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Electrical characterization of thermoelectric generators based on p-type $Yb_{0.6}Co_4Sb_{12}$ and n-type $Fe_{2.0}Co_{2.0}Sb_{12}$ thermoelectric materials

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ABSTRACT:

In this study, thermoelectric power generation (TEPG) device (D) was fabricated. The device based on p-$Yb_{0.6}Co_4Sb_{12}$ and n-$Fe_{2.0}Co_{2.0}Sb_{12}$, fabricated by using the solid state microwave. 8-couples of legs connected and attached to alumina substrates by Ag paste–Cu plate–Ag paste electrodes, with dimensions of 25 mm by 25 mm were used to fabricate the device. The maximum output power (P_{max}) and the open-circuit voltage (V_{oc}) was estimated based on the temperature difference (ΔT) of 210 K and the hot-side temperature (T_H) of 603 K for the module. We found the obtained open-circuit voltage (V_{oc}) was 18.046 mV and the maximum output power (P_{max}) was 12.732 μW.

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التوصيف الكهربائي للمولدات الكهروحرارية على أساس النوع الموجب $Yb_{0.6}Co_4Sb_{12}$ والنوع السالب $Fe_{2.0}Co_{2.0}Sb_{12}$ من المواد الحرارية

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الكلمات المفتاحية:

– توليد الطاقة الكهروحرارية
– تحويل الطاقة المباشر
– المواد الكهروحرارية

الـــخُـــلاصـــة:

في هذه الدراسة، تم تصنيع جهاز مولد الطاقة الكهروحرارية استند هذا الجهاز على نوعين من المركبات نوع p-$Yb_{0.6}Co_4Sb_{12}$ و النوع n-$Fe_{2.0}Co_{2.0}Sb_{12}$ ، المحضرة بطريقة مايكرويف الحالة الصلبة. التي تشمل ثمانية أزواج من القطبان الموصلة مع بعضها والمرتبطة بقاعدة من الألومينا بواسطة (Ag paste) ومن ثم اقطاب النحاس (Cu) ومن ثم (Ag paste) للأقطاب الكهربائية، حيث كان لقاعدة الالومينا أبعاد (٢٥ مليمتر X 25 مليمتر). تم حساب القدرة الخارجة العظمى (P_{max}) وفولطية الدائرة المفتوحة (V_{oc}) أعتماد على إختلاف درجة الحرارة ٢١٠ درجة مطلقة وكانت درجة حرارة الجانب الحار ٦٠٣ درجة مطلقة للجهاز. حيث كان فولطية الدائرة المفتوحة الناتجة(V_{oc})18.046 mV ، القدرة الخارجة العظمى الناتجة(P_{max}) 12.732 μW.

1. INTRODUCTION

A thermoelectric power generation (TEG) device produces a voltage because of Seebeck thermoelectric effect when a temperature difference exists between the cold and the hot sides of the device [1]. The advantage of generators phenomenon include solid-state operation, the absence of toxic residuals, small, maintenance free operation of moving parts or chemical reactions, along life span of reliable operation, lightweight, and environmentally friendly [2,3,4]. Thermoelectric devices can be used for power generation. The applications of TE devices can span different areas and industries. Waste heat energy harvesting in automotive is one promising application for such technology [5]. Remote space missions use thermoelectric devices for power generation to consequently enhance the doping effective is optimized the thermoelectric properties. To illustrate, recent devices have used $CoSb_3$, a semiconductor that, when alloyed with (Yb) or (Fe), becomes an efficient TE material for power generation because of the variations in carrier mobility and carrier concentration [6, 7]. In this study 8 couples of thermoelectric (TE) generation devices were fabricated and focused on the properties of the device using $Yb_{0.6}Co_4Sb_{12}$ as p-type and $Fe_2Co_2Sb_{12}$ as n-type materials.

