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Performance Investigation of Sodium Cobalt Oxide/Cu-Zn Alloy Thermoelectric Module

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ABSTRACT

This work focuses on performance investigation of a low cost thermoelectric module fabricated from p-type sodium cobalt oxide and n-type Cu-Zn alloy. The waste heat conversion measurements indicated that the developed module generated output voltages of 0.35 mV/K and 0.85 mV/K at temperature differences of 1-6 K and 8-14 K, respectively. As the result, this thermoelectric module may be suitable candidate as an electrical generator in moderate voltage applications.

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INTRODUCTION

Thermoelectric materials have gained a great interest as sustainable materials due to their capability to convert waste heat to useful electrical energy. Oxide materials have received extensive interest as thermoelectric materials due to their easy-to-prepare procedure, chemical and thermal stability, non-toxicity and low cost. Cobalt-oxide-based layer-structured crystals such as NaxCoO2 [1,2], Ca3Co4O9 [3], and LaCoO3 [4] have been reported as p-type thermoelectric materials of high performance in a wide range of working temperature (250-800^{o}C). Particularly, excellent thermoelectric efficiency of sodium-cobalt oxide (NaxCoO2) was reported indicating its significantly high thermoelectric power factor and low electrical resistivity [1]. Thermoelectric performance is described in terms of a value of power factor (P.F), which can be calculated by P.F =$\sigma S2$, where σ is electrical conductivity and S is Seebeck coefficient. Although obtaining new thermoelectric materials with high σ and S is significant, it is necessary to investigate whether these materials can be fabricated as device giving acceptable output voltage under conditions studied. In this work, a small thermoelectric module was developed by connecting sodium-cobalt oxide bulk material as a p-type conductor and Cu-Zn alloys bulk material as n-type material. To our best knowledge, there is no report on the performance of this thermoelectric module available. Measurements of output voltage values at various range of temperature gradients were carried out in order to obtain the information on practicality of the developed thermoelectric module.

MATERIALS AND METHOD

Polycrystalline sodium cobalt oxide sample was synthesized by a solid state reaction method. In brief, NaCO3 and Co3O4 is mechanically mixed with a Na:Co molar ratio of 0.7:1. Then the powder mixture was pressed in to pellets and calcined in air ambient condition at 1023 K for 12h [6]. The calcined product was sintered at 850°C for 24 h. Next, the fired samples were grounded and shaped in to rods with dimension of 6 mm in diameter and 15 mm in height, using PEDOT: PSS as binder. The PEDOT: PSS solution was dissolved in Dimethyl sulfoxide by 1:4 molar ratios. Powder X-ray diffraction (PXRD, Bruker Axs model D8 advance, Cu kα radiation) was employed to confirm the crystalline phase of all samples. Each powder pattern was run with the 2-theta range of 10-80°. Moreover, thermoelectric properties of sodium cobalt oxide were measured by

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ULVAC-RIKO ZEM-3. Seebeck Coefficient/Electric Resistance Measuring System at the Thermoelectric and Nanotechnology Research Center, Faculty of Science and Technology, Rajamankala University of Technology Suvarnabhumi. Cu-Zn alloy (60:40 wt./wt.) was used to be n-type materials was No. UNS C2800. It has electrical conductivity, 1.62×107 S/m, and thermal conductivity, 123 W/mK, at room temperature. In general, value of Cu-Zn alloy was around 1 kg/USD. For this work, size of Cu-Zn alloy was 5 mm diameter, 10 mm height and 1.6707×10-3 kg weight.

Thermoelectric module:

Sodium cobalt oxide was connected with Cu-Zn alloy that was commercial material. They were connecting with RC circuit to measure output voltage as shown in Fig. 1. The RC circuit is composed of 2KΩ resistance to allow current flow on circuit and capacitor 220 μF to store charges. Voltage output were measured by digital multimeter, Fluke 189 and temperature difference were measured by IR thermometer, EXTECH 42507.

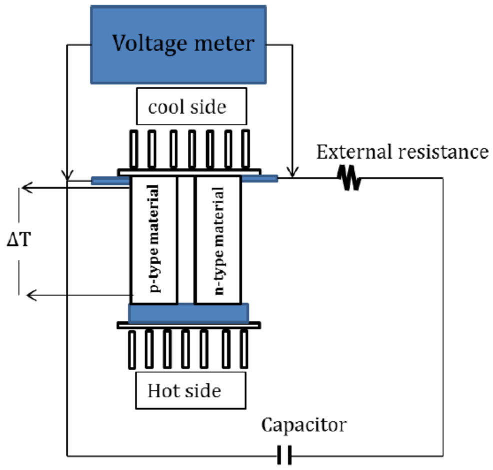

Fig. 1: Thermoelectric module containing p-type sodium cobalt oxide and n-type Cu-Zn alloy.

RESULTS AND DISCUSSION

Figure 2 represents powder X-ray diffraction pattern of the successfully prepared sodium cobalt oxide sample with a single phase of gamma sodium cobalt oxide phase of hexagonal crystal system, P63/mmc space group.

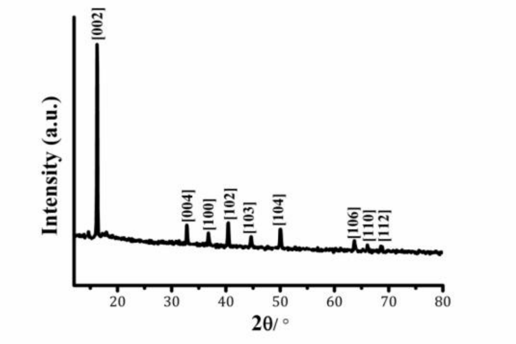

Fig. 2: PXRD patterns of sodium cobalt oxide sample.

