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Analysis and Study of the Electrical Properties of Nano ZnO.Cu/Al Schottky Diode

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A B S T R A C T

Schottky diode (semiconductor/metal) ZnO.Cu/Al was prepared by using the bar-coating method to prepare films of ZnO.Cu on aluminum substrate. Powders of zinc oxide doped with copper were previously prepared with different Cu doping ratios. These powders were characterized using X-ray diffraction showed the have a polycrystalline structure, and also using a field emission scanning electron microscope to confirm the morphology of the prepared powders, which it turned out to be nanostructures with a relatively uniform distribution. The properties of the prepared Schottky diode were studied, and the diode parameters were calculated, including voltage barrier, saturation current, ideality factor, and rectification factor through the relationship between current and voltage at forward and reverse bias as a function to the different Cu doping ratio and the best rectification factor was 4.91at highest Cu doping ratio.

***Keywords*: *Schottky diode, ZnO.Cu, bar-coating method, ideality factor*.**

1. Introduction

Pure zinc oxide (ZnO) is one of the chemical compounds of zinc and is a semiconducting material. It belongs to the group of transparent conducting oxides (TCOs), which are characterized by high transmittance in the visible region of the spectrum and reflectivity in the infrared region, in addition to having an electrical conductivity of 22.6. S.cm-1 is of the negative type(n-type). Zinc oxide is a solid, white compound that turns yellow when heated due to deformations of the lattice. It is also a non-toxic substance, unlike cadmium compounds. It does not dissolve in water or alcohol, it dissolves in acetic acid and mineral acids, and in ammonia, ammonium carbonate, and alkaline hydroxides, so it is amphoteric oxide. Zinc oxide is prepared chemically from Zinc salts, as well as from burning zinc in the air or by thermal decomposition of its carbons or nitrates [1-2]. Zinc oxide has very great potential for use in various electronic devices due to its superior wide energy gap properties and exciton binding energy compared to its counterparts such as gallium. These properties

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make ZnO an ideal candidate for the fabrication of UV-emitting diodes, laser diodes and sensors. To fabricate such devices, n- and p-type conductivity are essential, but the literature indicates that there are some difficulties in preparing p-type zinc oxide [3-4]. One of the important properties of zinc oxide, in addition to being a relatively cheap material compared to other materials, is that it can be grown on bases such as glass, quartz, silicon, and aluminum at relatively low temperatures [5]. Zinc oxide nanoparticles differ from those found in bulk materials due to the fact that quantum confinement makes their properties unique, so zinc oxide is one of their most important semiconductor properties for nanostructure applications. Zinc oxide can be doped with different metal atoms to enhance their properties [6]. Pure zinc oxide exhibits n-type conductivity due to the presence of original defects. It has a high electrical resistance, but this defect can be reduced by doping with third group ions B^{+3}, Al^{+3}, Ga^{+3}, Ln^{+3}. These ions ensure the presence of additional electrons and improve the optical, electrical, thermal, and magnetic properties of zinc oxide [6-7]. According to recent experimental and theoretical reports, various elements can be used to prepare p-type ZnO nanostructure, including grafting of group I elements on Zn sites, group V elements, and group III and V elements as co-grafting of ZnO [8]. Schottky contacts based on zinc oxide were introduced in 1960, and since then, due to the properties of the Schottky junction based on zinc oxide, much research and studies have been devoted to manufacturing and studying its properties. Studies have shown the wide applications of this junction in ultraviolet detection devices, high-performance field-effect transistors, and gas sensors [9-10]. As a result, much research in the past five decades has been devoted to the fabrication and characterization of Schottky diodes based on ZnO and various metals. For example, Yadav et al. reported that they prepared a Schottky diode using the sol-gel method to prepare zinc oxide thin films deposited on palladium metal substrates and tested them for a gas sensing application. According to extensive literature, large thickness ZnO films have been employed to fabricate Schottky diode. It is very important to develop a low power Schottky diode with improved barrier height and reverse saturation current. For low power and fast response [11]. In this work, zinc oxide powders doped with copper will be prepared in different ratios to obtain a p-type semiconductor, and then these powders will be deposited on aluminum bases to obtain a Schottky diode and study its electrical properties and parameters of this diode, in order to obtain easy to prepare and inexpensive diode, can be used in rectifier and electronic circuits.