2. EXPERIMENTAL PROCEDURE

The polycrystalline alloys of p-type $Y_{0.6}Co_4Sb_{12}$ were grown by the solid state microwave after the addition of Yb with n-type $Fe_{2.0}Co_{2.0}Sb_{12}$ ingot. All samples were grinded, and the resultant powders were compressed into pellets (5 mm in width and 3.5 mm in thickness) by cold pressing at 5 tons. Alumina plates with measurements of 25 mm × 25 mm for congregations of 8 couples. Functioned as the cold and hot ends for the thermoelectric n-and p-type leg. Cu plates (5 mm in width and 10 mm long) were glued on the alumina utilizing silver paste. The Cu and the TE legs on the alumina were agglutinated by Ag paste, as shown in Figures 1 (a) and (b). The put of p-n couples from thermoelectric pellets was set between two alumina, as shows in Figure 1 (c). The terminals from Ag paste– Cu plates– Ag paste were introduced on the inward surfaces of the alumina substrates. The device was then dried at room temperature for one day to metalize the electrodes on the device.

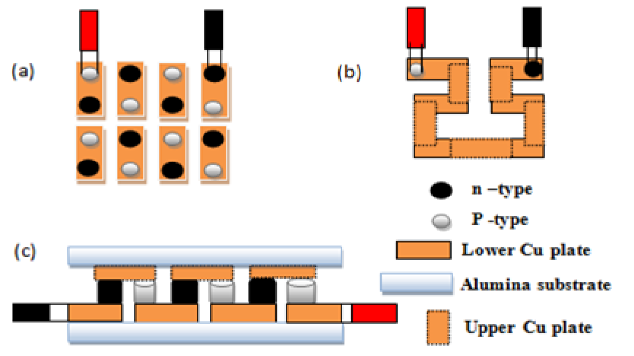

Figure1: (a) n- and p-type pellets (8-couples) on Cu plates and alumina substrate fixed by Ag paste, (b) association of n-and p-type couples by Cu plates, and (c) schematic chart of the thermoelectric generation module.

3. RESULTS AND DISCUSSION:

Our results involved the determination of the I-V output characteristic of the thermoelectric generator device (TEGD). A temperature difference ΔT was induced between the hot and cold sides of the generators, where the V_{out} was measured versus the I_{out} and the maximum output power was also measured. Figures 2 and 3 show the relationship of the output voltage (V_{out}) and output power (P_{out}) with the output current (I_{out}) in the eight fabricated couples, the V_{out} dependence on the I_{out} and output power (P_{out}) based on the temperature difference of the device (D). As expected, the output voltage increased with increasing the temperature difference ΔT. The open-circuit voltage (V_{oc}) is computed as the intercept of the I-V plot. The temperature difference (ΔT) of 210 K and the hot-side temperature (T_H) of 603 K, where the open-circuit voltage (V_{oc}) reached upto 18.046 mV.

This small voltage could have originated from numerous factors including low thermal conductivity of alumina substrate [8] and unfavorable junctions between the TE legs and the electrodes [9]. The main factor the responsible for the unfavorable junctions could be attributed to dry joints, including some pores, originating from the differences between the legs and the electrodes [9, 10].

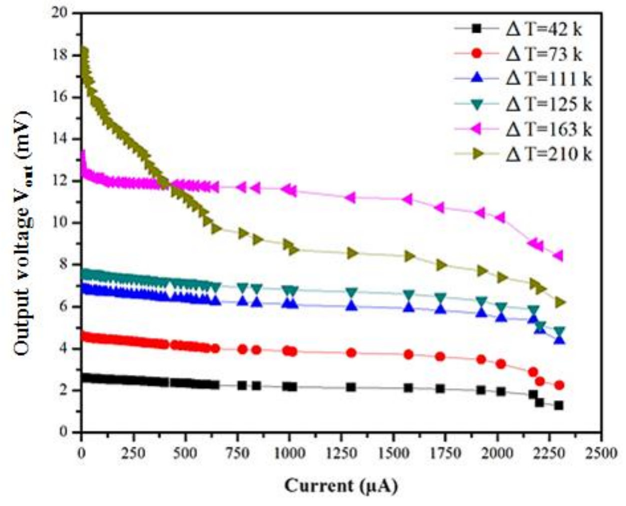

Figure 2: Output voltage as a function of electric current of the TEG device (D) that comprises 8-couples, where ΔT =42, ΔT=73, ΔT=111, ΔT= 125, ΔT = 163, and ΔT=210 K.

