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The C-V and I-V properties of Mg_xZnO_{1-x}/n-Si heterojunction

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Abstract– **In this paper was prepared Mg_xZnO_{1-x}/n-Si heterojunction by using a chemical spraying pyrolysis (CSP) technique is an easy and convenient way of deposition over large areas. Water used Zn acetate $Zn(CH_3COO)_2.2H_2O$ as a source of ZnO and Mg acetate and water $Mg(CH_3COO)_2.4H_2O$ as a source MgO. The grow mixed solutions Mg_xZnO_{1-x} different proportions volumetric (0,30,50,70,and 90)% and clean and heated at temperature (450) °C was installed thickness by installing a number of sprays. The thickness of the films between all(80 ±5) nm was used as a gas holder nitrogen under pressure (4.5) bar. The effect of Mg-content on the electrical properties of electrical properties of Mg_xZnO_{1-x}/n-Si heterojunciton was studied. The results showed that theMg_xZnO_{1-x}/n-Si heterojunciton abrupt type, through measurements (C-V), (C-V) and (I-V) measurements. The built in potential (V_{bi}) was determined, it was increased with Mg-content increase.**

Index Terms— **Heterojunction, MgZnO/n-Si, C-V and I-V properties**

I. INTRODUCTION

The semiconductors materials have electrical properties as a function of temperature, optical excitation, magnetic field, electromagnetic, and impurity content multicomponent materials like compound semiconductor and their alloys are of considerable technical interest in the field of electronic and optoelectronic devices [1,2]. It is difficult to prepare these materials in bulk form due to the limited solubility of materials in each other, in addition their growth is costly process[3,4]. The physics of semiconductor nanostructures has attracted great interest for many years because these are systems of reduced dimensionality with properties different from bulk semiconductor properties. $Mg_xZn_{1-x}O$ belong to the class of transparent conductive oxides (TCOs). TCOs are a unique class of materials,because they exhibit both, transparency and electronic conductivity, simultaneously [5].Usually,conductive materials, such as metals, are not transparent, while transparent materials, such as insulators, are not conductive. TCOs combine these two properties due to their large band gap (≥3 eV), leading to the transparency in the visible spectrum of the light, and a low effective mass of the electrons, which can be attributed to the high dispersion and the s-type character semiconductor devices such as solar cells, light-emitter circuits [8]. A heterojunction is a junction formed at the interface of two semiconductors which are assumed to have different and gaps (E_g), different permittivity's (ε_s), different work functions ($\emptyset_m$) and different electron affinities (χ). Work function and electron affinity are defined as the energy required to remove an electron from the Fermi level (E_F) and from the bottom of the conduction band (E_C) respectively, to a position just of the conduction band, explaining the high conductivity [6,7]. The aim of this research is to identify junction capacitance, concentration of the carriers, width of depletion layer and built-in-potential of the heterojunction, through a relationship of capacitance- voltage. Through the relationship of the current-voltage can be determined reverse saturation current, barrier height of potential and ideality factor.

II. THE THEORETICAL PART

Heterojunctions play an ever more important role in diode, photodetector, solid state laser and integrated

outside the material (vacuum level) [9]. In principle it is possible to construct heterojunctions in which both semiconductors have the same energy gap. However most studies of heterojunctions have involved two semiconductors comprised of different values of energy gaps this is called lattice mismatch[8].

III. ELECTRICAL PROPERTIES OF HETEROJUNCTION

The electrical properties, which characterize a heterojunction, are the capacitance-voltage (C-V) and current- voltage (I-V) characteristics. In fact, it is these properties which not only yield information regarding the band structure of a heterojunction but also enable one to determine its device usefulness [10].

