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Effect of Annealing Temperature on Electric Properties of ZnO

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A B S T R A C T

Zinc oxide (ZnO) is a semiconducting material exhibits piezoelectric or pyroelectric properties and can be used in different devices. The aim of this research is the study of annealing temperature effect on the current voltage relationship, conductivity and resistivity using Ohm's circuit. Zinc metal, zinc sulphide, zinc sulphate and commercial zinc oxide in a powder form were collected from different areas in Khartoum State, Sudan. These samples were annealed in ambient oxygen at furnace 1000ºC for 3, 6, and 9 h respectively except the commercial zinc oxide which was used as a control. Results revealed that the voltage increased smoothly with respect to the current for all ZnO samples at high temperature with the increase in time. Zinc oxide obtained from zinc metal showed a higher conductivity values (13.492-14.391 Ohom. m) than that of zinc sulphide (13.332-13.805 Ohom. m), zinc sulphate (13.289-13.606 Ohom. m) and commercial zinc oxide (13.703 Ohom. m). The resistivity of ZnO samples obtained from Zn samples represented the best results ranging between 0.0741192 Ω. m and 0.0694869 Ω.m when compared with the ZnO samples obtained from ZnS, ZnSO4 and commercial ZnO.

Keywords: *Annealing temperature, Electric properties, Piezoelectric, Pyroelectric, Semiconductor.*

INTRODUCTION

Nowadays ZnO has attracted much attention as "future material" due to its unique properties. It is a promising substance to be fabricated in different forms and used to produce different devices. It will be used to produce transparent electrics, ultraviolet (UV) light emitters, piezoelectric devices, chemical sensor and spin electronics (Nomaro, 2003; Pearton, 2004). ZnO thin films can be produced such as invisible thin film transistors from ZnO, which are highly effective than amorphous silicon thin films (Nishii, 2003; Norris, 2003). Many process in new generation solar cell can be understand by controlling ZnO structure at nanosize level and enhancing electrical mechanical, chemical and optical properties (Wang, 2005; Liu, 2006, Jagadish and Pearton, 2006). There are various properties that distinguish ZnO from other semiconductors or oxides and render it to be useful for different applications. i.e. direct and a wide band gap which is 3.44eV at low temperature and 3.3eV at room temperature(Malik, 1997), large exciton binding energy (60 m eV) and exhibits an efficient excitonic emission at room temperature and higher (Aranovich, 1980, Baganall, 1997), large piezoelectric constant, strong luminescence and exhibits high radiation hardness (Tominaga, 1988; Look, 2001).

Materials and methods

Zinc metal (Zn), zinc sulphide (ZnS), zinc sulphate ($ZnOSO_4$) and commercial ZnO in a powder form were collected from different parts in Khartoum State, Sudan. Three grams of each investigated sample were put in a crucible and oxidized in a furnace (England, Maximum Temperature 1200ºC) at 1000^{O}C for 3, 6, 9 hours respectively. To characterize the electrical properties and measure the resistivity of the oxidized powdered samples, three grams of each samples were taken and fabricated into a disc form (1.7cm) using an old pressing machine (Holmatro, Hydraulics, BREDA- Holland) under pressure 25 tons and internal radius about (1.7cm) at Physics section, Faculty of Science, Al-Neelain University, Sudan. Then the samples in a disc form were put in a glass tube with the same radius connected with Ohom circuit connected with Microvolt DMMV (model 177 Microvolt DMM-US), Peico Ammeter (model 642 electrometer- KETHLEY. US), Power Supply (modle 52105-LEYBOLD-Germany), and Albert Van Perk n.v(model 801754-HUYGENS-Holand) to measure the voltage and current. The following formula used to calculate the resistivity and then conductivity was calculated as reverse of resistivity.

