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Evaluation of Temperature-Dependent Effective Material Properties and Performance of a Thermoelectric Module

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We devised a novel method to evaluate the temperature-dependent effective properties of a thermoelectric module (TEM): Seebeck coefficient (S_{m}), internal electrical resistance (R_{m}), and thermal conductance (K_{m}). After calculation, the effective properties of the module are converted to the average material properties of a p–n thermoelectric pillar pair inside the module: Seebeck coefficient (S_{TE}), electrical resistivity (ρ_{TE}), and thermal conductivity (k_{TE}). For a commercial thermoelectric module (Altec 1091) chosen to verify the novel method, the measured S_{TE} has a maximum value at bath temperature of 110°C; ρ_{TE} shows a positive linear trend dependent on the bath temperature, and k_{TE} increases slightly with increasing bath temperature. The results show the method to have satisfactory measurement performance in terms of practicability and reliability; the data for tests near 23°C agree with published values.

Key words: Thermoelectric, Seebeck coefficient, electrical resistance, thermal conductivity, temperature-dependent properties, measurement

INTRODUCTION

A thermoelectric module (TEM) is a solid-state device that can serve as either a refrigerator, according to the Peltier effect, or a power generator, according to the Seebeck effect. As a refrigerator, the module, called a thermoelectric cooler (TEC), converts electricity into a temperature potential, and is commonly applied to control temperature by cooling and heating. As a power generator, the module, called a thermoelectric power generator (TEG), converts a heat flux into electricity, and is capable of use in temperature sensing or for harvesting waste heat.

Three main properties represent the performance of a thermoelectric material or module: the Seebeck coefficient (S), electrical conductivity (σ), and thermal conductivity (k). These properties are combined into two performance indices: the power factor (PF = $S^2\sigma$) and the figure of merit ($ZT = S^2\sigma T/k$). The power factor expresses the ability of a TEG to generate power; the figure of merit represents the efficiency of energy conversion of a TEG or TEC.

Some methods and related equipment have been well developed and adopted by previous authors[1,2] to determine the thermoelectric properties of a material by measuring the material itself. The Seebeck coefficient is generally determined by measuring the voltage drop (ΔV) and temperature difference (ΔT) across a sample and using the Seebeck equation: $S = \Delta V/\Delta T$; the electrical conductivity is measured with a four-wire technique and corrected using an equation for the thermoelectric field: $V = S \cdot \Delta T + I \cdot R$ (I, current; R, electrical resistance); the thermal conductivity is determined

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