Characterization of n-CdO:Mg /p-Si Heterojunction Dependence on Annealing Temperature

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Abstract

In this research, thin films of CdO: Mg and n-CdO: Mg/ p-Si heterojunction with thickness (500±50) nm have been deposited at R.T (300 K) by thermal evaporation technique. These samples have been annealed at different annealing temperatures (373 and 473) K for one hour. Structural, optical and electrical properties of {CdO: Mg (1%)} films deposited on glass substrate as a function of annealing temperature are studied in detail.

The C-V measurement of n-CdO: Mg/ p-Si heterojunction (HJ) at frequency (100 KHz) at different annealing temperatures have shown that these HJ were of abrupt type and the built-in potential (V_{bi}) increase as the annealing temperature increases.

The I-V characteristics of heterojunction prepared under dark case at different annealing temperatures show that the values of ideality factor and potential barrier height increase with the increase of annealing temperature.

Keywords: Thermal Evaporation, heterojunction (HJ), I-V characteristics, C-V measurement, Cadmium Oxide.

Introduction

Cadmium Oxide (CdO) is n-type semiconducting having a direct band gap (2.2-2.5) eV and is one of the transparent conductive oxide (TCO) thin films have attracted considerable attention for different applications such as solar cells and photodiodes [1, 2], due to its high optical transmittance in the visible and NIR region of the solar spectrum, high electrical conductivity nearly metallic conductivities, and high carrier concentration. [1-5]

Also it finds in applications of phototransistors, gas sensors, liquid crystal displays, optical communications and IR detectors. [2, 6]

Cadmium oxide (CdO) doping by different elements such as Cu, Ga, F, In, Al and Sn to improve the electrical properties for optoelectronic application [7-13]. Various deposition techniques are used to prepare CdO and CdO doped films such as spray pyrolysis [13], dc magnetron sputtering [14], sol-gel [9], pulsed laser deposition [15], chemical path deposition [16], vacuum evaporation[17] etc. Many researchers focused on the development of heterojunction with low–cost and high efficient for photovoltaic application. The aim of the present work is to fabricate (n-CdO/p-Si) heterojunction by using vacuum evaporating technique and study the effect of annealing temperature on its characteristic.

Experiment

Sample Preparation

CdO: Mg and n-CdO: Mg/ p-Si heterojunction prepared by thermal evaporation technique under high vacuum of ($3x10^{-6}$) torr using Edward coating unit model (E 306). These films were deposited by two steps: In the first step, pure metal Cadmium thin films with thickness (500 ± 50) nm was deposited on glass and on substrates of p-type single crystal (111) Si wafers at room temperature (300K) from molybdenum boat were the distance from boat to sample holder was about (18 cm), then using thermal oxidation processes at temperature (673K) for one hour with exist air flow to get CdO thin films. In the second step, these films have been doped with 1% Magnesium (Mg) at substrate temperature (473K).

Then the samples were annealed at (373, 473) K for one hour by using (Kilns Furnaces). Thermal evaporation vacuum system was used to make Al electrodes on these samples as contact material for electrical and (HJ) measurements. The films thicknesses were measured by using the weighing method using a sensitive balance whose sensitivity of the order (10^{-4}).

Characterization of Samples

X-ray diffractometer system (SHIMADZU Japan XRD 600), of CuK_α radiation of wavelength (λ=1.5405 $\mathring{A}$) with generator setting of current (20mA) and voltage (40KV) was used to study the structural properties for CdO:Mg films by recording the intensity verses Bragg's angle θ from (10-80). From Bragg's law it could be calculated the inter planer distance for different planes d (hkl): [18]

$$2d\sin\theta = n\lambda \quad \ldots\ldots (1)$$

Where n is the reflection order. The lattice constant (a) is expressed by: [18,19]

$$a = d\,(h^2+k^2+l^2)^{1/2} \quad \ldots\ldots (2)$$

The grain size dimension (D) can be determined from diffraction line broadening using the Scherrer equation [19]:

$$D = k\lambda / \beta\cos\theta \quad \ldots\ldots (3)$$

Where k is a constant (0.9), and β is full width half maximum (FWHM) of the preferential plane.

