Thin Film Solid State Refrigerators for Spot Cooling of Integrated Circuits

Ali Shakouri, Daryoosh Vashaee, James Christofferson, Xiaofeng Fan*, Chris Labounty*
Jack Baskin School of Engineering
University of California at Santa Cruz
Santa Cruz, CA 95064-1077, USA
Tel: (831) 459-3821
Fax: (831) 459-4829
ali@cse.ucsc.edu

* Electrical and Computer Engineering
University of California Santa Barbara, CA 93106

Abstract

The on-chip temperature of the packaged VLSI circuits not only can reach as high as 100C on average, but also can vary by as much as a few tens of degrees from one location to another (see Fig. 1). Because the failure rate of microelectronic devices depend heavily on the localized operating temperature, hot spots due to high local-power dissipation have become a long-term IC reliability concern in diverse applications such as high-performance microprocessors and digital signal processing chips. As integration level and clock speeds increase and device feature size decreases, overheating and hot spots is becoming more of a problem in conventional metal-oxide-semiconductor (MOS) circuits as well. One of the key reliability issues, electromigration, is exponentially dependent on temperature. So cooling by as little as 10C can increase the mean time to failure by a factor of 2 or 3.

In this talk we will review the performance of conventional BiTe thermoelectric coolers and describe recent advances in SiGe and III-V thin film solid-state refrigerators. We will also examine how thin-film coolers could be integrated with IC chips in order to remove the hot spots and make the chip temperature more uniform. Current commercial thermoelectric devices range is size from 1.8x3.4x2.4 up to 62x62x5.8 mm^2 and they can cool by as much as 70C at room temperature. However they are fabricated out of BiTe compounds in a bulk manufacturing technology that is not compatible with IC processing. In addition the cooling power density is limited to 10's of W/cm^2 (see Fig. 2). On the other hand, recently SiGe-based superlattice devices have demonstrated 4C cooling at room temperature and cooling power densities exceeding 500W/cm^2 (see Fig. 3). These refrigerators can be grown directly on a silicon substrate and they can be used to control the temperature on a short time scale (tens of micro seconds) over small areas down to hundreds of microns square.

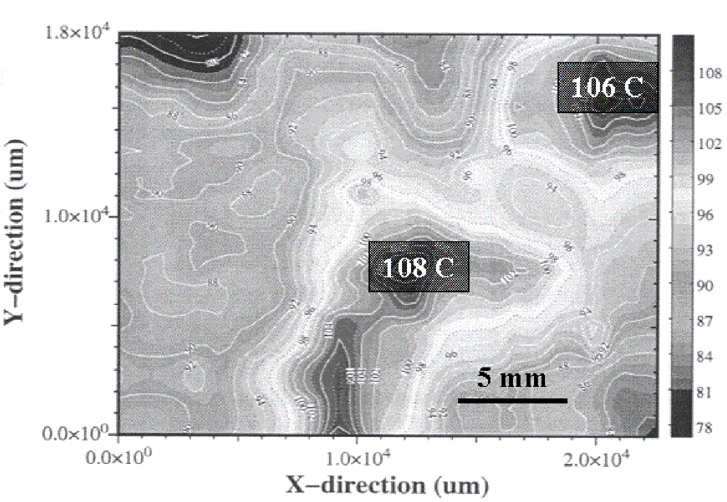

Fig. 1 Simulated temperature distribution in a VLSI Chip showing hot spots (Y-K Cheng et al. "Electrothermal analysis of VLSI Systems," Kluwer 2000).

Typical values for
Bi_2Te_3Seebeck=200 mV/K
resistivity=0.001 Ωcm
thermal conductivity=0.015 W/(cmK)

Device diameter=40□m, T_0=300K,
device length=1mm

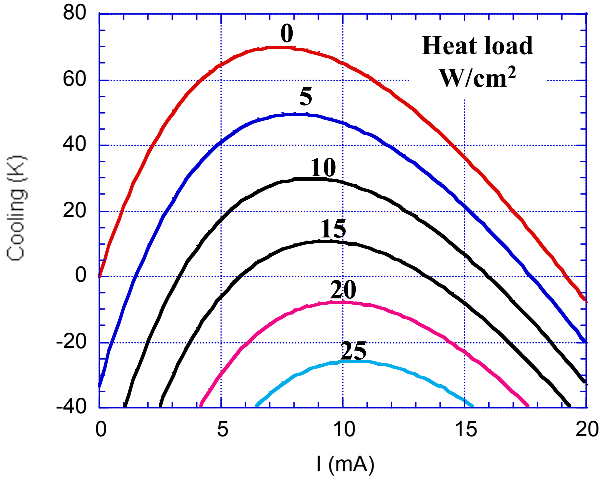

Fig. 2 Cooling versus current for different heat load power densities for of a conventional BiTe thermoelectric cooler.

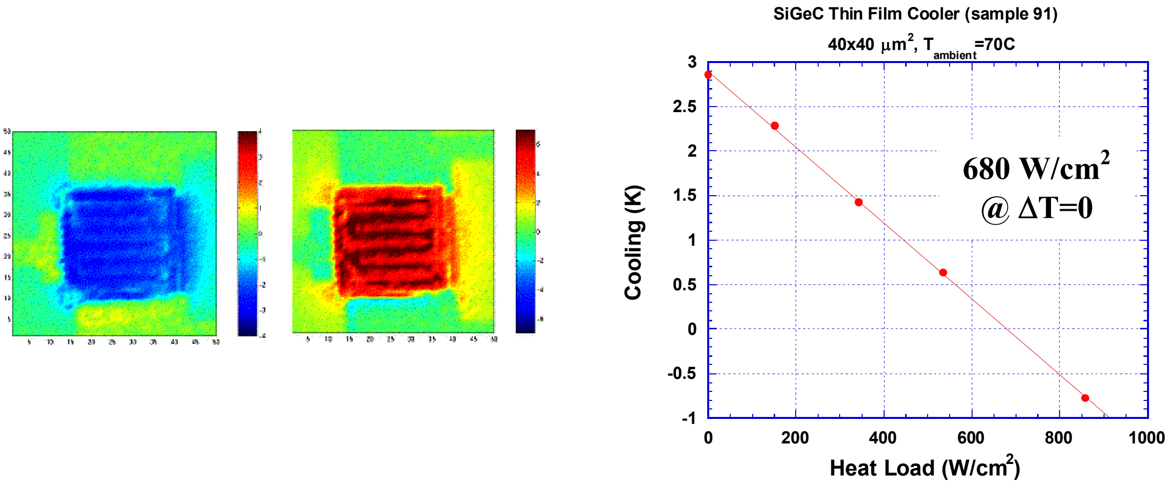

Fig. 3 Maximum cooling of a 40x40μm^2 n-SiGeC refrigerator versus heat load power density.