Nextreme THERMAL SOLUTIONS

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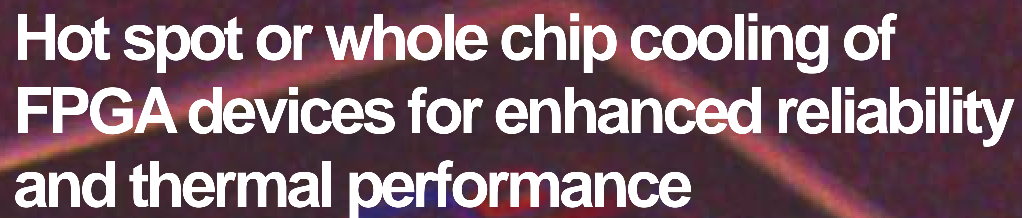
Embedded Thermoelectrics



Nextreme Thermal Solutions
April 28, 2007

Background

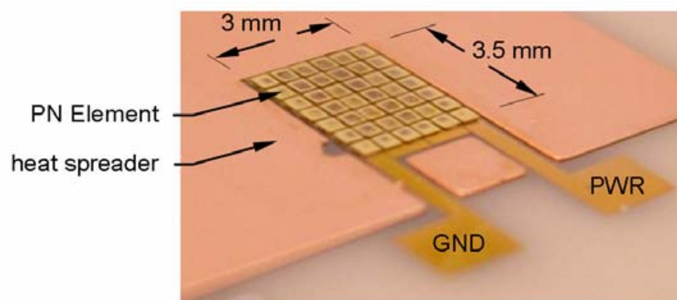
The challenge of removing heat from ICs has increased significantly during the rapid evolution of IC design. Thermal management in electronics has become problematic as a result of faster, denser circuits being packaged more tightly and generating more heat. With the emergence of nanoelectronics (90 nm feature size process technology going to 32 nm by the end of the decade), localized areas of high heat flux will dominate the performance of electronics at both the chip and the board level. Mitigating the effects of die-level hot spots through localized cooling in the vicinity of the on-chip heat source will be the primary driver for innovation in electronics cooling.

The Problem: Thermal Management of FPGAs in Thermally Constrained Environments

FPGA chips have a number of significant thermal challenges, resulting from the following requirements:

- Size, weight and reliability requirements can often prohibit the use of complex thermal solutions involving fans and/or water cooling.
- Hot spots on ICs arise from die-level power dissipation non-uniformity. These localized high heat flux areas create hot spots that are significantly above the average die temperature. Hot spots limit the IC’s performance, reliability and yield, which are all very sensitive to small changes in temperature. As CMOS process technology scales to smaller feature sizes, hot spots will become more pronounced.
- Packing circuit boards more densely can create board level hot spots putting additional pressure on system level thermal solutions.

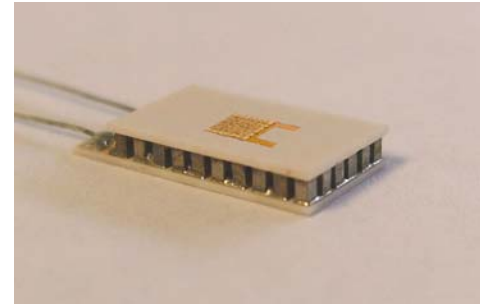
Solution: The Embedded Thermoelectric Cooler (eTEC™)



• Figure 1: Thin Film Thermoelectric Module

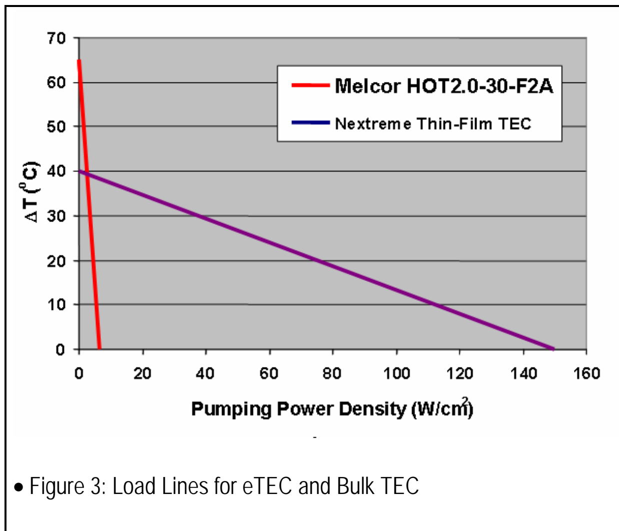
A significant amount of development has been focused on thin-film thermoelectric devices to help address site specific thermal management problems. Thin-film thermoelectric materials can be grown and integrated by conventional semiconductor deposition methods and micro-fabrication techniques. The resulting devices (see Figure 1) are much smaller and thinner than conventional products and show promise for direct integration into modern manufacturing methods.

