The I-V characteristics of hydrothermal growth ZnO nanorods

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Abstract. This study aims to analyze the conductivity of ZnO nanorods grown by using the hydrothermal method. We use the I-V characteristic test to determine the conductivity. In this research, the process of making samples of ZnO nanorods was carried out in two stages: preparing the seed layer and then growing ZnO nanorods using the hydrothermal method. After testing the characteristics of using SEM, the resulting crystal structure of ZnO nanorods is hexagonal wurtzite with the direction of growing perpendicular to the substrate. Besides, the resulting I-V characteristics indicate a physical phenomenon that occurs at a temperature variation of ≥ 190°C which means a peak. While the details of phenomena still need to be elaborated. Besides, a gas effect test was also conducted which showed that the sensor was at a maximum working temperature of 190°C with an input voltage of 8 volts and reached a gas sensitivity at 220°C.

1. Introduction

The semiconductor-metal oxide material that can be used as a gas sensor is ZnO, SnO2, WO3, Ga2O3, TiO2, Fe2O3 [1]. ZnO material is a gas detection material used because of its high electron conduction mobility and good thermal stability [2]. Besides able to used as a gas sensor, ZnO has semiconductor properties and can be used as luminescence, catalyst, ferrite, photoconductive and photochemical [3]. The ZnO nanorods are nanostructures that have high gas sensitivity and the high surface-volume ratio [4]. It mechanism detects gas-based types of control on the surface which includes, the size of the rods, the width of the surface and the quantity of oxygen adsorption to the gas. In testing the effect of gas in a vacuum, the ZnO sensor has a high electron intensity.

In the process of growing, ZnO nanorods need the appropriate method. There are several methods of growing nanomaterials on a substrate including sol-gel, solid-state reaction, coprecipitation, thermal evaporation [5], vapor transport deposition (VTD), sputter deposition, and surface-depletion. However, these methods require growth conditions with high temperatures and pressures, even some methods including the use of chemicals that are quite dangerous.

Along with the progress of research on the field of nanotechnology for the last two decades, there is a simple method that can be used to synthesize nanorod ZnO, namely hydrothermal method [4-11]. The
The hydrothermal method refers to the synthesis of a chemical reaction in the form of a solution above the boiling point of the solution. The morphology produced by the hydrothermal method will affect the sensitivity of the sensor produced to the gas and the speed of the sensor's response time to gas, it can be called response time [12,13]. A gas sensor that has good gas sensitivity is needed and has a short response time and recovery time. So that in this study, we analyzed the conductivity of ZnO nanorods grown by using the hydrothermal method. We use the I-V characteristic test to determine conductivity.

2. Experimental setup and method

The growth of ZnO nanorods was carried out in two stages: making the seed layer then growing by using the hydrothermal method. The process of preparing the seed layer can function to control the morphology, texture, and orientation of the crystal growth that will be grown. After the substrate through the seed layer coating process, then the substrate can be treated with the growth of ZnO nanorods by the hydrothermal method.

After finishing the samples, the next step is to test the characterization of samples. It conducts by the effect of gas using CO gas by using voltage variations of 1, 4, and 8 Volts, and changes in the working temperature of 150ºC-250ºC. After testing the gas effect then testing the sample using a Scanning Electron Microscope (SEM) to determine the morphology and graph of Energy Dispersive Spectroscopy (EDS) composition of ZnO nanorods which have been grown on interdigitated electrodes. The next sample test uses EDS which aim to determine the content of the elements formed in the ZnO nanorods layer. The next test uses X-Ray Diffraction (XRD) which aims to determine the crystal structure of ZnO nanorods which have been grown on the interdigitated electrode.

3. Results

3.1. The crystal structure analysis

The Crystal structure is obtained through testing carried out using X-Ray Diffraction. XRD analysis has been carried out processing using High Score Plus software. In the XRD analysis, this study used references by the International Center for Diffraction Data (ICDD).

![ZnO nanorods](image)

Figure 1. X-ray diffraction pattern.

