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CHARACTERIZATION OF $(ZnO)_{1-X}$-$(CuO)_x$/GaAs HETEROJUNCTION SOLAR CELL GROWN BY PULSED LASER DEPOSITION

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$ZnO)_{1-X}$-$(CuO)_x$ composite films with different x content (0.2, 0.4, 0.6, and 0.8) were prepared through pulse laser deposition method at room temperatures (RT). The $(ZnO)_{1-X}$-$(CuO)_x$ film was deposited on GaAs substrate to form the $(ZnO)_{1-X}$-(CuO)x / GaAs heterojunction. The influence of varying x content (0.2, 0.4, 0.6, and 0.8) wt.% on characterization of $(ZnO)_{1-X}$-$(CuO)_x$ /GaAs heterojunction solar cell have been investigated. electrical properties of C-V measurements at two frequencies (100, 200) kHz and I-V measurements under dark and light condition have been studied, C-V measurements for heterojunctions show an increment in built in voltage (V_{bi}) with increasing x content. I-V measurement for heterojunctions show that the approach of forward current is coincides with mechanism of the recombination- tunneling. The open circuit voltage (V_{oc}), short-circuit current (I_{sc}), and fill factor (F.F) have been studied, The best achieved efficiency was obtained around 5.7% at (x=0.2,) also the value efficiency for $(ZnO)_{1-X}$-$(CuO)_x$/ GaAs heterojunction decreases with increasing x content for all samples.

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1. Introduction

Semiconductor materials from the second to sixth group have been studied extensively in the last years [1]. ZnO is an II-VI n-type material that has E_g =3.3eV at room temperature, large exciton binding energy (60meV) and optic transparency [2]. The characteristics of the ZnO with direct band gap and high exciton binding energy are considerably higher compared to these of other commonly utilized materials of the wide-band-gap. Additionally, it has interesting characteristics like the; ready availability, low cost, high chemical stability, non-toxicity in environments of reduction. ZnO emerges as one of the alternative candidates to the more expensive indium SnO2 due to the fact that the earth's crust of zinc [3]. Avariety of nano-structures of the ZnO, which includes nano-wires [4–5], CuO is a p-type material with E_g = 1.2eV, showing the interesting catalytic and electro-chemical characteristics. The low CuO band gap makes the possibility of absorbing throughout visible spectrum. It is of low costs of production; low levels of toxicity and is abundant on the earth [6]. A p-type CuO combination and n-type ZnO thin films were researched for the applications. The thin films of the ZnO that may be created by a number of the approaches like pulse lazer deposition, reactive evaporation [7], spray pyrolysis, sputtering [8], chemical vapor deposition, sol-gel technique, electro-chemical deposition [9], and pyrolysis of the spray. Amongst those, we will be focused on the PLD approach for the production $(ZnO)_{1-X}$-$(CuO)_x$/GaAs hetero-junction solar cell. The hetero-junction is the interface occuring between 2 layers or areas of the dissimilar semiconductors of the crystalline [9]. It is usually beneficial engineering bands of the electronic energy in numerous of the device applications of the solid state which include the semi-conductor lasers, solar cells and transistors. GaAs is that it includes a direct band gap, meaning that it may be utilized for the efficient absorption and emission of light. As a wide direct band gap material with the resultant resistance to the damage of radiation, GaAs is a very good material for the optical windows and space electronics in the applications of high power. Due to wide band gap, the pure GaAs has high resistivity. In combination with high dielectric constant, this characteristic has made the GaAs an excellent electrical substrate and in contrast to the Silicon it is providing the natural isolation between the

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circuits and the devices. In the present study, the PLD is a versatile and simple approach, allowing the growth of the stoichiometry of a massive group of the composite materials to precipitate a thin layer of good property and nanoparticle generations [10-11]. The aim of the present study is the production of the $(ZnO)_{1-X}$-$(CuO)_x$ / GaAs Hetero-junction solar cell and researching the effects of x content on the electrical characteristics.

2. Experimental

The pure ZnO and CuO supplied with a 99.99%, and 99% purity respectively, have been utilized as start materials for the preparation of the films with a 350nm thickness by the PLD approach at different x content (0.20, 0.40, 0.60, and 0.80), using Nd:YAG laser with λ=1,064nm, 15ns, pulse duration, 6Hz repetition rate, 700 mJ Laser energy, number of pulses equal to 400, and vacuum is $8x10^{-3}$mbar. The distance between base and target is (1 cm), those materials have been mixed in the gate mortar for 1h. Then, the mix has been pressed at 5Ton for the purpose of forming a target with a diameter of 2.5cm and a thickness of 4cm. Ultimately, the targets have been sintering to temperature 873 K for ensuring the materials' homogeneity. The target has to be of a maximum density and homogeneity for the purpose of ensuring the ideal deposit quality. $(ZnO)_{1-X}$-$(CuO)_x$ films prepared on the GaAs base for the production of $(ZnO)_{1-X}$-$(CuO)_x$/GaAs hetero-junction at another x content with the PLD approach and researching their characteristics. An n-type GaAs substrate with orientation (111) was prepared by etching in a H_2SO_4: H_2O_2:H_2O (5:1:1) solution for 5 min and thoroughly rinsed in dual ionization water and then dried by blowing air. Before deposition, the substrates were heated in a vacuum oven at 473 K for 30 min. for the purpose of measuring the electrical characteristics, the ohmic contacts have been required. It has been obtained through the evaporated under the high purity Al wire vacuum. The optimal condition for the sufficient ohmic contact has been satisfied with a 200nm layer.

