The Thermal Barrier: A Thin-Film Thermal Solution For Hot Electronics

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For the past 50 years, the thermal management industry has offered only heat sinks, fans and thermal grease as methods for electronics thermal management. While these techniques have been refined and improved over the years, nothing new has been introduced to address the exponential growth of thermal issues in modern-day electronics.

The electronics industry has reached a breaking point, a sort of thermal overload. As components, packages and systems continue to shrink in size, we are constantly adding new functionality. The heat generated in these dense electronic systems can be quite large and lead to significant increases in temperatures that in turn can cause component- and device-level failures.

The Problems with Heat

The source of the heat causing high temperatures is threefold. First, modern microprocessors, ASICs, memory and other components are consuming more power and therefore generating more heat. Second, system level products are shrinking in size. Third, system-level heat rejection systems are running out of performance headroom.

These factors lead to excessive heat build-up inside the device resulting in high interior temperatures that can affect the performance of some sensitive components such as embedded LCD displays. For example, consider a cell phone or another handheld device. Heat emanating from hot spots on the printed circuit boards directly behind display screens may lead to distortions on the screen.

The Thermal Barrier

Electricity is directional, meaning that it can only flow in conducting and semiconducting material, such as wiring and traces on boards, and only when there is a voltage difference. Heat, on the other hand, is omnidirectional. It will flow into any mechanical object in any direction when there is a temperature difference of only a few degrees. The question arises, how can you gain control of heat flow and channel it into other areas less sensitive to thermal issues?

A new approach to thermal management involves embedding thermal management functionality near an electronic component and in between the source of the heat using thin-film thermoelectric devices to create a small temperature inversion that channels thermal energy away from sensitive interfaces.

One such device is a thermal barrier, a fundamentally new tool for thermal management using embedded thermoelectric technology. An appropriately designed thermal barrier is small and thin enough to be unobtrusively incorporated into the interior of small form-factor equipment and can easily deliver cooling with millisecond response times. In most cases, a 3°C to 5°C temperature inversion is all that is necessary to cause the heat to flow away from a surface, in essence creating a thermal reflector, wall or thermal barrier.

Thin-Film Thermoelectrics and the Thermal Bump

The thermal barrier is constructed from thin-film thermoelectric material ranging from fractions of a nanometer to several microns in thickness. Thin-film thermoelectric materials can be grown using MOCVD (metal-organic chemical vapor deposition) deposition methods and fabricated using conventional semiconductor fabrication processes.

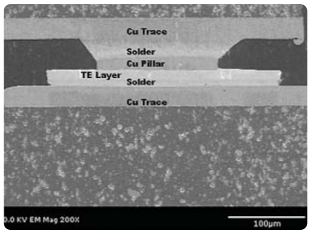

Figure 1: SEM image of a thermal bump

At the core of the thermal barrier is the Thermal Copper Pillar Bump, which is also referred to as the "thermal bump." The thermal bump is a thermoelectric device made from a thin-film thermally active material embedded into flip-chip interconnects (in particular copper pillar solder bumps) for use in electronic packaging.

The thermal bump was developed as a method for integrating active thermal management functionality at the chip level in the same manner that transistors, resistors and capacitors are integrated in conventional circuit designs today. Unlike conventional solder bumps that provide an electrical path and a mechanical connection to the package, thermal bumps act as solid-state heat pumps and add thermal management functionality locally on the surface of a semiconductor chip or other electrical component.

Thermal bumps are extremely small, currently 238 µm (microns) in diameter by 60 µm high. The size of the thermal bump enables the integration of thermal management capabilities into everyday products that interface with humans such as laptop computers and handheld devices.

The thermal bump uses the thermoelectric effect (figure 2), which is both the direct conversion of temperature differences to an electrical voltage and the movement of heat via the application of a voltage. This effect can be used to generate electricity, to measure the heat flow into or out of an object, to cool objects, or to heat them.

