ELECTRICAL PROPERTIES of ZINC OXIDE (ZnO) NANORODS for FET APPLICATIONS

Nur Adzzida Binti Mohd Azalli
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
*Email:adzidaazalli@gmail.com

Abstract – ZnO nanorods have being growth using chemical bath deposition (CBD) method. This is done to investigate the consequences of different annealing temperature and different volume of solutions to the electrical properties of ZnO nanorods. The IV characteristic has been determined by using IV probe measurement system while optical properties have been analyzed by using Perkin Elmer (LAMBDA 750) UV-VIS spectrophotometer. The surface morphologies of ZnO nanorods were examined by using FESEM JOEL JSM-7600F. The result depicts that with the different annealing temperature, it showed the sample that annealed at 500°C has the highest conductivity (low resistivity). Meanwhile, with the different volume of solutions, it depicts that 50ml gave the conductive behavior compare to the other volumes but for the transparent visible light behavior, 200ml gave the best result due to highest optical transmittance.

Keywords – Zinc Oxide (ZnO) nanorods; MgZnO; chemical bath deposition (CBD); FETs; electrical properties; optical properties

I. INTRODUCTION

According to the Moore's Law, the number of transistors possibly field effect transistor (FET) will doubles every two years. As a result, the size become smaller and smaller around 250nm to 100nm [1] and can be below than that. Due to this problems, one dimension of ZnO based material has attracted many researchers efforts due to its unique properties and applications including in field effect transistor (FET), transparent electronics, light emitting diodes (LED), solar cells, chemical sensor and piezoelectric devices [2].

ZnO is a semiconductor with direct band gap of 3.37eV and has large excitation binding energy of 60meV at room temperature [3-4] where it gives more efficient emission at room temperature as it has unique characteristics. It also made ZnO become transparent to visible light. ZnO can be group to transparent conducting oxide (TCO) [5] where it can be used as transparent electrode in electronic devices. TCO is very important in ZnO thin film which it can be the most capable materials where necessary in high transmission and low resistivity [6].

ZnO nanorods have hexagonal wurtzite structure where oxygen atom exist on hexagonal site while zinc atom in tetrahedral site [7]. The use of aligned zinc oxide nanorods will produce a better result on reducing energy loss during electron transportation.

There are several methods to synthesis ZnO such as radio-frequency magnetron sputtering, evaporation, chemical vapour deposition, spray pyrolysis, electrochemical deposition and chemical bath deposition [2]. Among these, CBD method was chosen because it is more effective, low cost technique, low process temperature and can produced very well aligned ZnO nanorods. In this research, the growth f ZnO nanorods are presented by using CBD method and the characterization of the nanorods at different annealing temperature and different volume of solutions has been studied.

II. METHODOLOGY

The Zinc Oxide (ZnO) nanorods samples were prepared in a clean room on glass substrates by using chemical bath deposition (CBD) method with different annealing temperature and different volumes of solution. Before deposition taken a place, the substrate has gone through a cleaning process before being used. The substrates have being washed with acetone and methanol simultaneously. Then, it being washed and rinsed with deionized water. Hydrofluoric acid has been used for the cleaning purpose together with the deionized water. By using ratio of 1:10, the cleaning process was put in a sonicator for 10 minutes. This process is done to convince that no particles on the top of the substrates surface where it can cause contamination to the sample which it can effect the growth of MgZnO thin film [8].

Two solutions need to be prepared for testing the electrical properties of ZnO nanorods. First step need to be considered was preparing MgZno solution. The starting material that used was zinc acetate dehydrate [$Zn(CH_3CO)_2.2H_2O$], together with solvent, 2-methoxythenol

$[C_3H_8O_2]$, mono-ethanolamine $[C_2H_7NO]$ as a stabilizer and magnesium nitrate hexahydrate $[Mg(NO_3)2.6H_2O]$ as a dopant. The weightage of each chemical have been calculated before mixed and stirred together in one solution respectively. The deposition of a thin film was done by using sol-gel spin coating method. To get a thin film thickness approximately 300nm [8], 5 layers were coated with a spinning speed at 3000rpm for 1 minute. Each layer of 10 drops sol was pre-heated at 150°C for 10 minutes. Annealing process takes place after finish all those 5 layers at 500°C for 1 hour.