For optical measurements, a double beam spectrophotometer (UV/VIS) was used to record the transmittance (T) and absorbance (A) spectrum in the range of wavelengths (300 – 1100) nm. The electrical properties including the D.C. and Hall Effect measurements, for D.C. measurement the variation of electric resistance (R) as a function of temperature in the range

(303-503) K was performed using Keithly model 616. The electrical conductivity (σ) can be determined by the formula [20]:-

$$\sigma_{d.c} = \frac{1}{\rho} \quad \ldots\ldots (4)$$

Where ρ is the resistivity which is calculated from the relation:[20]

$$\rho = \frac{R \cdot w \cdot t}{L} \quad \ldots\ldots (5)$$

Where w is electrodes width, t is film thickness and L is distance between two Al electrodes.

For Hall Effect measurement Keithly model 616 has been used to measure the Hall voltage (V_H) as a function of current (I) at constant magnetic field (0.11) Tesla.

For C-V measurement, the capacitance of n-CdO: Mg/ p-Si hetrojunction was examined at frequency (100 KHz) as a function of the reverse bias voltage within the range (0 to -3) Volt by using (LCR-Meter) model Gwinstek: LCR-8110G to determine the type of heterojunction, concentration, built-in potential and the width of junction.

Current voltage measurements (I-V) for the hetrojunction were carried out under dark case at forward and reverse bias voltage at the range (0-3) Volt using D.C power supply model Dazheng: PS-303D, Keithley 616 digital electrometer and voltmeter.

Results and Discussion

Structural Properties

Figure (1) shows X-ray diffraction of 1%Mg doped CdO thin films coated on glass substrate before and after annealing (373 and 473)K, this Figure revealed that all samples are polycrystalline structure with cubic phase. The diffraction peaks corresponding to (111), (200) and (222) planes as compared with ASTM card No.05-0640[21], with preferential orientation along (111) and it is became sharper and more intense after annealing due to the crystallinity of these films being improved after heat treatment. The lattice constant (a), d (hkl) and grain size dimension (D) values are presented in table (1). These results are in good agreement with [1,2,3,4 and 17].

Optical Properties

$(\alpha h\nu)^2$ against (hν) for allowed direct transition at $(\alpha h\nu)^2 = 0$ (figure 3) according to Tauc formulas: [22]

$$(\alpha h\nu) = B (h\nu - Eg^{opt})^{r} \quad \ldots\ldots (6)$$

Where r is a constant takes values 2, 3, 1/2, 3/2 depending on the material and the type of the optical transition, B is a constant inversely proportional to amorphousity and α is absorption Figure (2) shows the variation of the transmittance (T) with wavelength range (300 – 1000)nm before and after heat treatment for CdO:Mg thin films. It is clear from this figure that the value of transmittance increase with increase of wavelength and have high values in NIR region also these values increase with increase annealing temperature because the heat treatment causes improvement of the crystallinity in these films, growth of small grain and decrease of grain boundaries lead to increase transmittance and decrease absorbance values. The value of optical energy gap (Eg^{opt}) for these films determined from extrapolating the straight portion of the plot of coefficient which is calculated from equation: [22]

$$\alpha = 2.303 \, (A / t) \quad \ldots\ldots (7)$$

It is seen from figure (3) and table (2) that the values of optical energy gap for CdO:Mg films increase with increase of annealing temperature, due to reduction in the number of defects in films , decrease the density of localized states in the Eg after heat treatment .The value of the optical energy gap is in agreement with[2,4 and 17].

Electrical Properties

The relationship of lnσ versus $10^3/T$ for CdO:Mg films in the temperature range (298- 473) K as a function of annealing temperature (R.T,373 and 473)K is shown in figure (4), observed from this figure that these films have two mechanisms for electrical conductivity characterized by two temperature ranges with different conductivity slopes lead to two values of activation energy (Ea_1, Ea_2). The conduction mechanism at higher temperature range (373-473) K is due to carriers excited into extended states beyond the mobility edge while the conduction mechanism at lower temperature range (293- 363) K is due to carriers excited into the localized states at the edge of the band and hopping. Figures (4,5) and table (2), show that the electrical conductivity values decrease while the activation energies showed opposite trend after heat treatment, this behavior can be attributed to the decrease number of carriers available for transport, because the increase of temperature leads to the improvement in the films structure due to reducing localized states through energy gap , dangling bonds and defects like voids.

