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Modeling and analysis of the effect of thermal losses on thermoelectric generator performance using effective properties

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HIGHLIGHTS

- Modeling captures the contributions from thermal losses and interfacial resistance.
- The effective properties provide a precise description of the transport properties.
- Quantification of actual figure-of-merit with thermal losses is performed.
- The performance of TEG is explained quantitatively through effective properties.
- The modeling method is applied to various materials to confirm the feasibility.

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ABSTRACT

A mathematical model for a thermoelectric generator (TEG) based on constitutive equations has been developed to analyze temperature dependent performance in terms of output power and efficiency. Temperature dependent material properties and thermal losses, which occur as conductive and radiative heat transfer, were considered in the finite element model. Effective material properties were invoked for understanding the influence of temperature dependence of material parameters and related adverse effects on the model TEG. It is shown that analytical equations with effective properties can provide excellent estimation of the performance of a TEG over a broad operating range. The model was simulated, analyzed and validated to examine the effects of different operating conditions and geometry that interact with thermal losses inside the TEG. We believe that this model will further expedite the optimization of TEGs being developed using new material compositions.

1. Introduction

Currently, conventional fossil fuels meet most of the energy demands, which has raised concern about increasing ambient temperature and resulting climate change [1]. Therefore, significant effort is being placed on identifying and developing sustainable energy harvesting methods to provide new renewable energy sources [2]. There are many types of ambient and kinetic energy sources from which energy can be harvested, such as thermal energy, ocean waves, wind, solar and mechanical vibrations. Thermal energy is available everywhere and is one of the most attractive energy sources due to the fact that every thermodynamic process is accompanied by the release of wasted energy as heat. Thus, there is a strong interest in developing high efficiency solid state thermal-to-electrical energy harvesting devices that can be utilized in wide ranges of temperature. Thermal energy harvesters are also desired for remote power applications, for example, soldiers camping in remote areas require portable power generators that can convert liquid fuel into electricity. Thermoelectric generators show promise in such applications due to their low weight, noise, and vibration as compared to mechanical systems.

Semiconductor-based thermoelectric (TE) devices utilize the Seebeck effect in order to generate electricity directly from heat without chemical reactions, noise, or harmful byproducts, and thus have attracted much attention as a prospective energy conversion technology. In past, thermoelectric generators (TEGs) have been modelled and characterized to quantify key parameters influencing the performance and understand the quantitative correlation between material/device parameters and performance of the device [3–7]. Internal electrical resistance and thermal conductance causes TEG performance to fall far below the Carnot limit, and their effects on TEGs

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