$R= \rho * L / A$ (1)

Where:

R = resistance. ρ = resistivity

L = length and volume of 8 cm

A = area

Where the area equivalent to

$\Pi r^2/ 2 = \Pi d^2/ 4$ (2)

RESULTS AND DISCUSSION

As seen from the results in Fig. 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10, there is a direct proportional relationship between the current and voltage which was represented by linear fit red line. This may be attributed to the use of high temperature for a long time

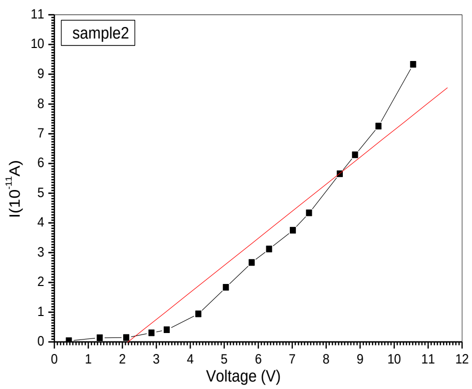


Fig.4.1. Current-Voltage of ZnO obtained from Zn annealed at 1000°C for 3 hours

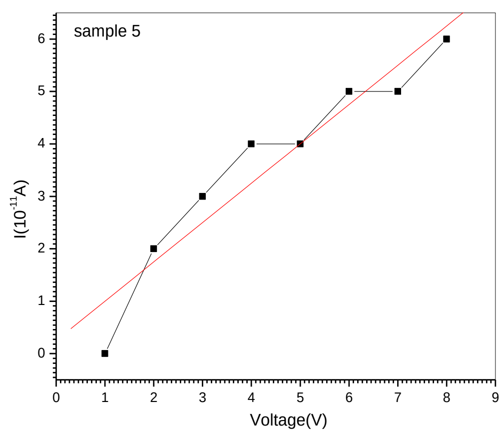


Fig.4.2. Current-Voltage of ZnO obtained from Zn annealed at 1000°C for 6 hours

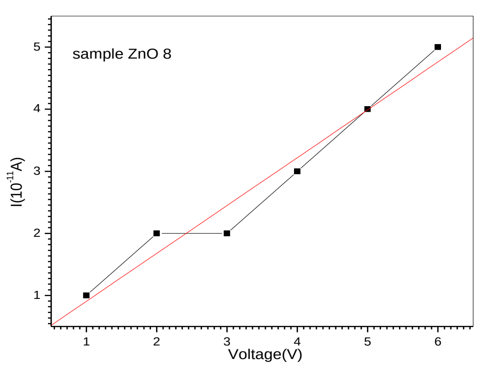
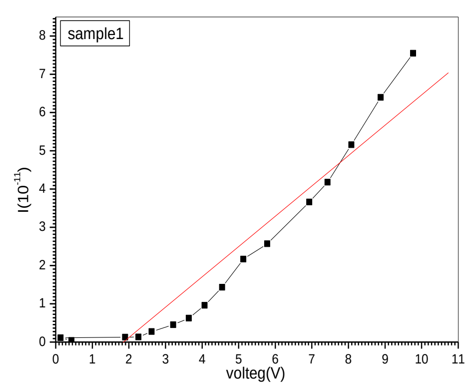


Fig.4.3. Current-Voltage of ZnO obtained from Zn annealed at 1000°C for 9 hours



Fif.4.4 Current-Voltage relation of ZnO obtained from ZnS annealed at 1000°C for 3 hours

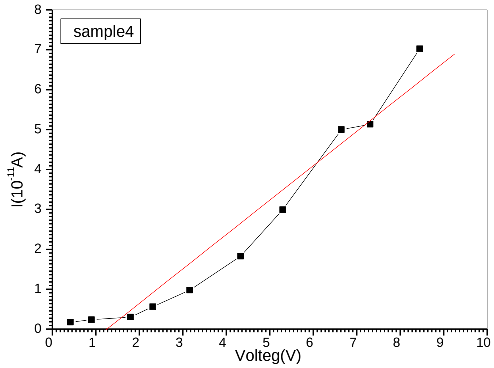


Fig.4.5. Current-Voltage of ZnO obtained from ZnS annealed at 1000°C for 6 hours

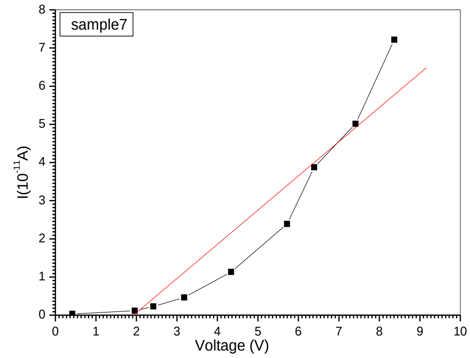


Fig.4.6.Current -Voltage relation of ZnO obtained from ZnS annealed at 1000°C for 9 hours

