

## Effect of Deposition Temperature and Ph Value on Structure, Optical and Electrical Properties of Cdo Prepared by CBD

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### ABSTRACT

In this work CdO films were prepared by using chemical bath deposition, which is a simple and inexpensive technique suitable for large deposition area. Many growth parameters have been considered in this work to specify the optimum condition, namely (deposition temperature, and pH value). Structure and electrical properties of CdO films are investigated and analyzed extensively with respect to growth conditions. The high conductivity and high visible transmission (> 80%) make the films suitable for use in the transparent electrodes.

**Key word:** chemical bath deposition, temperature of solution and pH effect, CdO films, Structure, optical, and electrical properties

تأثير درجة حرارة الترسيب وقيمة الحماضية على الخصائص التركيبية, البصريه والكهربائيه لاغشية اوكسيد الكاديوم المرسبه بطريقة الحمام الكيميائي

### الخلاصه

تم في هذا البحث تحضير أغشية أكسيد الكاديوم بتقنية الترسيب بالحمام الكيميائي والتي تعتبر طريقه غير مكلفه ومناسبه لترسيب مساحات واسعه. حيث تضمن البحث دراسة تأثير عاملين مهمين من معاملات الترسيب وهي (درجة حرارة الترسيب، حامضية المحلول) على خصائص الاغشيه المرسبه وذلك للحصول على الظروف المثلى للتحضير. كما تضمن البحث دراسة وتحليل الخصائص التركيبية, البصريه, والكهربائيه للاغشيه المحضره بظروف مختلفه. التوصيليه الكهربائيه

العاليه والنفاذيه البصريه العاليه لاكثر من ٨٠% ت من هاه جعلت من هذه الاغشيه مناسبه لاستخدامها كاقطاب شفاه.

## **INTRODUCTION**

**S**emiconductors are considerable technical interest in the field of electronic and electro optical devices. In general, it is difficult to prepare these materials in bulk form; however, synthesis can be achieved in case of thin films [1]. The commonly used methods of preparation thin films of semiconductors are vacuum thermal evaporation, spray pyrolysis, sputtering, sol gel and molecular beam epitaxy, and the most of these techniques are expensive and require high vacuum and controlled formation conditions [2, 3, 4]. Chemical bath deposition (CBD) represents less common technique but inexpensive and convenient method for large preparation of thin films at low temperatures [5, 6]. The semiconductors oxide such as CdO, ZnO, BaO, Fe<sub>2</sub>O<sub>3</sub>, BiClO and Cu<sub>2</sub>O thin films have studied extensively as a result of wide range of technical applications, specifically in the field of photovoltaic solar cells and other optoelectronic devices [7,8] , cadmium oxide (CdO) one of these important semiconductors oxide which has high optical properties. According to these properties it has vast applications. Where show high transparency in the visible region of solar spectrum and has high electrical properties which were represented low ohmic resistance [9]. Although it is difficult to obtain simultaneously a high transmission coefficient and good conductivity these properties of CdO thin films have been carried out [10, 11].

The unique combination of CdO thin films properties which were represented by high electrical conductivity, high carrier concentrations and high transparency in the visible range of electromagnetic spectrum, made it suitable for wide range of applications in different fields [12, 13]. The applications of CdO thin films as Phototransistors [9, 14, 15], photodiodes [8, 11], antireflection coatings [9], IR detectors [14], gas sensors [8, 4, 9, 11], transparent electrodes, and it has been used as heat mirrors, due to its high reflectance in the infrared region together with transparency in the visible region [11].

## **EXPERIMENTAL**

### **Substrate Preparation**

Substrate used for the deposition of CdO is borosilicate glass slides, which were first cleaned in distilled water in order to remove impurities and residuals from their surfaces, followed by rinsing in sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) (for two days), to introduce functional groups called nucleation

and / or epitaxial centers, which formed the basis for the thin films growth [16]. Then the samples were washed repeatedly in deionized water, after that dried and kept to be used in time.

### **Solution preparation**

Cadmium Oxide films were prepared from cadmium nitrate which were provided from (SEELZE-HANNOVER) with 99.99% pure.

The deposition of CdO films is achieved by using cadmium nitrate solutions, consist of 20ml of 0.2M cadmium nitrate ( $\text{Cd}(\text{NO}_3)_2$ ), 20ml of 0.5M potassium hydroxide (KOH), 2ml hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) and deionized water were mixed slowly at room temperature. KOH acted as both a complexing agent and a pH stabilizer in the alkaline medium, and it represented as a source of ( $\text{OH}^-$ ) ions, while the role of  $\text{H}_2\text{O}_2$  is to avoid the spontaneous precipitation of any solid phase in the reaction.

### **2.3. Deposition of the CdO Films:**

Films were deposited on glass slides by using  $\text{Cd}(\text{NO}_3)_2$  as a source of  $\text{Cd}^{2+}$  ions with KOH solution and  $\text{H}_2\text{O}_2$  (with molarities and volumes as above mentioned) ,in addition to deionized water were mixed slowly at room temperature with continuous stirring. Substrates were then immersed vertically in a beaker containing the reaction mixture. The beaker was placed in a water bath at temperature ( $80 \pm 3 \text{ C}^\circ$ ). The solution was stirred with a magnetic stirrer type (LMS-1003). Then, it was heated with continuous stirring to the required temperature of deposition, the pH measured by pH meter type (HANA, pH211 Digital); where as the measure pH in the start of the deposition process takes place was (9). Substrates were then taken out after a suitable time; they were washed with distilled water, and then dried. After KOH was added to the solution the color of solution becomes milky. The value of pH of the solution in the case of KCN added is (10.5). By heating the solution, the ions of  $\text{Cd}^{2+}$  (from cadmium nitrate solution) and  $\text{OH}^-$  ions (from potassium hydroxide solution) will react with each other to form the white film of cadmium hydroxide  $\text{Cd}(\text{OH})_2$  which convert to CdO film after the annealing process, due to the removal of  $\text{H}_2\text{O}$  vapor from the film structure .

### **ELECTRODES DEPOSITION**

In order to measure the electrical properties, ohmic contacts were needed. It was obtained by under vacuum of indium wire evaporation with high purity (99.99%). The evaporation process was started at a pressure of  $10^{-5}$  Torr. Ohmic contact from indium wire on CdO film was made through a metal mask made aluminum (Al) foil.