The Hall Effect measurement shows that the CdO:Mg films are n-type conductivity, this result is in agreement with references [2,3,4and17]. From Hall measurement, the carrier concentration is calculated by the relation: [23,24]

$$n_H = \pm 1 / R_H.e \quad \ldots\ldots (8)$$

The mobility is related to the Hall coefficient by equation: [24]

$$\mu_H = \sigma / n_H .e = \sigma . \left| R_H \right| \quad \ldots\ldots (9)$$

Where σ is the conductivity.

The carrier concentration and Hall mobility for CdO:Mg films as a function of annealing temperature are presented in figures (6 and 7) respectively. It is clear from these figures and Table (2) that the carrier concentration decreases while Hall mobility values increase with increasing annealing temperature. This indicates that the improvement in the films structure after heat treatment is due to the decrease of defects, dangling bonds and localized states through energy gap. The values of concentration and carrier mobility are in contrast with the result obtained by reference.[4]

C-V characteristic

Figure (8) shows the variation of the capacitance with the reverse bias voltage within the range (0 to -3) Volt as a function of annealing temperatures (300, 373 and 473) K for n-CdO: Mg/ p-Si hetrojunction fabricated at fixed frequency (100 KHz). It is noticed from this figure that in general the capacitance decreases non-linear with increasing the reverse bias voltage and annealing temperature, this behavior is in agreement with the equation capacitance per unit area for the junction of an abrupt an isotype heterojunction which is written as: [25,26].

$$C/A=[q N_n N_p \varepsilon_n \varepsilon_p / 2(\varepsilon_n N_n + \varepsilon_p N_p)]^{1/2} (V_{bi}-V_a)^{-1/2} \quad \ldots\ldots (10)$$

Where ε_n and ε_p are the dielectric constant of n-type and p-type semiconductor respectively, N_n and N_p are the donor and acceptor concentrations respectively, V_a is the applied voltage, V_{bi} is the built-in junction potential and A is the area of the junction.

From plots of the relation between the inverse capacitance square($1/C^2$) with applied reverse bias voltage as a function of annealing temperatures for n-CdO:Mg/ p-Si hetrojunction, see figure (9) can be determined the built-in potential (V_{bi}) from the interception of the straight line with the voltage axis at ($1/C^2 = 0$). It is observed from this figure the straight line relationship which indicated that the junction was an abrupt type [25,26].

Also the width of the depletion layer (W) can be calculated by using the equation: [25,26]

$$W= \boldsymbol{\varepsilon}_s/C_o \quad \ldots\ldots (11)$$

Where C_o is the capacitance at zero bias Voltage and $\boldsymbol{\varepsilon}_s$ is the dielectric constant for hetrojunction which are calculated from equations[25 and26]

$$\varepsilon_s = \varepsilon_n\varepsilon_p /(\varepsilon_n +\varepsilon_p) \quad \ldots\ldots (12)$$

From the same figure, the carrier concentration (N_d) can be calculated from the slope of the straight line a according to equation: [25and26]

$$1/C^2=[2(\varepsilon_n N_n + \varepsilon_p N_p)/ q N_n N_p \varepsilon_n \varepsilon_p] (V_{bi}-V_a) \quad \ldots\ldots\ldots\ldots\ldots..(13)$$

Where $[2(\varepsilon_n N_n + \varepsilon_p N_p)/ q N_n N_p \varepsilon_n \varepsilon_p]$ is the slope.

Table (3) represents that the capacitance values at zero bias voltage (C_o) for n-CdO:Mg/ p-Si hetrojunction decrease with the increase of the annealing temperatures this behavior is attributed to the increase in the depletion region width because the surface states which lead to increase the value of built in potential. Also it is found that the carrier concentration (N_d) decreases with increasing annealing temperature for same reasons as we mentioned before and this result is in good contrast with our result for Hall effect measurements.

characteristics under dark

The current-voltage (I-V) characteristics at dark condition for n-CdO:Mg/ p-Si hetrojunction with applied forward and reverse bias voltage (-3 to 3) Volt before and after annealing (373 and 473)K are illustrated in figure (10). It is clear from this figure that the current increases with the increase of annealing temperature, this may be due to rearrangement of the interface atoms and reduce the dislocation ,dangling bond and surface states at interface layer between CdO:Mg and c-Si after heat treatment which leads to improvement of the junction characteristics. Also this figure shows that the forward current has two regions with two mechanisms as voltage increase , first region at low voltage represents recombination current and the second at high voltage region represents tunneling current then the current approximately rises exponentially with the increase of voltage , this indicated that the mechanism of the forward current is subjected to the tunneling- recombination mechanism, such observations were also seen by references.[1and 4]

