Study of microwaves energy conversion into electric current on semiconductor material Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z}

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Abstract. Converting microwaves energy into electric current has been studied through co-precipitation and sintering process on the semiconductor material. Most of the application of these methods still had a challenge of lowering the resistivity value of semiconductor material. Some researches indicated by adding molten salt into semiconductor material can reduce the resistivity value. In this study, the synthesis process by combining the co-precipitation and sintering method of transition metal (titanium and copper) and alkali metal (Sodium) shown an improvement in lowering resistivity problems. Composition ratio, temperature, and distance of radiation were the variable of measurement in this research. Three semiconductor materials Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z} were synthesized by using 60 ml of hydrochloric acid (HCl) and 80 ml of ammonium hydroxide (NH\textsubscript{4}OH) as a reagent in co-precipitation method and sintering at temperature 500 °C. An Olympus microscope was used to analyze the microstructures of all three materials. Fractions x, y, and z in the materials were determined by analysis of X-ray spectrograph model 2501. The resistivity values of three materials, namely as Na\textsubscript{0.52}Cu\textsubscript{0.37}Ti\textsubscript{0.11}, Na\textsubscript{0.26}Cu\textsubscript{0.39}Ti\textsubscript{0.35}, and Na\textsubscript{0.26}Cu\textsubscript{0.67}Ti\textsubscript{0.07} were obtained by varying the temperature of measurement. The microwave radiation was measured by observing the output voltage and current along with the radiation at a variable distance (60, 90, 10, 150, 180, and 210 cm) through the semiconductor material. The experiment showed that material Na\textsubscript{0.52}Cu\textsubscript{0.37}Ti\textsubscript{0.11} had low resistivity and small bandgap energy as 0.875 eV and able to convert microwave energy from 1.624 \times 10^{-24} \text{ Watt} to 9.137 Watt at 60 cm of microwaves radiation distance.

1. Introduction
Energy harvesting technologies seem developed to deliver green energy from diverse types of sources such as solar, thermal, kinetic, and electromagnetic by converting them into electric current [1]. Microwave as a part of an electromagnetic wave is one of alternative for efficient power transmission [2,3]. Microwave radiation can be directed to any desired location, can be collected and converted back to electricity, also can pass unimpeded through clouds and precipitations [4]. A number of methods have been used to produce semiconductor material in order to absorb microwaves and convert them into electric current such as sol-gel, solvothermal, sintering, and co-precipitation [5–7]. Most of the application of these methods still had a challenge to lowering sintering temperature and the resistivity value of semiconductor material [8,9]. Some researches indicated by adding molten salt into semiconductor material can reduce the resistivity value [10,11]. This study intended to make semiconductor material Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z} in low resistivity and convert microwave energy to electrical current by adding molten salt (NaCl).

2. Materials and Methods
The Synthesis of semiconductor material Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z} has been performed in material R1, R2, and R3 by co-precipitation and sintering method. The co-precipitation method was conducted by mixed the
basic compound of material in order to get the pure homogeneity composite. Whereas the sintering method was performed in purpose to obtain the compact semiconductor material.

2.1. Co-Precipitation of NaₓCuᵧTi₂

Some materials Titanium dioxide (TiO₂), Sodium Chloride (NaCl), Copper dichloride (CuCl₂), Hydrochloric acid (HCl) 32%, and Ammonium Hydroxide (NH₄OH) 25% were prepared from Merck. Synthesis preparation started by determining composition ratio of semiconductor material. TiO₂ nanoparticles were prior synthesized by precipitation method of 80 ml Hydrochloric acid to make similar form as a variable of composition ratio with other (molten salt) compound NaCl and CuCl₂. Then, all three compounds (R1, R2, and R3) are synthesized by co-precipitation method by adding Sodium hydroxide (NH₄OH) and heating at the temperature 50°C along 30 minutes. The deposits were precipitated and rinsed to clean the remaining acid and base. The precipitation of NaₓCuᵧTi₂ filtered and dried in the oven at temperature 100°C for two hours. The product of this co-precipitation process was powder NaₓCuᵧTi₂.