### **MEASUREMENTS**

#### **Thickness Measurement**

Film thickness is measured by optical interferometer method. The method is based on interference of the light beam reflection from thin film surface and substrate bottom. He – Ne Laser (632.8 nm) is used and the thickness is determined using the formula:-

$$d = \frac{\Delta x}{x} \cdot \frac{\lambda}{2} \quad (1)$$

Where: x is fringe width,  $\Delta x$  is the distance between two fringes and  $\lambda$  is the wavelength of the laser light.

### Structure Measurement

To determine the nature of the growth films and the structural characteristics of CdO films, X – ray diffraction measurement has been done and compared with the ASTM (American Society of Testing Materials) cards, using (lab X-XRD 6000/shimadzu) of  $\lambda = 1.54 \text{ \AA}$  from Cu - K $\alpha$ . The average grain size ( $G_S$ ) of the polycrystalline material can be calculated from the X - Ray spectrum by means of Full Width at Half Maximum (FWHM) method (Scherrer relation):

$$GS = \frac{A \lambda}{\Delta \theta \cos \theta} \quad (2)$$

Where  $\Delta \theta$  is the full – width at half maximum of the XRD peak appearing at the diffraction angle  $\theta$ , A represents the shape factor, the value of which depends on the crystalline shape, is 0.94 and generally it is 1. The micro strain was produced through growth of thin films can be calculated from the follows formula [59, 60].

$$\delta = \frac{|a_{ASTM} - a_{XRD}|}{a_{ASTM}} * 100\% \quad (3)$$

Where a: is the lattice constant.

### Optical Measurements

UV-VIS, Phoenix-2000V device was used to record the optical transmission for CdO/glass thin films before and after annealing in the range (380 – 900 nm). The data from transmission spectrum can be used in the calculation of the absorption coefficient ( $\alpha$ ) for CdO films, according to the following equation [17]:

$$\alpha = \frac{1}{d} \ln \frac{1}{T} \quad (4)$$

Where d is the thickness of thin film, and T is the transmission. The value of extinction coefficient (K) was calculated using the following equation:

$$K = \frac{\alpha \lambda}{4\pi} \tag{5}$$

The nature and value of band gap (Eg) were determined from the graph of  $(\alpha h\nu)^2$  versus  $(h\nu)$  for the thin film.

Both transmittance (T) and absorbance (A) were converted to reflectance values (R), in terms of  $(R+A+T=1)$ .

The reflectance can be expressed in terms of optical constants, (n) and (K) as [17] :

$$R = \frac{(n-1)^2 + K^2}{(n+1)^2 + K^2} \tag{6}$$

Where n is the refractive index and (K) is the extinction coefficient. In the range of frequencies in which the films are weakly absorbing  $K^2 \ll (n-1)^2$  so that:

$$R = \frac{(n-1)^2}{(n+1)^2}, \text{ or } n = \frac{(1+R^{1/2})}{(1-R^{1/2})} \tag{7}$$

Values of refractive index were calculated using equation (3.7). For non magnetic materials, the square of refractive index is the dielectric constant. The complex dielectric constant is given by the following equation [18] :

$$\epsilon = \epsilon_r + i\epsilon_i = (n+iK)^2 \tag{8}$$

Where  $\epsilon_r$  and  $\epsilon_i$  are the real and the imaginary parts of  $\epsilon$  and  $(n+iK)^2$  is the complex refractive index. From equation (3.6) we obtain:

$$\epsilon_r = n^2 + K^2, \text{ and } \epsilon_i = 2nk \tag{9}$$

This equation was used in calculating the real and imaginary dielectric constants.

### Electrical Measurements

The electrical resistivity of CdO films is a very important parameter for all applications. It can be calculated from the current - voltage measurements. Also can be measured through the change of thin film resistance with temperature. This was done by putting the samples inside the (electrical blast dry box, model WG 20), and it attached with a thermocouple (Digital Multimeter) to measure the film temperature

,also the sample was connected to hp 343A,Multimeter device to record the current through the film, and then resistivity was determined by equation [16] :

$$\rho = R \frac{bd}{l} \quad (10)$$

Where  $\rho$  is the electrical resistivity of CdO film and l, b and d are the length, width and thickness of the film respectively and thus the resistance of the film.

The type of conductivity of the CdO films is deduced using Hall Effect measurement. The shape of CdO film is square; four (In) electrodes are deposited on its sides. When the magnetic field ( $B=0.538\text{KG}$ ) is applied perpendicular to the electric field, it yields a current (I) then the transverse electric magnetic field is called Hall voltage ( $V_H$ ), which set a cross up the sample, hence the Hall coefficient ( $R_H$ ) is given by [19]:

$$R_H = \frac{1}{nq} \quad (11)$$

Where q is the electron charge, n is the carrier density related to the Hall voltage by the following equation:

$$n = \frac{B}{qd} \cdot \frac{I}{V_H} \quad (12)$$

Where d is the thickness of the film. And the mobility of carriers  $\mu_e$  is calculated by

$$R_H = \frac{\mu_e}{\sigma_e} \quad (13)$$

Where  $\sigma_e = nq\mu_e$  (14)

The sign of the Hall coefficient ( $R_H$ ) determines the type of the semiconductor that is under investigation [20].

## RESULTS AND DISCUSSION

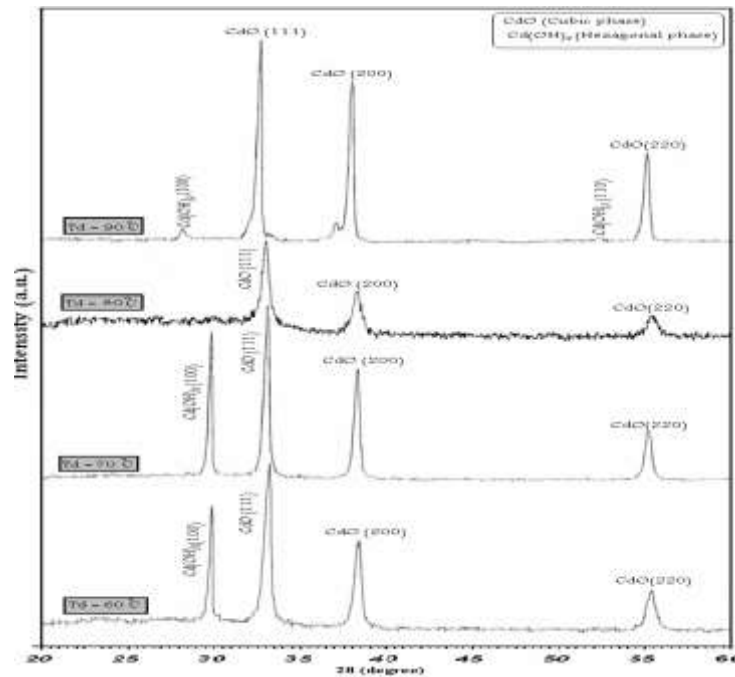
### Structure Properties

The crystallinity of the produced thin films was characterized using X-ray diffraction (XRD), which was also employed to give an indication about the grain size

of the prepared thin films ,where all structure parameters are strongly depend on the deposition conditions[1].

