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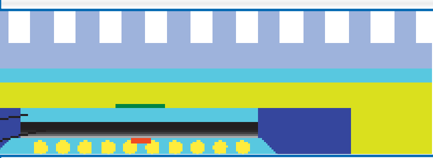

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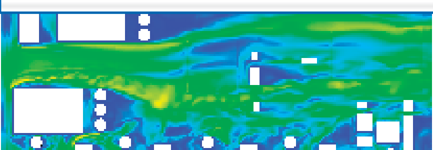

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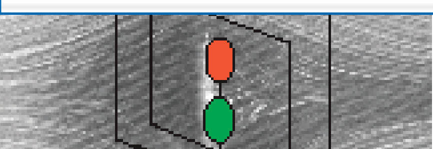

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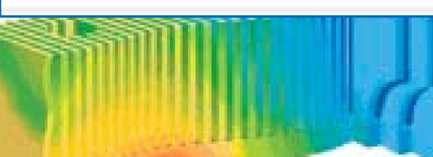

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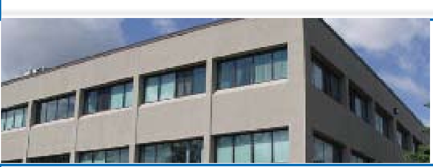

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FUTURE COOLING

Micro TECs for Spot Cooling of High Power Devices

Introduction

As component packages shrink, and power densities increase with higher operating frequencies, challenges to thermal engineers are greater than ever for cooling such devices. One thermal management technique of growing interest is to cool localized areas of high heat flux that create so called "hot-spots" or areas of high-temperature on die surfaces, as shown in Figure 1.

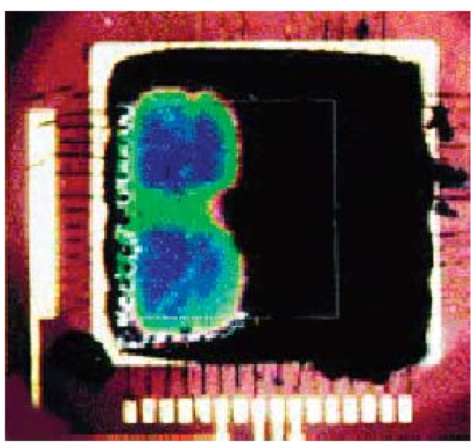

Figure 1. Component with Hot Spot as Demonstrated by Liquid Crystal Thermography.

Hot spot temperatures can be 5 to 30K higher than other areas of the microprocessor, and their temperature differences can surpass 100K for optoelectronic components [1].

A typical thermal solution would be to design a heat sink to cool the entire component, i.e. both the hot-spot and surrounding areas of the chip. But this blunt force approach is very inefficient because the heat sink will cool both the critical areas (hot spots) and the non-critical (lower temperature) areas of the chip. This results in a greater than necessary heat load to the system. One possible approach is to use a micro TEC (small thermoelectric coolers) at the source of the hot spot to remove the heat only in the critical areas as shown in Figure 2. This will reduce the hot spot temperature and may eliminate the thermal stress on the device.

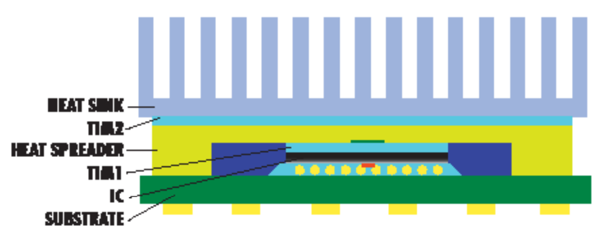

Figure 2. Typical Application for micro TEC Cooler [1].

Micro TECs can also be embedded in the heat spreader or lid of the component, as shown in Figure 3. The eTEC (embedded thermoelectric cooler) lies directly above the hot spot on the die, and a layer of high thermal conductivity interface material is used between the eTEC and die to minimize thermal contact resistance. Finally, a larger heat sink is used to remove the heat that is generated by the eTEC and the device.

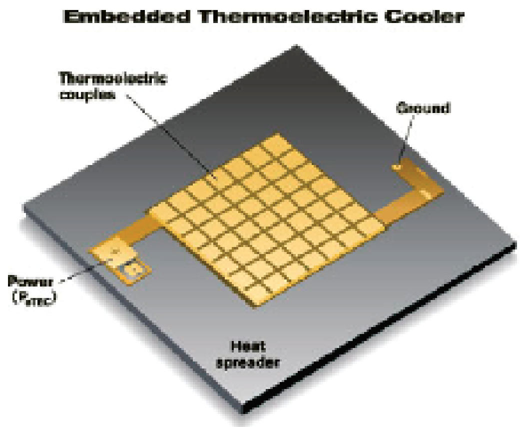

Figure 3. Heat Spreader with Embedded TEC [2].

What is a micro TEC and how does it work?

A micro TEC is a small thermoelectric cooler approximately 2-3 mm square x 1 mm high. It is constructed from thermoelectric pellets of Bi_2Te_3 and Sb_2Te_3 or similar material, which are sandwiched between two ceramic substrates. The essential principles of operation for micro TECs are the same as for commercial bulk TECs.

A general mathematical model can be constructed to describe TEC performance, using the governing equations shown in Equations [3], [4].

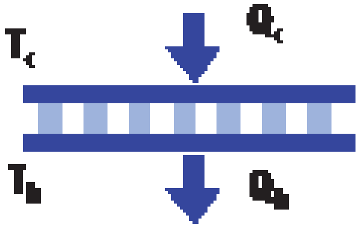

Figure 4. Schematic of a TEC Showing Important Variables [3].

