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Development of flexible thermoelectric cells and performance investigation of thermoelectric materials for power generation

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Abstract

This paper presents experimental performance results for custom made thermoelectric generator. Two fabrication methods, powder compaction and painting over flexible substrate have been proposed and investigated. Experimental performance results have been presented for thermoelectric cells made from alloying Bismuth (Bi), Tellurium (Te) and Antimony (Sb). Powdered P-type (Bi0.4Sb1.6Te3) and N-type (Bi2Te3) thermoelectric materials were chosen for the construction of the thermoelectric cell. Experimental results showed that P-type Bi0.4Sb1.6Te3 had Seebeck coefficient of 211.77 µV/°C and while N-type Bi2Te3 had a Seebeck coefficient of 109.09 µV/°C. The flexible thermoelectric generator has shown linear increase in open circuit voltage with increase in temperature difference across the cold and hot side.

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Keywords: Flexible Thermoelectric cells; Seebeck coefficient; Semiconductor; Figure-of-merit; thermoelectric generator; Powder compaction, printing

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1. Introduction

Due to the consistent global rise in energy consumption, along with the ever increasing demand for electricity, heating, refrigerating, etc., greenhouse gas emissions are on the incline globally [1]. Majority of the primary energy consumption is in form of thermal energy and is exhausted to the atmosphere as low temperature waste heat.

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Thermoelectric cells (TEC) directly convert heat into electricity via the Seebeck effect of TE materials and are considered by many to have potential to utilize this low temperature waste heat for producing power [1]. The Seebeck coefficient (S) can be obtained by applying a thermal gradient across a sample, measuring the differential voltage (ΔV) across two ends of that sample and having temperatures TH and TC at the respective ends [2]. This is under the condition that no current flows through the sample whilst measurements are being taken [3].

In order to measure S, two different methods can be utilized, the integral and differential method [3]. In the integral method, one end is kept at a constant temperature whereas the other end of the sample is slowly heated. When following the differential method, the entire sample is heated to a higher temperature, with temperature differentials being created between the ends. The linear voltage drop (ΔV) versus the temperature difference (ΔT) gives the S for a specific temperature step [3]. This research paper follows the differential method, creating a testing environment in which the whole sample is slowly heated with ΔV measurements being taken with corresponding ΔT values, to estimate S. Materials which are thermal insulators and good electrical conductors with high S generally reflect good TE properties [4]. The laws of physics make this extremely hard to achieve. The Wiedemann-Franz law states that the “electronic part of thermal conductivity to be proportional to electrical conductivity” and the Pisarenko relation limits the simultaneous enlargement of Seebeck coefficient and electrical conductivity” [5].

The most common material in today’s TEG is Bi2Te3 (Bismuth Telluride). Over the past 30 years, various alloys idealized around bismuth telluride have been researched and optimized for TE applications [6]. Recent studies have shown that high performing p-type Bi0.4Sb1.6Te3 materials have been manufactured via mechanical alloying (MA) and hot extrusion in the temperature range of 360°C – 450°C. Figure of Merit value of 1.2 at room temperature for extrusion temperatures of 400°C have been recorded [7].

Power generation through the deployment of TEGs has already been utilised in many areas, including; transport tools, aerospace facilities and industry utilities [8], where the main focus is utilising waste heat to generate electrical power. Recent developments have found effective use in harvesting waste heat from the human body for wristwatches, designed by Seiko and Citizen [9]. There are many desirable features in the deployment of TEGs. They are extremely environmental friendly in the electricity production for using waste heat as an input source and they also allow the use of energy efficiently [10, 11]. TE products can be used with a reliable life of 25 years [9], requiring no maintenance. They are quiet when operating and have no moving parts [12].

Thermoelectrics is an area with a wide scope for further research and experimentation. This research paper looks into two cost effective fabrication methods, firstly through the exploration of metallurgy powder compaction using a steel cylindrical template and hydraulic press and second by using painting on flexible substrate. P-type Bi0.4Sb1.6Te3 and n-type Bi2Te3 alloys are compared and tested using S-type testing rig. Custom made TE generator is constructed and its performance tested. Results and important findings are discussed throughout this paper.

2. Thermoelectric materials fabrication

In order to optimize thermoelectric properties, it is essential to calculate and measure weight ratios of the elements accurately. In order to do this, we must know the molar mass (M) of the TE material as well as the atomic mass (ma) of the individual elements that make up the TE material. In order to calculate the correct weight percentage, we divide the total mass of each element by the overall molar mass of the TE material. For simplicity purposes, 10g powders for both p-type and n-type TE materials were produced by crushing pure bismuth, tellurium and antimony (approximately 99.9% purity).

Method 1: Accurately measured portions of Bismuth, Tellurium and Antimony are then placed into a glass tube which is then connected to a vacuum pump to extract any air. While under vacuum the glass tube is heat sealed. The vacuumed tube is then placed upright in a furnace to melt and form TE alloy. To ensure that the individual elements are evenly infused, the glass tube is shaken for a few seconds every 20 minutes. The process takes about an hour. After which, the glass tube is removed out from the furnace and allowed to be cooled to the ambient temperature. Then the alloy is grinded into fine powder.

Method 2: After determining the required mass of each element required to create 10 grams of powder samples, the following steps are followed. Firstly, pure elements are weighed out using laboratory scales (accuracy to 0.01g) to their required mass. Once the desired mass is achieved, the element is then grinded into a fine powder. Now all