A- Deposition temperature effect:

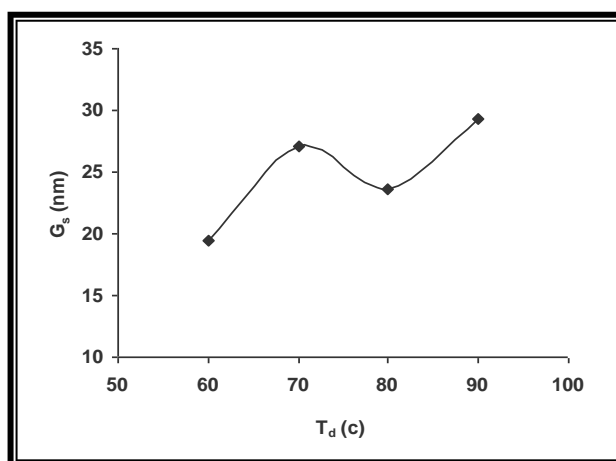
Figure (1) shows X-ray diffraction pattern for CdO thin films samples which growth at different deposition temperatures (60, 70, 80, and 90C°) for constant molarity of cadmium nitrate of (0.2M). These patterns display an intense diffraction peaks at approximately (33.02°), which coincides with a preferred orientation in the C(111) diffraction line. For all deposition temperatures there were two minor at (2θ) approximately 38.1° and 55° where identified as C(200) and C(220) consequent of the predominant plane C(111) and as mentioned earlier XRD was corroborated all these crystalline planes refer to polycrystalline CdO phase. The diffraction patterns of deposition temperatures (60 and 70 C°) indicate the presence of a sharp peaks at 2θ=29.7651° and 29.7642° respectively which were reflected from H (100) plane and in comparison with reference data from Cd(OH)<sub>2</sub> ASTM card. It has been found that peak refer to hexagonal Cd(OH)<sub>2</sub> phase. The presence of Cd(OH)<sub>2</sub> phase in the structure of the CdO thin films which were deposited at deposition temperatures of (60 and 70C°) appreciate is the main reason to the high diffraction intensity. The disappear of this phase thoroughly in the deposition temperature of (80 C°) leads to the decreasing of intensity. In the diffraction patterns of films were deposited at deposition temperatures of (60 and 70C°) both of the hexagonal as well as the cubic phase are exist in these films structure. This implies a larger number of Bragg planes and hence a higher diffraction intensity.



**Figure (1): The X-ray diffraction of CdO films for different deposition temperatures with M=0.2 and at 30 min.**

These results are constituent with other published results such as results of T.P. Gujar et al [21] and V.R.Shine et.al.[16]. There is another explanation to the high intensity, where high intensity in case of presence Cd(OH)<sub>2</sub> phase may be due to enhancement effect which occurs when the radiation of another element inside the structure of the specimen, this element acts to excite the analyte element caused secondary radiation [22]. The rise of deposition temperature to 80C° leads to decrease in XRD intensity (although to be that the film thickness which deposition at 80C° larger than that deposited at 60 or 70C°). When deposition temperature increases to (90 C°) the intensity return to increase with the appearing of small peaks of cadmium hydroxide at 2θ=28.8306 and 52.31° correspond to the diffraction from H(100) and H(110). The high intensity in this deposition temperature can be attributed to the thickness increasing with deposition temperature increasing in addition to effect of Cd(OH)<sub>2</sub> which residual in film. From all above mentioned it can be deduced that the deposition temperature 80 C° is very suitable because of obtaining a pure phase of CdO, while other temperatures is not suitable because the structure nature of the films which deposited at these deposition temperature not promoted to the removal of all H<sub>2</sub>O vapor from the film structure during annealing and converting it to the pure phase of CdO.

The residual hydroxide phase in the film structure also has a effect on the average grain size, where the film thickness increases with the solution temperature increasing. This means that the grain size increases as a result of kinetic energy increasing and growth increases. But due to hydroxide accumulated along the grain boundaries of the crystallites constituting the film acting to change this behavior especially at 70C° as shown in Figure (2).





**Figure (2) : The average grain size as a function of deposition temperature.**

### **B- PH effect**

Most preparation processes by (CBD) were carried out at alkaline medium. This point out to the importance of [pH] value in deposition of (CdO) films which can be adjusted by using different molarity of potassium hydroxide (KOH). The samples were studied for the [pH] range from (8.1) to (11.9), and the other deposition conditions such as cadmium ion concentration of (0.2M) in an aqueous solution which was heated to 80C° for 30min. Figure (3) represents the structural changes of CdO films, where obviously can be notice that the diffraction patterns are consistent with the presence of pure polycrystalline CdO thin film with cubic (NaCl) structure, showing a number of characteristic peaks assigned for every value of [pH]. For pH=8.1, there are eight peaks at  $2\theta=29.3941^\circ, 32.9864^\circ, 38.2839^\circ, 48.9484^\circ, 52.31^\circ, 55.2136^\circ, 56.096^\circ,$  and  $58.757^\circ$  which corresponding to diffraction from H(100), C(111), C(200), H(102), H(110), C(220), H(111), and H(003) planes respectively. The three peaks C(111), C(200), and C(220) refer to cubic phase of polycrystalline CdO films, while the others reflected from hexagonal phase of Cd(OH)<sub>2</sub>. These peaks were produced of the excess growth of grains with decreasing of pH value and not all the water vapor could be released from the film structure. As to the pattern of the film which deposited at pH of 9 reveals three peaks at  $2\theta=33.0261^\circ, 38.3071^\circ,$  and  $55.3135^\circ$  corresponding to crystalline planes C(111), C(200), and C(220). All three peaks refer to cubic phase of polycrystalline CdO films.