The thickness was measured by interferometer of the Laser of range (350± 20nm). The properties of the capacitance-voltage of hetero-junctions have been evaluated with the use of the LRC type of apparatus (Agileut 429uA Precision Impedance Analyzer) at a (100kHz, 200kHz) frequency. The capacitance at various reverse bias voltage at range (0V-1.20V) has been evaluated for the determination of the hetero-junction type (graded or abrupt), the built-in voltage (VD) value, and the junction width (W) value, and concentration of the carrier (n). The measurements of the current–voltage for the $(ZnO)_{1-X}$-$(CuO)_x$ /GaAs hetero-junctions in dark have been researched with the use of the Keithly Digital Electrometer 616 and DC power supply. The bias voltage differs from (0 to 1.2) volt for the reverse and forward connections. I–V measures under illumination have been made in the case where films have been exposed to the Halogen Lamp type Philips120 Watt intensity $25mW/cm^2$ from $(ZnO)_{1-X}$-$(CuO)_x$ films side, with the use of the Keithly Digital Electrometer 616, voltmeter and DC power supply under the reverse and forward bias voltage that was in a range between (0 and 1.2) volt. The V_{oc}, I_{sc}, F.F and η for the solar cell has been calculated.

3. Results and discussion

The structure, AFM and optical characteristics of those films were studied in previous research [7]. The Electrical properties of the prepared heterojunction solar cell have been investigated. Figure 1 shows the capacitance versus reverse bias voltage (V_r) at a range between (0 and 1.2) volt with two frequencies 100 kHz and 200kHz for $(ZnO)_{1-X}$-$(CuO)_x$/GaAs heterojunction at different x content. The capacitance per unit area for junction is related to the voltage. Also, it's observed from Table (1) that the capacitance is decreased with the increase in the voltage of the reverse bias, Which is attributed to the increase depletion width that results in increasing the built– in voltage value as in Figure 2. This figure shows the variation of C^{-2} with applied reverse voltage, and it is give a linear dependence in the reverse bias direction. The $1/C^2$vs V plot is straight line, of which intercept with voltage axis provides the built-in potential value. It's observed that all junctions have abrupt type (linear relation). This result is in agreement reported by [9]. Also, it can be noticed that capacitance at zero value of the bias voltage (C_o) is decreased with an increase in x content as shown in Figure 1 and Table 1 and this has been a result of decreasing surface states that could result in increasing the layer of the depletion and as a result, decreasing capacitance. The depletion layer width may be computed with the use of the equation

$$W = \varepsilon_s / C_o \quad (1)$$

It can be noticed from Table1. that depletion width is increased from (0.15 to 0.31) and from (0.16 to 0.31) with increasing of the x content from 0.2 to 0.8, at (f=100 and 200) kHz respectively. The effect of frequency as well as x content is shown in Figure 6. It can be observe that the variation of zero bias capacitance (C_o) decreases from (34,29,25,20) to (33,28,24,20) with the increase of frequency (100 to 200) kHz respectively, this result is in agreement with Romero[12].

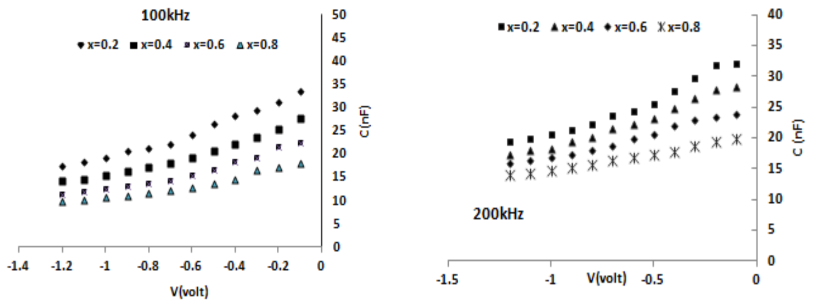

Fig. 1. The variation of capacitance as a function of reverse bias voltage for $(ZnO)_{1-X}$-$(CuO)_x$ /GaAs heterojunction at different x content and two frequencies100 and 200kHz.

