Journal of ELECTRONIC MATERIALS, Vol. 42, No. 7, 2013
DOI: 10.1007/s11664-012-2453-3

Impact of Thermal Radiation on the Performance of Ultrasmall Microcoolers

RYAN P. SHEA,[1,2] ANAND S. GAWARIKAR,[1] and JOSEPH J. TALGHADER[1,3]

1.—University of Minnesota, 200 Union St SE, Minneapolis, MN 55117, USA. 2.—e-mail: Sheax074@umn.edu. 3.—e-mail: joey@ece.umn.edu

On extremely small scales, traditional microcooler performance estimates must be corrected to include losses due to radiation. We present a method for analysis of microcoolers having a significant radiative contribution to their thermal conductance. We have fabricated ultrasmall microcoolers from sputtered Bi_2Te_3/Sb_2Te_3 thermoelectric junctions with cooling volumes of 200 μm $\times$ 200 μm $\times$ 65 nm, which we believe to be the smallest microcoolers ever made. The devices are highly thermally isolated with total thermal conductance under 5×10^{-7} W/K in vacuum at room temperature. By fitting the temperature response to input power of the devices in vacuum, we have quantified the nonlinearity of the response to calculate the radiative and film contributions to the total thermal conductance of the device. Three device geometries are presented, with radiative contributions to thermal conductance of 15%, 26%, and 100% depending on their emissive area and support structure. The cooling capabilities of these devices are also measured with maximum cooling of 3.1 K for the 15% radiation-limited device and 2.6 K for the 26% radiation-limited device, with power consumptions below 5 μW.

Key words: Microcooler, radiation, heat transfer, MEMS

INTRODUCTION

As the scaling of thermoelectric coolers progresses from the cooling of entire modules to individual electronic devices, the surface-area-to-volume ratio of the thermoelectric and supporting films increases drastically. In addition, the allowable power draw for microcoolers will drop rapidly with size. In order to minimize power consumption, film thicknesses must be reduced and thermal isolation increased to maximize cooling. Microcoolers are affected by four main heat transfer mechanisms: material thermal conduction through the thermoelectric films and support structure, thermal conduction through air, convection of air near the cooler, and radiation. Material thermal conduction is a fundamental loss source for thermoelectric coolers. This source can be minimized by material advancements and is vital to the figure of merit of thermoelectric materials. Conduction through air is not a fundamental process because it can be eliminated through vacuum packaging, a common technique used in infrared imaging and some other electronic technologies. Convection plays a very minor role on the microscale and can also be eliminated using vacuum packaging. Radiation is a fundamental heat transfer mechanisms for all devices, but in the analysis of current state-of-the-art microcoolers it has been ignored as the surface-area-to-volume ratio of the devices is not high enough for radiation to be significant. However, in very small microcoolers that are designed to minimize power consumption, radiative heat transfer becomes a source of loss that must be addressed.

We first present a theoretical analysis of microcooler performance including radiative transport. An analysis of the power transfer mechanisms of a thermally isolated device allows for the fitting of separate coefficients related to film and radiative

(Received July 6, 2012; accepted December 28, 2012; published online February 21, 2013)