The last pattern which represents the XRD pattern of the film which deposited with pH value of 11.9. There is a special case, where the pattern contain one clear peak only at  $2\theta=33.0414^\circ$  reflected from C(111) peak with other four peaks have very low intensity at  $2\theta=29.499^\circ, 38.584^\circ, 48.8121^\circ,$  and  $55.513^\circ$  for H(100), C(200), H(102), and C(220) respectively. The two minor peaks for C(200) and C(220) represented the peaks of CdO films which were disappeared to the very low intensity at this pH value. This can be attributed to the reverse relation between growth rate and pH value while others refer to hydroxide phase which reside in the film even after annealing and causes clear increasing in average grain size.

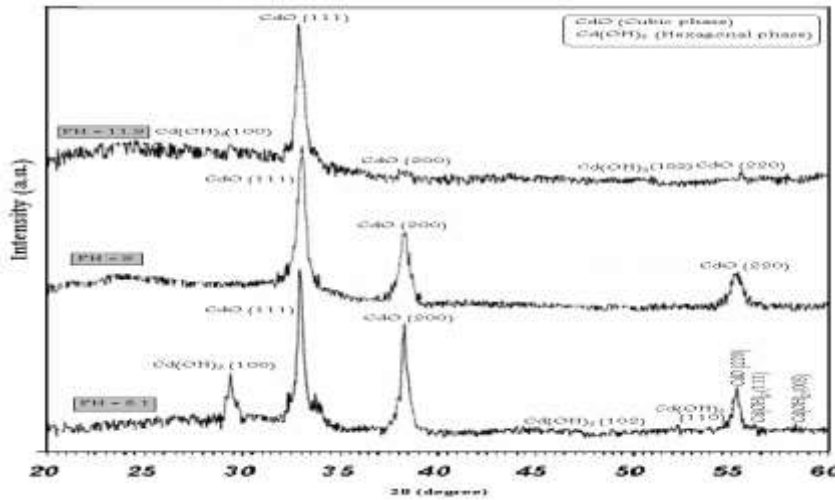


Figure (3): The X-ray diffraction of CdO films for different pH values with M=0.2 , 80 C°, and 30 min.

The average grain size showed have an inverse relationship to the [pH] value, therefore the preferred orientation of CdO films at  $(2\theta = 33)$  are due to the controlled nucleation process associated with the low deposition rate. In other words when [pH] values increases the film thickness and growth are decreased due to more  $(OH^-)$  ion concentration which gives colloidal precipitation during heating (because of high  $(OH^-)$  ion concentration leading to high and fast reaction to produce  $Cd(OH)_2$  as a precipitate in solution during heating ). Therefore the reaction life is short with low growth rate, and this gives low thickness of film as follows small grain size with low diffraction intensity. These results are shown in Figure (4). Results of X-Ray diffraction with the deposition conditions of the film structure are given in Table (1).

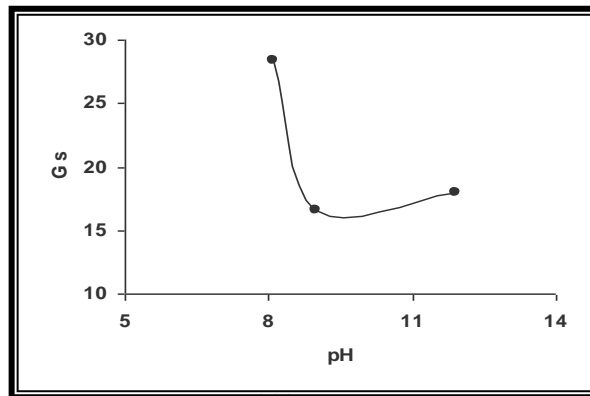


Figure (4): The average grain size of CdO films as a function of pH of solution.

Table (2): The obtained results of the XRD for CdO films.

Deposition conditions		2θ	hkl XRD	d(nm) XRD	d(nm) ASTM	a(nm) XRD	a(nm) ASTM	Average grain size (nm)
Deposit-ion temp. effect	60 C°	33.0379	C(111)	0.270915	0.2712	0.46924	0.46973	19.406
	70 C°	33.0260	C(111)	0.27101	0.2712	0.46938	0.46973	27.100
	80 C°	32.9680	C(111)	0.271469	0.2712	0.4702	0.46973	23.590
	90 C°	32.4978	C(111)	0.27529	0.2712	0.4768	0.46973	29.280
pH effect	8.1	32.9864	C(111)	0.271326	0.2712	0.46495	0.46973	28.395
	9	33.027	C(111)	0.271101	0.2712	0.4694	0.46973	16.565
	11.9	33.0414	C(111)	0.270887	0.2712	0.46919	0.2712	17.946

**Electrical properties.**

The electrical conductivity of the CdO films which deposited at different deposition conditions was found to be in the range 8-125(Ω.cm)<sup>-1</sup> at room temperature. The effect of different deposition conditions to the electrical conductivity is shown in Figure (5).The bath temperatures shows clear effect on the conductivity of CdO films ,where the conductivity reveals slight increase at temperature range (60-70C°). More probably to this behavior is may be referred to the presence of hydroxide phase inside the structure of these films which resist the electrical conduction between the CdO grains. The electrical conductivity of the film deposited with deposition temperature 90C° decreases due to presence of hydroxide phase in the film structure. While the film with deposition temperature 80C° shows high conductivity for pure phase of CdO thin film. The conductivity is clearly affected by the pH value and the highest conductivity is attained with pH=9, where the structure of films with other values of pH contain to the hydroxide phase which act to decrease the electrical conductivity. In addition of disappearing of the crystalline peaks of CdO phase at pH=11.9 and also decreasing the average grain size at this value. From above results it can be said that the optimum conditions which give suitable value of conductivity of CdO thin films was with 0.2M ,30min ,80C° and at pH value of 9 which give conductivity value reach to 88(Ω.cm)<sup>-1</sup>

at room temperature. The last result is in consistent with the results of XRD pattern and optical properties study; where we will be discuss the increasing of this value with temperature effect, annealing process and with adding some chemical solutions to the deposition bath in next items, as we did with the structure and optical properties.

All deposited films have n-type conductivity; this is concluded from the relationship of Hall voltage and electric current. Figures (6) show these results for CdO films prepared at different deposition temperatures.

As the cadmium oxide is an n-type semiconductor the carriers are electrons, which may be available from non-stoichiometric composition due to the presence of their interstitial cadmium or oxygen vacancies[11,23], these results agree with that in published literature [24].

