The Thermoelectric Cooler Performance Coefficient Based on Configuration of p-type and n-type Semiconductors of Bi$_2$Te$_3$ Materials

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1. Introduction
Thermoelectric cooler is a module that can replace refrigerant freon which does not cause greenhouse effect [1,2]. The thermoelectric module works based on the Seebeck effect and the Peltier effect [3,4]. Thermoelectric modules have advantages that other instrument types do not have, they are solid state modules, small volume and controllable temperatures [4]. However, with these advantages, current thermoelectric modules have not been developed to the fullest. With these advantages and low performance coefficients, thermoelectric becomes a very important aspect to be developed[5,6,7].

Thermoelectric module research has been done a lot. Mijangos et al stated that the pyramidal thermoelectric material is able to improve the module performance coefficient. In this study mentioned that the module with the pyramid material leg has ZT of 0.73 while the rectangular module is 0.43 [20]. In his research, Ming Ma et al stated that thermoelectric with cascade arrangement has an optimum performance coefficient of 0.05. The length of the foot on the hot side material is lower than the cold side as it can reduce the heat flow rate[17].

The greatest challenge faced in the development of thermoelectricity is its low effectiveness [8,9]. The voltage generated by the thermoelectric module depends on the temperature difference...
(thermopower) which is high enough or in this case is called the seeback coefficient (S) must be large. The resulting electric current passes through the components of the thermoelectric module. Thus, the thermoelectric module must have high electrical conductivity (\( \sigma \)) and low thermal conductivity (\( \kappa \)). The quantities affecting the thermoelectric output are formulated into a quantity called figure of merit (ZT). The matrix of merit can be formulated as follows. \( ZT = \frac{\sigma S^2 T}{\kappa} \) Where \( \sigma \) is the electrical conductivity, \( \kappa \) is the thermal conductivity, \( S \) is the seeback coefficient, and \( T \) is the temperature. In its application, thermoelectric modules are widely used from p-n junction semiconductor materials\[7,8,9,10,11,12,18\].

Heat must be added or removed continuously to keep current flow through the module. The total heat released and added is proportional to the current flowing. This is called the peltier effect and satisfies the equation \( Q_{(\text{peltier})} = \Pi_{AB} I \) where \( \Pi_{AB} \) is the peltier coefficient, the overall \( Q_{\text{peltier}} \) of heat is added or excreted by the system, and \( I \) is the electric current passing through the thermoelectric element\[13\].

The metal alloys Bi2Te3 and Sb2Te3 are thermoelectric materials working at a temperature of 200-400 K \[14\]. The material has a single Figure Of Merit (ZT) and is the best material for thermoelectric at room temperature compared to other solid materials. Improved material performance is performed by Poudel et al. in 2008 when they obtained a ZT value of 1.4 at 373K by introducing a feature of nanoscale crystals in a pure-type BixSb2-xTe3 p-type metal alloy. This solid is made by hot pressing method of nano powder obtained from ball-milling on semiconductor Bi2Te3 and Sb2Te3 at atmospheric temperature\[15, 16\].

Chromogen is a group of thermoelectric materials that have high stability in the air and have high melting point. Because of its strong flexibility in receiving other materials and small electronegativity differences between sulfur, tellurium, and selenium, the chalkogenic material is highly potential for thermoelectric materials with a wide temperature range. Among the various compounds, Bi2Te3 and its various solids such as p-type Bi2-xSbxTe3 and n-type Bi2Te3-xSex are highly potential to be used as cooler thermoelectric materials. \[13\].

Coefficient of Performance (COP) a Thermoelectric Cooler can be determined by an equation \( COP = \frac{Q_c}{Q_h - Q_c} \) where \( Q_h \) is a heat released on the heat and \( Q_c \) is the heat that is absorbed by the cold side.

2. Model of Thermoelectric Cooler and The Mathematical Equations
The thermoelectric module to be studied is a one-stage module which will be thermally connected parallel and in electrical file connected in series as shown in Fig. 1 below.