1. Capacitance–voltage(C-V) characteristics

The measurement of the junction capacitance (C=dQ/dV) as a function of reverse bias is often used as a powerful experimental technique for the analysis of the depletion region potential and the charge distribution in a heterojunction.The expression of the capacitance per unit area under reverse bias voltage can be written as [11].

$$C = \frac{dq}{dv} = \frac{\varepsilon_s}{w} \qquad (1)$$

Where ε_s is the semiconductor permittivity of the two semiconductor materials,v applied voltage, and w depletion width layer. The cross point ($1/C^2$=0) of the ($1/C^2$- v) curve represents the built-in potential of the heterojunction, the charge-carrier density N_d and width of the depletion layer for both devices are calculated by the following equations [12].

$$N_d = \frac{2}{q\varepsilon_s}\left[1/d(1/C^2)/dV\right] \qquad (2)$$

Where q charge of electron, and it equals ($1.6*10^{-19}$) C.

$$w = \left[\frac{2\varepsilon_s V_{bi}}{qN_d}\right]^{1/2} \quad (3)$$

Where V_{bi} built-in- potential, is calculated by the following equation.

$$V_{bi} = V_{a+\frac{KT}{q}} \quad (4)$$

Where V_a is the applied voltage.

2. Current–voltage characteristics

(I–V) characteristics have been measured. These measurements usually provide a valuable source of information about the junction properties, such as the rectification ratio R_F , the ratio of the forward current to the reverse current at a certain applied voltage is defined as the rectification factor, tunneling factor γ , the barrier height Φ_B , the reverse saturation current density J_S , and the ideality factor η [13].The total dark current of the heterojunctions can be represented as a sum of several components such as generation-recombination current, diffusion current, tunneling current, surface leakage current, and emission current [14]. If generation-recombination and diffusion mechanisms are dominant, then the dark current I_d obeys the following formula [15].

$$I_d = I_s[e^{qV/\eta KT} - 1] \quad (5)$$

Where, I_s is the reverse saturation current and is given as:

$$I_s = A_j A^* T^2 e^{-q\Phi_B/\eta KT} \quad (6)$$

Where A^* is Richardson constant, V is the applied voltage, Φ_B is barrier height, and $T$is the temperature in Kelvin. The η ideality factor is calculated from the(I-V) characteristics by using the following equation [16].

$$\eta = \frac{q}{KT}\left(\frac{dV}{dlnI}\right) \quad (7)$$

The value of the η is determined from the slope of the straight line region of the forward bias logarithm of the current as a function of the applied voltage [17]. The current is due to tunneling that dominates across the junction and it could be represented by the expression [18].

$$I = I_s e^{\gamma V} \quad (8)$$

This expression is justified for tunneling–recombination mechanism. The reverse bias characteristics of these heterojunction show a linear variation at low reverse voltage[19]. Optoelectronic properties of heterojunctions were study under illumination, it can be classified into two groups, one which deals with the generation of photocurrent due to the absorption of photons while the other deals with the emission of photons as a result of electronic excitation in heterojunctions. There are two important absorption processes which often have an influence on the photoelectric properties of heterojunctions: the creation of free electrons or holes (i.e. photo-excitation of an impurity or interface state) and of free electron - hole pairs(i.e. electron transition from the valence band into the conduction band). The free carriers generated by these processes at the interface or within a diffusion length from it, in the two semiconductors forming a heterojunction, give rise to photocurrents in the heterojunction [20].