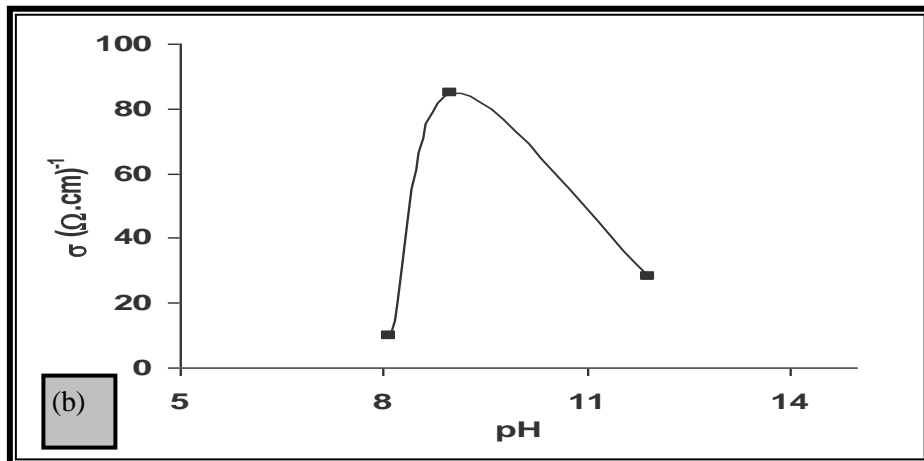
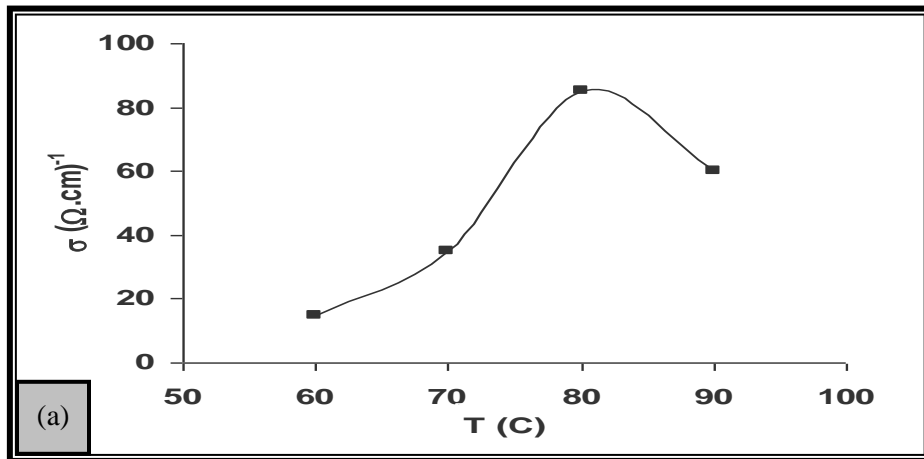


Figure (5): Variation in conductivity as a function of deposition parameters : (a) for different deposition temperatures with 0.2M for 30min and, (b) for different pH values at 80C° and 0.2M for 30min.

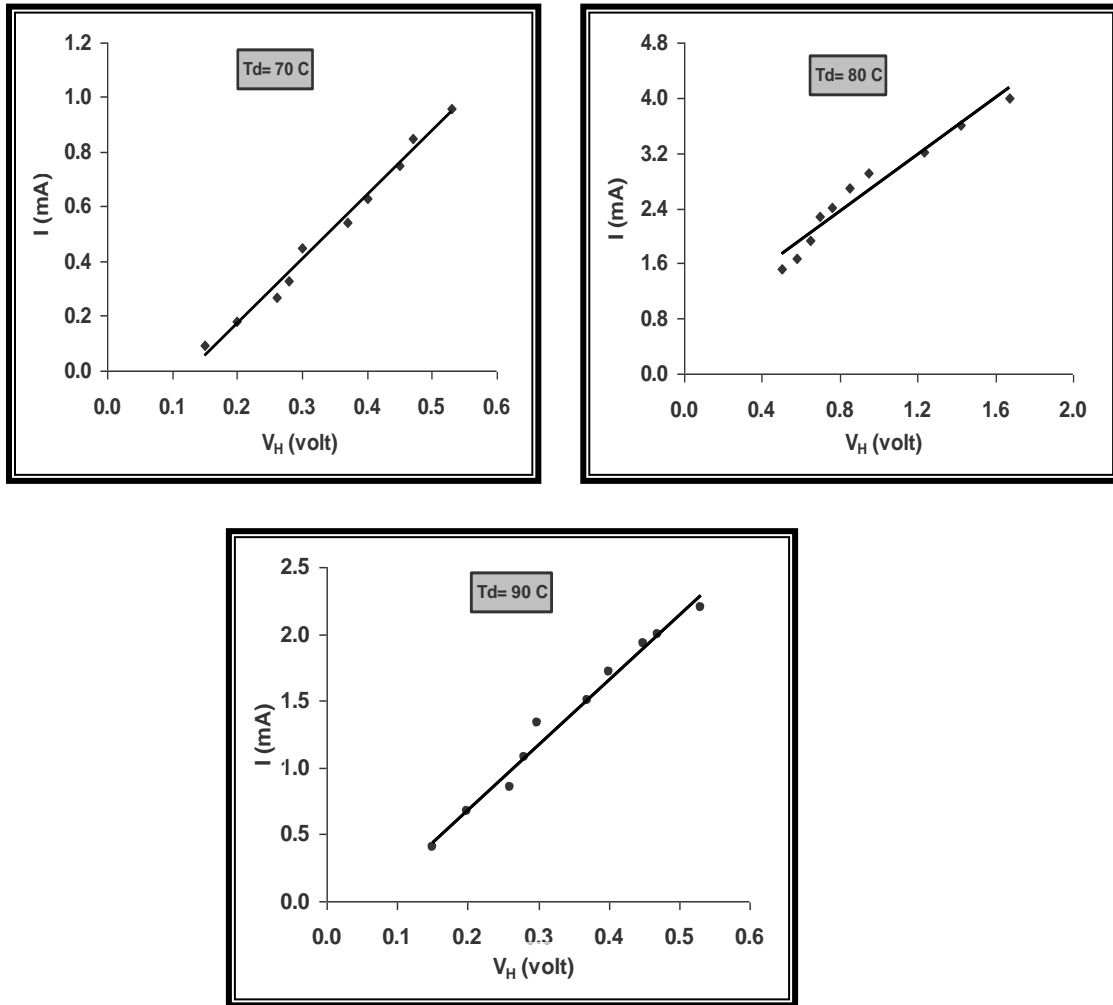


Figure (6): The relationship between the Hall voltage and electrical Current for different deposition temperatures.