Figure 1 shows the XRD pattern for the ZnO nanorods sample on the interdigitated electrode. Based on the ICDD 00-036-1451 reference it is known that the crystal structure obtained is hexagonal wurtzite, with diffraction peaks oriented at (100), (002), (101), (102), (110), (103), (112) dan (201).
3.2. *The morphological analysis and size distribution of ZnO nanorods*

In the results of ZnO nanorods growth, it is important to know the morphology and size distribution produced by the hydrothermal method, then SEM testing and measurement using software infinity analyze are carried out.

![SEM results of ZnO nanorods on the interdigitated electrode](image)

**Figure 2.** The SEM results of ZnO nanorods on the interdigitated electrode with (a) 5000 × (b) 10000 × (c) 20000 × magnification variations.

Figure 2(a) shows the surface of the sample that has been grown by ZnO nanorods for 10000 × magnification. Figure 2(b) with 10000 × magnification can be seen that ZnO nanorods have been successfully grown with sufficiently varied growth directions, that is, perpendicular to the substrate and some nanorods grow inclined with a certain slope angle. In Figure 2 (c) it shows that the nanorods that grow between each other are quite tight. Furthermore, the characterization of graph I-V is carried out on the sample by varying the working temperature of the sensor which is 150°C – 250°C with an increase of 100°C. This characterization aims to determine the effect of temperature on the I-V graph; this will be related to the performance of the gas sensor.

![Graph the relationship between current and voltage](image)

**Figure 3.** Graph the relationship between current and voltage (a) I-V in sample 1 (b) I-V in sample 2.
Figure 3 shows that the temperature affects the value of the current obtained, the higher the working temperature given to the sample, the lower the current obtained, this is because when the temperature is high the phonon energy in each atom will increase which results in higher atomic movements electrons that will flow past the atom will be blocked. This results in a decrease in the value of the current at each increase in temperature. Figure 3 confirms that the characteristics of I-V experience an increase in non-linear currents; this refers to the Schottky contact structure of the connection of metal (Au) and semiconductor (ZnO).

In the results of the study, it is known that the graph of the relationship between current and voltage forms nonlinear at a working temperature of 190°C to 250°C. Events that occur at temperatures in that range differs from the Schottky barrier profile in general, the graph formed at that temperature has a peak with a given voltage variation, 3 - 5 volts, this can be seen in Figure 4.

![Figure 4](image-url)

**Figure 4.** The I – V Graph with a temperature variation of 190°C - 250°C: (a) sample 1, (b) sample 2.

Figures 4 (a) and (b) have peaks that begin to emerge when the sample work temperature is 190°C, this event is similar to the tunnelling diode characteristic, but this only occurs in low temperature and low voltage conditions. In Schottky contact conditions, there is a barrier between metal and semiconductors, the height of the barrier on the contact can be obtained using data processing derived from the characteristics of I-V, then analyzed using Richardson Plot. Figure 5 shows the Richardson Plot; this aims to determine the effect of temperature on the value of current and resistance at any given voltage and know the properties possessed by Schottky contact.

The use of voltage variations of 1 Volt, 4 Volt, and 8 Volt is due to the voltage being the phase that refers to Figure 4, peak and after the peak. In Figures 5 (a), (c) and (b) it can be seen that the graph obtained is non-linear; this is indicated because of the series resistance [14]. Series resistance is an additional effect on Schottky contact; this can occur because of two important effects, namely, related to devices configuration and non-ideal of a system [15].
Figure 5. Richardson current against temperature and resistance against temperatures: (a) and (b) when 1 Volt, (c) and (d) when the 4 Volt and (e) and (f) when the voltage is 8 Volt.

4. Summary
The structure of the ZnO nanorods crystal is hexagonal wurtzite, and the direction grows perpendicular to the substrate. Temperature affects the value of the current obtained, the higher the temperature conditions given, the lower the current value. Characteristics I-V show the existence of physical phenomena that occur in temperature variations ≥ 190°C which indicates a peak. Details of phenomena still need to be elaborated. The gas effect test shows that the sensor is at a maximum working temperature of 190°C with an input voltage of 8 volts and reaches a sensitivity to the gas at 220°C.

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