The power- current plots illustrated in Figure 3, where P_{out} is the parabolic curves, where the dissipated power in the external load ($P_{out}=I^2_{out}R$). The maximum output power (P_{max}) was 12.732 μW at ΔT = 163 K and TH = 533 K. The power of the module was improved by increasing the temperature to 533 K and then decreased with increase temperature. This decrease of the power in the device at T_H=603K and ΔT=210 K could be related to increase of the contact resistance (R_c) which could be due to oxidation that can be visually observed [11]. In fact, it is well known that $Yb_{0.6}Co_4Sb_{12}$ begins to oxidize in air at 500 K [12]. This observation may be resulted from the rise of the ΔT, the consequence of which is an increase in V_{out} Table 1. The internal resistance (R_{in}) was directly obtained for each device by the measurement system, based on the slope of the I-V plot. The ideal internal resistance (R_{id}) was determined from the sum of the resistance values of p-type and n-type samples, which is defined as [13, 14, 15].

$$R_{ideal}= n_i(R_p+R_n) \qquad 1$$

Where ni is the number of thermocouples in series and Rn ,Rp are the internal electrical resistance of n- and p-legs, respectively. The contact resistance (R_c) can be obtained from the Rid and R_{in}, using the equation $R_c = R_{in} - R_{id}$ [16]. The R_{in}, R_{id} and R_c of device (D) are 5.492, 1.778 and 3.714 Ω, respectively.

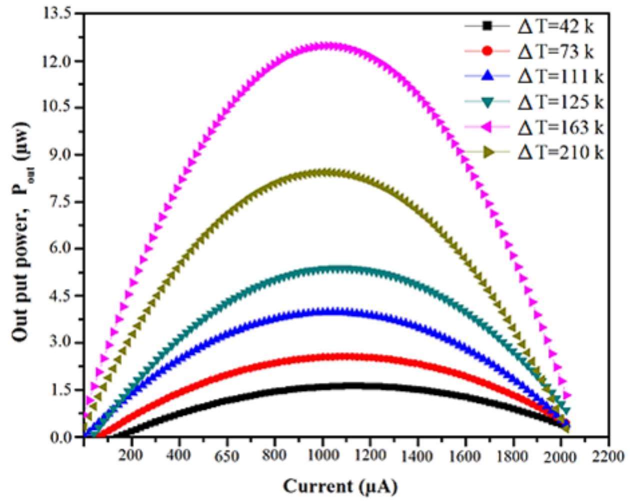

Figure 3: Output power as a function of electric current of the TEG divice (D) that comprises 8-couples, where ΔT =42 K, ΔT=73 K, ΔT=111 K, ΔT= 125 K, ΔT = 163 K, and ΔT=210 K.

Table 1: Maximum open-circuit voltage (V_{oc}) and maximum output power (P_{max}) for the TEG device (D).

ΔT (K)	V_{oc} (mV)	P_{max} (μW)
42	2.271	1.294
73	4.083	2.360
111	6.454	4.319
125	7.302	5.682
163	13.104	12.732
210	18.046	8.873

4. CONCLUSION

This research fabrication the n-type $Fe_2Co_2Sb_{12}$ and p-type $Yb_{0.6}Co_4Sb_{12}$, TE materials were prepared by solid state microwave synthesis. The device with eight couples of n-type and p-type, were fabricated and characterized in terms of their high V_{oc} and P_{max}. The TEG device (D), which was based on n-type $Fe_2Co_2Sb_{12}$ and p-type $Yb_{0.6}Co_4Sb_{12}$, The obtained open-circuit voltage (V_{oc}) was 18.046 mV, and the maximum output power (P_{max}) was 12.732 μW, P_{max} increased with increase the value of ΔT and the number of p–n couples. Therefore, the TEG device was stable and demonstrated satisfactory thermoelectric performance. TE performance of device suggests the great potential of these low temperature doped thermoelectric materials towards future energy generation applications.

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