Figure (11) shows the relation between the logarithm initial part of forward current and bias voltage at dark condition for CdO:Mg/ Si HJ, the saturation current(I_s) can be determined from intercepting the straight line with the current axis at zero voltage bias. From the first region in this figure the ideality factor (β) can be calculated from the relation : [25and26]

$$\beta = (q/ K_B T) [V_F/ \ln (I_F/I_S)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(14)$$

Where q is charge of electron ,K_B is the Boltzmann's constant, T is the absolute temperature ,V_F is the forward bias voltage ,I_F is the forward bias current and I_S is the saturation current. Also the potential barrier height (Φ_b) can be determined by the relation: [25and26]

$$Js = A^* T^2 \exp (-q \Phi_b /K_BT)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(15)$$

Where A^* is the effective Richardson constant.

The saturation current (I_s) , identity factor (β) and potential barrier height (Φ_b) values with different annealing temperatures for CdO:Mg/ Si HJ are shown in Table (4). These values indicate that the value of saturation current decreases while the value of the ideality factor and potential

barrier height increases with increasing annealing temperature. This behavior is due to the improvement of crystal structure at interface layer, reduction of dangling bonds and the density of interface states.

Conclusion

In the present work, thin films of CdO: Mg (1%) and n-CdO: Mg/ p-Si heterojunction is synthesized successfully by thermal evaporation method, the effect of annealing temperature on the structural, optical and electrical properties of CdO: Mg films deposited on glass substrate are investigated, and the effect of annealing temperature on the characteristic of n-CdO: Mg/ p-Si heterojunction are studied in detail. XRD measurements show that the films have cubic structure oriented in (111) direction and there are no additional peaks after doping with Mg which indicates the solubility of the dopant in the crystal structure as well as improvement in the films structure after heat treatment. Optical measurements show that CdO: Mg films have high transmittance and low reflectance at wavelengths longer than 500 nm, this makes them suitable for solar cell application as antireflection, the optical energy gap values increase when annealing temperature increases. Conductivity measurements demonstrate that the films contain two types of transport mechanisms, while Hall effect measurements induct that these films were n-type, we should mention that the electrical conductivity, activation energies, mobility and carriers concentration are seen to be dependent on the annealing temperature. C-V measurements of n-CdO:Mg/ p-Si heterojunction at fixed frequency (100 KHz) deduce that the junction was an abrupt type, also it is found that the depletion region width and built in potential increase with the increase of annealing temperature. I-V characteristic under dark case indicated that the mechanism of the forward current is subjected to the tunneling- recombination mechanism, both identity factor (β) and potential barrier height (Φ_b) values increase with the increase of annealing temperature.

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Table (1): XRD results of CdO: Mg thin films at different annealing temperatures

Ta	2 θ (ASTM)	d(A°) (ASTM)	2 θ Observed	d(A°) Observed	a(A°) ASTM	a(A°) Observed	D nm)(	(hkl) ASTM
R.T	33.00 38.283 69.284	2.7120 2.3490 1.3550	33.05 38.34 69.33	2.707 2.3456 1.3542	4.695	4.689 4.691 4.6911	48.204	111 200 222
373 K	33.00 38.283 69.284	2.7120 2.3490 1.3550	33.06 38.35 69.34	2.7068 2.3450 1.3540	4.695	4.6883 4.69 4.6903	51.651	111 200 222
473 K	33.00 38.283 69.284	2.7120 2.3490 1.3550	33.08 38.35 69.36	2.7056 2.3451 1.3537	4.695	4.686 4.6902 4.689	57.848	111 200 222

Table (2) : The optical and electrical properties of CdO: Mg thin films at different

Ta (K)	E_g^{opt}(eV)	$\sigma_{R.T}$ $(\Omega.cm)^{-1}$	Ea_1(eV)	Ea_2(eV)	Carrier Concentration n_H (cm^{-3})	Carrier Mobility μ_H (cm^2/v. s.)
R.T	2.08	2.03 E+2	0.2143	0.6156	8.343 E+17	15.247 E+2
473	2.15	1.73 E+2	0.2789	0.6316	5.78 E+17	18.699 E+2
673	2.2	1.47 E+2	0.3259	0.6517	4.787 E+17	19.19 E+2

Table (3): Values of zero bias capacitance, built in voltage ,depletion region width, and carrier concentrations for CdO:Mg/Si HJ