IV.THE EXPERIMENTAL PART

Si-wafer was n-type (111) with resistivity about (1.5-5) Ω.cm and (500±10) μm thickness. Square-shaped n-type silicon samples, each of (1.5×1.5) cm^2 area were prepared using a steel-cut machine. Silicon wafers were washed ultrasonically in distilled water and were immersed in ethanol with a purity of (99.9)% in order to remove dirt and oil, while native oxide layer removed by etching in dilute (2:10) HF: H_2O for(3)min. the silicon wafers were cleaned in distilled water and dried in furnace at (100) ^oC. Mg_xZnO_{1-x}/n-Si films with different Mg-contents were deposited on silicon substrate by chemical spray pyrolysis (CSP) technique under ambient atmosphere. Two kinds of aqueous solutions, zinc acetate $Zn(CH_3COO)_2.2H_2O$ of (99.9)% purity and molecular weight equal to (219.52) g/mol and Mg acetate $Mg(CH_3COO)_2.4H_2O$ of (99.2)% purity and molecular weight equal to (214.46)g/mol, were chosen as the sources of zinc and magnesium respectively. In order to obtain Mg_xZnO_{1-x}/n-Si films with different Mg-contents (x=0,30,50,70,and90)%, the deposition parameters were the same for the series of Mg_xZnO_{1-x}/n-Si films. The pure zinc acetate, pure magnesium acetate, and distilled water were mixed thoroughly to get the solution with a concentration of (0.1)M and a few drops of glacial acetic acid were then added to stabilize the solution were added to the (100) mL solution to increase the solubility of the compounds. The substrate temperature of (450) ^oC during the films growth. The solution was stirred for (30) min. with a magnetic stirrer. The solutions was deposited by using (CSP), after so was done sedimentation the electrodes on the samples using a silver paste. Measurements included (I-V) characteristics in dark and under illumination by halogen lamp of Mg_xZnO_{1-x}/n-Si heterojunction are done using keithly digital electrometer 616 and DC power supply. The (C-V) characteristics under reverse biasing at range (0.1-1) volt using (LCR) meter were measured to determine the type of heterojunction. The effect of Mg-content on the electrical properties of the heterojunction was investigated.

V. RESULT AND DISCUSSION

That the results and analysis of experimental measurements of the Mg_xZnO_{1-x}/n-Si hetrojunction. Includes the results of capacitance-voltage (C-V) and current-voltage (I-V) measurements for Mg_xZnO_{1-x}/n-Si hetrojunction the prepared by the chemical spray pyrolysis (CSP) technique.

1. Capacitance-voltage measurements (C-V) of Al/Mg_xZnO_{1-x}/n-Si/Al hetrojunction

The change of capacitance as a function of reverse bias voltage in the range of (0-1)Volt and at frequency equal to (0.6-1) MHz has been studied, for Mg_xZnO_{1-x}/n-Si hetrojunction at different Mg-content, as shown in Fig.1. It is clear that the capacitance decreases with increasing of the reverse bias voltage, and decreasing be non-linear. Such behavior is attributed to the increasing in the depletion region width, which leads to increase of the value of a built–in potential. An enhancement of the capacitance of zero bias voltage (C_o) with the increasing of Mg-content of Mg_xZnO_{1-x}/n-Si hetrojunction as shown in the Table1. behavior attributed to the surface states which leads to an increase in the depletion region and decreasing of the capacitance. The width of depletion region can be calculated using equation (3).We can notice from Table1 that the depletion region width increasing with increasing Mg-content, which is due to the decreasing in the carrier concentration, and therefore leads to decrease of the capacitance. The inverse capacitance square is plotted versus a reverse bias voltage for Mg_xZnO_{1-x}/n-Si hetrojunction at different Mg-content of (x)%, as shown in Fig.2. The plots revealed straight line relationship which means that the junction was of an abrupt type. The interception of the straight line with the voltage axis at ($1/C^2=0$), represents the built–in potential [21]. We noticed from Table1 that the built–in potential an increases with increasing of Mg-content.