For reference, a thin-film TEC is shown relative to a conventional bulk TEC (Melcor HOT2.0-30-F2A) in Figure 2. The thin-film TEC is ~6x smaller in its x-y dimensions and ~18x smaller in the z dimension leading to a ~110x reduction in volume.



• Figure 2: eTEC compared to Bulk TEC

In terms of performance, thermoelectric modules are most commonly compared on the basis of their respective load lines: the temperature difference sustained across the TEC thickness as a function of heat-pumping power. Figure 3 shows load lines of the Nextreme and typical bulk devices, both measured at room temperature.



• Figure 3: Load Lines for eTEC and Bulk TEC

The comparison in Figure 3 illustrates a fundamentally new operating regime offered by thin-film TECs. The thin-film TEC produces a maximum ΔT_{max} of 40°C across the thickness of a piece of paper. It pumps a maximum power density (Q_{max}/area) of 150 W/cm^2 in comparison to less than 10 W/cm^2 for the bulk TEC. The response time of the eTEC device is on the order of milliseconds compared to seconds for bulk devices.

Unlike bulk TECs, Nextreme uses semiconductor processing techniques to create a nano-structured thin-film used for the P and N elements. Nextreme's thermoelectric thin-film is typically 20x thinner than the thinnest pellets used in bulk TECs, resulting in several benefits. 1) Heat flux, which is inversely proportional to the thickness of the thermoelectric material, is 20+ times greater than bulk TECs. 2) Nextreme's eTECs can operate in a high COP (Coefficient of Performance) regime while still pumping a high heat flux. COP is a measure of efficiency defined as cooling power divided by input power. 3) The input power can be dynamically controlled to provide active cooling. 4) Nextreme's eTECs have very fast, millisecond response time for rapid cooling and heating to maintain a precise temperature. 5) Nextreme's eTECs are very thin, enabling unobtrusive integration close to the heat source.

Site-Specific Thermal Management

The eTEC's small footprint means it is perfectly suited for site-specific cooling. Focusing the cooling on the hotspots, and not pumping heat from the cooler surrounding device area, reduces the amount of power required for the eTEC thermal solution. For example, given a 3W hotspot on a chip with a total heat dissipation of 50 W, an eTEC positioned in the package to cool only the hot spot (and operating at a COP of 1) contributes only 3 additional W of heat to the overall system. In contrast, a large TEC, positioned to cool the entire 53 W chip (at a COP of 1) would contribute an extra 53 W to the system! Furthermore, with a footprint of 2 mm x 2 mm, a 3 W hot spot has a heat flux density of 75 W/cm^2—an excellent match for an eTEC but well beyond the capability of a bulk TEC.

A number of ways exist to integrate the eTEC device into a thermal system. The existing package often limits which solution can be applied. Nextreme has successfully integrated eTECs into, and cooled chips in both lidded and lidless devices (see figure 4). When considering cooling inside the package, Nextreme's device is the only one with the form factor and heat pumping density required to meet the challenges facing today's high heat flux chips.

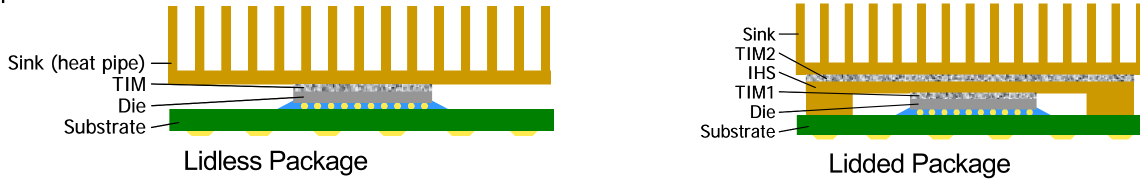
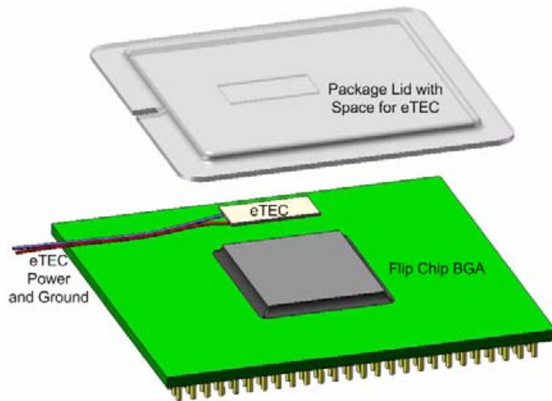
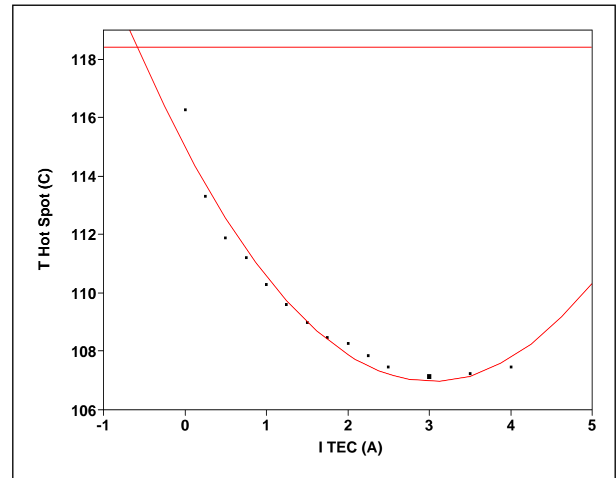