2. Experimental

Zinc oxide powders doped with copper were prepared through chemical reactions by mixing zinc chloride $ZnCl_2$ (Fisher Scientific Comp. with 99% purity) and copper chloride dihydrate $CuCl_2.2H_2O$ (both from Fisher Scientific Comp. with 99% purity) in a ratio (Z1=3.5:0.5, Z2=3.25:0.75, Z3=3:1) of $CuCl_2.2H_2O$ and $ZnCl_2$, dissolved in 50 ml of deionized water, where Z represents the sample symbol. After that 0.9M of KOH (Vissnu Scientific Comp. with 98% purity) added drop by drop to the previously solution of zinc chloride and copper chloride dihydrate. For 30 min the solution remained under constant stirring at room temperature, a few drops are added of ethanol also to the solution. The solution is then placed in an airtight container and placed inside the oven at a temperature of 170^{o}C for 20 hours. After that, a white precipitate was obtained. The obtained precipitate was washed using ethanol and distilled water. Finally, the precipitate was kept for drying in the oven at a temperature of 130^{o}C for 1.5 hours. The resulting powders were characterized using X-ray diffraction and Field effect-scanning electron microscopy. After that, Schottky diode was manufactured by depositing the prepared powders on aluminum bases. The powders were mixed by taking half a gram and mixing it with 3 ml of acetic acid (0.05%) and stirring it well until it became a homogeneous solution free of lumps. The solution was left for two hours before Usage. After that, it is spread in the form of lines on the surface of the aluminum bases. The bar-coating method is used to prepare the films on the surface of the bases. The films are then dried at 200^{o}C to get rid of the acetic acid. The structural properties of the samples are investigated with an X-ray diffraction type Phillips Xpert, and the morphological features of the samples are investigated with an FE-SEM type Tescan Mira3. Electrodes of silver paste are added on both sides of the junction, and measurements (current and voltage) are carried out under the dark, where the current was measured at the forward and reverse bias, and by depended on the (I-V) curve, the parameters of the diode were calculated.

3. Results and discussion

Figure (1) shows the X-ray diffraction patterns of prepared samples of zinc oxide doped with different ratio of copper, the results of the diagnosis by X-ray diffraction technology for the prepared samples showed the samples have a polycrystalline structure, Hexagonal Wurtzite, this is consistent with published research findings and standard card data JCPDS NPCM104P466-474. The X-ray diffraction patterns of ZnO powders and films that prepared by bar-coating method are similar, so the presentation was limited to the powders only, this is consistent with the results of Bakayoko et. al. [12]. It was observed that the peak intensity of (100), (101), (111), (102), (200), (020), (110), (103) and (201) in the X-ray diffraction spectrum increases slightly with increasing copper doping ratio, and this indicates an improvement in the crystalline state of the samples, and this is consistent with what researchers found in references [13-14].

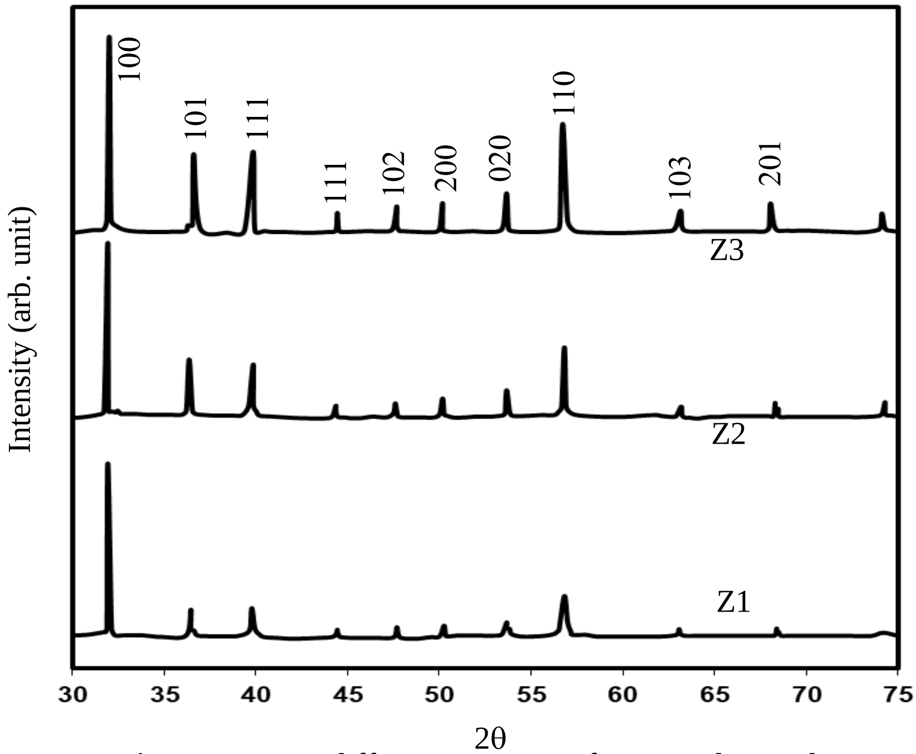

Figure 1. X-ray diffraction pattern of zinc oxide powders doped with copper in different ratio.