Ta (K)	C_0 (nF)	V_{bi} (Volt)	W (cm)	Carrier Concentration (cm^{-3})
R.T	67.42	1.48	0.999 E-5	12.77 E+20
473	57	1.6	1.1827 E-5	10.163 E+20
673	50.23	1.85	1.342 E-5	8.597 E+20

Table (4): Values of saturation current(I_s), identity factor (β) and potential barrier height (Φ_b) for CdO:Mg/Si HJ

Ta (K)	I_s (μA)	β	Φ_b (eV)
R.T	16.147	1.405	0. 705
473	14.68	1.575	0. 707
673	12.66	2.180	0.711

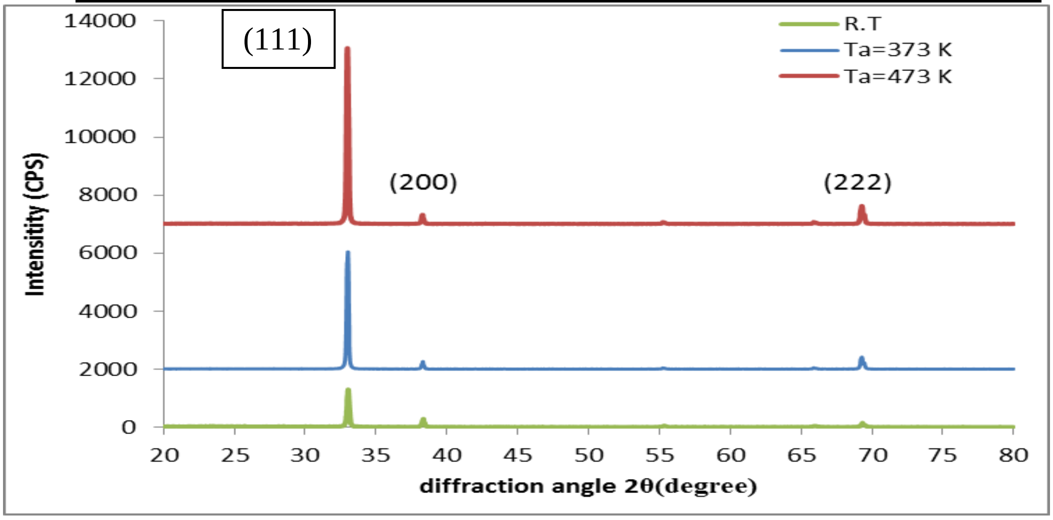


Figure (1): X-ray diffraction pattern of CdO: Mg thin films at different annealing temperatures

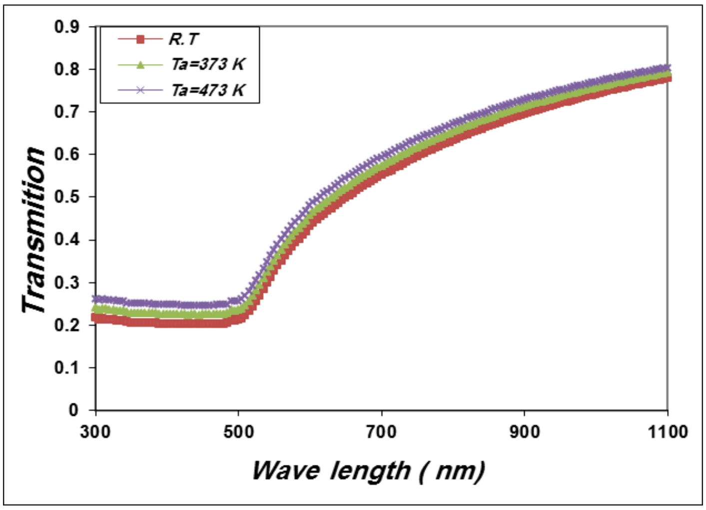


Figure (2): Transmittance with wavelength of CdO :Mg films at different annealing temperatures

