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The Measurement of Thermal Conductivity with Comparative Methods for Thermolectric Materials

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Abstract

Research on the thermal conductivity of thermoelectric materials is still being carried out to control the flow of heat through the material so as to obtain a good thermoelectric material. The focus of this research was conducted to determine how to measure thermal conductivity using a comparative method, determine the value of the thermal conductivity of each sample, and determine the the effect of the porosity value on thermal conductivity. Measurements were made using variations of two types of materials, namely n-type $Bi_{0.58}Te_{1.42}$ and p-type $Sb_{0.405}Te_{0.595}$ and two sample sizes, namely (4×4×4) mm^3 and (6×4×4) mm^3. The measurement of thermal conductivity using the comparative method, namely heater, thermocouple 1, aluminum metal, thermocouple 2, sempel, thermocouple 3 and heat sink are arranged in series to obtain data T_1, T_2, and T_3 for each increase in room temperature of 30℃ to 300℃. The importance of low thermal conductivity in thermoelectric materials is to be efficient when converting the material. The data obtained through measurement are then used to calculate the value of thermal conductivity. Based on the results obtained in this study, the lowest thermal conductivity value is $Bi_{0.58}Te_{1.42}$ (4×4×4) mm^3 at 4.12 W/(mK). The thermal conductivity of the thermoelectric materials will be smaller at the smaller the porosity for each sample variation. In the sample $Bi_{0.58}Te_{1.42}$ (4×4×4) mm^3, the smallest porosity value was 0.087 %. So in this research a good thermoelectric material is $Bi_{0.58}Te_{1.42}$ (4×4×4) mm^3.

Keywords: thermal conductivity, measurements, thermoelectric materials

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INTRODUCTION

The level of demand for electrical energy sources is directly proportional to population growth every year. In 2050, Indonesia's electricity needs are predicted to reach eleven times the electricity needs of 2015. This has led to a crisis of electrical energy (Nugraha, 2016). One of the technologies that utilize heat energy is thermoelectric. One of the thermoelectric efficiency is the low thermal conductivity of the forming material. The best material to increase thermoelectric efficiency must have a high Seebeck coefficient, low electrical resistivity, high electrical conductivity but low thermal conductivity (Mukherjee, 2020).

So far, research on the thermal conductivity of thermoelectric materials is still being carried out to control the flow of heat through the material in order to obtain a good thermoelectric material (Yüksel, 2016). Research on thermoelectric materials in measuring thermal conductivity was carried out by varying PbTe samples every 30 seconds for 4 minutes (Sahdianingrum, 2019). Based on previous research, this research will use bismuth telluride and antimony telluride because these materials are good for use at room temperature up to approximately $200°C$ (Al-Fath, 2020). Materials are measured for their thermal conductivity. The method used in measuring the thermal conductivity of thermoelectric materials is a comparative method.

The value of the thermal conductivity of a material shows the rate of heat transfer flowing in a material. Thermal conductivity can be known through conduction heat transfer. Heat conduction requires direct physical contact between two objects. Particles in a body with a high temperature transfer heat energy to a body with a low temperature without being accompanied by the movement of intermediate particles. As a result, objects with high temperatures lose heat, while objects with low temperatures gain heat (Fraden, 2016)

Thermal conductivity is affected by several factors, including temperature, water vapor content, density and porosity. The effect of temperature is inversely proportional to thermal conductivity, in general the temperature increases, the thermal conductivity will also decrease. The influence of the water vapor content, the thermal conductivity will increase as the water vapor content of an object increases. The effect of the density and porosity of an object affects the conductivity of an object, the more cavities in the object, the greater the percentage of porosity, the greater the porosity causes the conductivity value to decrease (Setiawan, 2016)

The process of measuring thermal conductivity requires a comparative method. This technique, which is also a low heat steady-state technique, achieves the best results when the thermal conductivity value of sample 1 is comparable to that of sample 2 (Tritt, 2004). It is recommended in ASTM E1225-13. One-dimensional heat flow occurs through the sample and reference material. Under stable conditions (temperature variation of less than $\pm 0{,}05\ K/h$), the heat flux can be calculated from the temperature gradient measured in the reference sample (Yasmin, 2023). The heat flux in the system can be determined by measuring the temperature on each side of the sample. The heat flux passing through sample 1 is the same as the heat flux passing through sample 2. If sample 1 is likened to a measuring element whose thermal conductivity value is known (κ_1), then the thermal conductivity value of sample 2 (κ_2) can be determined by Equation (1).

$$\kappa_2 = \kappa_1 \left(\frac{A_1 \Delta T_1 L_2}{A_2 \Delta T_2 L_1}\right) \quad (1)$$

EXPERIMENT

The experiment in this study consisted of three parts, namely comparative method design, thermocouple calibration, temperature measurement and porosity measurement.