Table (2) shows values of the carriers concentration and mobility for different temperatures which were obtained by using equations (12), (14) respectively. Through the results in Table(2) we found that the carriers concentration of the film which

deposited at deposition temperature 80C° value lower than carriers concentration of films deposited with other deposition temperatures (70 and 90 C°). The carriers mobility of the film which deposited at 80C° higher than carriers mobility of films were deposited with other temperatures. We think this result refers to that the film with deposition temperature 80C° represent pure phase of CdO. At 70 and 90 C° we discovered the presence of hydroxide phase within the structure of films. The residual hydroxide inside the structure of films act to obstruct the movement of carriers and as a consequence decrease the mobility.

**Table (2): The experimental results.**

Deposition conditions	Temperature effect		
	70 C°	80 C°	90 C°
Carriers concentration(cm <sup>-3</sup> )	5.64*10 <sup>19</sup>	3.68*10 <sup>19</sup>	5.99*10 <sup>19</sup>
Carriers mobility(cm <sup>2</sup> /V.sec)	3.88	17.68	6.26

**Optical properties.**

**Transmission and Absorption**

Optical transmission and absorption spectra depend on the chemical composition, crystal structure, energy of incident photon, film thickness, and films surface morphology .The effect of different deposition parameters on these spectra are shown in Figures (7) and (8). Optical transmission spectra shows that all deposited films with different parameters reveals unsharpness increases but gradually increases in visible region and some saturation take place at infrared region. Generally, we have found that the films have high transmission at long wavelengths which reach to the (91%) and low transmission of (10%) at short wave length. Also it can be noticed a relative shift of the absorption edge towards long wavelength with increasing in every parameter. The spectral transmission of the CdO films, where we noticed that the transmission decreases with increasing deposition temperature, while increases with increasing pH value. These opposite effects could be attributed to the increase of the size in the single crystallite overgrowth.

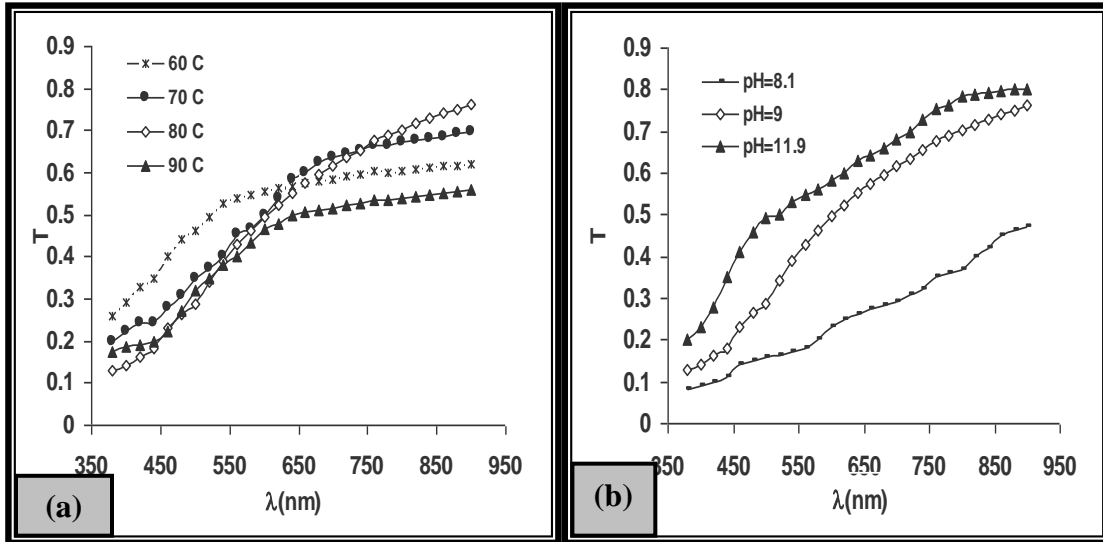


Figure (7): The optical transmission spectra as a function of wavelength of CdO films for different deposition parameters (a) deposition temperatures, and (b) [pH] values.

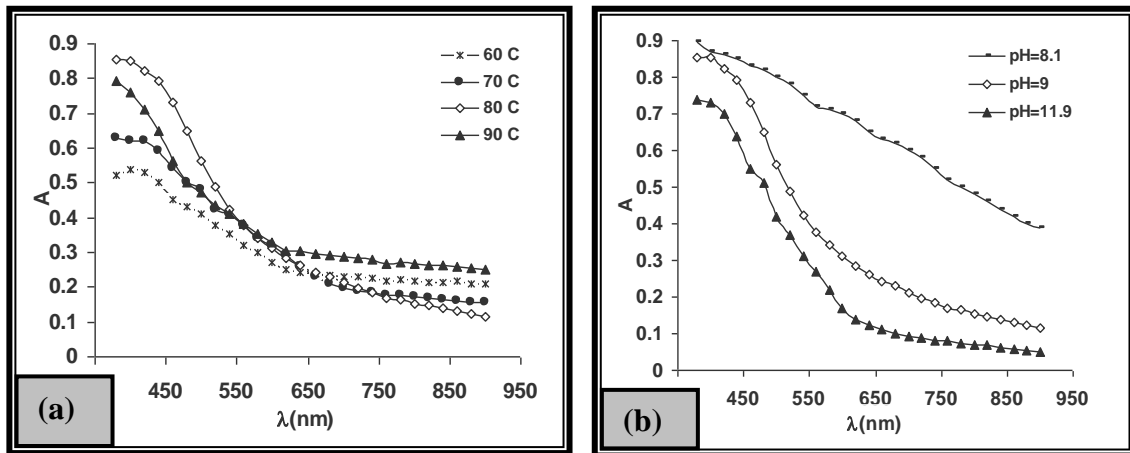


Figure (8): The optical absorption spectrum as a function of wavelength

of CdO films for different deposition parameters  
(a)deposition temperatures, and (b)[pH] values .

The presence of hydroxide phase in the films structure which deposited at 60 C°, 70 C° and 90C° causes the transmission to decrease and also due to change in the films thickness with the [pH] of the solution. With this results we think that pH=9 and deposition temperature 80C° are the optimum values to depositing CdO films. The previous behavior of transmission inversely reflected in the spectral absorption as shown in Figure (8) where the value of absorption exponentially decreased.