For a second step, prepare aqueous solution, ZnO that contains zinc nitrate hexahydrate $[Zn(NO_3)_2.6H_2O]$ and hexamethylenetetramine [HMT $(C_6H_{12}N_4]$. Prepare four bottles that contain deionized (DI) water but fixed the volume at 200ml for all the solutions. Then, the mixture was mixed into the DI water and was stirred for 2 hours. After that, the substrates were placed in the bottles filled with the prepared solution. Put the substrates in a slanting condition and totally immersed in the solution. By using molarity 0.05mol, all the solutions were immersed about 4 hours. After all the samples completed immersed, annealed them for different temperature where 400°C, 450°C, 500°C and 550°C for 1 hour simultaneously. For the metallization purposed, thermal electron beam evaporator has been employed to deposit aluminum. Then, all the samples were characterized by using UV-VIS to analyze the optical properties, FESEM to measure surface morphology and I-V measurement to measure the electrical properties.

Continue the previous steps for the different volume of solutions. The volumes needed are 50ml, 100ml, 150ml and 200ml. Do the steps as the previous method. After completed, annealing process takes place where all the substrates were annealed only at 500°C for 1 hour. Lastly, after done doing all the process characterized all the samples as the previous one. The illustration of the process is shown in Fig. 1 for better understanding.

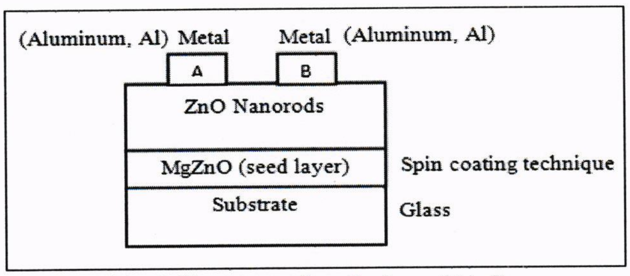

Figure 1. Illustration configuration layer of thin film

Flow charts below summarize the process of the project.

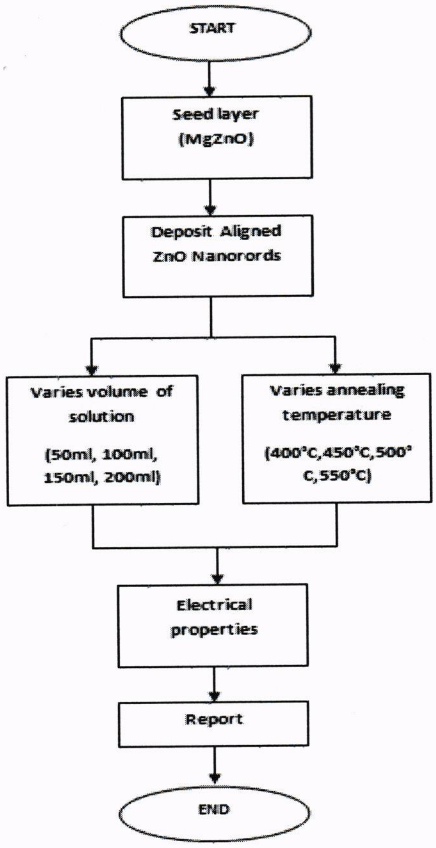

Figure2: Flow chart of the experimental procedure for the project

III. RESULT AND DISCUSSION

Different Annealing Temperature

A. IV Measurement

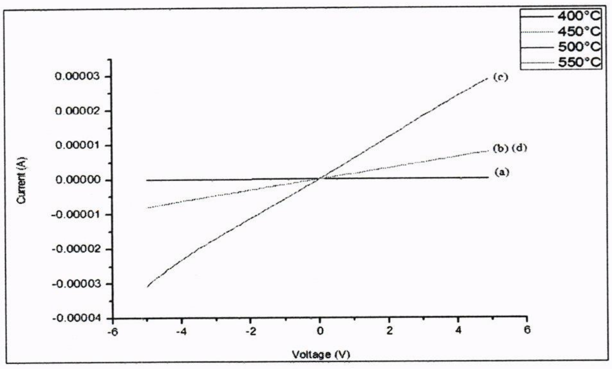

Figure 3. The IV characteristics of ZnO nanorods for sample annealed at (a) 400°C; (b) 450°C; (c) 500°C; (d) 550°C

The IV characteristic of ZnO nanorods with different annealing temperature was determined by the equation of resistivity and conductivity [2, 9]. From the Fig.3, it can be describe sample that annealed at 500°C has the highest current value which is 30μA. It is due to the manipulation of contact resistance and the appearance of the defect on the ZnO surface [2]. The value of resistivity and conductivity was calculated and shown in Fig.4 and Fig.5. The equations to calculate the resistivity and conductivity are shown below.

$$\rho = R\frac{(wt)}{l} \quad (1)$$

$$\sigma = \frac{1}{\rho} \quad (3)$$

where ρ is electrical resistivity, l is distance between metal contact, w is width of metal contact, R is resistance of material and σ is electrical conductivity.