| Variation | R1 | R2 | R3 |
|-----------|----|----|----|
| Material  | %  | %  | %  |
| NaCl      | 50 | 25 | 25 |
| TiCl₂     | 25 | 50 | 25 |
| CuCl₂     | 25 | 25 | 50 |

2.2. Sintering of NaₓCuᵧTi₂

In order to make compact semiconductor material, material powder NaₓCuᵧTi₂ was milled in the mortar, weighed to obtain the appropriate volume in the cast (15.07 cm³) and pressed with the pressure 0.106 N/m². The material was sintered at temperature 500°C for 4 hours. Size of semiconductor material NaₓCuᵧTi₂ was proposed to validate the effect of microwave distribution that converted to electric current. In this research, main material was designed with the diameter 8 cm and the thickness 0.3 cm and was put in the cast made from Aluminium (Al) with the diameter 10 cm and the thickness 1 cm.

2.3. Measurement of Resistivity

The electrical and optical properties of a semiconductor are dependent upon the energy gap [12]. Measurement of resistivity material at various temperatures was intended to get the value of energy bandgap. Material is considered to be a semiconductor if energy band gap E_g is small (0 – 4 eV), and material is considered to be an insulator if E_g large (4 - 12 eV). Energy band gap for every semiconductor material is determined by the temperature [13]. The measurement of resistivity was obtained by measurement of output voltage and current. The measurement was applied three times with variation of temperature 303, 308, 313, 318, 323 °K, average data, and deviation standard used for calculation. The input voltage for resistivity measurement were 9 and 12 Volt. If current (I) flow through the material with the area (A) and length (L) which is connected with input voltage (V), the resistance can be obtained by the equation R = V/I. where the relationship between resistance (R) and resistivity (ρ) is written as follow:

\[ \rho = \frac{RA}{L} \]
Because the resistivity ($\rho$) inversely proportional to conductivity ($\sigma$), so conductivity value could be achieved, and the energy bandgap ($E_g$) of material could be obtained by the equation (3).

\[
\sigma = \frac{1}{\rho} \tag{2}
\]
\[
\ln \sigma = \ln \sigma_0 - \left( \frac{E_g}{2k_B} \right) \frac{1}{T} \tag{3}
\]

2.4. Measurement of Microwave Radiation
Measurement of microwave radiation of semiconductor material Na$_x$Cu$_y$Ti$_z$ was proposed to determine the amount of electric current that could be converted for every second of microwave radiation. Microwave radiation measurement is done by observing the output voltage and current on digital multimeter KW0600276 along with the microwave radiation at variation distance 60 cm, 90 cm, 120 cm, 150 cm, 180 cm, and 210 cm. The energy source from microwave generator is $1.014 \times 10^{-5}$ eV or similar to $1.624 \times 10^{-24}$ Watt/s with 12.24 cm wavelength. This value was known from the input frequency of microwave generator used in this measurement (2.45 GHz). Microwave power generated by the microwave generator, then microwave power stabilized by stabilizer and transmitted to the magnetron. In the receiving side, the receiver 1 and receiver 2 reflected the microwave radiation in order to reduce radiation loss. The semiconductor material Na$_x$Cu$_y$Ti$_z$ transmitted the microwave power and converted it into direct current shown by the fluorescence of the light bulb. Then, voltage and electrical current of fluorescence of light bulb measured by a multimeter.

![Figure 2. Scheme of Resistivity Measurement](image)

![Figure 3. Block Diagram of Microwave Radiation](image)
3. Result and Discussion

3.1. Synthesis of Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z}
Microstructure of semiconductor material Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z} was observed by Olympus microscope D-20 with 11 times magnification.