2. I-V Characteristics for Mg_xZnO_{1-x} /n-Si heterojunction

Current-voltage (I-V) characteristic is one of the important parameters of a heterojunction measurement is a which explains the behavior of the resultant current with the applied forward and reverse bias voltage. Figs.(3a, and b) shows (I-V) characteristic for Mg_xZnO_{1-x}/n-Si heterojunction at forward and reverse bias voltage with different Mg-content of (x)%, and substrate temperature (450) ^oC. The forward dark current is generated due to the flow of majority carriers and the applied voltage injects majority carriers, which lead to the decrease of the built-in potential, as well as the width of the depletion region. As the majority and minority carrier concentrations are higher than the intrinsic carrier concentration which generates the recombination current at lower voltage region (0-0.3)Volt. This is because the excitation of electrons from the valence band (V_B) to the conduction band (C_B) will recombine them with the holes which are found at the (V_B) , and this is observed by the little increase in recombination current at low voltage region [22]. Either, the diffusion current is represented in the high bias voltage region (>0.3Volt), where there is a fast exponential increase in the current magnitude with increasing the bias voltage, which dominates the process. The bias current also contains two regions. In the first region of low bias voltage (<0.3Volt), the current slightly increases with increasing of the applied bias voltage, and the generation currently dominates, while at the second high bias voltage region (>0.3Volt), the diffusion current dominates [23]. From Fig.3a, we can observe that the value of the current decreases with increasing Mg-content of (x)% these results have good agreement with[24]. Which is attributed to involving defects and dislocations that have an effect on the mobility of charge carriers. These defects are within the levels inside the energy gap, these defects are within the depletion region act as active recombination centers, and consequently they decrease current flow across the junction. A semilogarithim scale of (I-V) characterization for the forward bias is presented in Fig.4. These figures show that forward current mechanism correspond with the recombination mechanism. The mechanism of transport current is estimated from the value of the ideality factor (η) where the saturation current can be calculated from intercepting the straight line with the current axis at zero voltage bias. It is clear from the Table 2 that the ideality factor and saturation current decreases with increasing Mg-content of (x)%. The optoelectronic characteristics are the best for photodetector hetrojunction since these characteristics determine how the incident light power converts to photocurrent. This photocurrent is observed in reverse bias only. When the detector is illuminated, the electron- hole pairs are generated, performed in the minority carrier which able to diffuse to the edge of the depletion layer before recombination takes place. The internal electric field in the depletion layer can separate of the electrons and holes, this electric field is much higher where the device is in reverse biased. Figs.(5a, 5b,5c,and 5d) show that the reversed (I-V) characteristics of the device measured in different light intensity illumination, the photocurrent under a (60-100) mW/cm² tungsten lamp illumination. It can been reversed current value is at a given voltage for Mg_xZnO_{1-x}/n-Si photodetector under illumination which is increases with the increasing of light intensity. It is noticed that increasing the light intensity results in the increased the photocurrent. This can be attributed to the number of absorbed photons become greater and a large number of electron-hole's pairs are generated in the junction. In the linear region ,the thermionic emission and the carrier velocity will increase when the sample illuminated with light of change intensity power. From the Figs.

(5b,5c,and 5d) we can note that the current value at a given voltage for $Mg_{0.9}ZnO_{0.1}$/n-Si under illumination is higher than $Mg_{0.3}ZnO_{0.7}$ /n-Si, the photocurrent increased from ($1.88*10^{-8}$ to $1.28*10^{-7}$), corresponding to the ratio of Mg-contents (30)% to (90)% as shown in Figs.(5b to 5d).This can be attributed to the increased energy gap with increasing Mg-content.

VI. COCLUSIONS

Low ideality factor with increasing the Mg-content in the films, this is a good indicator to signify the improved material properties of the Mg_xZnO_{1-x}/n-Si heterojunction. At high Mg-content ratios (90)% there is not a clear effect of the difference in the intensity of light incident on the Mg_xZnO_{1-x}/n-Si heterojunction, that's why exclude such ratios in the photodetectors manufacturing.

