will not propagate later during use due to pump out or migration. This important property assures a higher end-of-life performance.

Thermal solders provide the best physical connection of all TIMs. Using solder eliminates the issue of bleed-out from the thermal greases while providing very good adhesion. This mechanical attachment is a particular advantage when external clamping is not feasible. To take advantage of these properties, interfaces and the assembly are designed to ensure proper wetting of the device surfaces, which minimizes voiding.

Solder Alloy Selection

Thermal expansion of components in a thermal assembly may stress solder TIMs. For this reason, brittle alloys should not be used as thermal interface materials. Bismuth containing alloys are especially poor choices because of their low thermal conductivity and brittle nature. Au/Sn alloys handle stress well, although they may not be soft enough for some applications where the heated materials expand at markedly different rates. It is important to choose a solder that will be able to compensate for CTE mismatch. Design of the solder thermal interface requires understanding the interconnect materials to minimize the effects of intermetallic formation and performance degradation. Additionally, the solder must provide for the compliance of the thermal expansion mismatch between the semiconductor and the heat sink. Solder alloys with a range of mechanical strength from <300 psi to >20,000 psi and can be tailored to the strength or compliance needed for the application.

Concerning interface compliance, indium may be the best solder to use as a thermal interface. Pure indium metal provides a unique combination of high conductivity (86 W/m-ºC) and compliance (60 psi shear flow stress and no work hardening). Indium is applied in the mechanical sealing of metallic and non-metallic surfaces with excellent integrity. Since indium will wet to non-metallic substrates, it is especially well suited for use against many materials that are commonly used in semiconductor packages. This mixture of properties makes indium uniquely suited to thermal interface solutions with or without reflowing. Indium can also be cold welded in applications where normal soldering temperatures are detrimental to the device.

Conclusion

As electronic devices become evermore compact and powerful, more efficient cooling will be necessary to dissipate excess heat. No single solution will be applicable to every interface and sometimes the best option may not be easy to recognize. High power device performance can be optimized by knowing what properties improve a materials heat transfer. As industries push the boundaries of electronics, finding the right TIM will become more important than ever.

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