![Figure 1: Thermoelectric Module Scheme](image-url)
A mathematical equation to determine the quality of a module termoelektrik cooler is determined by a dimensionless quantity called the coefficient of performance. The coefficient of performance is the comparison of the heat absorbed by the module with the power used by the module.

\[ COP = \frac{\dot{Q}_c}{P} \]  

(1)

Where is the power \( P \) is the difference of the heat absorbed by the capacity of the cooling modules \( (\dot{Q}_h - \dot{Q}_c) \). To determine the value of the absorbed heat and heat equations are commonly issued to termoelektrik cooler as follows.

\[ \dot{Q}_h = \alpha IT_h - K (T_h - T_c) + \frac{1}{2} RI^2 \]  

(2)

\[ \dot{Q}_c = \alpha IT_c - K (T_h - T_c) - \frac{1}{2} RI^2 \]  

(3)

Where the first equation above is the effect of peltier and is a process of reversibel. The greater the effect of the larger peltiernya. The second form is the process and including the Joule was Irreversibel. The third form is the conductance and include such processes. The direction of the heatflow into attention an important to determine whether the module was working as a termoelektrik cooler or generator. To determine the conductance which generally occurs in parallel physical and electrical resistance composed in seisebeck coefficient and the module, use the equation below.

\[ K = N (k_n + k_p) \frac{A}{L} \]  

(4)
\[ R = N\left(\rho_n + \rho_p\right) \frac{L}{A} \quad (5) \]
\[ \alpha = N(|\alpha_p| + |\alpha_n|) \quad (6) \]

Where \( N \) is the number of pairs, the broad \( A \) is the base and \( L \) is the thickness of material \([17,18,19]\).

3. Methodology

3.1 Fabrication of Module

After finishing in the next stage, namely do fabrication module with soldering method. The dimensions of the alumina used fabrication that is 22x20x1 mm. Copper used is 6x2, 5x0, 3 mm. semiconductor element while the size 2, 5 x 2, 5 mm 5x1. Fabrication done by mensketsa alumina with a pencil. Then the copper has been cut pasted on top of alumina with glue. Furthermore the material p-type and n-type is placed above a copper suit designs using solder. Ensured the connection between material-copper fit the design. Then, the above material is placed above a copper and brass, placed on the upper side of the alumina. At each tip ends of the modules on the connect cable. Then the measured resistance of the modules, if his resistance in units of ohms, connections between components in the corresponding module.

![Fabrication Module](image)

3.2 Result of Measurement

The measurement is performed with a current drain on the module. The TEC module is connected to the power supply. On the hot side of the module affixed water block as the cooler to remove the heat generated by the module. Then on both sides of the module type-k thermocouples attached to record temperature simultaneously. Then the tip of the thermocouple type-k others associated with ADC Converter to convert the analog signal towards digital. ADC converter is connected to the personal computer. Data recording temperature by thermocouples type k is displayed on the PC so that it can be known to avoid the temperature between the two sides. Data retrieval is performed Over 400 seconds for one measurement. The difference in temperature is obtained from the measurement results are as following figure 4.
In module 1, peltier effect has been going on since the module module current 0, 5A. It is characterized by the occurrence of temperature difference between the hot side and the cold side. However, for module 2, peltier effect began to appear when the module is attached to a current of 1.5 Ampere. On three modules, peltier effect appears when the three modules with a current of Ampere.