The temperature difference between the hot and cold sides of the TEC can be expressed as:

$$\Delta T = T_h - T_c \qquad (1)$$

ΔT= Temperature difference across the TEC

T_h = The "hot" side temperature of the TEC

T_c = The "cold" side temperature of the TEC

All temperatures are expressed in K (absolute temperature). The heat pumping capacity then becomes,

$$Q_c = \alpha T_c I - \frac{1}{2} I^2 ß - \xi \Delta T \qquad (2)$$

Q_c = Heat pumping capacity of the TEC in Watts,

α = The Seebeck coefficient in volts/K.,

ß = The module resistance in Ohms,

ξ = The Module thermal conductance in Watts/K

I = The current through the module in Amps.

The Seebeck coefficient, module thermal conductance, and module thermal resistance are temperature dependent properties specific to each TEC. They can be determined through experimentation or by contacting the TEC manufacturer.

For micro TECs or eTECs it can also be said that the maximum heat pumping capacity is inversely proportional to the length of the thermoelectric modules as shown in Equation 3 [1].

$$Q_{max} \propto \frac{Af}{l} \qquad (3)$$

A = Plan area of the thermoelectric cooler

f = Fraction of area covered by thermoelectric elements

l = Length of the thermoelectric elements.

If the length of the elements is decreased, the heat pumping capacity will increase. Thus, the thinner the eTEC, the better the performance.

Generally speaking, the efficiency of micro TECs (or bulk TECs for that matter) is described by the coefficient of performance equation (Equation 4).

$$COP = \frac{Q}{IV} \qquad (4)$$

Q = Heat removed by the TEC in Watts

I = Input current in Amps

V = Input voltage in Volts

IV = Input power

Clearly, the higher the COP the better, as the result is greater heat pumping capacity with respect to input power.

Finally, when deciding if and when to use a micro TEC, the central issue is to determine if adding one will result in improved performance over just the heat sink alone. This condition is true if the inequality below is satisfied (see Equation 5) [1].

$$\Delta T_{TE} COP > Q_c (R_{SPREAD} + R_{TIM} + R_{SINK}) \qquad (5)$$

ΔT_{TE} = Temperature difference across the TEC

COP = Coefficient of performance (defined in Equation 4)

Q_c = Required heat pumping capacity (cold side of TEC)

R_{SPREAD} = Thermal resistance due to spreading

R_{TIM} = Thermal resistance due to thermal interface material

R_{SINK} = Thermal resistance from heat sink

A micro TEC typically needs a high COP and large to ΔT_{TE} provide improved hot spot cooling over the use of a heat sink alone. If the correct micro TEC is chosen it can have a significant impact on the junction temperature of a hot component. This is shown in Figure 5.

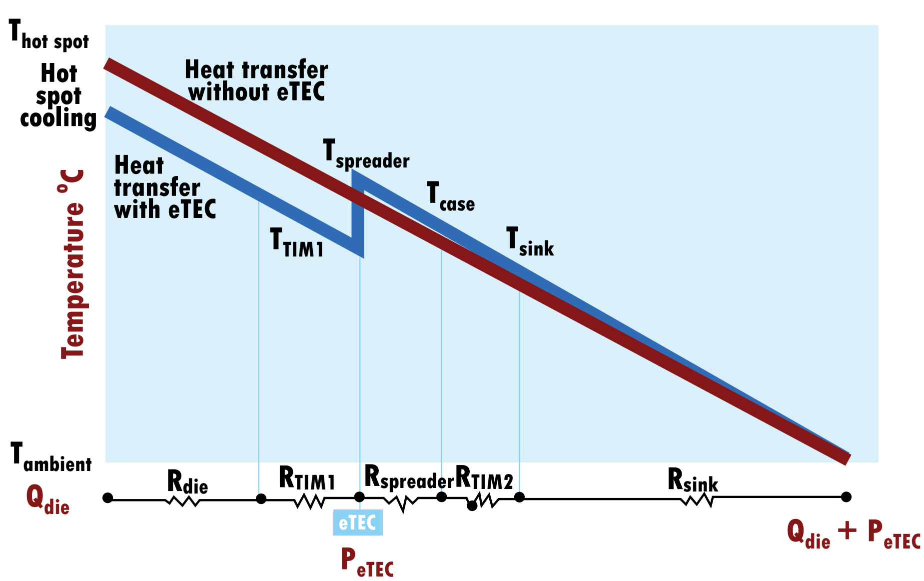

Figure 5. Comparison of Hot Spot Temperature With and Without Use of an eTEC [2].

Conclusion

The use of micro TECs offer an attractive solution to the thermal engineer who needs to address the issue of cooling component hot spots. Micro TECs can be seamlessly integrated into component packages and heat spreaders to focus cooling where it is needed most. The result can be an effective thermal solution that allows for improved thermal management of hot devices [1].

When designing with micro TECs one should select devices with high COP and large ΔT_{TE} capability. The micro TECs should be as thin as possible as this will allow for the best thermal performance and highest level of responsiveness. From a practical standpoint, the technology exists to fabricate TECs directly on to the die or component heat spreader using microfabrication techniques such as thick film electroplating, vacuum deposition, and chemical vapor deposition. These processes result in extremely thin TECs with high performance [1].

Finally, while the best micro TECs are now made from Bi_2Te_3 and Sb_2Te_3 the world of new materials is ever expanding. It is reasonable to expect that the micro TECs of the future will be better and faster than those of today.

References:

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