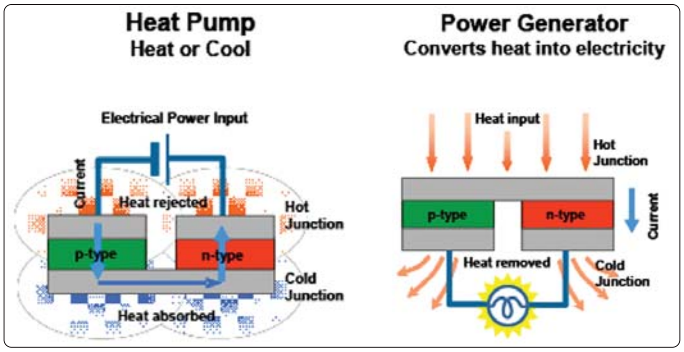

Figure 2: The Thermoelectric effect

For each bump, thermoelectric cooling or heating occurs when a DC current is passed through the bump. The thermal bump pulls heat from one side of the device and transfers it to the other as current is passed through the material. This is known as the Peltier effect. The direction of heating and cooling is determined by the direction of current flow and the sign of the majority electrical carrier in the thermoelectric material.

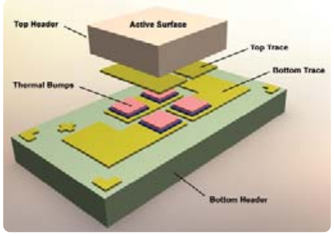

Figure 3: Exploded View of an eTEC module

When combined with a feed-back mechanism, the temperature of a target surface can be controlled and maintained by changing the current amplitude or systematically toggling the direction of the current flow.

This module contains four thermal bumps arranged under a top header or substrate. This single "unit cell" serves as a building block for all of Nextreme's discrete devices. Unit cells can be fabricated into different arrays and with different packing densities to address customer design requirements for optimum cost and efficiency.

When incorporated into a thermal solution, the eTEC essentially becomes a thermal barrier, redirecting heat away from the surface.

Inside the Thermal Barrier

Developed for applications such as laptop computers and other handheld devices, the thin-film thermal barrier, as initially designed, is less than 0.65 mm thick and typically achieves a moderate cooling of 5°C to 10°C at the target surface. It can also be incorporated into an existing heat sink system to provide site-specific cooling for improved overall functionality and ergonomics.

The thermal barrier is constructed of several eTEC thermal elements connected electrically in series. However, from a thermal perspective, the modules are connected in parallel – heat flows from the top to the bottom plate through all the modules simultaneously.

In Figure 4, the individual thermal modules are arrayed and held together at the top and bottom by two headers.

When current flows through the thermoelectric elements, a temperature difference, ΔT, is generated between the top and bottom plates. The magnitude of the difference depends on both the amount of current flowing and the amount of heat being pumped through the device. Nextreme's thermal barrier technology, for example, has broad flexibility and can be tailored to meet the requirements of a particular application.

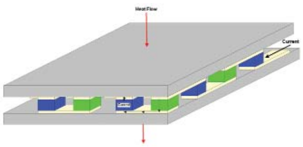

Figure 4: The Thermal Barrier

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Application of the Thermal Barrier in Laptop Computers

The thin-film thermal barrier is ideally suited for implementation in portable and small form-factor devices and works well for applications where thickness is constrained. Such applications typically require no more than ~10ºC reductions in temperature, which is well within the thermal barrier's capabilities.

The overall design, number of modules, their spacing, and the heat spreader materials and dimensions determine the characteristics of the thermal barrier.

For example, two eTECs—each consisting of an array of tightly packed PN couples—on a 1 cm by 1 cm heat spreader, shown in Figure 5, are placed to cool two individual hot spots on a target surface.

In contrast, the thermal barrier consisting of an array of loosely packed PN couples on a 1.0 cmby 1.2 cm heat spreader, shown in Figure 6, is configured to cool a larger area with a lower heat density requirement.