Table1: The variation of the C_o ,W ,V_{bi} , and N_D for Mg_xZnO_{1-x} /n-Si hetrojunction at different Mg-content

Sample	C_o (nF)	W (nm)	V_{bi} (Volt)	N_D (cm^{-3})
ZnO (pure)	663.328	12.06	0.55	5×10^{17}
$Mg_{0.3}ZnO_{0.7}$	369.700	13.12	0.60	2×10^{17}
$Mg_{0.5}ZnO_{0.5}$	333.500	14.78	0.63	4×10^{16}
$Mg_{0.7}ZnO_{0.3}$	178.750	27.58	0.70	1.5×10^{16}
$Mg_{0.9}ZnO_{0.1}$	205.873	24.14	0.84	2×10^{15}

Table 2: Values of ideality factor (η), saturation current (I_s) for Mg_xZnO_{1-x} /n-Si heterojunction at different Mg-content

Sample	η	I_s (nA)
ZnO (pure)	1.709	60
$Mg_{0.3}ZnO_{0.7}$	1.184	0.767
$Mg_{0.5}ZnO_{0.5}$	1.450	0.240
$Mg_{0.7}ZnO_{0.3}$	1.293	0.163
$Mg_{0.9}ZnO_{0.1}$	1.164	0.100

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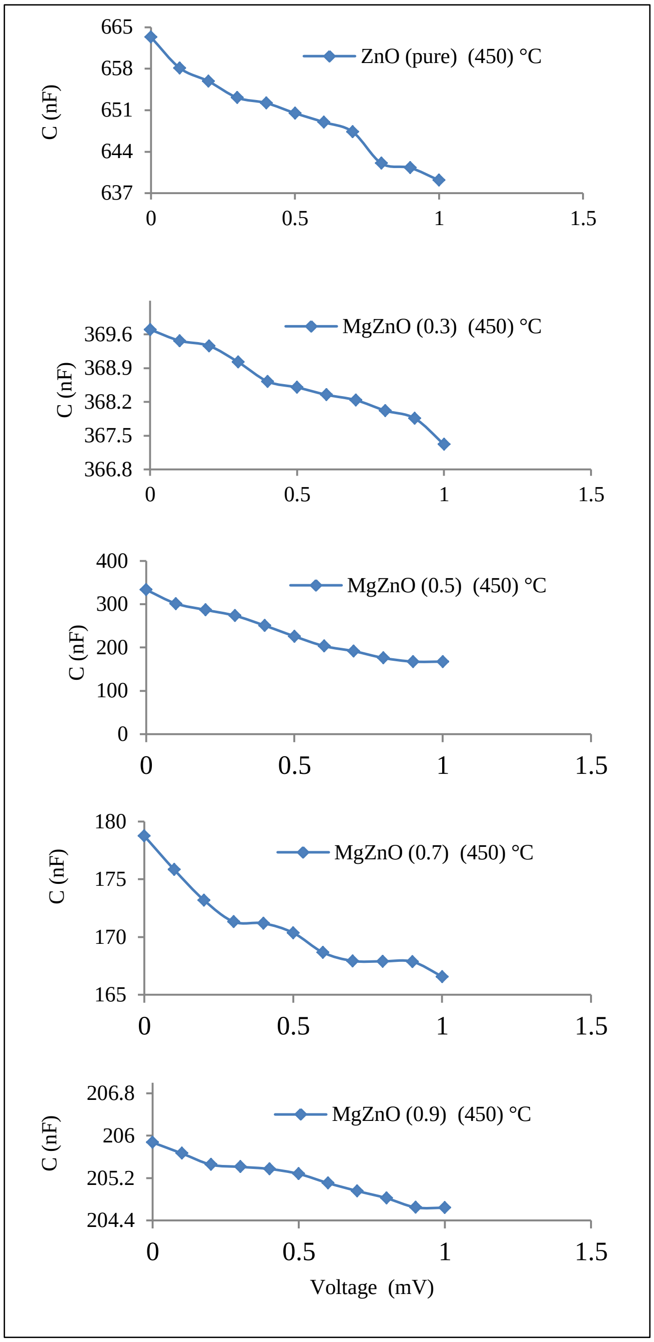

Fig.1:The variation of capacitance as a function of voltage for Al/MgZnO/n-Si/Al hetrojunction photodetectors with different Mg-contents (0,30,50,70, and 90)% and substrate temperature (450) ^{o}C

