Thin Film Thermoelectrics

As components, packages and systems continue to shrink in size, the heat generated in these dense electronic systems can be quite large and can lead to a significant rise in temperatures that in turn can cause device and system-level failures.

Heat has always been an issue for system designers, but only recently has the problem become so severe that thermal management solutions can no longer be introduced as an afterthought. Thermal management must be considered from the beginning of the design process in order to avoid causing severe problems at the system level. This is an important consideration because at the system level, the thermal operating space is more limited (i.e. the temperatures that can be tolerated) and any solution employed at the system is likely to be more expensive than one implemented at the chip level.

A new approach to thermal management involves embedding thermal management functionality deep inside an electronic component at the source of the heat using thin film thermoelectric devices.

Introduction

TEMs (thermoelectric modules) are solid-state heat pumps that operate using the Peltier effect. When an electric current is driven through a circuit containing two dissimilar materials, heat is absorbed at one junction (the cold side) and released at the other junction (the hot side). The design of most Peltier devices requires the use of both an n-type semiconductor and a p-type semiconductor. Since heat naturally flows down a temperature gradient from hot to cold, a TEM’s ability to move heat from cold to hot in a solid-state fashion is unique. By reversing the polarity of the applied DC current, heating is also possible. This attribute is especially useful for applications requiring both cooling and heating to maintain precise temperature control.

Conventional TEMs, sometimes referred to as “bulk” TEMs, have been used for decades to control the temperature of electronics. However, as the size and power density requirements of new applications are changing, conventional bulk thermoelectric technology has not kept pace. In some instances, designers choose to place the cooling device outside the package if it is too large to be placed inside. Cooling the device by cooling the entire package is at best an inefficient method for thermal management and often leads to over sizing of the TEM and input power requirements, which results in more waste heat in the system.

Advantages of Thin Film Technology

Conversely, thin film thermoelectrics target the source of the heat flux to provide thermal management and control. These embeddable TEMs use semiconductor processing techniques to create a nano-structured thin film used for the P and N legs. Thin film TEMs are typically 5 to 20µm thick, versus 200µm for conventional bulk TEMs, resulting in several differences. The heat flux, which is inversely proportional to the thickness of the thermoelectric material, is more than 20 times greater than bulk TEMs. Thin film TEMs can also pump a maximum heat flux of 100 to 400W/cm² versus less than 10W/cm² for conventional bulk TEMs. Thin film TEMs can operate in a high coefficient of performance (COP) regime and still pump a reasonably high heat flux of 20 to 40 W/cm². COP is a measure of efficiency defined as cooling power divided by input power.

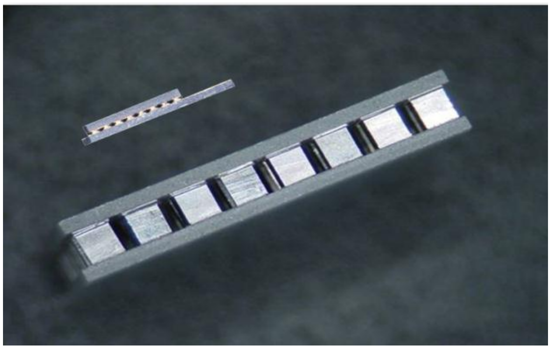

Figure 1:Ccomparison of thin film vs bulk device

Depending on the design, thin film TEMs may have thermal response times as low as milliseconds enabling very rapid cooling and heating to maintain precise temperature control. They are known to have higher heat pumping capability than standard bulk TEMs, but for temperature control applications, the superior switching speed of the devices may ultimately prove to be their most valuable asset.

Thermoelectric Cooling

The most basic representation of the operational space for a thermoelectric module is a performance chart as shown in Figure 2.