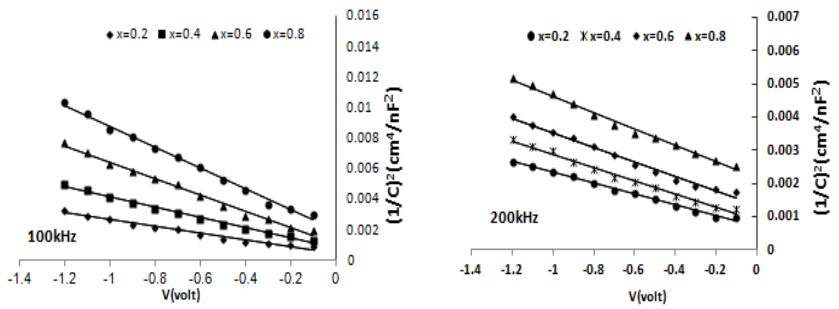

Fig. 2. Variation of $(1/C)^2$ with voltage for $(ZnO)_{1-X}$-$(CuO)_x$ /GaAs at different x content and two frequencies100 and 200kHz.

Table 1. C-V parameters for $(ZnO)_{1-X}$-$(CuO)_x$ /GaAs heterojunction at different x content and at f=100 and 200kHz.

Frequency (KHz)	x content	C_ox10^{-9} (F/cm^2)	W (μm)	Nx10^{14} (cm^{-3})	V_{bi} (volt)
100	0.2	34	0.15	1.18	0.28
	0.4	29	0.19	0.72	0.3
	0.6	25	0.24	0.40	0.45
	0.8	20	0.31	0.39	0.51
200	0.2	33	0.16	1.72	0.3
	0.4	28	0.20	1.07	0.48
	0.6	24	0.25	0.79	0.6
	0.8	20	0.31	0.70	0.75

To determine the photovoltaic characterization of the $(ZnO)_{1-X}$-$(CuO)_x$ /GaAs Hetrojunctions, the properties of the current–voltage of films under dark and lighting conditions were studied as shown in Figure 3. And Figure 4. at different x content (0.2,0.4,0.6,0.8). At dark condition the prepared hetero-junction has shown good rectifying behaviors and dark current has been increased with applied voltage and x content. From Figs.(3&4) at logarithm scale, it can be recognize two regions in this figure; the first one stands for recombination current, whereas the second one stands for the current of the tunneling. The first region may be approximated through an expression1 of type I~ $\exp(qV/\beta k_BT)$, where β is the ideality factor. So the factor of the ideality was computed as shown in figure (4). It can be observe that the value of β is 3.5 when x content equals to 0.2, and the β increases from 1.4 to 2.6 when x value increases from 0.4 to 0.8. The Value of β>1 can be a result of the re-combination of the electrons and the holes in depletion area as well as to an increased applied voltage effect [13].

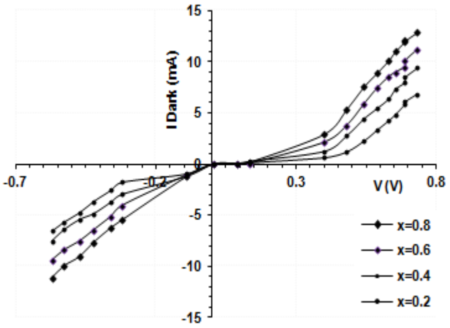

Fig. 3. I-V properties under dark for $(ZnO)_{1-X}$-$(CuO)_x$ /GaAs heterojunction at forward and reverse bias voltage at different x content.