As shown in figure 4 (a), (b), and (c), the Synthesis of material Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z} by co-precipitation and sintering at 500°C affected the grains in compact material. Semiconductor material R1 with a high composition of molten salt (NaCl) has better particles grown than R2, and R3 where the porous of material formed in such a diameter around 30.9 μm, 43.6 μm, and 45.09 μm. All of the three materials seem colored light blue because of the reaction between copper chloride (CuCl\textsubscript{2}) and ammonium hydroxide (NH\textsubscript{4}OH). Value of fraction x, y, and z of the semiconductor material Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z} was measured by X-Ray spectrograph model 5201. The fraction value of semiconductor material R1, R2, and R3 were Na\textsubscript{0.5}Cu\textsubscript{0.36}Ti\textsubscript{0.11}, Na\textsubscript{0.25}Cu\textsubscript{0.38}Ti\textsubscript{0.34}, and Na\textsubscript{0.25}Cu\textsubscript{0.64}Ti\textsubscript{0.07}.

3.2 Band Gap Energy of Semiconductor Material Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z}

![Graph](image)

As shown in figure 4 (a), (b), and (c), the Synthesis of material Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z} by co-precipitation and sintering at 500°C affected the grains in compact material. Semiconductor material R1 with a high composition of molten salt (NaCl) has better particles grown than R2, and R3 where the porous of material formed in such a diameter around 30.9 μm, 43.6 μm, and 45.09 μm. All of the three materials seem colored light blue because of the reaction between copper chloride (CuCl\textsubscript{2}) and ammonium hydroxide (NH\textsubscript{4}OH). Value of fraction x, y, and z of the semiconductor material Na\textsubscript{x}Cu\textsubscript{y}Ti\textsubscript{z} was measured by X-Ray spectrograph model 5201. The fraction value of semiconductor material R1, R2, and R3 were Na\textsubscript{0.5}Cu\textsubscript{0.36}Ti\textsubscript{0.11}, Na\textsubscript{0.25}Cu\textsubscript{0.38}Ti\textsubscript{0.34}, and Na\textsubscript{0.25}Cu\textsubscript{0.64}Ti\textsubscript{0.07}.
Figure 5. The slope of bandgap energy with input voltage (a) 9 Volt and (b) 12 Volt.

The graph of \( \ln \sigma \) versus \( 1/T \) linear equation of \( y = ax + b \). Where, \( \ln \sigma = y \), \( \ln \sigma_0 = a \), \(-\frac{E_g}{2k_B T} = b \), and \( 1/T = x \). Slope \( b \) refers to bandgap calculation, while \( k_B \) is Bolztmann constant = \( 8.617 \times 10^{-5} \) eV/K. \( R^2 \) is correlation coefficient. For both input voltages (9 and 12 volt), increasing the temperature tends to decrease the resistivity of materials R1, R2, and R3. As the conductivity is inverse of resistivity, the value of band gap energy of materials R1, R2, and R3 for each input voltage 9 and 12 were 0.875, 0.985, and 1.575 eV.

3.3 Converting Microwave into Electrical Current

According to the graph of microwave power conversion to radiation distance in figure 6, the production power of material R1, R2, and R3 were decreasing as the farther distance of microwave radiation. Material R1 converted microwave energy from \( 1.624 \times 10^{-24} \) watt to 9.137 watts at a distance of microwave radiation 60 cm while material R2 and R3 converted it around 1.09 watt and 0.168 watts.

4. Conclusions

The Synthesis of material \( Na_{x}Cu_{y}Ti_{z} \) by using co-precipitation and sintering methods could produce semiconductor material in order to convert microwave energy into the electrical current with low resistivity and bandgap energy. Material \( Na_{0.5}Cu_{0.36}Ti_{0.11} \) was a semiconductor material with the highest composition of molten salt (NaCl) produced electrical power as 9.137 watts in radiation distance 60 cm.
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