Thermocouple calibration

Thermocouple calibration is carried out to determine whether the thermocouple used in the study is appropriate or not with standard equipment. The calibration method used is the comparison method. The thermocouple used in the study was compared with the Lutron TM-903A Thermometer. The object being measured is boiling water. Measurements were made immediately after the water in the pot boils. Measurements are taken every 30 seconds for up to 20 repetitions.

Sample temperature measurement

The test was carried out using a test sample that had been prepared, namely by the comparative method, aluminum metal as the bottom block, the specimen was placed on top of the aluminum. The temperatures to be obtained are the temperatures at T_1, T_2, and T_3. T_1 is measured from the heater attached to the aluminum. T_2 is the top side of the aluminum attached to the specimen. T_3 is the upper side of the specimen attached to the heat sink. Data collection was carried out at temperatures of 30, 50, 100, 150, 200, 250 and 300 ℃ every 30 seconds for 4 minutes and at a temperature increase of 30 ℃ every 30 seconds up to 300 ℃. Measurements were made on several variations, namely Bi_2Te_3 and Sb_2Te_3 specimens. After obtaining the values of T_1, T_2, and T_3 for each variation, calculations are performed using Equation (1) to obtain the value of thermal conductivity.

Porosity measurement

Porosity measurement, the sample is heated so that the water content in it is close to zero. The material is weighed using a digital balance to determine the dry mass value. The suspended material is then dipped into the water fluid to determine the wet mass so that no air bubbles come out. After that, the material is removed and slightly drained, weighing is carried out using a digital balance to determine the wet mass.

RESULTS AND DISCUSSION

Thermocouple calibration

The thermocouple used is ensured for its accuracy and precision. In this measurement there are 3 pieces of thermocouples used. Each to measure T_1, T_2, and T_3. The Lutron TM-903A thermometer has specifications for accuracy of $\pm\,(0.5\% + 1°C)$ and compared to the measurements taken it has an accuracy of 96.5%, 97.1% and 96.9%. According to the graph in Figure 9, the K-type thermocouple used has the same trend as the Lutron TM-903A Thermometer and the results are quite good.

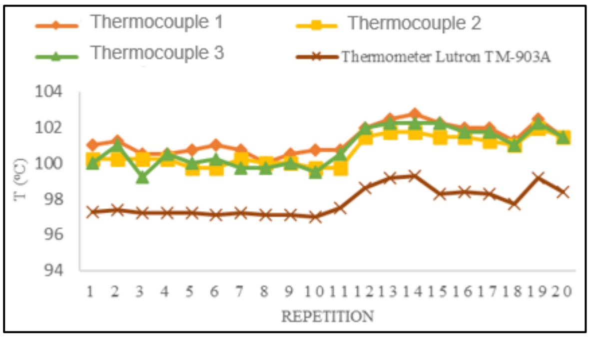


Figure 1. The results of the K-type thermocouple readings on the lutron TM-903A thermometer.

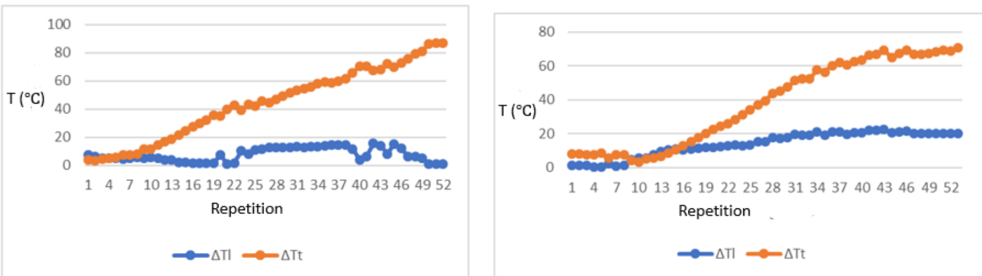
Analysis and calculation of thermal conductivity

Data from the calculation of the smallest thermal conductivity value in each sample can be seen in Table 1.

Tabel 1. Calculation data for the smallest thermal conductivity value.