The lowest temperature value produced of each module in a row produced by the three modules, module, and the module one. As for the value of the lowest temperature of the resulting module three is 15, 99234°C ± 0, 00001°C on the current input five Ampere, on two modules is 21,99714 °C ± 0, 00001°C on the current input Amperage and 4.5 on a single module is 22.50381 °C ± 0, 00001°C on the current four-input Amper. Although the three modules have the lowest temperature difference but the cold temperatures that produced the lowest among the three modules of the third module

4. Result and Discussion
Following are the results of calculation of electrical resistance, conductance, and seebeck coefficients. For electric resistance on one module, the module two, and three modules have differences because of different preparation of p-type material konfiguasi and n-type. Using equation (2), (3) and (4) obtained results as in table 1.

|                   | Modul 1   | Modul 2   | Modul 3   |
|-------------------|-----------|-----------|-----------|
| Electrical        |           |           |           |
| Resistance (Ohm)  | 0,644     | 0,161     | 0,071     |
| Thermal           |           |           |           |
| Conductance (S)   | 0,141     | 0,141     | 0,141     |
| Seebeck           |           |           |           |
| Coefficient (V/K) | 0,0072    | 0,0072    | 0,0072    |

Next is to calculate the voltage works on modules. to calculate the voltage module, use the following equation

\[ V = \alpha(T_h - T_c) + RI \]  

(7)
The value of the voltage of the three modules can be seen in Figure 5.
Figure 5: Voltage in Modules

In Figure 5, explained that the value of the voltage at the module continues to increase linearly on the third module. And modules that have the highest voltage is module one. This is in accordance with Ohm's law where at the same current, resistance and voltage is proportional. Then, to calculate the power works on the module used the following equation.

\[ P = \alpha (T_h - T_c) + RI^2 \]  

(8)

Figure 6: Power Work in Modules

Power entry modules is the difference between the power emitted by the hot side and the cold side is absorbed by the module. From Figure 6, to see that the input power is proportional to the square of the flow that enters the module. Of the three modules can be seen that the higher the value of the square of the current, then the power input will also be getting bigger. The resistance of the third module of the highest value to the lowest row is module 1 of 0.644 ohm, 2 modules of 0.161 ohm, and module 3 sebesar0.071 ohm. Then, the influence of resistance to the power input is directly proportional, the greater the value of resistance of the module, then power input also will be even greater on each the same input stream.
Figure 7: Coefficient of Performance

Figure 7 explains that the coefficient of performance module is inversely proportional to the current flowing on the module. The greater the value of the current then the coefficient of performance will be getting smaller. The influence of flow against the performance coefficient can be seen on the third module. The third module has resistance. The resistance of the third module of the highest value to the lowest row is one module of 0.644 ohm, 2 modules of 0.161 ohm, and module 3 of 0.071 ohm. If views influence the resistance of the module, then the smaller the resistance of a module, then the coefficient of performance will be even greater, when attached to the same current.

Simulation with ANSYS software is used to know cold temperature that can be generated by module when powered by electric current. there are four input variables in the simulation, namely voltage, electric current, heat temperature, and heatflow. The voltage is set to zero and placed on the copper over the most p-type p-type material. The current is set from 0.5 A to 5 A and placed on the most end-type n-material. Hot temperatures are placed at the bottom of the module. While the heatflowdilekttaakn on the top side of the module with the direction down.

Heatflow is the amount of heat energy flowing from the cool side of the module to the hot side every second. Heatflow is placed on the top side module assuming the top side of the module is cold side. Heatflow can be interpreted as the heat absorbed by the cold side of the module. Heat value calculation is done by calculating the calorific value absorbed at cold temperature every second according to equation (3).

After simulation on three modules, the temperature difference of the simulation result is obtained. Next is formed a graph showing the comparison of different temperature simulation results and measurements as in Figure 8 below.

Figure 8: Beda Temperatur Hasil Simulasi dan Pengukuran
The error temperature value of the simulation and measurement results for modules 1, 2, and 3 are respectively 7.04%, 5.58%, and 10.39%.

5. Conclusion

After the fabrication and measurement, it can be concluded that the resistance of the three modules from the highest to the lowest is: module 1 is 0.644 ohm, module 2 is 0.161 ohm, and module 3 is 0.071 ohm. The smaller the resistance, the power that works on the module is smaller and the module performance coefficient is also getting better.

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