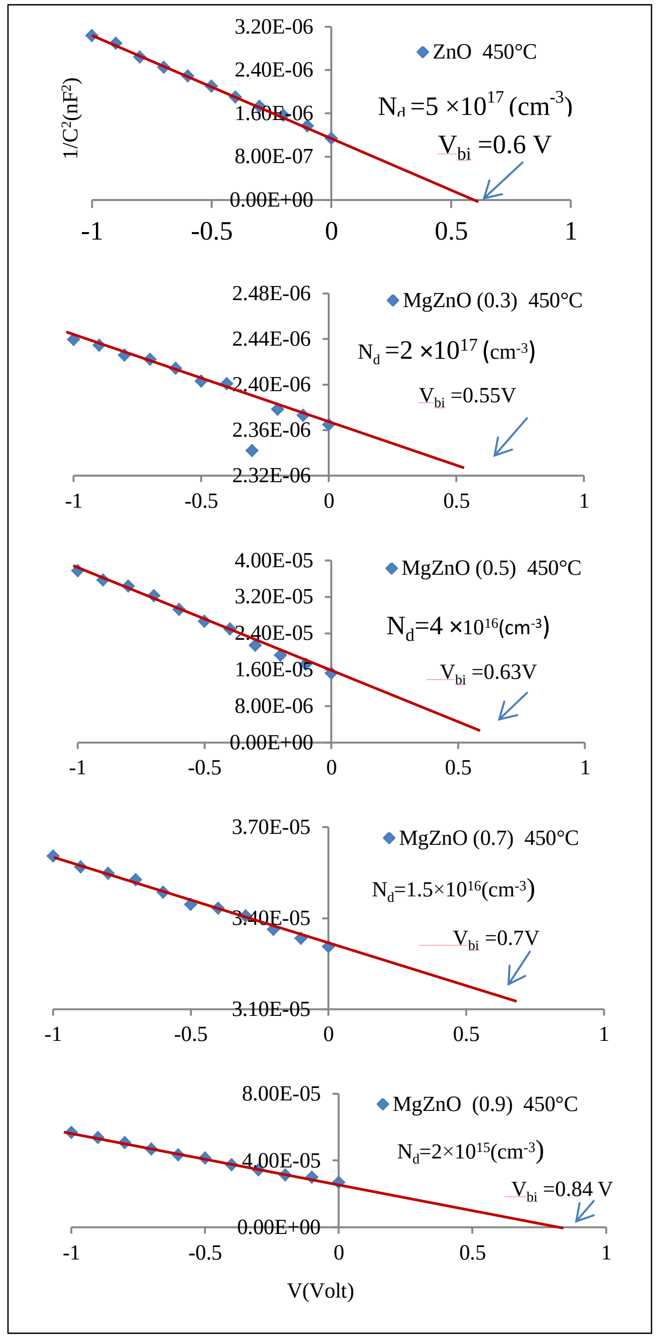

Fig.2: The variation of $(1/C^2)$ as a function of reverse bias voltage at different Mg -contents (0 ,30, 50,70, and 90)% for Mg_xZnO_{1-x} /n-Si hetrojunction at substrate temperature $(450)^{o}$C.