Figure 4: Examples of "lidded" and "lidless" packaging solutions.

Figure 5 shows an example of an eTEC integrated into a "Lidded" package. The package lid has been modified to accommodate the small additional height of the eTEC and the power and ground leads at the lid edge. Figure 6 shows the temperature of a 2 W hot spot as a function of electrical current applied to the eTEC. In this case, at 3 A current, the hot spot temperature is suppressed by more than 10 degrees Celsius.



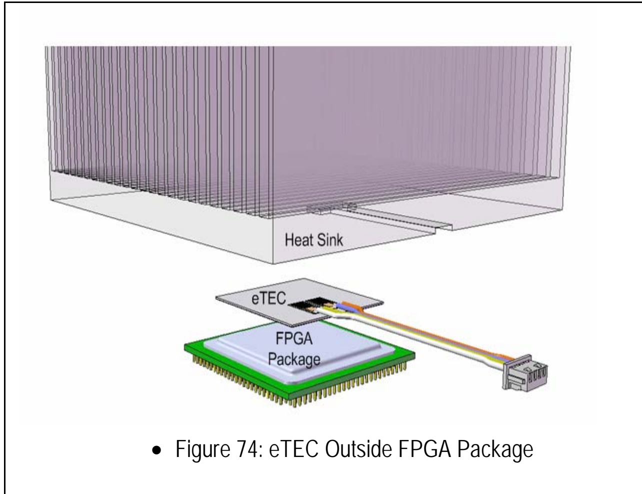
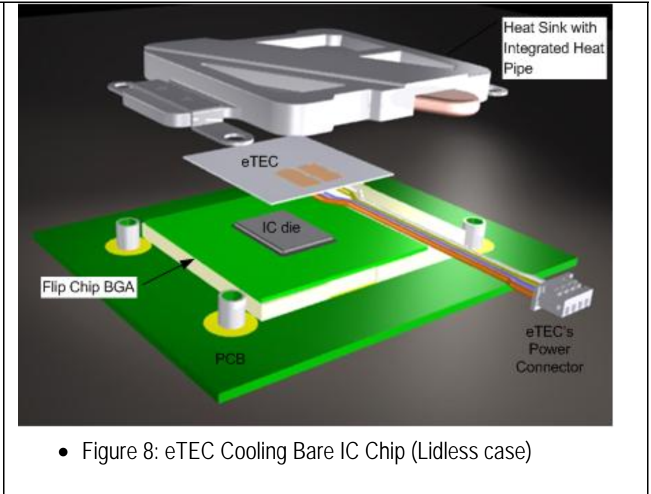
- Figure 5: eTEC Integrated Into FPGA Package



- Figure 6: eTEC Produces 10 K Cooling of a 2 W hotspot

Figure 7 shows an example of an eTEC integrated into a "Lidded" package solution. In this case, the eTEC is placed on a thin heat spreader between the top of the lid or chip and the heat sink. The advantage of this system is that it does not disrupt the standard packaging manufacturing flow and allows the end user (OEM or ODM) to integrate the eTEC.

Figure 8 shows an example of a "Lidless" package integration wherein the eTEC is placed between a bare IC and the cold plate. Mobile CPU chips and GPU chips are examples of lidless devices that Nextreme has successfully cooled.

 • Figure 74: eTEC Outside FPGA Package	 • Figure 8: eTEC Cooling Bare IC Chip (Lidless case)