Material	Size (mm^3)	κ_t ($W/(mK)$)
$Bi_{0,58}Te_{1,42}$	4×4×4	4.12
	6×4×4	13.94
$Sb_{0,405}Te_{0,595}$	4×4×4	4.33
	6×4×4	14.81

A large temperature difference occurs due to heat transfer from aluminum to $Bi_{0.58}Te_{1.42}$ by conduction which then conditions heat to $Bi_{0.58}Te_{1.42}$ on aluminum, so that the temperature of $Bi_{0.58}Te_{1.42}$ is colder than it should be. This condition occurs at maximum temperature, because the larger the surface area of the sample being tested, the larger the sample surface that is in contact with aluminum, therefore the conduction effect of aluminum is not significantly visible at room temperature because the value may be very small. In addition, there is also radiation between the kecooper heaters, so this adds to the cause of being very volatile, as can be seen in Figure 2.



(a) (b)

Figure 2. Temperature difference graph $Bi_{0.58}Te_{1.42}$ (a) (4×4×4) mm^3 (b) (6×4×4) mm^3.

One of the thermoelectric efficiency is the low thermal conductivity of the forming material. In measuring thermal conductivity, samples whose temperature measurement is higher have overall lower thermal conductivity (Sahdianingrum, 2019). This is because the heat transfer from the aluminum surface to the $Bi_{0.58}Te_{1.42}$ surface is very small. Based on measurements, the n-type sample $Bi_{0.58}Te_{1.42}$ has a lower thermal conductivity value than the p-type sample $Sb_{0.405}Te_{0.595}$. At room temperature, all samples have a fairly large thermal conductivity value. This is because the temperature difference between T1, T2, and T3 is very small. This very small temperature difference occurs shortly after the device is turned on. In Figure 3 one of the thermal conductivity calculation graphs.

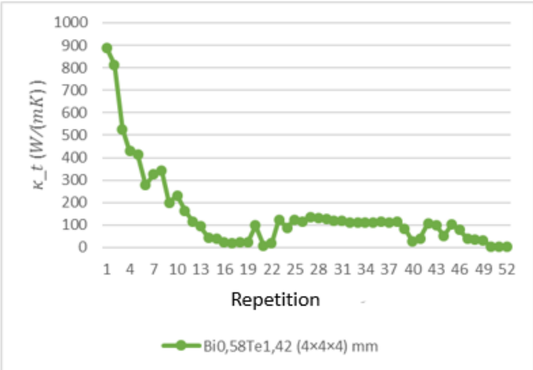


Figure 3. Graph of κ_t calculation result.

This relative error is too large because during the experiment the aluminum and sample were not placed tightly enough so that there was a leakage of heat flow. This will affect temperature changes resulting in the thermal conductivity value far from the reference value. From the experiments carried out, different values of thermal conductivity were obtained as shown in Figure 3. The semiconductor material used may not contain the same material as the material contained in the reference. The material must be well isolated from the environment so as to maintain the quality of the material and will not affect the thermal conductivity of the material. Because the distribution of heat in the tool is not homogeneous, the most stable part is in the middle.

Data from the calculation of the porosity value for each sample can be seen in Table 2.

Table 2. Porosity calculation data

Material	Size (mm^3)	m_1 (gr)	m_2 (gr)	Porosity (%)
$Bi_{0,58}Te_{1,42}$	4×4×4	0.4608	0.4612	0.087
	6×4×4	0.6888	0.6899	0.16
$Sb_{0,405}Te_{0,595}$	4×4×4	0.5262	0.5267	0.095
	6×4×4	0.6928	0.694	0.173

CONCLUSION

Based on the results of the research that has been done, it can be concluded as follows. Thermal conductivity measurement using the comparative method. Heater, thermocouple 1, aluminum metal, thermocouple 2, seal, thermocouple 3 and heat sink are arranged in series. The temperature given is 30 °C to 300 °C. The results of measuring the thermal conductivity of thermoelectric materials in the form of the smallest bulk are samples with a length of 4 mm. The thermal conductivity produced by each sample is Bi0.58Te1.42 (4×4×4) mm is 4.12 W⁄((mK)), Bi0.58Te1.42 (6×4×4) mm is 13.94 W⁄((mK)), Sb0.405Te0.595 (4×4×4) mm is 4.33 W⁄((mK)), and Sb0.405Te0.595 (6×4×4) mm is 14.81 W⁄((mK)). The effect of the porosity value on the thermal conductivity is that the smaller the porosity of the sample used, the smaller the resulting thermal conductivity. In the Bi0.58Te1.42 (4×4×4) 〖mm〗^3 sample, the smallest porosity value was 0.087%.

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