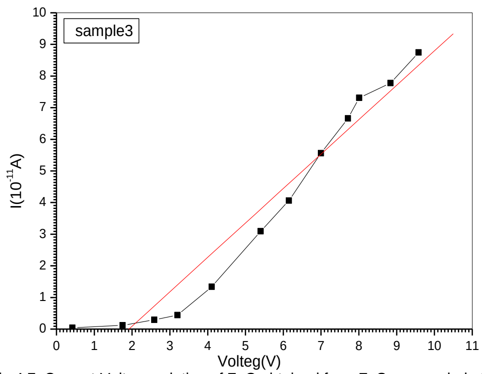


Fig.4.7. Current-Voltage relation of ZnO obtained from $ZnSo_4$ annealed at 1000°C for 3 hours

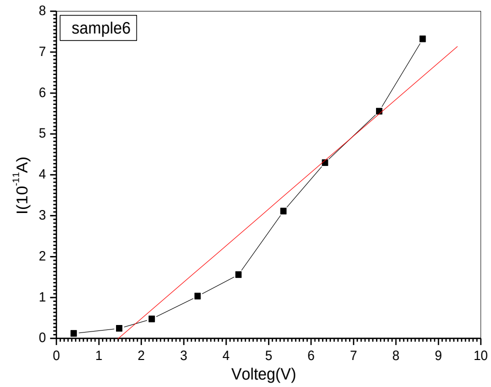


Fig.4.8. Current-Voltage relation of ZnO obtained from $ZnSO_4$ annealed at 1000°C for 6 hours

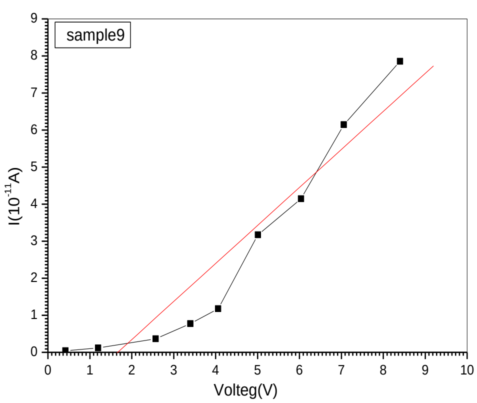


Fig.4.9. Current -Voltage relation of ZnO obtained from $ZnSO_4$ annealed at 1000°C for 9 hours

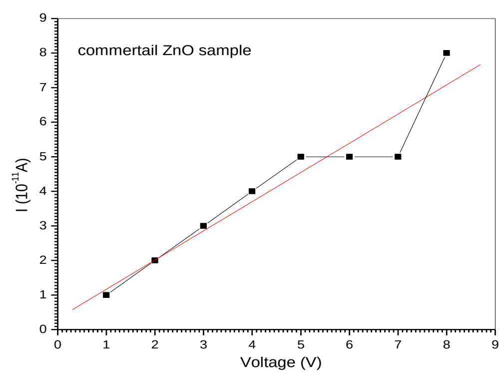


Fig.4.10. Current-Voltage relation of commertial ZnO

which enhances and improve the electrical properties. ZnO grain size and crystalinity were increased and the thin film electrical properties were improved when the temperature raised to 800°C (Natsume, V,1992). But at 100°C silicate was observed, leakage current and roughness of the film were increased.