Table 1.

RESISTIVITY and CONDUCTIVITY of ZNO NANORODS for DIFFERENT ANNEALING TEMPERATURE

Temperature, (°C)	Resistivity,(ρ)	Conductivity,(σ)
400	8.51E+00	1.18E-01
450	4.23E+00	2.36E-01
500	1.05E+00	9.52E-01
550	3.25E+00	3.08E-01

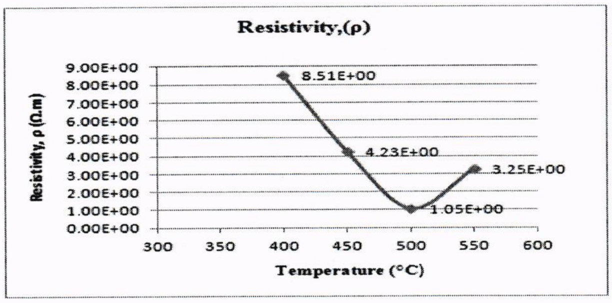

Figure 4. The measured value of resistivity of ZnO nanorods for all samples

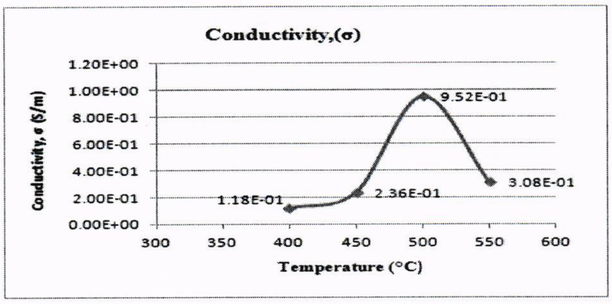

Figure 5. The measured value of conductivity of ZnO nanorods for all samples

From the calculation, it describe the resistivity value for 400°C is 8.51 Ω.m decreased to 1.05 Ω.m at 500°C but then it increased again to 3.25 Ω.m at 550°C annealed temperature.

To get the value of the conductivity, the value of resistance need to be inversed. Meanwhile, starts from 400°C, the value of the conductivity we get is at the lowest point which is 0.178 S/m but it increased rapidly to 0.952 S/m (max point) at 500°C. However, it decreased again to 0.308 S/m when it annealed at 550°C. From that, it can be conclude the capability of ZnO nanorods to perform electric current is higher at 500°C.

B. Optical Transmittance Studies

Based on this reasons, the observation of the IV measurement is depending on the optical properties of ZnO. PerkinElmer SOP was used to measure the optical transmittance. Fig.3 showed at 500°C annealing temperature, the optical transmittance in Fig.6 is higher which exceeds 80% compared to the other temperature. This is due to the capability of the light that passed through the sample to the intensity of the light when entered the sample.

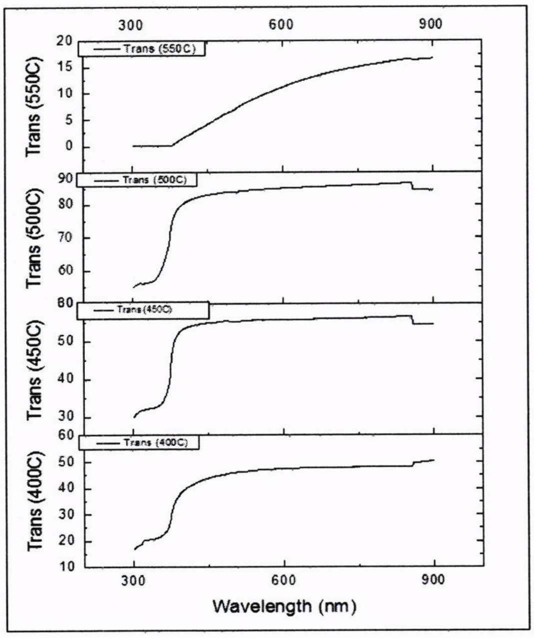

Figure 6. Optical transmittance of ZnO nanorods with different annealing temperature

