Asian Journal of Chemistry; *Vol. 31, No. 3 (2019), 633-636*

ASIAN JOURNAL OF CHEMISTRY

https://doi.org/10.14233/ajchem.2019.21728

Synthesis and Characterization of Some Useful Thermoelectric Materials

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Received: 27 September 2018; *Accepted*: 21 November 2018; *Published online*: 31 January 2019; AJC-19259

This paper aims to introduce the synthesis and characterization of some useful thermo electric pellets in order to determine their ability to convert waste heat into electricity. The thermo electric pellets of Bi_2Pb_3, Bi_2Te_3 and Pb_2Te_3 in cylindrical dimensions are prepared by 15 mm mixture of different compositions. The research work explores the facts that how such kind of the semiconducting materials can be utilized as thermo-electric power generation elements. The performance of these pellets analyzed not only in the normal mode but also under the effect of electric and magnetic fields, which can exist already or applied in the condition of their operation. Thermo-emf generation is carried out in the normal mode and under the influence of applied electric and magnetic fields of different magnitudes in the temperature range of 190 °C. Hence, the paper is an outlet of the waste heat utilization with the influence of electric or magnetic field towards their conversion of waste heat into electricity by special sized thermoelectric pellets and the suitable chemical method of their preparation.

Keywords: Thermo emf, Pellets, Chemical method of preparation, Temperature gradient, Electric field, Magnetic field.

INTRODUCTION

In the last few decades, the energy consumption and its demand of society causes world energy crisis. In all the utilities, the efficiency of electrical, mechanical and electronics based systems approaches only to 25 %, thus, causing a large content of heat energy to be just wasted. This all needs techniques and materials which having the ability to convert heat into electricity. One of such technique is the thermoelectricity (Seebeck effect) generation. In thermoelectricity, thermo power is the output due to temperature gradient at the two junctions or ends of two different materials. These kinds of materials are known as thermo generator elements. These thermo generator elements become a useful tool due to simple design, easy operation, lack of the moving parts and their pollution free nature.

The output of thermoelectric based system can be recycled to the same system (whose waste heat is to be converted into electricity) and also in some other reliable resources. This can implement not only the waste heat content of vehicles and generators but also of the domestic regions [1-5]. Along with the conversion efficiency, the temperature gradient-thermo emf relations are applied on resistive temperature detective (RTD) materials, which are functionalized as the temperature sensors in all industrial and technical fields [6].

Thermoelectric materials are characterized by the dimensionless parameter called figure of merit (ZT), which is the measure of their ability to convert the heat into electricity. As the thermocouple is an assembly of two different materials for which the figure of merit can be calculated from the expression [7] as given below:

$$ZT = \frac{(\alpha_a - \alpha_b)^2}{[(\rho_a\lambda_a)^{1/2} + (\rho_b\lambda_b)^{1/2}]^2} \quad (1)$$

where α_a, α_b are the Seebeck constants, ρ_a, α_b are the resistivities and λ_a, λ_b are the thermal conductivities of two thermoelectric materials of the thermocouple, respectively. This is clear that both the thermal and electrical conductivities of thermoelectric materials affect the figure of merit. However in most of the times both the conductivities get increased and decreased hand by hand with the variation of temperature of operation. This has been confirmed from the literature that the advanced technologies like nanotechnology, enables to prepare the thermoelectric materials of improved figure of merit by the logic of thermal and electrical conductivities within the nano dimensions [8-11].

EXPERIMENTAL

The three kinds of thermoelectric materials (Bi, Pb and Te) selected in the present analysis are chemically less toxic but still considered as pollutants and have to be handled with care and precaution. These semiconducting thermoelectric materials like Bi, Pb and Te are considered as efficient thermoelectrics due to their improved figure of merits and of many advanced applications [12,13]. The present research work is oriented to investigate the thermo emf generation for the pellets of these materials, which can be of use as the energy generation elements along with their chemical use in designing, crystallization *etc*. The investigations are carried out for the thermo emf generation for each of the three pellets in the temperature range of 190 °C (below the melting point of all three materials) not only in the normal mode but also under the effect of applied electric and magnetic fields. The external parameters (electric and magnetic fields) are considered because sometimes they exist already in the environment of operations of thermo generator elements and due to their pronounced effects on the thermoelectric properties [13-17], even can applied externally.

