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A Novel 3D TCAD Simulation of a Thermoelectric Couple configured for Thermoelectric Power Generation

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Abstract. This paper documents the novel design, modelling and 3D simulation of a single thermoelectric couple using the Technology Computer Aided Design (TCAD) semiconductor simulation software package by Synopsys. Preliminary simulation results are presented for thermoelectric power generation, and successfully demonstrate the basic thermoelectric effects, and how the application of a temperature gradient to a thermoelectric couple results in a small amount of electrical power being generated at a load resistor. The TCAD simulation model will enable further investigation in the future into different material structures, thermoelectric couple and module design, and the improvement in efficiency and thermoelectric module performance.

Key words

Thermoelectric, Seebeck, micro-power generation, TCAD, 3D simulation

1. Introduction

This paper begins with a short background review of thermoelectric technology, followed by an overview of a typical thermoelectric module construction, highlighting the main elements and material structure, and a detailed description of a single thermoelectric couple connected for thermoelectric power generation. The 3D modelling of a thermoelectric couple is presented, including preliminary simulation results obtained for the thermal and electrical characteristics of the device when it is connected as a thermoelectric generator. The simulation results are discussed with reference to basic thermoelectric theory, and the paper draws conclusions on the validity and effectiveness of the 3D TCAD thermoelectric couple simulation model.

2. Background

Thermoelectric technology is the focus of significant research and can make an increasing contribution to the need to find alternative methods of power generation, heating and cooling. The technology can also be used in applications where other renewable technologies could not be used, or in combination with other renewable technologies, in order to enhance a systems overall performance. The concept of using thermoelectric technology to generate electrical power from waste heat in a system has been considered for some time, although the technology is often overlooked in discussions surrounding renewable energy sources. This is partly due to the relatively low levels of electrical power generated from a typical thermoelectric module, usually in the milli-watt (mW) or micro watt (μW) range, and a typical conversion efficiency of 5% to 10% [1]. However, with the addition of relatively simple electronic signal-conditioning techniques, for example low-power DC to DC conversion, coupled with electrical storage in supercapacitors, enables the electrical power output from a thermoelectric power generation system to be increased to a useful level, and can output sufficient electrical power to operate low-power electronic systems, recharge or replace batteries in many applications, and is considered an environmentally friendly and renewable energy source. The technology is not limited to low-power applications, with significant focus and research into thermoelectric power generation from waste heat in the automotive market, and is extensively used to provide power to space-craft.

Thermoelectricity utilises the Seebeck, Peltier and Thomson effects that were first observed between 1821 and 1851. Practical thermoelectric devices emerged in the 1960's and have developed significantly since then with a number of manufacturers now marketing thermoelectric modules for power generation, heating and cooling applications [2]. Ongoing research and advances in thermoelectric materials and manufacturing techniques, enables the technology to make a greater contribution to address the growing requirement for low-power energy sources typically used in energy harvesting and scavenging systems.

Commercial thermoelectric modules can be used to generate a small amount of electrical power, typically in the mW or μW range, if a temperature difference is maintained between two terminals of a thermoelectric module [3]. Alternatively, a thermoelectric module can operate as a heat pump, providing heating or cooling of