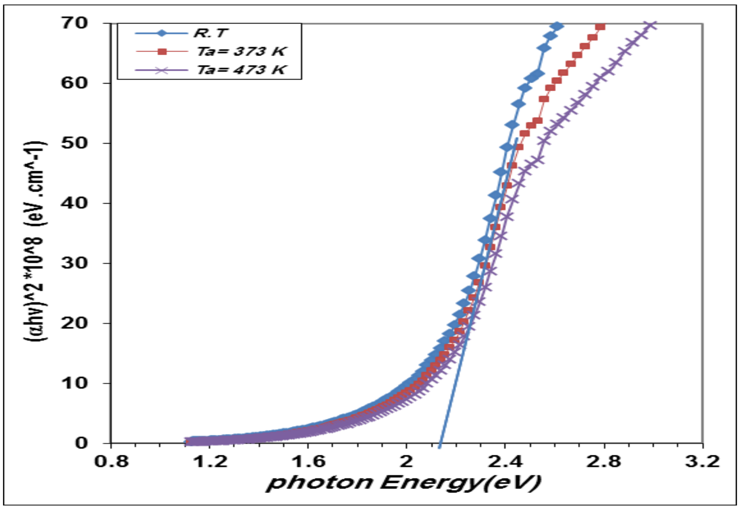


Figure (3): $(\alpha h\nu)^2$ with photon energy of CdO: Mg films at different annealing temperatures

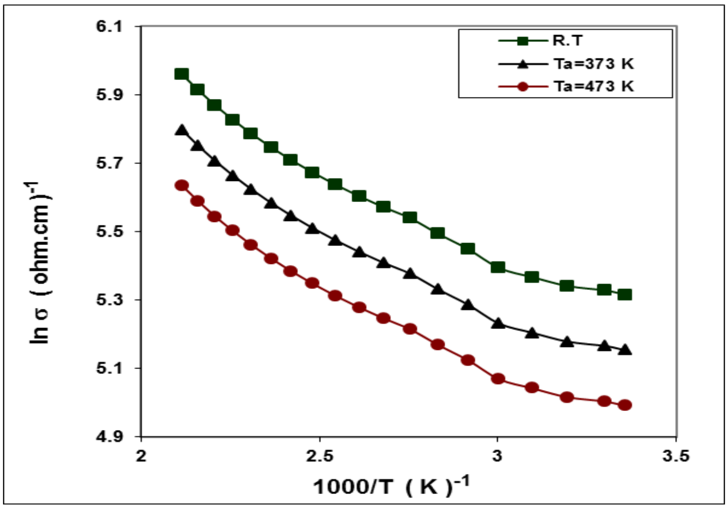


Figure (4): lnσ versus 10^3/T of CdO: Mg thin films at different annealing temperatures temperatures

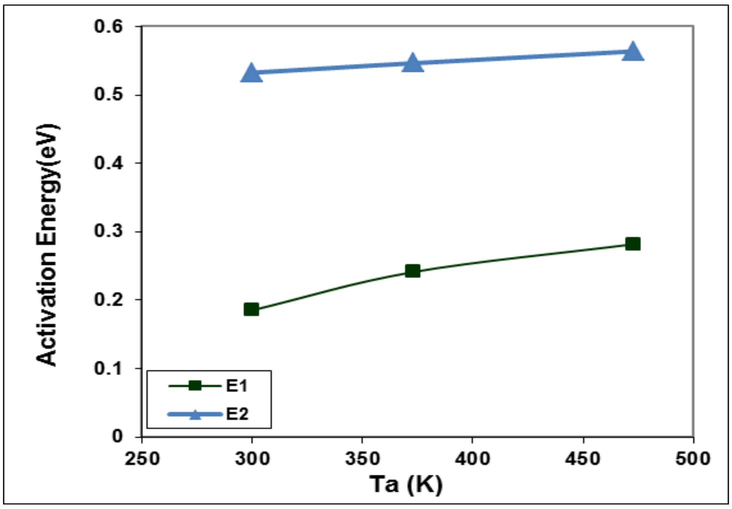


Figure (5): Activation energies of CdO: Mg thin films at different annealing

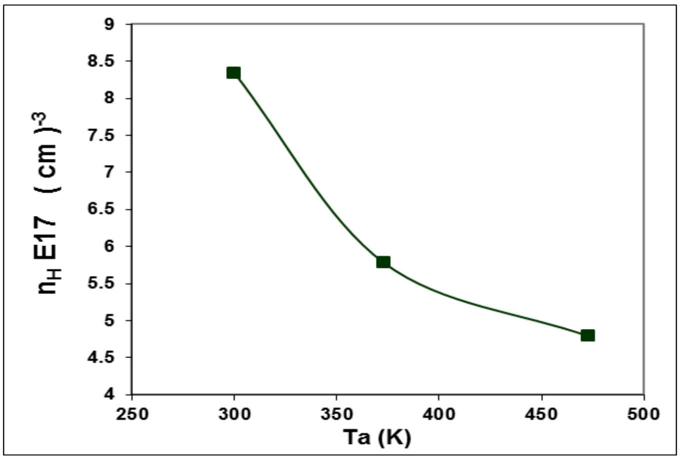


Figure (6): Charge carrier's concentration of CdO: Mg thin films at different annealing temperatures temperatures