C. Scanning Electron Microscopy

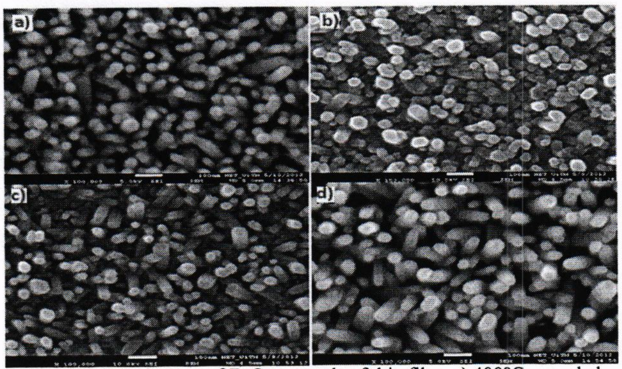

Figure 7 . SEM images of ZnO nanorods of thin film: a) 400°C annealed temperature; b) 450 °C annealed temperature; c) 500°C annealed temperature; d) 550°C annealed temperature.

Fig. 7 describes the different surface morphology of ZnO nanorods with different annealing time. FESEM JOEL JSM-7600F was used to measure surface morphology. The SEM results shown in Fig. 7 indicate the different surface morphology of ZnO nanorods at different annealing time. Fig. 7 a) shows ZnO nanorods growth on the substrate for 400°C annealed temperature. Fig. 7 b) shows ZnO nanorods growth on the substrate for 450°C annealed temperature. Fig. 7 c) shows ZnO nanorods growth on the substrate for 500°C annealed temperature. Fig. 7 d) shows ZnO nanorods growth on the substrate for 550°C annealed temperature.

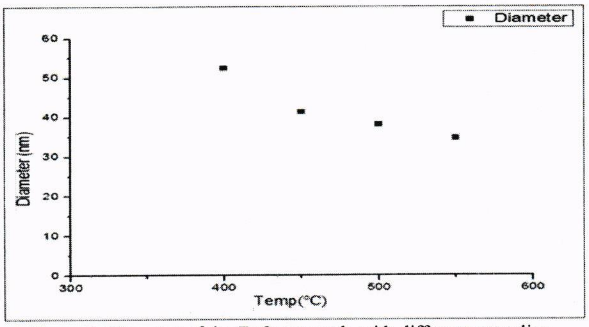

Figure 8. Diameter of the ZnO nanorods with different annealing temperature

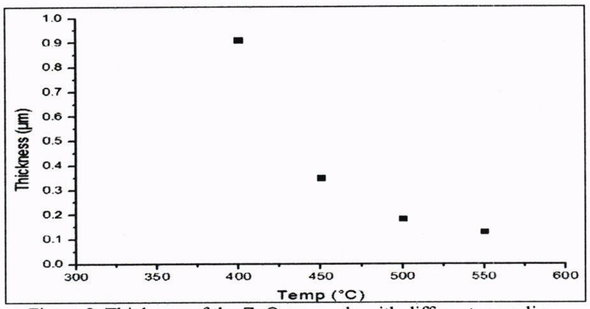

Figure 9. Thickness of the ZnO nanorods with different annealing temperature

Fig. 8 showed the diameter of the rod gained between 30nm to 60nm. It depicts that it is still below in the range of 100nm. For the cross-sectional SEM measurements in Fig. 9, the SEM image represents the ZnO nanorods growth of thickness is between 0.91μm (for 400°C annealing temperature), 0.35μm (for 450°C annealing temperature), 0.183μm (for 500°C annealing temperature) and 0.13 (for 550°C annealing temperature). At the 500°C, it showed that packed structure of nanorods ZnO on the substrate cross-sectional SEM and it can provide the optimum electrical characteristic compared to others [2]. It can be proven by referring to the optical transmittance shown before.