**Absorption Coefficients**

The data from the transmission spectrum were used to calculate absorption coefficient by using equation (4). Figure (9) shows the optical absorption spectra recorded with the CdO films for different deposition parameters.

It is clear that several films having high absorption coefficient at short wavelengths in the range (380-550nm) then decrease at different rates dependence on the films structure ,where reach approximately constant values at long wavelengths to above (540 nm) for all the samples with some difference. The Figure shows results of the films prepared at low temperature, and high pH value which have high optical absorption coefficient, where the value reaches to more than (1.5\*10<sup>5</sup> cm<sup>-1</sup>). The high value of absorption coefficient of films deposited at these conditions as a result to the presence of hydroxide phase.

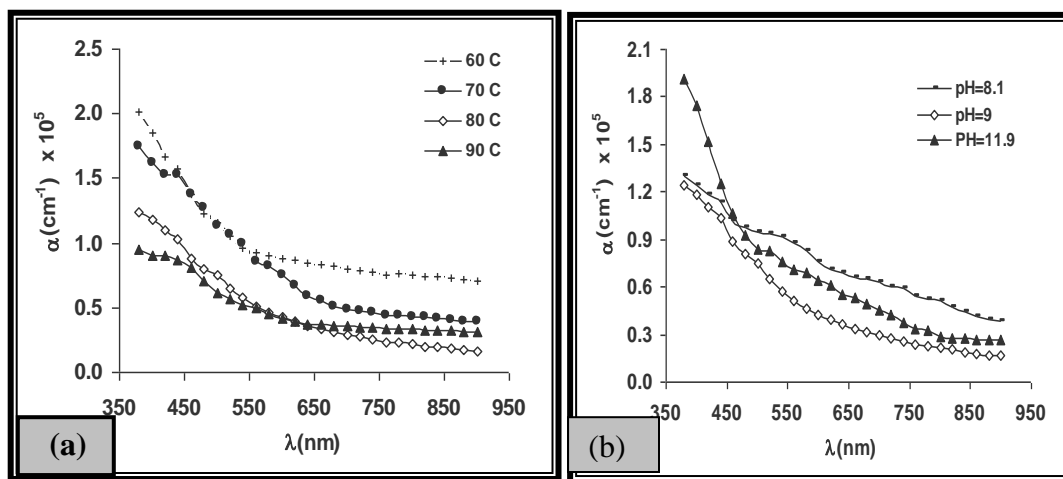


Figure (9) :The optical absorption coefficient as a function of wavelength of CdO films for different deposition parameters (a) deposition temperatures, and (b)[pH] values .



### Optical Energy Gap

The energy gap values depend in general on the films crystal structure and the arrangement and distribution of atoms in the crystal lattice. Direct energy band gaps were calculated from the  $(\alpha h\nu)^2$  versus photon energy respectively for different deposition parameters as shown in Figures (10). The determination of  $(E_g)$  was made by extrapolating the linear portion of the curves until they intercept the photon energy axis.

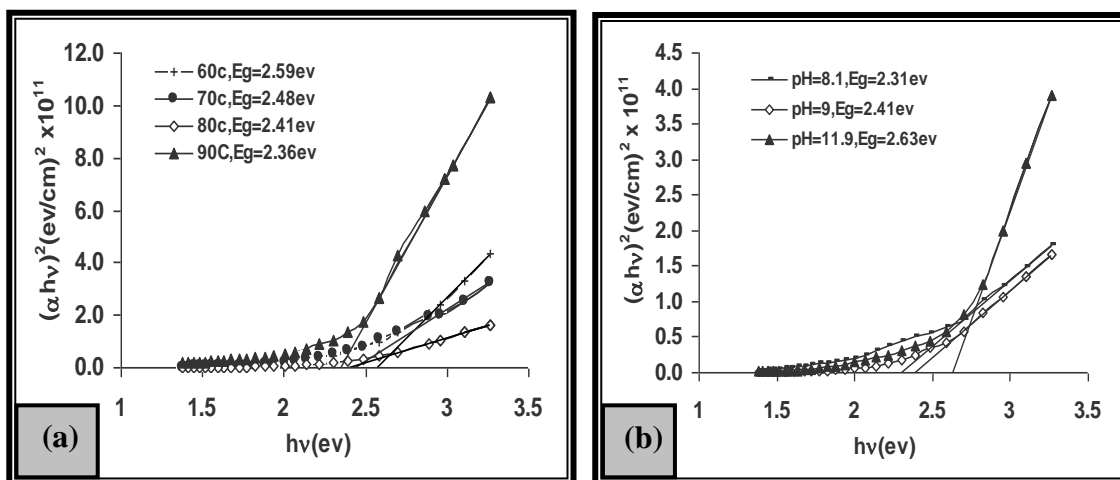


Figure (10): A plots of  $(\alpha h\nu)^2$  versus  $(h\nu)$  of CdO films for different deposition parameters (a) deposition temperatures, and (b) [pH] values.

The linear dependence of  $(\alpha h\nu)^2$  with  $(h\nu)$  indicates direct band gap. The value of energy gap affected by deposition temperature. The values of energy gap variations from 2.59 eV to 2.36 eV depending upon the vary (increasing and decreasing) in the grain size as a result of hydroxide phase residual in the films structure where deposited with (60, 70 and 90°C) deposition temperatures. The energy gap of the pure phase of CdO film was deposited at (80 C°) is 2.41 eV. The band gap changes with the [pH] of the solution at constant  $Cd^{2+}$  ion concentration, where band gap value increases with the increasing of pH value because of the growth rate increases with decreasing in pH value. For all preparation conditions the values of band gaps are found to be approximately close to the band gap of cubic phase of CdO polycrystalline thin films prepared by CBD[13] and other techniques[2,3,10].

### Extinction coefficient

The extinction coefficient represents the amount of attenuation of an electromagnetic wave that is traveling in a material, where it values depends on the density of free electrons in the material and also on the structure nature. The extinction coefficient was evaluated using the relation (5) as function of photon energy for different deposition parameters which is shown in Figure (11). The values of extinction coefficient are directly related to the absorption of light. For all deposition parameters, it can be noticed that there is a slight increase of extinction coefficient values at energies higher than (2.25eV). After that, there is an increase with increasing photon energy and this is a general behavior, the deposition temperature and [pH] value effect the amount of attenuation occurs for the light traveling through the material. The maximum value of extinction coefficient which was recorded at photon energy of (3.3eV) decreases with deposition temperature increasing for all range of temperatures from (60 to 90C°) even becomes 0.3 (lower value) at 90 C°. The value of extinction coefficient of the pure phase of CdO deposited at 80 C° equal to 0.37 as a result of removal of hydroxide phase from the structure of the film and average grain size decreasing. The film which was deposited with deposition temperature (60C°) reveals maximum value of (K) at the same photon energy was reached to (0.6). This value of (K) may be due to appearing of hydroxide phase within the structure of the film. We found that the maximum value of [pH] caused large mout of attenuation to the incident light opposite to the value [pH] of 9. This also attributed to the crystal structure of the film (size and number of CdO grains).