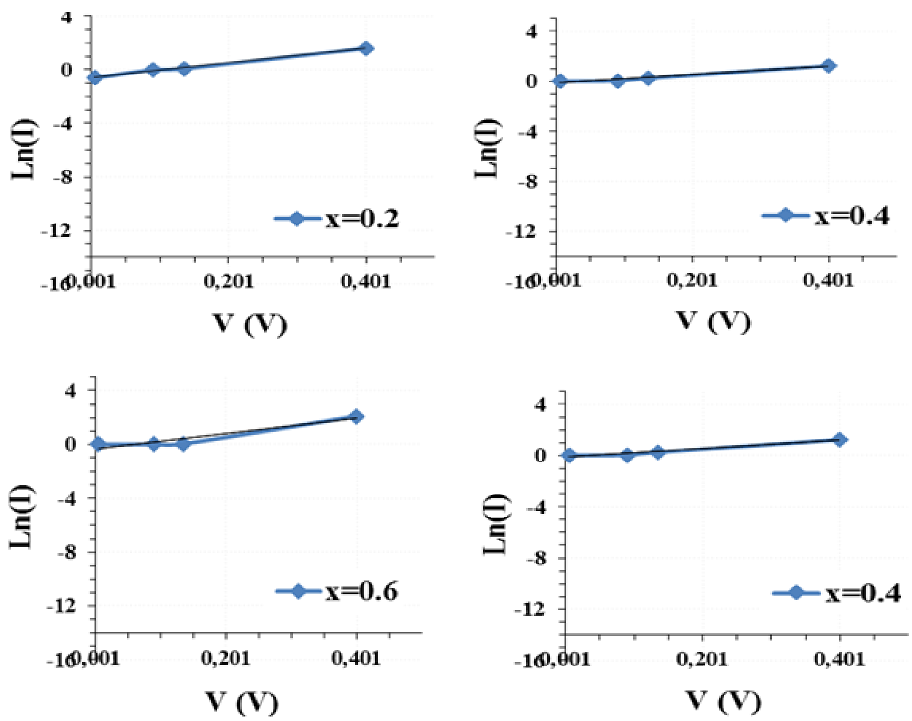

Fig. 4. Variation of ln(I) with V at dark for $(ZnO)_{1-X}$-$(CuO)_x$/ GaAs hetrojunctions at different x content(0.2 , 0.4, 0.6, and 0. 8).

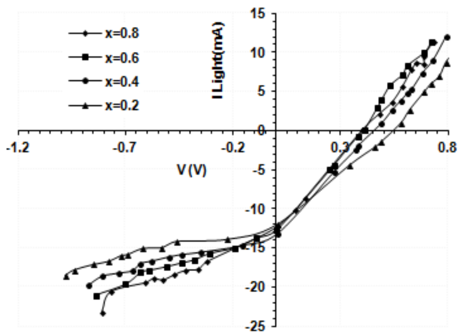

Fig. 5. Dark and light I-V properties for $(ZnO)_{1-X}$-$(CuO)_x$/GaAs hetrojunctions sola cell at different x content (0.2, 0.4, 0.6, and 0.8).

The I- V characteristic of $(ZnO)_{1-X}$-$(CuO)_x$ /GaAs heterojunction solar cell at light and dark condition can be calculated from Figure 5,at different x content (0.2,0.4,0.6,0.8) with power intensity of 25mW/cm^2. This figure illustrates that V_{oc} and I_{sc} have been specified through the intersection of the photo-current curve with the x and y axes. In addition to that, the maximal current and voltage for the solar cell have been found; the F.F and efficiency (η) were computed with the use of the equation:

$$F.F = \frac{P_m}{V_{oc}\, xI_{sc}} \tag{2}$$

and

$$\eta = \frac{V_{oc}\, xJ_{sc}xF.F}{\mathrm{p_{in}}} \tag{3}$$

respectively. The photo-current has been considered as the significant parameter, playing an important part in the solar cells.

Table 2 Shows I-V parameters for $(ZnO)_{1-X}$-$(CuO)_x$/GaAs solar cell with different x content. The quantum efficiency (η) is one of the most significant parameters in photovoltaic devices that have been identified with optoelectronic effects. In general it can be notice that efficiency is decreased with increased of x value. it can be observe that the values of efficiency decrease (5.7,5.6,4.9 and 3.5) with increasing of x content (x=0.2,0.4,0.6,0.8)% respectively, The best x content(x=0.2) which gives high value of efficiency (η= 5.7%). The comparison results have been listed in the table2 results in that the chosen x content is one of the good choices for the fabrication of the solar cells. That result has been coinciding with the results that have been presented by J. Katayama etal[14].

Table 2. I-V parameters for $(ZnO)_{1-X}$-$(CuO)_x$/GaAs hetrojunctions at different x content.

x content	I_{sc} (mA)	V_{oc} (V)	I_m (mA)	V_m(v)	F.F	η%	β
0.2	2.16	0.46	4.8	0.3	1.45	5.7	3.5
0.4	2.46	0.37	5.2	0.28	1.6	5.6	1.4
0.6	4.38	0.27	5	0.25	1.05	4.9	2.16
0.8	13	0.4	3	0.3	0.17	3.5	2.6

4. Conclusions

$(ZnO)_{1-X}$-$(CuO)_x$ film was successfully making by pulse laser deposition. The impact of x ratio on characteristics of $(ZnO)_{1-X}$-$(CuO)_x$/GaAs Heterojunction were investigated. The C-V Measurements and I-V Measurements were investigated. The junction is an abrupt type, Also it is noticed that the capacitance and carrier's concentration is decreased with the increase in x content and reverse bias voltage. Also, width and built – in depletion layer voltage is increased with the increase in x content. From I- V measurement at dark condition, the forward current mechanism is coinciding with mechanism of the recombination- tunneling and dark current is increased with the increase in x content. From I- V measurement at light condition the maximum efficiency was obtained around 5.7 % at (x=0.2) . Its value efficiency decreases and photocurrent increases with increase x ratio for all samples. The optimum outcome are at (x=0.2).

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