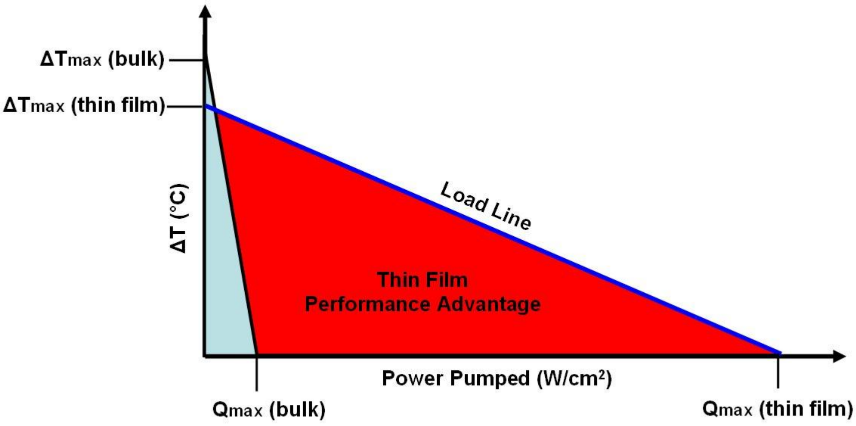

Figure 2: TEM Performance Chart.

The load line represents the ΔT and power pumped conditions possible for a given TEM drive current. At the maximum drive current for the module, the load line is generated from two key parameters: 1) the maximum power the device can pump, Qmax; and, 2) the maximum temperature difference that the device can sustain between its top and bottom substrates, ΔTmax.

The load line defines the operational space for TEMs and is the best and most usual way to illustrate cooling capacity for a particular temperature condition.

System Level Considerations

The TEM, being an active thermal device, creates a thermal inversion that dramatically changes the thermal profile inside the package. Figure 3 shows a comparison of the thermal profile through the cross section of the module in two cases, a) with no TEM, or in other words, a passive solution only, and b) with a TEM actively cooling the junction. It can be clearly seen that the introduction of the TEM provides a substantial net cooling benefit.

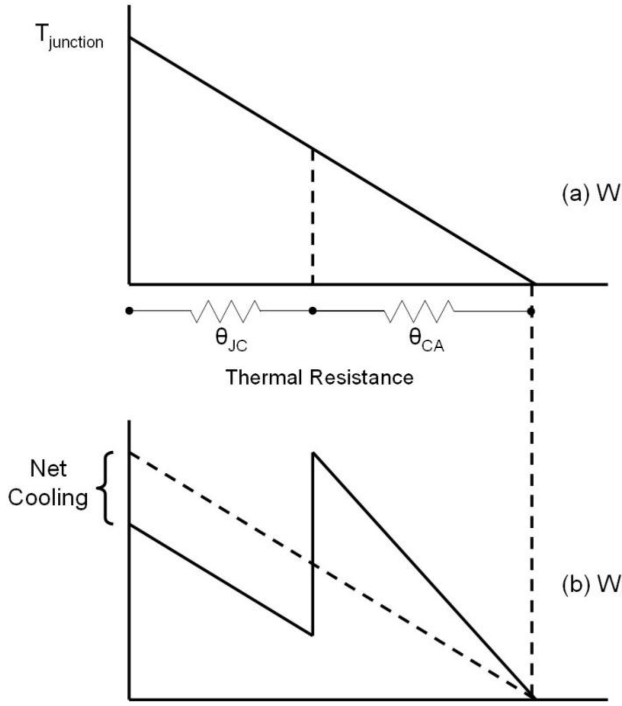

Figure 3: Temperature profiles through the cross section of a package from the junction to the case (θJC), and case to ambient (θCA) without (a) and with (b) a TEM. The temperature inversion created by the TEM lowers the junction temperature relative to the no-TEM case.

The heat that is pumped by the device and the additional heat created by the TEM in the course of pumping that heat will need to be rejected into the system. Since the performance of the module can be improved by providing a good thermal path for the heat rejected, it is beneficial to provide high thermally conductive pathways. For small packages, this is typically accomplished through the electrical connections themselves, and depending on the operating characteristics, this level of thermal management might be sufficient. For packages with higher heat densities, thermally-conductive feed-throughs or posts may be needed to remove the heat.