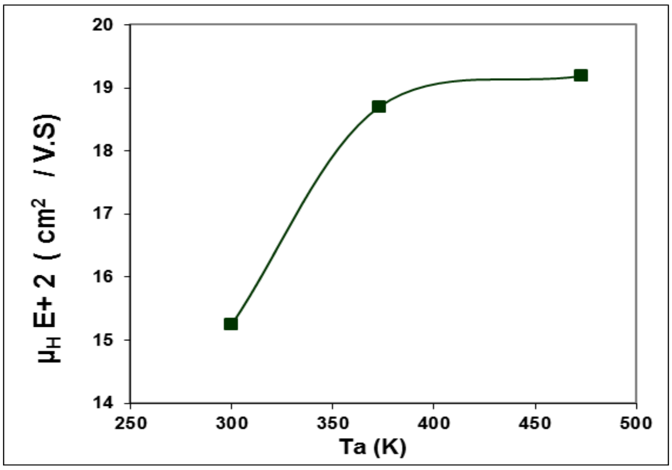


Figure (7): Hall mobility of CdO: Mg films at different annealing

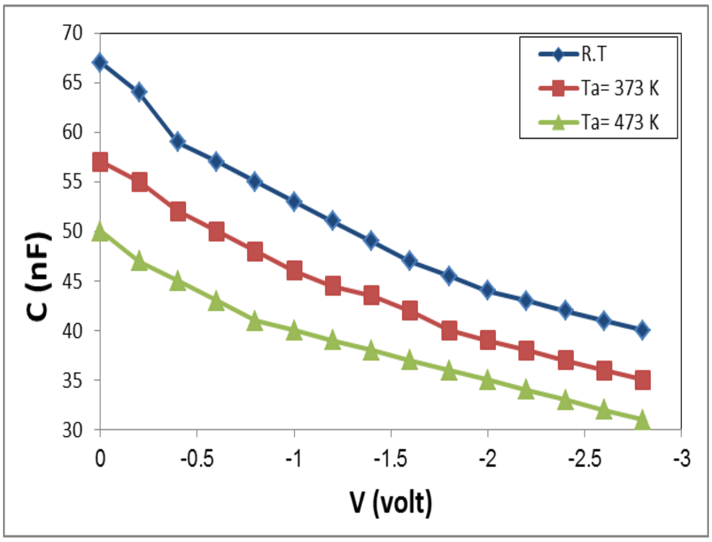


Figure (8): Capacitance with reverse bias voltage of CdO: Mg thin films at different annealing temperatures

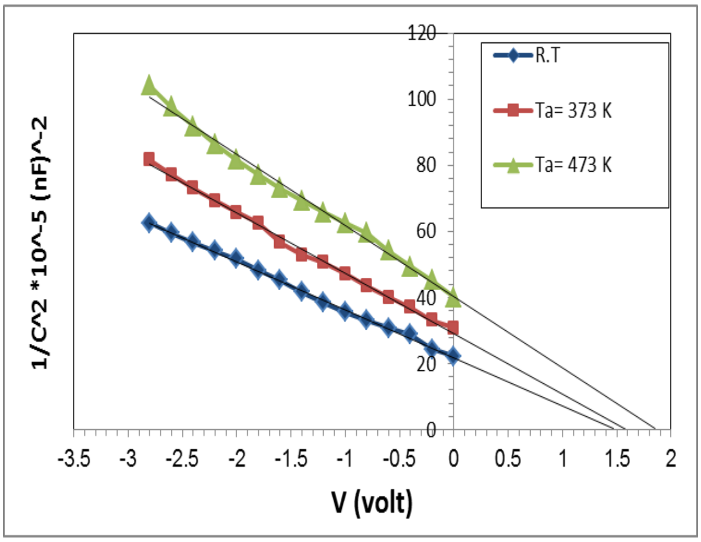
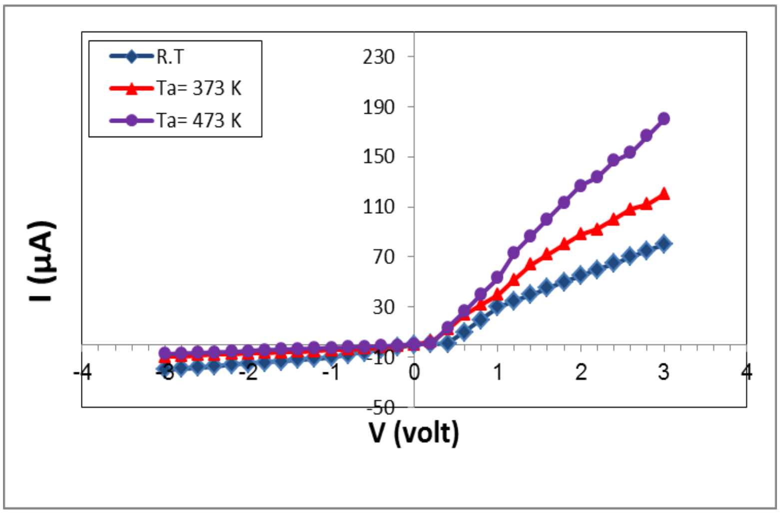