With respect to the resistivity, it was found that the resistivity of ZnO samples obtained from Zn samples was varied from 0.0741192 Ω. m after annealing at 1000°C for 3 hours, to 0.0700187 Ω. m after annealing at 1000°C for 6 hours, and then to 0.0694869 Ω. m after annealing for 9 hours, while the resistvity of ZnO samples obtained from ZnS annealed at 1000°C for 3, 6, and 9 hours was 0.750071, 0.0734983, and 0.0724370 Ω. m respectively. The resistivity of ZnO samples obtained from ZnSO4 annealed at 1000^{o}C for 3, 6, and 9 hours was 0.0752571, 0.0748182, and 0.0729781 Ω. m respectively. With respect to the commercial ZnO sample the resistivty was found to be 0.0729781 Ω. m (Table 1). The resistivity decreased as the time and temperature increased for bulk ZnO and hence the conductivity increased, which showed the semi-conductivity properties with negative coefficient indicated that these samples have the same nature. Similar result was obtained by [Ahmed, 2010] who found that when the temperature increased, the resistivty will be decreased. She found that the commercial ZnO showed better results compared with ZnS annealed at different temperature for three hours (unpublished data). Another study carried out by (Sundaram, 1997) who cited that the resistivity decreased rapidly with the increase of substance temperature to a minimum of $6.12x10^{-2}$ Ω. m at 150^{o}C. Van de Wall (2001) reported that the decreases of ZnO and ZnMnO thin films resistivity correspond to the increase of temperature which indicated the semi-conductive properties of ZnO. As found by William, (2006).

Table 1. Resistance, Resistivity and Conductivity of ZnO samples obtained from different sources annealed at 1000^{o}C for 3, 6, and 9 hours

Sample No	Sample	Time (hours)	Resistance R (Ohom)	Resistivity ρ (Ohom.m)	Conductivity (Ohom. m)
1	Zn	3	0.95747	0.0741192	13.492
2	ZnS	3	0.96894	0.0750071	13.332
3	ZnSO4	3	0.97217	0.0752571	13.289
4	Zn	6	0.90450	0.0700187	14.282
5	ZnS	6	0.94945	0.0734983	13..606
6	ZnSO4	6	0.96650	0.0748182	13.366
7	Zn	9	0.89763	0.0694869	14.391
8	ZnS	9	0.93574	0.0724370	13.805
9	ZnSO4	9	0.94942	0.0734960	13.606
10	Commercial ZnO	-	0.94273	0.0729781	13.703

Zinc oxide films annealing in air could raise resistivity about nine orders (10^{-3}-10^{-6} Ohom. cm).The decrease of ZnO samples resistivity may be attributed to the high temperature (1000^{o}C) that applied and subjected for a long time (3, 6, 9 hours) and improve the properties of ZnO samples obtained from different sources. High annealing temperature has been found to improve ZnO film characteristics of piezoelectric application (Sharma, 2002).

As seen from the results in Table (1), Zn annealed at 1000^{o}C for 3 hours had a higher conductivity (13.492 Ω/m) than that of ZnS sample (13.332 Ω /m) followed by ZnSO4 sample (13.289 Ω/ m) annealed at the same conditions. With respect to the samples (Zn, ZnS, ZnSO4) annealed at 1000^{o}C for 6 hours, the conductivity of the sample obtained from Zn was higher (14.282 Ω/ m) than that of the samples obtained from ZnS (13.606 Ω/ m) followed by the sample obtained from $ZnSO_4$ (13.366 Ω/ m). As for the samples annealed at 1000^{o}C for 9 hours, the result showed high value of conductivity of about 14.391, 13.805, and 13.606 Ω/ m for Zn, ZnS, and ZnSO4 respectively. However, Zn samples annealed at 1000^{o}C for 3, 6 and 9 hours showed higher conductivity values than that of ZnS, $ZnSO_4$ and commercial ZnO.

This may be due to the fact that as the annealing temperature increases more and more Zn atoms are combined with O_2 to form ZnO and the concentration of Zn atoms decreases. This it is proposed that the higher temperature for complete transformation of zinc lattice to zinc oxide should be tried. Sheng-Yuan, (2003) pointed that the band gap energies of films increases with increase in the annealing temperature. Also they reported that the annealing temperature appears to be an important parameter for molecular packing in the solid state structure and influence the properties. However, higher annealing temperatures resulted in dramatic improvements. The annealing at 950^{o}C appears to be the threshold required to remove the scratches on ZnO (Gu, X, 2004). Furthermore, ZnO annealed at 1050^{o}C showed a terrace-like surface, which can facilitate smooth two-dimension (2-D) growth of GaN epilayer without deleterious effects of damage substrate surface. Results revealed the use of high annealing temperature for a long time will improve the electric properties of ZnO

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