Thermoelectric Properties of SbTe

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Abstract. From the research to determine the thermoelectric properties and crystal structure of SbTe material synthesized by ball mill at 350 rpm for 10 h and sintered with hot press. The hot press method was varied at the time of hot press for 1, 2 and 3 h. The hot press temperature is 400 °C with a pressure of 25MPa. Then all materials were tested by XRD and ZEM 3. Based on the XRD test performed, all materials had hexagonal crystal structures. From ZEM 3 measurement known that the best thermoelectric properties value is in sample 3 which has an electrical resistivity 0.35 mΩcm at 331 K, Seebeck coefficient 147 µV/K at 473 K and power factor 4.53 mW/mK² at 331 K.

1. Introduction

At present many alternative renewable energies are developed, including geothermal energy, sea, wind, and solar heat. To utilize renewable energy requires a variety of technologies. One of them is thermoelectric [1]. In addition to being more environmentally friendly, thermoelectric technology is also efficient, durable, and capable of producing energy on a large or small scale. Thermoelectric technology works by converting heat energy into direct electrical energy (thermoelectric generator) [2]. The ability of thermocouples in heat energy to electrical energy is determined by a dimensionless quantity called the achievement number. The greater the value of the number, the better the quality of the thermoelectric material. The thermoelectric consists of type p and type n semiconductor materials arranged in large quantities. Current semiconductor materials that have the highest figure of merit values are materials consisting of the composition of tellurium-antimony-germanium [3].
Several studies on material synthesis for thermoelectric have been carried out. Mahajan, et al., in 2018 conducted a study by synthesizing Bi-Sb-Te alloy nanopowder consisting of $(\text{Bi}_{0.75}\text{Sb}_{0.25})_2\text{Te}_3$ and $(\text{Bi}_{0.50}\text{Sb}_{0.50})_2\text{Te}_3$ using the mechanochemical method. The synthesized nanopowder shows clear crystal microstructure with several sizes of NM. $(\text{Bi}_{0.50}\text{Sb}_{0.50})_2\text{Te}_3$ shows the highest Seebeck coefficient value of $1.36 \times 10^{-3}$ (μV/K) at 318K temperature and for $(\text{Bi}_{0.75}\text{Sb}_{0.25})_2\text{Te}_3$ shows the highest Seebeck coefficient value of $4.62 \times 10^{-4}$ (μV/K) at 349K. The results show that Bi-Sb-Te nanopowder can be used as raw material for high-performance thermoelectric devices [4].

In 2018, Liu, et al. developed an easy energy-saving method by making Sb₂Te₃-Te nanocomposite and nano-sized Te powder. Fabrication not only avoids the use of organic chemicals, but also keeps energy consumption to a minimum. Sb and Te nano powder are produced at room temperature followed by hot press at 400°C with a pressure of 70MPa for 1 hour. The Sb₂Te₃-Te nanocomposite produced shows an increased power factor. The $ZT$ value (figure of merit) of the Sb₂Te₃-Te nanocomposite is 0.29 at a temperature of 475K [5].

The Seebeck thermoelectric effect is the conversion event directly from heat energy to electrical energy or vice versa because of the temperature difference of a material. The thermoelectric generator material is made of semiconductor material consisting of type P which lacks electrons (holes) and type N excess electrons. The Seebeck coefficient is material properties and gives the speed of change between the thermoelectric voltage (E) and (T) indicated by the equation:

$$ S = \frac{dV}{dT} \quad (1) $$

The Seebeck coefficient value greatly influences the characteristics of the thermoelectric module. This Seebeck coefficient value will be used in calculating the figure of merit ($ZT$) value [6].

Figure of merit is the main factor that must be considered from a conductor material in the manufacture of a thermoelectric module, the ability of materials to conduct electricity properly, can occur electron transfer in the material, which is only with a relatively low temperature difference and the ability of materials to receive high heat continuously for a long time it is all needed to form a good module. The conversion efficiency of thermoelectric devices depends on the nature of the material, namely the level of profit $ZT$ stated in the equation:

$$ ZT = \frac{S^2 T}{\rho \kappa} \quad (2) $$

where $T$ is the absolute temperature, $S$ is the Seebeck coefficient, $\rho$ is electrical resistance, and $\kappa$ is thermal conductivity. The higher the $ZT$ material, the higher the efficiency of thermal conversion to electricity from the thermoelectric system. From equation 2, it can be seen that good thermoelectric characteristics are those that have high electrical conductivity, have a large Seebeck coefficient for maximum changes from heat to electric power or electric power to cooling performance and have low heat conductivity to prevent heat conduction through material [7].