Figure (2) shows field-emitting scanning electron microscope images that show the morphology of zinc oxide powders doped with copper in different ratio It was noted that sample Z1 has a morphological structure as form of large flakes with nanoscale thicknesses up to 33 nanometers, spread out in an almost regular manner and free of clumps, while the image of sample Z3, in which the ratio of copper doping is higher, shows that it also has flakes nanostructures, with a thickness about 18 nanometers. It also turns out that increasing the ratio of copper leads to a decrease the flakes size, as well as a decrease in their thickness and spread more randomly than the sample with less copper ratio.

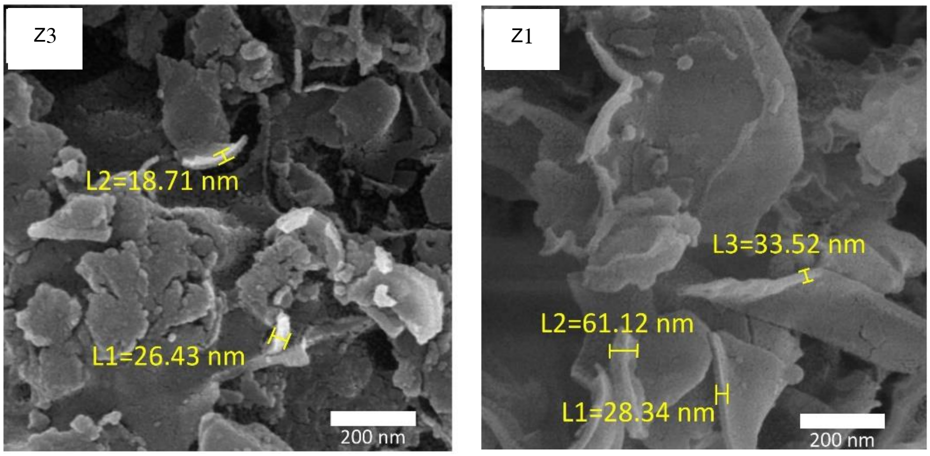

Figure2. Field-emitting scanning electron microscope images of zinc oxide powders doped with copper.

The current-voltage characteristics of the junction show the behavior of the current with the applied voltage in the forward and reverse bias cases. Figure (3) shows the change in forward and reverse bias current as a function of bias voltages for prepared Schottky ZnO.Cu/Al junction in the dark and with different doping ratios. clearly noticed the exponential relationship between the current and applied voltage at forward bias and the relative stability of the current with reverse bias, i.e. asymmetry in the case of forward and reverse bias, On the other hand, noticed an increase in the forward current with an increase in the copper doping, and this may be attributed to the increase in charge carriers with an increase in the copper doping ratio, this means improved diode properties. The ideality factor n*, the rectification coefficient Rf, and the saturation current Js were calculated for the prepared ZnO.Cu/Al diode, and the conductive mechanism was determined based on the equations below [15-17].

$$\ln J = \ln J_s + \left(\frac{qV}{n^* K_B T}\right) \quad (1)$$

$$n^* = \frac{q}{K_B T}\left[\frac{d(\ln(J/J_S))}{dV}\right]^{-1} \quad (2)$$

where J current density, q electron charge, V voltages, KB Boltzmann constant, T absolute temperature. The saturation current density can be calculated by plotting between the forward bias voltage and (ln J) and taking the intersection with the y-axis, by drawing the relationship between and the applied voltages of the forward bias and taking the slope of the curve, it is then possible to apply eq. 2 and calculate the ideality factor, Where the quantity $[(d(\ln(J/J_s))/dV]$ represents the slope of the straight line obtained from a plot of the current $\ln(J/J_s)$ with the applied forward bias voltage. When the ideality factor is approximately equal to one (n*=1-1.2) the process of conducting current is the result of injecting electrons over the barrier, but when the value of n* is high, the conducting mechanism be through (Generation- Recombination) or Multistep Tunneling [18].

The barrier height Φ_b was calculated from equation [19]

$$J_s = A^* T^2 \exp(\frac{q\Phi_b}{K_B T}) \quad (3)$$

Where A* is Richardson's constant and equal to 120 $A/cm^{-2}K^{-2}$

Table (1) shows the value of the ideality factor, the rectification coefficient Rf, and the saturation current Js and barrier height Φ_b that calculated from Figs (3 and 4) where noticed an increase in both the rectification factor and the saturation current with an increase in the Cu doping ratio, which led to an improvement in the properties of the diode. Also notice a slight decrease in the barrier height, this is attributed to improve in crystal structure, and the diffusion increases when Cu content increased. Also there is a decrease in depletion width by adding more Cu which leading to increase in reverse saturation current. The high values obtained for the ideality factor, they may be attributed to the type of conducting mechanism mentioned previously, and this is consistent with what found by Kaufman et. al., in 2021 [18].