Different volumes of solution

A. IV Measurement

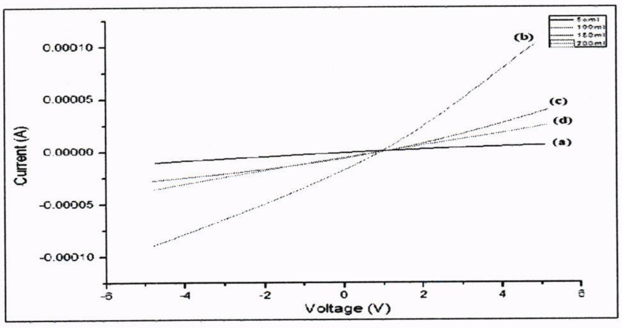

Figure 10. IV characteristics of ZnO nanorods for sample volumes at (a) 50ml; (b) 100ml; (c) 150ml; (d) 200ml

Table 2.

RESISTIVITY and CONDUCTIVITY of ZNO NANORODS for DIFFERENT VOLUME OF SOLUTIONS

Volume,(ml)	Resistivity,(ρ)	Conductivity,(σ)
50	7.44E+00	1.34E-01
100	4.78E+01	2.09E-02
150	3.26E+01	3.07E-02
200	5.27E+01	1.89E-02

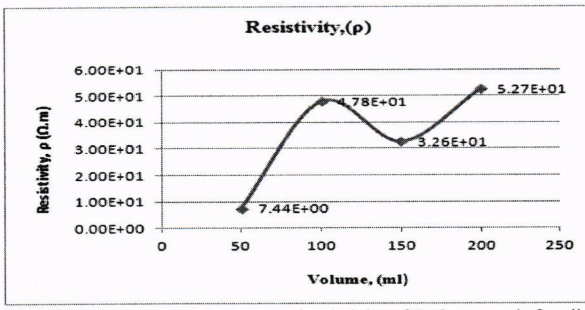

Figure 11. The measured value of resistivity of ZnO nanorods for all samples

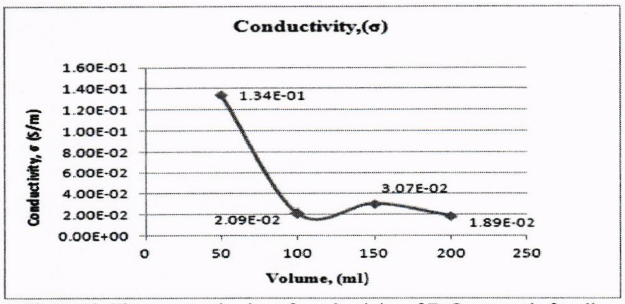

Figure 12. The measured value of conductivity of ZnO nanorods for all samples

Keithly measurement system has been used to study IV characteristic. From the calculation above, it depicts that the resistivity value starts from (min point) 7.44 Ω.m for 50ml. Then, it increased rapidly to 47.8 Ω.m for 100ml. In this time, at 150ml it decreased a little bit to 32.6 Ω.m but then increased again to (max point) 52.7 Ω.m at 200ml.

The conductivity was obtained inversely from the measured value of resistance. From the Fig.12, the value of conductivity is higher at 0.134 S/m for volume 50ml. However, the conductivity value at 100ml declines sharply to 0.0209 S/m since the nanorods become thicker. At 200ml volumes, the value of conductivity decreased again to 0.0189 S/m (min point). It means that a 50ml volume is very conductive to produce electrical current due to high conductivity although the current is smaller.

To support this statement, SEM characterization was measured to observe the surface morphology. The diameter and thickness of the nanorods were determined to see the dependencies of the resistivity and conductivity of the IV measurement.

B. Scanning Electron Microscopy

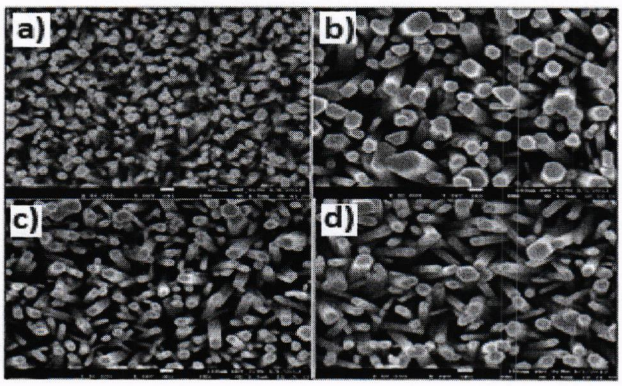

Figure 13. SEM images of ZnO nanorods of thin film: a) 50ml volume of solution; b) 100ml volume of solution; c) 150ml volume of solution; d) 200ml volume of solution

Field Emission Scanning Electron Microscopy, FESEM was observed to investigate the surface morphology of the growth of ZnO nanorods with different volumes of solution. In Fig. 5 the SEM images of ZnO nanorods of thin film grown by the aqueous solution deposition technique on a) 50ml volume of solutions; b) 100ml volume of solutions; c) 150ml volume of solutions; d) 200ml volume of solutions.