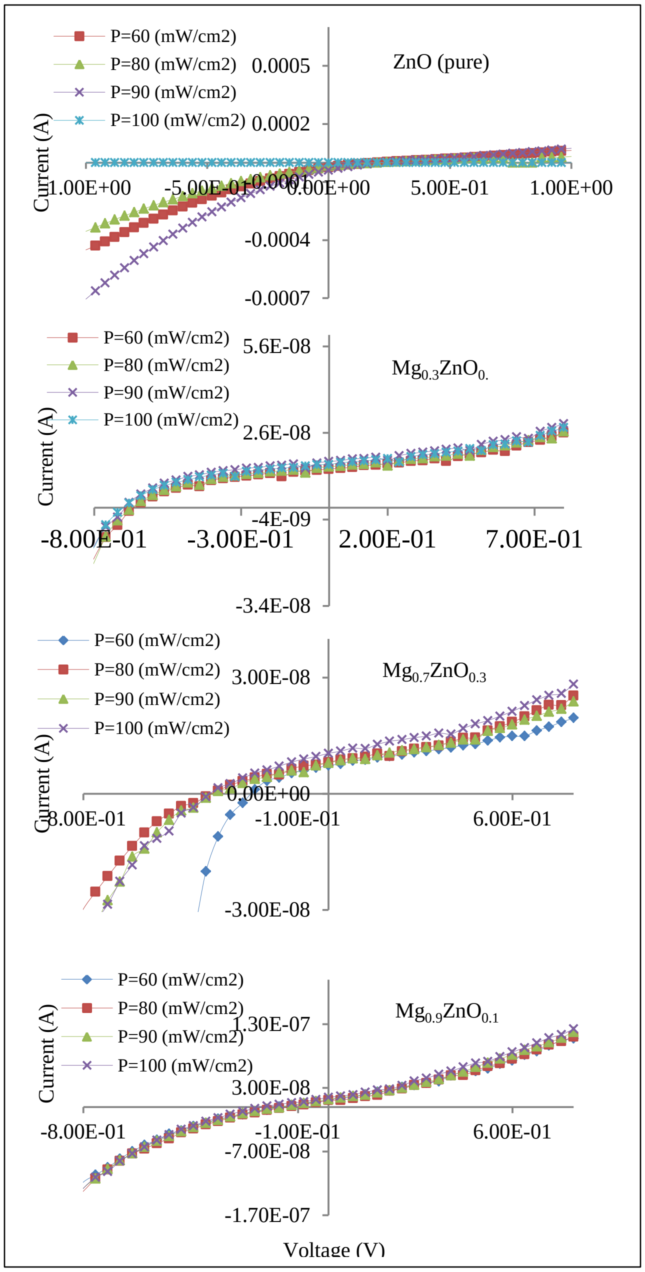

Fig.4: The I-V characteristics at different incident power intensity for Mg_xZnO_{1-x}/n-Si heterojunction at reverse bias voltage.

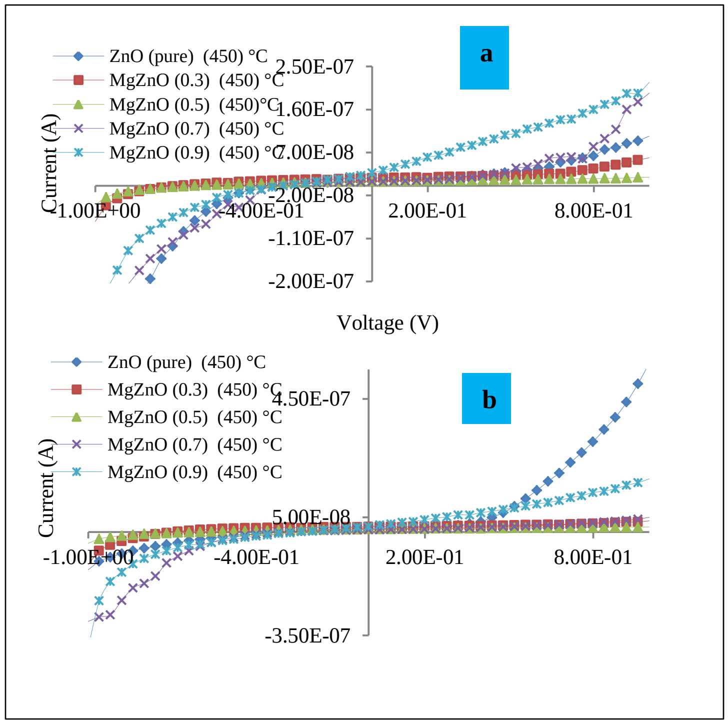

Fig.3: I-V characteristics in the dark for Mg_xZnO_{1-x} /n-Si heterojunction (a- forward , and b- reverse).

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