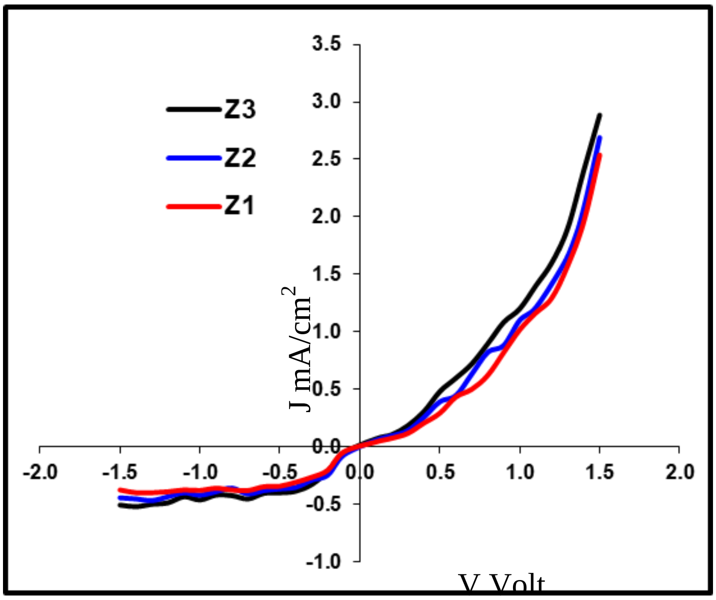

Figure 3. Current-Voltage characteristics in the dark condition as a function of increasing the ratio of copper doping.

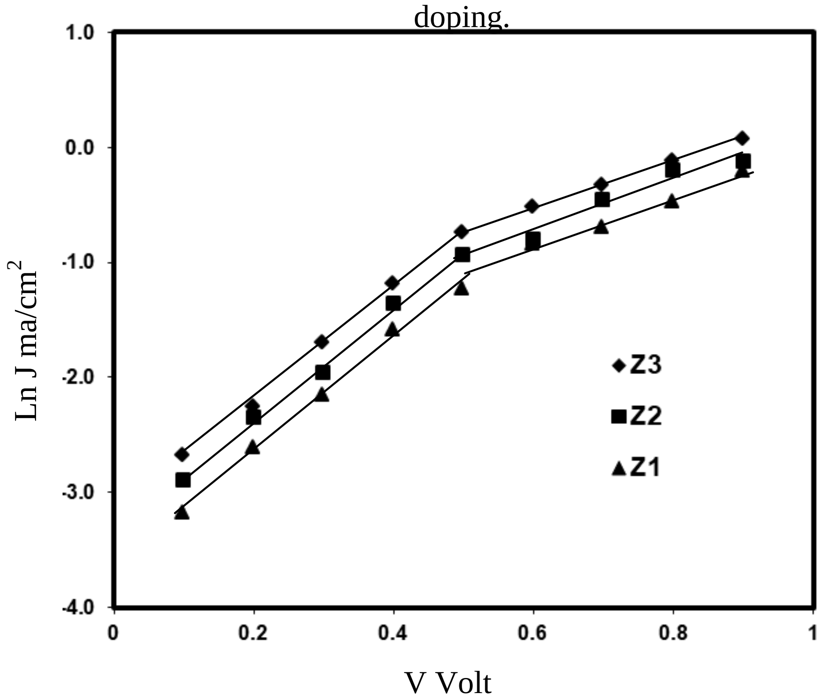

Figure 4. Characteristics of the ln J-V at the forward bias of the ZnO.Cu/Al junction at different copper doping.

Table 1. Parameters of the prepared ZnO.Cu/Al junction with different Cu doping ratio.

Sample	Js mA/cm^2	R_f	n*	Φ_b eV
Z1	0.024	5.69	4.53	0.543
Z2	0.033	6.05	4.88	0.534
Z3	0.040	6.88	4.91	0.529

4. Conclusions

It was shown from the above study that it is possible to successfully prepare nanostructured copper doped zinc oxide powders using the chemical method, which shows that these powders have a polycrystalline structure that improves with increasing the doping ratio. It was also shown that it is possible to successfully prepare heterojunction Schottky diode by depositing the prepared powders on Aluminum bases by paint strip method. The prepared junction had good properties, which were demonstrated by the asymmetric behavior of the (voltage-current) curve at forward and reverse bias, the optimum result of diode was at higher Cu doped with J_s =0.040 mA/cm^2, R_f=6.88, n*=4.91 and Φ_b = 0.529 eV.

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