On-Chip Silicon 'Microcoolers' for Microprocessor Hot Spots

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As semiconductor-based technology has rapidly developed, producing ever smaller and faster silicon-chip computer processors, effectively cooling these chips has remained a problem. Now, researchers have developed a way to cool hot spots using tiny on-chip silicon "microcoolers."

The research, performed by scientists at the University of Maryland at College Park, is published in the August 2, 2007, online edition of the *Journal of Applied Physics*.

"Hot spots can severely degrade a microprocessor's performance and reliability, but cooling methods that address the entire chip cause unnecessary over-cooling, as well as raise the cost, weight, and volume of the cooling solution," said corresponding researcher Avram Bar-Cohen to *PhysOrg.com*.

Building on prior analytical work*, Bar-Cohen and co-researcher Peng Wang, both mechanical engineers, developed a three-dimensional mathematical model of the thermal behavior of a silicon chip using computer software. The model accounts for all aspects of heating and cooling on the chip, including localized cooling, hot-spot heating, background heating from nearby circuitry, and conductive/convective cooling through the back of the chip.

The model predicts that when an electric current is applied to a region of "highly doped" silicon (silicon with a high level of added impurities) on

the back of a chip, a cool region will be created on the chip. If the cool region is located opposite a microprocessor hot spot, it will absorb heat and lower the hot spot temperature. This localized cooling phenomena occurs via the thermoelectric effect – the use of electrical energy to transfer heat against the natural hot-to-cold thermal gradient. The silicon and the metal lead that brings electric current to the back of the chip have very different thermoelectric sensitivities. As a result, a cooling effect occurs at the contact-cap and cap-silicon junctions and heat is pulled up out of the hot spot.

“Although thermoelectric cooling is not a new technology and thermoelectric coolers made of bismuth telluride have been available for many years, the use of the silicon chip itself as the thermoelectric cooler is a novel and groundbreaking approach to hot spot remediation,” said Bar-Cohen.

He and Wang initially programmed their model to consider a chip 12 millimeters (mm) square with a hot spot 70 micrometers (millionths of a meter) square. From there, they varied the thicknesses of the chip and the cap to investigate how the cooling performance changed. They found that, in general, microcoolers that are approximately five times the chip thickness (up to 1-2 mm in size) and thinner chips (a few hundred micrometers thick) yield the best results.

Similar microcooling systems have been proposed, such as thin-film thermoelectric coolers, or TFTECs, which consist of two layered ultra-thin semiconductor lattices, such as silicon-germanium on top of silicon. Like the silicon microcoolers, TFTECs are positioned on the back of the silicon chip to pull away heat. Among their advantages are compactness and fast cooling response. One main disadvantage, however, is that for such TFTECs a thermal “interface” resistance is present between the chip and the thin film, reducing the cooling effect.

Citation: Peng Wang and Avram Bar-Cohen, “On-chip hot spot cooling using silicon thermoelectric microcoolers” *Journal of Applied Physics* 102, 034503 (2007)

*Peng Wang, Avram Bar-Cohen, Bao Yang, Gary L. Solbrekken, and Ali Shakouri, “Analytical modeling of silicon thermoelectric microcooler” *Journal of Applied Physics* 100, 014501 (2006)

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