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Error Modeling of Seebeck Coefficient Measurements Using Finite-Element Analysis

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Using finite-element analysis, we have developed a metrology simulation to model errors in the measurement of the Seebeck coefficient. This physical parameter is the constant of proportionality relating the electric potential generated across a conductor to the applied thermal gradient. Its measurement requires careful attention to the electrical and thermal contact interfaces. Furthermore, it is essential that the electric potential and temperature difference be acquired at the same time and at the same location. We have performed Seebeck coefficient measurement simulations to quantitatively explore the effect of temporal perturbation to the voltage and temperature correspondence, by comparing simultaneous and staggered data acquisition techniques under the quasi-steady-state condition. Using a similar method, we have developed an error model to explore the effect of misalignment between the voltage and temperature probes on the measurement of the Seebeck coefficient. This approach enables the exploration of experimentally inaccessible data spaces under ideal conditions.

Key words: Seebeck coefficient, metrology, finite-element analysis, thermoelectric

INTRODUCTION

The Seebeck effect is the direct conversion of a thermal gradient into an electric potential. This effect can be quantified through a constant of proportionality termed the Seebeck coefficient,

$$S_{\mathrm{ab}} = \lim_{\Delta T \to 0} \frac{\Delta V_{\mathrm{ab}}}{\Delta T}, \tag{1}$$

where ΔV_{ab} is the electric potential between two different materials a and b, and $\Delta T = T_2 - T_1$ is the applied temperature difference measured between the hot (T_2) and cold (T_1) location.[1–7] According to this definition, the measured Seebeck coefficient S_{ab} requires the correction $S_{\mathrm{ab}} = S_{\mathrm{b}} - S_{\mathrm{a}}$, where S_{b} is the contribution of the second conductor, to obtain S_{a}, the Seebeck coefficient of the sample. Materials that exhibit large absolute Seebeck coefficient ($\sim$100 μV/K to 200 μV/K), in addition to other optimal physical properties, are considered candidates for use in thermoelectric (TE) applications.[5–7] The low conversion efficiency of TE devices currently limits their widespread commercial practicality to niche (but useful) applications, including automotive waste-heat recovery, deep-space and/or remote power generation, temperature measurement, sensor and integrated-circuit spot cooling, and electronic refrigeration. Furthermore, TE devices are environmentally friendly, require minimal maintenance (with few moving parts), and offer reliable, quiet, and compact operation.

The continued development of higher-efficiency TE materials requires thorough characterization of the electrical and thermal transport properties, to both fully evaluate the structure–property relationships and to illuminate the underlying physics of these new systems. Due to its intrinsic sensitivity to the electronic structure, the Seebeck coefficient is one essential physical parameter used to identify a material's potential TE performance. However, researchers employ a variety of techniques, conditions, and probe

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