Journal of ELECTRONIC MATERIALS, Vol. 42, No. 3, 2013
DOI: 10.1007/s11664-012-2366-1

Thermal Cycling, Mechanical Degradation, and the Effective Figure of Merit of a Thermoelectric Module

M. T. BARAKO,[1,2] W. PARK,[1] A. M. MARCONNET,[1] M. ASHEGHI,[1] and K. E. GOODSON[1]

1.—Department of Mechanical Engineering, Stanford University, Stanford, CA, USA. 2.—e-mail: mbarako@stanford.edu

Thermoelectric modules experience performance reduction and mechanical failure due to thermomechanical stresses induced by thermal cycling. The present study subjects a thermoelectric module to thermal cycling and evaluates the evolution of its thermoelectric performance through measurements of the thermoelectric figure of merit, ZT, and its individual components. The Seebeck coefficient and thermal conductivity are measured using steady-state infrared microscopy, and the electrical conductivity and ZT are evaluated using the Harman technique. These properties are tracked over many cycles until device failure after 45,000 thermal cycles. The mechanical failure of the TE module is analyzed using high-resolution infrared microscopy and scanning electron microscopy. A reduction in electrical conductivity is the primary mechanism of performance reduction and is likely associated with defects observed during cycling. The effective figure of merit is reduced by 20% through 40,000 cycles and drops by 97% at 45,000 cycles. These results quantify the effect of thermal cycling on a commercial TE module and provide insight into the packaging of a complete TE module for reliable operation.

Key words: Thermoelectric module, infrared microscopy, thermal cycling, figure of merit, Harman method

Nomenclature

A	Cross-sectional area, m^2
I	Electrical current, A
k	Thermal conductivity, W m^{-1} K^{-1}
L	Length of TE element, mm
q	Heat flow, W
q''	Heat flux, W m^{-2}
T	Temperature, °C
V	Voltage, V
x	Position along direction of conductive heat flow, mm
ZT	Thermoelectric figure of merit

Greek symbols

α	Seebeck coefficient, V K^{-1}
ρ	Electrical resistivity, Ω m
σ	Electrical conductivity, Ω^{-1} m^{-1}

Subscripts

0	At 0 cycles
E	Electrical component of voltage
OC	Open-circuit voltage
pp	Peak-to-peak voltage
ref	Reference layer
TE	Thermoelectric
TE leg	Single thermoelectric leg element
T	Thermoelectrical component of voltage
Total	Total voltage

(Received July 17, 2012; accepted November 16, 2012; published online December 8, 2012)

INTRODUCTION

Thermoelectric (TE) modules provide solid-state conversion between a temperature gradient and an electrical potential. Thermoelectric modules frequently operate in the power generation configuration, where an imposed temperature difference generates an electrical potential and current.