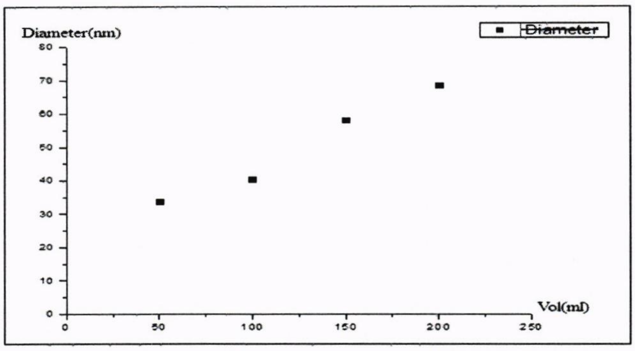

Figure 14. Diameter of the ZnO nanorods with different volumes of solutions

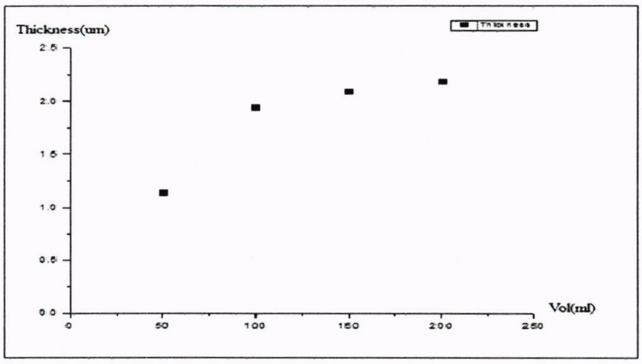

Figure 15. Thickness of the ZnO nanorods with different volumes of solution

From the SEM images, it can be seen that the nanorods more hexagonal zinc oxide structures but still randomly oriented [10]. It showed that the diameter of the nanorods increase as the volumes of the solution is increases. Fig. 14 showed the diameters of the rods obtained are between 30nm to 70nm where it still in the range of below 100nm. Cross-sectional SEM measurements in Fig. 15 reveal a thickness of the nanorods between 1.14μm (for 50ml), 1.94 μm (for 100ml), 2.09μm (for 150ml) and 2.19 μm (for 200ml). From the surface can be seen also defects where there are places which are not covered with ZnO and sometimes there are much bigger rods. This is caused by the impurities on the surface before spin coating procedure.

C. Optical Transmittance Studies

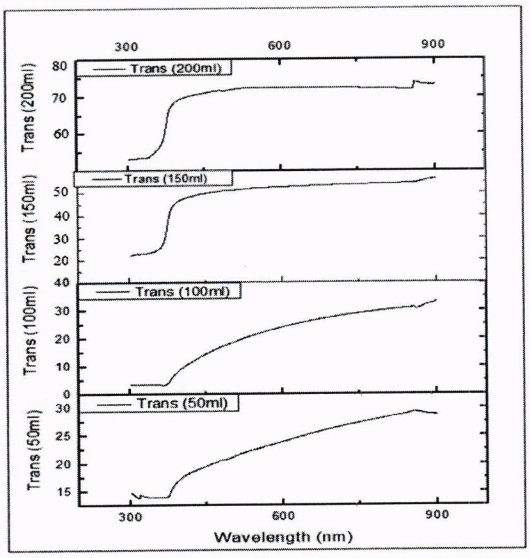

Figure 16. Optical transmittance of ZnO nanorods with different volumes of solutions

In the present analysis, the optical transmittance in Fig. 16 of the ZnO nanorods with different volumes of solutions was studied in the wavelength range between 300nm to 900nm. From the Fig.16, it can be seen that the ZnO nanorods are higher optical transmittance at 200ml volume of solutions which exceeds 70%. The increasing volumes of solutions will increase the visible light transmittance due to the ZnO nanorods become denser with the increasing of diameter of ZnO nanorods.