Synthesis: The pure metal powder of bismuth, lead and telluride materials was used to prepare the pellets of 20 mm diameter and 6 mm height in the cylindrical dimensions by the following steps:

(a) The pellets Bi_2Te_3, Bi_2Pb_3 and Pb_2Te_3 are prepared by the 15 milli mole mixture.

(b) The mass of the pellets Bi_2Te_3, Bi_2Pb_3 and Pb_2Te_3 are 12.042, 15.624 and 11.958 g, respectively.

(c) Pressure of 10 Ton is applied on each of the pellet by the hydraulic pressing machine.

(d) The binder, poly(vinyl alcohol) (PVA) is used for the proper binding of material particles.

(e) Each of the pellets are sintered at a temperature of 190 °C for 1 h.

Normal mode: The hollow copper pipes are used as the heating and cooling arrangements. One closed copper pipe was used to provide the required heat by the gas Bunsen burner. Other two pipes are framed as an arc to recycle the fresh water for the cooling arrangement. The pellet is placed vertically in between the heating and cooling cross sections. The digital multimeter (HP 34401A model) was used to measure the thermo emf in the temperature range of room temperature (35 °C) to 190 °C.

Applying magnetic field: The DC magnetic field was applied by placing the entire set up of pellet between the two poles of an electromagnet. Three magnitudes of the magnetic field (260, 360 and 460 gauss) are applied repeatedly for the accurate results.

Applying electric field: The electric field is applied with the help of two aluminum plates (25 cm × 22.6 cm) in the form of a parallel plate capacitor set up, having separation of 20 cm. The potential difference of 4, 8 and 12 V are applied to get the electric field of 20, 40 and 60 V m^{-1}, respectively.

RESULTS AND DISCUSSION

Normal mode: In this mode, it can be observed from the Fig. 1 that the Bi_2Te_3 pellet is the best thermo-emf generation element. It generates 2 mV thermo-emf at the minimum temperature gradient of 15 °C and about 5.6 mV at maximum temperature gradient of 155 °C. The other pellets Bi_2Pb_3 and Pb_2Te_3 generate only 2 and 1 mV at the minimum temperature gradient (15 °C), respectively but at the maximum temperature gradient of 155 °C thermo-emf generation is 4.6 and 4 mV, respectively. The exact order of conversion performance in the entire temperature range is $Bi_2Te_3 > Bi_2Pb_3 > Pb_2Te_3$.