Figure (9): $1/C^2$ with reverse bias voltage of CdO: Mg thin films at different nnealing temperatures



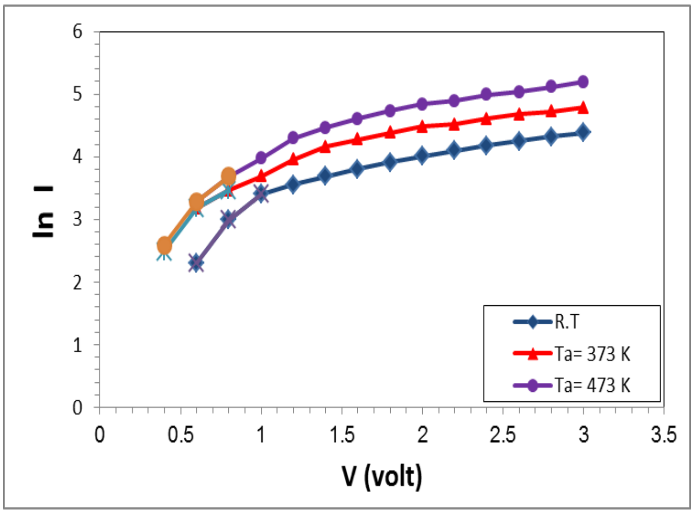


Figure (10): I-V characteristics of CdO: Mg/Si HJ at different annealing temperatures

Figure (11): Forward current and bias voltage of HJ at different annealing temperatures

اعتماد خصائص المفرق الهجين n-CdO:Mg /p-Si على درجة حرارة التلدين

بشرى كاظم حسون الميالي
قسم الفيزياء / كلية التربية للعلوم الصرفة (ابن الهيثم) / جامعة بغداد

استلم في : 17 /نيسان/2016 قبل في:8/مايس/2016

الخلاصة

تم في هذا البحث تحضير اغشية CdO: Mg الرقيقة والمفرق الهجين n-CdO:Mg/p- Si وبسمك nm (500±50) عند درجة حرارة الغرفة (300 K) باستعمال تقنية التبخير الحراري. ولدنت النماذج لمدة ساعة واحدة عند درجات حرارة تلدين مختلفة K(373,473) .
تم دراسة الخواص التركيبية والبصرية والكهربائية لاغشية (CdO: Mg%1) والمرسبة على ارضيات من الزجاج كدالة لدرجة حرارة التلدين بالتفصيل.
اوضحت نتائج قياسات C-V للمفرق الهجين n-CdO:Mg/p- Si عند تردد 100KHz وعند درجات حرارة تلدين مختلفة ان المفرق من النوع الحاد وان جهد البناء الداخلي يزداد مع زيادة درجة حرارة التلدين.
و اوضحت خصائص I-V في حالة الظلام للمفرق الهجين المحضر وعند درجات حرارة تلدين مختلفة ان كل من قيم عامل المثالية وارتفاع حاجز الجهد تزداد مع زيادة درجة حرارة التلدين.

الكلمات المفتاحية :- التبخير الحراري، المفرق الهجين HJ، خصائص I-V ، قياسات C-V ، اوكسيد الكادميوم .