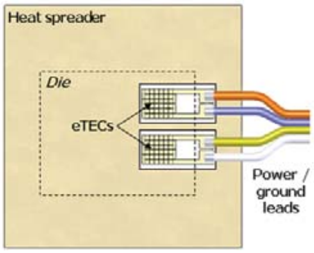

Figure 5: Two eTECs with tightly packed PN couples on 1 cm by 1 cm heat spreader

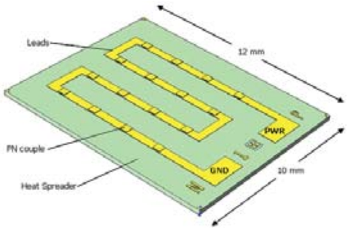

Figure 6: Thermal barrier with loosely packed modules on 1 cm by 1.2 cm heat spreader

Shown in Figure 7 is a low density thermal barrier consisting of 25 PN couples array-mounted over a 25 mm by 25 mm module. This module was developed specifically for demonstrating the skin cooling of a laptop computer.

As part of an initial evaluation, the module was attached to a 0.8 mm thick aluminum plate, simulating the skin of a laptop computer, and an IR photo was taken from the opposite side of the aluminum skin. The picture shown on the right side of Figure 8 is the IR image of this, showing the reduction in the average temperature over the area by approximately 5°C. Note that the peak temperature reductions over the spots corresponding to the individual PN couples are also clearly visible.

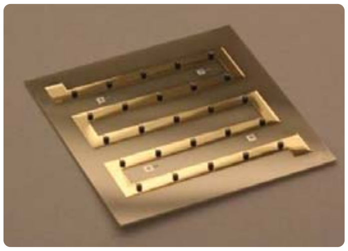

Figure 7a: A thermal barrier with loosely packaged 25 PN couples on 25 mm by 25 mm module

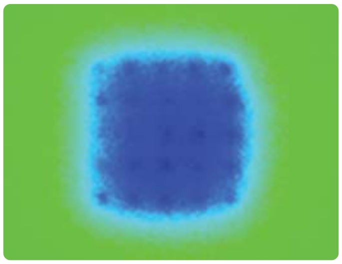

Figure 7b: An IR photo of a 0.8 mm thick aluminum skin cooled by the module, shown right, attached to the underside of the skin.

Figure 8 shows two thermal barriers placed over the interior of the bottom skin of a laptop computer. Note that the modules are mounted with the PN couples in contact with the skin. The total protrusion of the modules over the surface of the interior skin is approximately 0.3 mm.

In the example above, excessive heat was emanating from a circuit board located directly above the thermal barrier. After the addition of the thermal barrier, 5°C of cooling was demonstrated at the skin surface. In some cases, the thermal barrier can be integrated into other heat rejection devices (e.g. heat sinks, heat pipes, cold plates, etc.) to augment system level cooling efficiency.

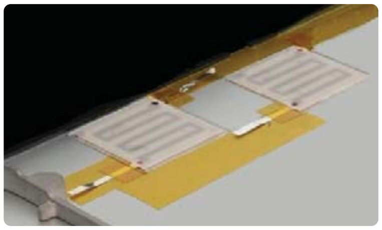

Figure 8: The bottom chassis skin of a laptop computer with two thermal barriers shown in Figure 7.

Thermal Protection with On-Demand Thermal Management

The thermal barrier can be activated when the temperature of the package, system, etc reaches a critical point, thus creating an "on-demand" thermal management solution.

A thermocouple can be embedded in the package and connected to a microcontroller in a closed loop fashion that would sense temperature changes and thus signal the operating voltage to the eTECs. In this way, the thermal barrier can be turned off to save power or extend the battery life of the device. Or the thermal barrier can be included in the overall power design for continuous operation.

Summary

The idea of a thermal barrier is new and is made possible by the use of thin film TECs as the design elements. Using TECs in this manner creates a new tool for system level thermal management and protection for embedded, active cooling solutions in a variety of electronics. Thin-film thermoelectrics deliver an unprecedented power-pumping density with thermal performance exceeding that of the best available technology. Because they are so small and thin, the devices can be integrated directly into a package to achieve localized cooling of the target component, something never before available to design engineers in small form-factor electronics.

Nextreme Thermal Solutions designs and manufactures microscale thermal and power management products for the electronics, telecommunications, semiconductor, consumer, and defense/aerospace industries. The company uses thin-film thermoelectric material to embed cooling, temperature control and power generation capabilities into the widely accepted copper pillar bumping process used in high-volume electronic packaging. Nextreme's headquarters and manufacturing facility are based near Research Triangle Park, North Carolina. For more information please visit www.nextreme.com

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