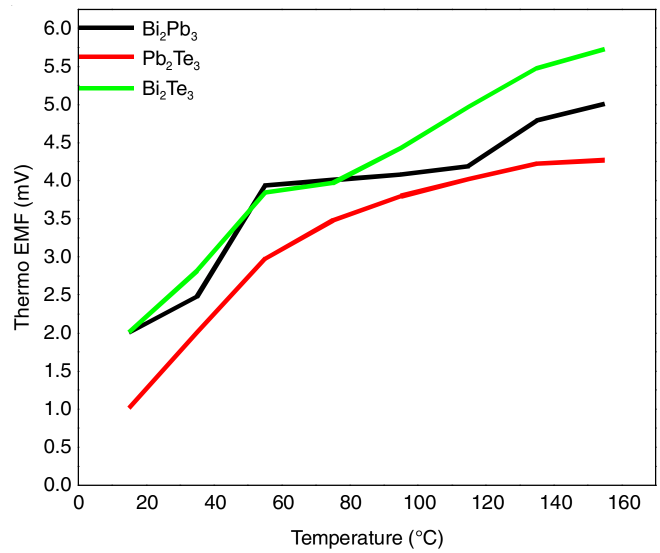

Fig. 1. Thermo-emf generation in normal mode

Influence of magnetic field

260 Gauss: Fig. 2 indicates that with the applied magnetic field of 260 gauss, the order of thermo-emf generation is $Pb_2Te_3 > Bi_2Te_3 > Bi_2Pb_3$. Thermo-emf generation for the first rank pellet Pb_2Te_3 approaches to 5 and 6 mV at the minimum (15 °C) and maximum (155 °C) temperature gradients, respectively. Similarly for the other pellets Bi_2Te_3 and Bi_2Pb_3 the thermo-emf generation is 2.8 and 2.6 mV, respectively at the minimum temperature gradient but at the maximum temperature gradient these are 4.6 and 4.5 mV, respectively. The thermo-emf generations for the entire temperature range are approximately linear that is evident from Fig. 2.

360 Gauss: Fig. 3 illustrates that the thermo-emf generation in this case is in the order as $Pb_2Te_3 > Bi_2Pb_3 > Bi_2Te_3$. For the best pellet Pb_2Te_3 thermo-emf values are 5.6 and 7.4 mV at the minimum and maximum temperature gradients, respectively. The minimum and maximum thermo-emf values at the corresponding temperature gradients are 2.5, 5.2 mV and 2.7, 4.5 mV for the 2^{nd} and 3^{rd} ranked pellets Bi_2Pb_3 and Bi_2Te_3, respectively.

460 Gauss: The order of thermo-emf generation is: $Pb_2Te_3 > Bi_2Te_3 > Bi_2Pb_3$. The minimum thermo-emf values are 5.2, 2.6 and 2.5 mV for the above three ordered pellets respectively corresponding to the minimum temperature gradient. But at the maximum temperature gradient these thermo emf values are 6.8, 5.6 and 4.7 mV respectively of the order that can be observed from Fig. 4.