2. Materials and Methods

The first step is to make materials for thermoelement. The materials used as thermoelement are Sb (Antimony) and Te (Tellurium). The mass of each Sb and Te powder is weighed according to the weight percentage of the atomic mass in a ratio of 1:1. Then the Sb and Te powder is mixed using the Planetary Ball Mill (PM-400) with a rotating speed of 350 rpm for 10 hours. After the material is removed from the Planetary Ball Mill machine (PM-400), the hot press is carried out at 400°C with a pressure of 25MPa for 1 hour for sample 1, with a temperature of 400°C with a pressure of 25MPa for 2 hours for sample 2, and at 400°C with a pressure of 25MPa for 3 hours for sample 3. After a hot press, the sample will turn into bulk. Samples that have become bulk are then polished for XRD testing. XRD testing at an angle2θ from 20 to 60 for all samples. Samples were cut using a cutting machine for ZEM-3 measurements. The measurement of ZEM-3 is done to determine the
value of the Seebeck coefficient, electrical resistivity and power factor in the sample. ZEM-3 measurements were carried out from a temperature of 0 to 200°C with 50 °C increase.

![Diagram process of experiment](image)

Figure 1. Diagram process of experiment

3. Results and Discussion

Figure 2 show the X-ray diffraction (XRD) patterns of hot press SbTe sample 1 at temperature 400°C with pressure 25MPa for 1 h, SbTe sample 2 at temperature 400°C with pressure 25MPa for 2 h, and SbTe sample 3 at temperature 400°C with pressure 25MPa for 3 h. The diffraction peaks of the SbTe 400 °C for 1 h (pink line) show hexagonal crystal structure with lattice parameters $a = 4.2880 \text{ Å}$, $c = 24.2970 \text{ Å}$, SbTe 400 °C for 2 h (green line) show hexagonal crystal structure with lattice parameters $a = 4.3162 \text{ Å}$, $c = 24.0548 \text{ Å}$ and SbTe 400 °C for 3 h (orange line) show hexagonal crystal structure too with lattice parameters $a = 4.3145 \text{ Å}$, $c = 24.0281 \text{ Å}$. The lattice parameters of SbTe 400 °C for 1 h, SbTe 400 °C for 2 h, SbTe 400 °C for 3 hand SbTe ICDD PDF 570493 are presented in table 1.
Figure 2. X-ray diffraction patterns of SbTe 400 °C for 1 h, SbTe 400 °C for 2 h, and SbTe 400 °C for 3 h with ICDD PDF 570493

Table 1. Lattice parameters of samples and ICDD PDF 570493

| Sample Description                     | a (Å)  | b (Å)  | c (Å)  | α  | β  | γ  |
|----------------------------------------|--------|--------|--------|----|----|----|
| SbTe 400 °C, 25MPa, 1 h                | 4.2880 | 4.2880 | 24.2970| 90°| 90°| 120°|
| SbTe 400 °C, 25MPa, 2 h                | 4.3162 | 4.3162 | 24.0548| 90°| 90°| 120°|
| SbTe 400 °C, 25MPa, 3 h                | 4.3145 | 4.3145 | 24.0281| 90°| 90°| 120°|
| SbTe ICDD PDF 570493                   | 4.2600 | 4.2600 | 23.9000| 90°| 90°| 120°|

Figure 3 show the temperature dependence on electrical resistivity. The electrical resistivity from SbTe hot press at 400 °C for 1 h is increases from 0.97 to 1.29 (mΩ cm), SbTe at 400 °C for 2 h is increases from 0.41 to 0.63 (mΩ cm), and SbTe at 400 °C for 3 h is increases from 0.35 to 0.51 (mΩ cm) with increasing temperature. Figure 4 show the temperature dependence on seebeck coefficient. The seebeck coefficient from SbTe hot press at 400 °C for 1 h is increases from 138 to 149 (µV/K), SbTe at 400 °C for 2 h is increases from 132 to 142 (µV/K), and SbTe at 400 °C for 3 h is increases from 133 to 148 (µV/K) with increasing temperature. From Seebeck coefficient values known that the SbTe material is p-type because have positive value. Figure 5 show the temperature on power factor. The power factor from SbTe hot press at 400 °C for 1 h is decreases from 1.95 to 1.73 (mW/mK²), SbTe at 400 °C for 2 h is decreases from 4.26 to 3.24 (mW/mK²), and SbTe at 400 °C for 3 h is decreases from 4.53 to 3.74 (mW/mK²) with increasing temperature.
Figure 3. The temperature dependence on Electrical resistivity

Figure 4. The temperature dependence on Seebeck coefficient
4. Conclusion

From three samples known that the different thermoelectric properties values are, the sample 1 hot press at 400 °C, 25MPa, 1 h has an electrical resistivity 0.96 mΩcm at 331 K, Seebeck coefficient 149 µV/K at 473 K and power factor 1.95 mW/mK² at 331 K. The sample 2 hot press at 400 °C, 25MPa, 2 h has an electrical resistivity 0.41 mΩcm at 331 K, Seebeck coefficient 143 µV/K at 473 K and power factor 4.26 mW/mK² at 331 K. And sample 3 hot press at 400 °C, 25MPa, 3 h has an electrical resistivity 0.35 mΩcm at 331 K, Seebeck coefficient 147 µV/K at 473 K and power factor 4.53 mW/mK² at 331 K. So the best thermoelectric properties value to be used as thermoelectric module is sample 3 because it has a lowest electrical resistivity, high Seebeck coefficient and higher power factor than other samples.

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