IV. CONCLUSION

In summary, the electrical properties of ZnO nanorods for FET applications were studied. Chemical bath deposition (CBD) method was use by using glass as a substrate to produce ZnO nanorods. The different annealing temperature and different volume of solutions was utilized to examine the electrical properties for FET application. Sample that annealed at 500°C has the highest value of current and optical transmittance due the manipulation of contact resistance. Other than that, it also has the highest conductivity (lowest resistivity). For the volume of solutions, it can be conclude that the molarity 0.05mol used does not change the density. For FET applications, it can be choose either 50ml or 200ml volume of solutions. To get more conductive behavior in the devices, 50ml can be use as it is more conductive to produce electrical current. Otherwise, for the devices that need transparency to the light it can choose 200ml as it has the highest optical transmittance. For the future research, it is recommended to synthesis ZnO nanorods using different deposition time and different molarity to see the changes in IV characteristic.

ACKNOWLEDGMENT

A sincerely appreciation goes to Nano-ElecTronic Centre (FKE) and NanoSciTech Centre (IOS) for the equipment facilities. A deeply gratitude goes to Puan Salina Mohamad and friends for her guidances and supports in other to complete the paper.

REFERENCES

[1] Richard C.Jaeger, Travis N.Blalock, "Microelectronic Circuit Design", McGraw Hill Interbational Edition, Chapter 4

[2] M. Salina[1], M. Z. Sahdan[1], N. F. Jusoh[1], R. A. Kadir[1] and M. Rusop[1,2] "The Consequences of Annealing Temperature to Optical and Electrical Properties of Zno Thin Film for FET Applications" Solar Cell Laboratory, Faculty of Electrical Engineering; Universiti Teknologi MARA, Selangor, Malaysia

[3] M. F. Malek[1], N. Zakaria[1], M. Z. Sahdan[1], M.H. Mamat[1], Z. Khusaimi[2] and M. Rusop[1,2] "Electrical Properties of ZnO Thin Films Prepared by Sol-gel Technique", Faculty of Electrical Engineering; Universiti Teknologi MARA, Selangor,

[4] Michal Byrczek, Mirosloa Malewicz, and Hlena Teterycz, Poland "The Growth of Zinc Oxide Nanocrystal on the Zinc Oxide Thin Film by Chemical Bath Deposition" Faculty of Microsystem Electronics and Photonics, Wroclaw University of Technology,

[5] M K Jayaraj*, Aldrin Antony and Manoj Ramachandran, "Transparent Conducting Zinc Oxide Thin Film Prepared Byoff-Axis Rf Magnetron Sputtering", Cochin University of Science and Technology, Kochi 682 022, India, Vol. 25, No 3, June 2002, pp. 227–230.© Indian Academy of Sciences

[6] Rui Song, Dan Xie*, Tianling Ren, "The Optical Properties of Zno Nanorod Arrays Prepared Through Hydrothermal Synthesis for Solar Cell Application", Institute of Microelectronics, Tsinghua University, Beijing 100084, China

[7] M. H. Mamat, M. Z. Sahdan, S. Amizam, H. A. Rafaie, Z. Khusaimi, A. Zain Ahmed,S. Abdullah, M. Rusop, "The Effect of Annealing Temperatures on Zinc Oxide Thin Films Properties for Electronic Devices Application", Solar Cell Laboratory, Faculty of Electrical Engineering; Universiti Teknologi MARA, Selangor

[8] M. Salina[1], M. Z. Sahdan[1], R. Ahmad[1], and M. Rusop[1,2]," Study on The Effect of Metal Contact (Pt, Pd and Au) to the Electrical and Physical Properties of Mg_xZn_x-1O Thin Film for FET Applications" [1]Solar Cell Laboratory, Faculty of Electrical Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

[9] C. Y. Yim, D. Y. Jeon, K. H. Kim, G. T. Kim, Y. S. Woo, S. Roth J. S. Lee and S. Kim, "Electrical Properties of the ZnO Nanowire Transistor and its Analysis with Equivalent Circuit Model", 48, 1565, (2005)

[10] M. Kauk, K. Muska, M. Altosaar, M. Danilson, K. Õunpuu, T. Varema and O. Volobujeva, "ZnO grown by Chemical Solution Deposition", Department of Materials Science, Tallinn University of Technology, Tallinn, Estonia