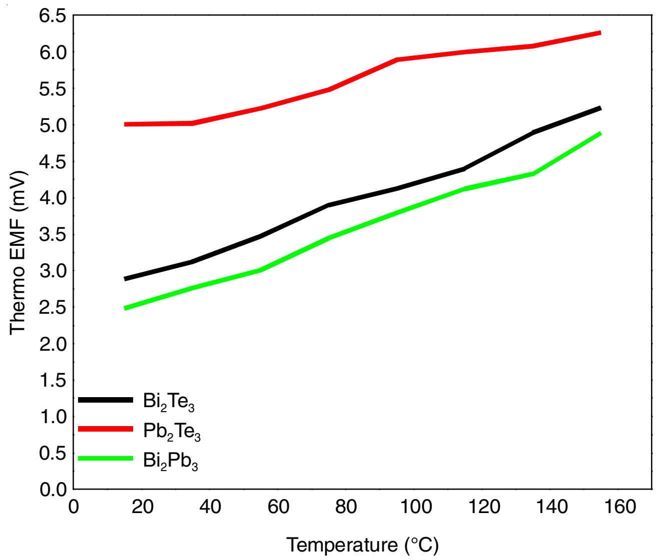

Fig. 2. Performance in magnetic field of 260 gauss

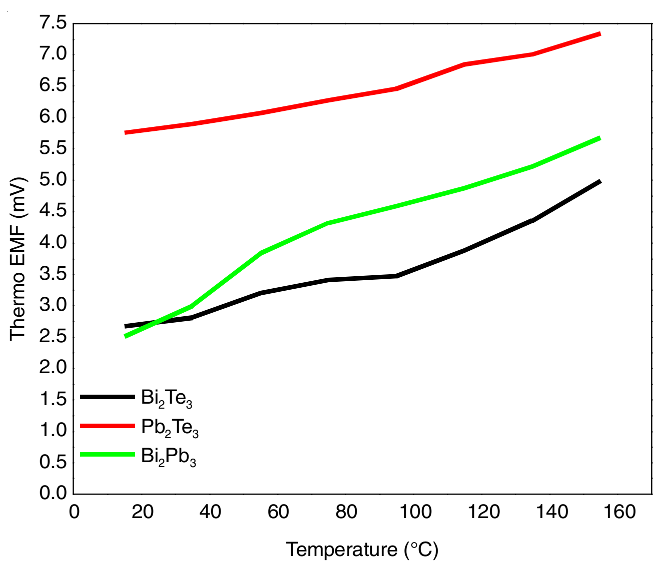

Fig. 3. Performance in magnetic field of 360 gauss

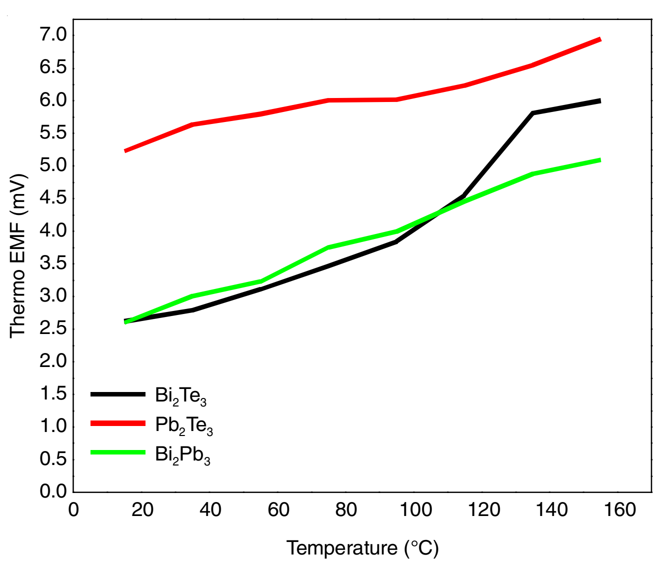

Fig. 4. Performance in magnetic field of 460 gauss

Electric field mode: With the electric field of 20 V m^{-1} (*i.e.* 4 V potential difference), we observed that the generation of thermo-emf is almost same for the pellets of Bi_2Pb_3 and Bi_2Te_3 except than the few oscillations; at the entire temperature range as illustrated in Fig. 5. The generated thermo-emf is 4.2, 4 and 3.7 mV for pellets of Bi_2Pb_3, Bi_2Te_3 and Pb_2Te_3 respectively at the maximum temperature gradient of 155 °C. Hence, there is the decrease in thermo-emf magnitudes for all considered pellets over the entire temperature range in comparison to the normal mode. However, at the electric field of 40 V m^{-1} (*i.e.*, 8 V potential difference), the magnitude of generated thermo-emf is about 4.8 mV for the pellets of Bi_2Pb_3 and Bi_2Te_3 but only 3.2 mV for Pb_2Te_3 at maximum temperature gradient (155 °C) as shown in Fig. 6. For the electric field of 60 V m^{-1} (*i.e.*, 12 V potential difference), although the pellets of Bi_2Pb_3 and Bi_2Te_3 gives the same magnitude of thermo emf (about 5.3 mV) at the maximum temperature gradient but the pellet of Bi_2Pb_3 exhibits its higher value over the entire range of temperature hence, Bi_2Pb_3 is proposed to be a better material for the generation of thermo emf which can be analyzed from

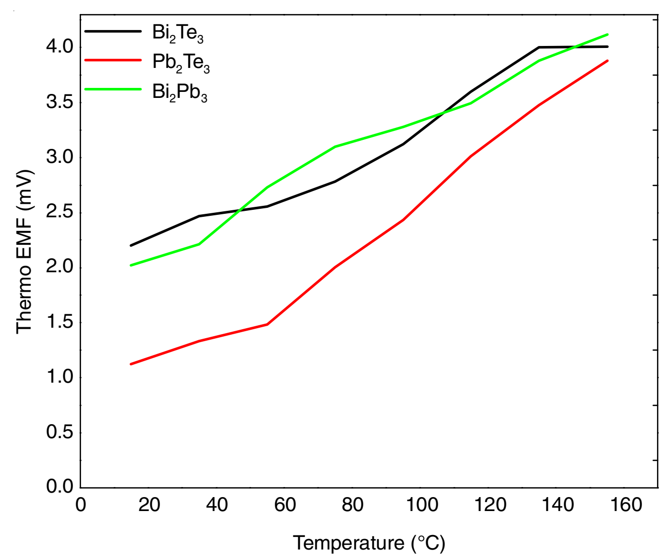

Fig. 5. Performance of pellets in electric field mode (20 V m^{-1})