Note that gamma sodium cobalt oxide is considered relatively high performance thermoelectric materials having power factor (P.F.) of 623.1 μW/K2m , comparing with alpha-phase (P.F. =75 μW/K2m) and beta-phase (P.F. =40.8 μW/K2m)[7,8].

In this work, thermoelectric properties of the synthesized sodium cobalt oxide i.e. electrical conductivity, seebeck coefficient and power factor were measured on a ULVAC-RIKO ZEM-3. The results were plot in a function of temperature as shown in Fig. 3.

As seen in Fig.3 (a), the electrical conductivity and Seebeck coefficient of the sodium cobalt oxide sample increase with temperature. Positive values of Seebeck coefficient suggested a p-type characteristics. At 320 K, the electrical conductivity of 3.63 S/m and Seebeck coefficient of 61.9 μV/K resulted in the P.F equal to 14×10-9 W/mK2. Nevertheless, the electrical conductivity of the sample is lower than that reported in Kenjiro Fujita work [2], possibly due to the utilizing of PEDOT: PSS binder having low electrical conductivity of 0.047×10-5

S/m [9]. Next, the sodium cobalt oxide sample was employed as p-type material connecting with n-type Cu-Zn alloy to construct an inexpensive thermoelectric module. Output voltage was measured in a function of temperature, and reported in Fig. 4.

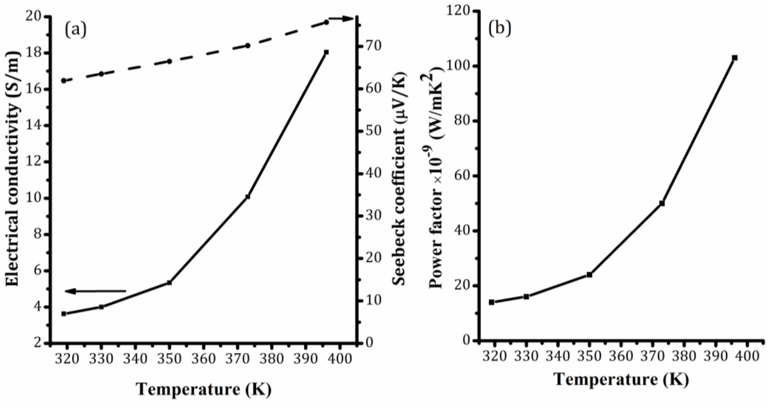

Fig. 3: Temperature dependence of thermoelectric properties of sodium cobalt oxide; (a) electrical conductivity and Seebeck coefficient, and (b) power factor.

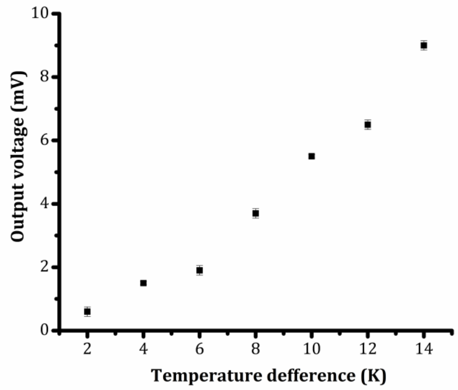

Fig. 4: Output voltage of the thermoelectric module for one cell, fabricated from sodium cobalt oxide and Cu-Zn alloy measured with temperature difference.

From the results, output voltage typically increased with increased temperature difference when gave more temperature difference. Assuming linear relationship between the output voltage directly and temperature difference in the temperature difference of 1-6 K and 8-14 K, the quantified increment of output voltage are 0.33 mV/K, and 0.85 mV/K, respectively. Wang and coworkers reported the increment of output voltage of less than 1 mV at temperature difference of 1 K can be obtained from commercial bismuth telluride thermoelectric module [10]. Therefore, the reported output voltage of sodium cobalt oxide/Cu-Zn alloy in this study gives thermoelectric performance comparable to the module fabricated by using commercial thermoelectric material. Hence, this implies the practicality in utilizing n-type Cu-Zn alloy together with p-type sodium cobalt oxide to produce thermoelectric modules.

The output power (P) of thermoelectric module was evaluated from the equation P=V2/R, by using the resistance (R) of the thermoelectric module at room temperature (27 KΩ), giving results shown in Fig. 5.

Output power values evaluated by output voltage and module resistance are shown in Fig.5. The module resistance (27 KΩ) and circuit resistance (2 KΩ) were connected in series which were 29 KΩ. It was found that the low thermoelectric properties of polycrystalline sodium cobalt oxide and high internal module resistance contribute to the low output power.

Conclusion:

Thermoelectric module of sodium cobalt oxide/Cu-Zn alloy was investigated for energy harvesting applied for low voltage application. Output voltage, 0.85 mV/K at temperature difference more than 8 K, suggested a possibility to use this low-cost and easy-to-fabricate thermoelectric module as an electrical generator. Future works aim to improve the output power of the thermoelectric module and decrease internal module resistance using modified device fabrication methods.

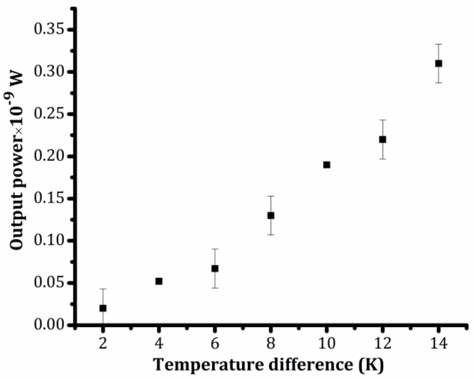

Fig. 5: Measured output power and temperature difference.

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