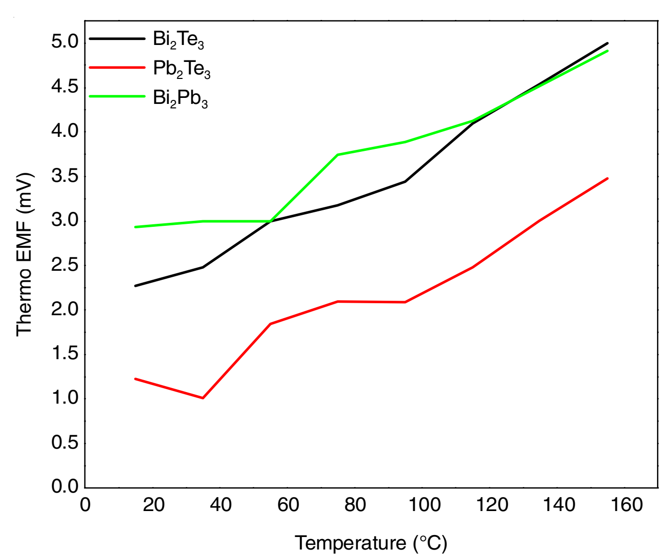

Fig. 6. Performance of pellets in electric field mode (40 V m^{-1})

Fig. 7. The pellet of Pb_2Te_3 generates only 3.8 mV and 1.4 mV thermo emf corresponding to 155 °C and 15 °C temperature gradients, respectively.

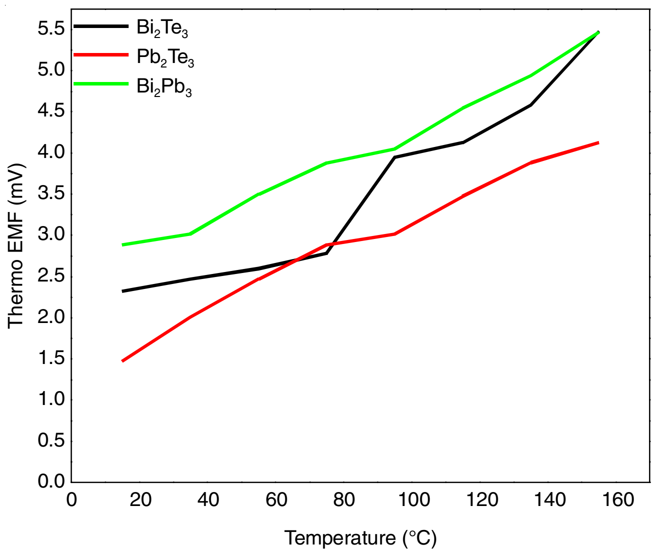

Fig. 7. Performance of pellets in electric field mode (60 V m^{-1})

Conclusion

Thermo-emf generation for each of the pellets in the magnetic field is slightly enhanced than that of their normal mode performance. In order of thermo-emf generation, first rank can be assigned to the pellet of Pb_3Te_3 in which the output thermo power is improved by several orders. Its conversion efficiency increases with increase in the strength of the applied magnetic field. As the thermo generator elements; these thermoelectric pellets are more efficient in the normal mode rather than under the influence of applied electric field. In the normal mode and in all electric field modes the pellets Bi_2Te_3 and Bi_2Pb_3 are having greater magnitude of thermo emf in the entire temperature range than the third pellet Pb_2Te_3. Finally, it can be concluded that this chemical method of preparation of the thermoelectric pellets can put these materials in the class of better thermo-emf generation elements in the applied magnetic field or electric field; wherever they exist or can be applied externally.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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