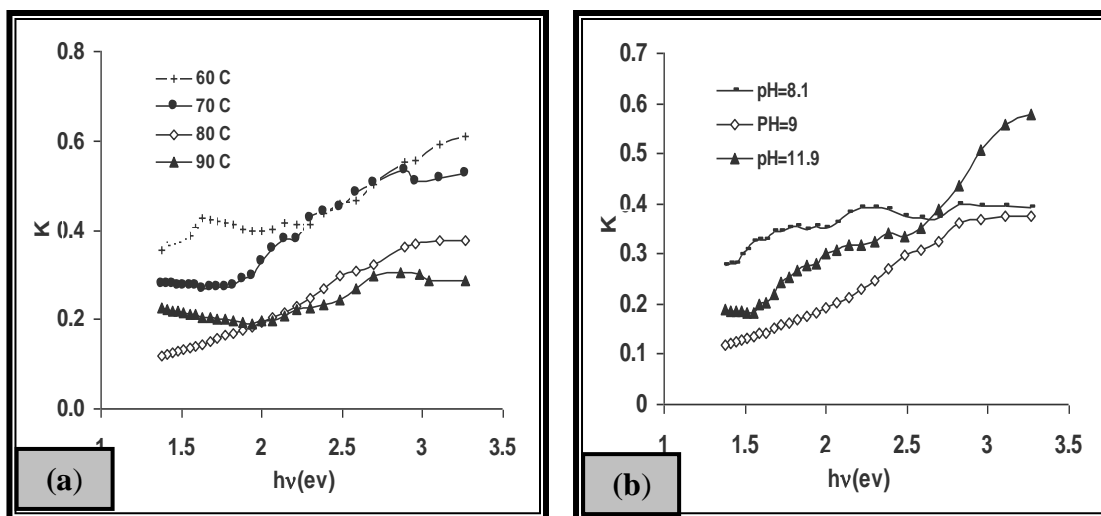


Figure (11): Variation of extinction coefficient as a function of photon energy of CdO films for different deposition parameters (a)deposition temperatures, and (b)[pH] values.

It can be observed from Figure (11), that the value of extinction coefficient was not reached to the zero value even at optimum conditions (0.2M, 30min, 80C°, and pH of 9). This important result indicates that in the case of polycrystalline films, extra absorption of light occurs at the grain boundaries. This leads to non-zero value of K for photon energies smaller than the fundamental absorption edge [25].

**Refractive index**

Refractive index can be defined as the ratio between the velocity of light in space to its velocity inside the material. The values of refractive index (n) were calculated using equation depending on the reflectance values which were calculated using the relation  $T+A+R=1$ . Figure (12) shows the variations in refractive index with the incident photon energy. This Figure reveals that the oscillatory behavior of the CdO films were deposited at different deposition parameters. The value of refractive index of CdO film (or any value in Figure (12)) of 2.5 that means electromagnetic radiation is 2.5 times slower in the Oxide films than in the free space. Throughout the curves of other films which were deposited at different deposition temperatures and pH values, we observe more than one peak of every curve which has values in the range of 1.75-3.2. These observations attributed to the structural changes of the CdO films and their thicknesses with the change of deposition conditions. The oscillatory behavior of the refractive index is very similar to the behavior of many polycrystalline films which prepared by different techniques especially chemically deposited such as ZnO films prepared by CBD [19] and CdS films prepared by thermal evaporation [25].

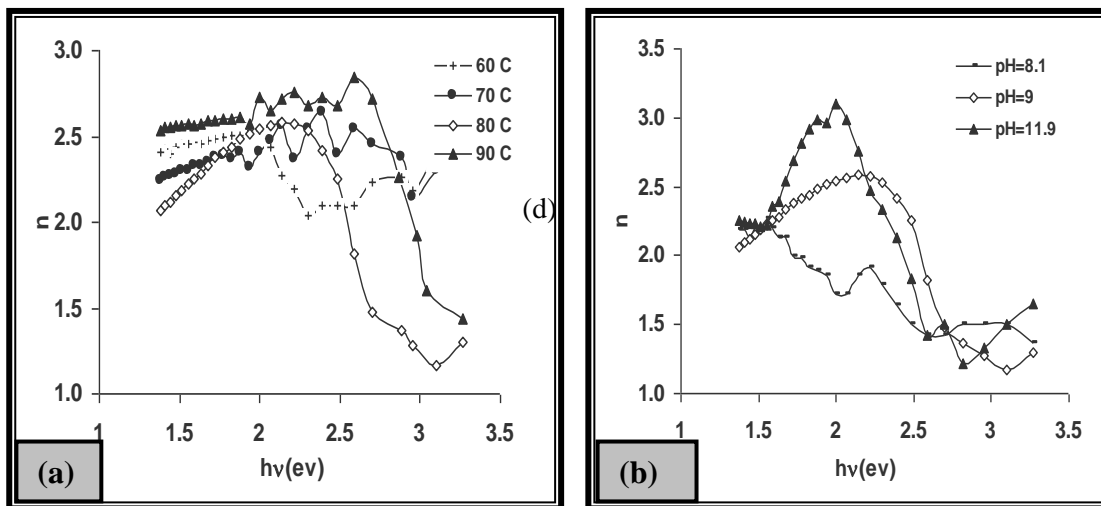


Figure (12) :Variation of refractive index as a function of photon energy of CdO films for different deposition conditions (a)deposition temperatures, and (b)[pH] values .

**Dielectric constant**

Figures (13) and (14) show the variation of real part of dielectric constant and imaginary part of dielectric constant as a function of photon energy. Where real part ( $\epsilon_r$ ) is the normal dielectric constant which represents the amount of actual saving of electrical energy and the imaginary part ( $\epsilon_i$ ) represents the absorption losing associated with free carriers. Two parts of complex dielectric constant were calculated using the relations (9). The curves for both parts are found to be oscillatory in nature for all deposition conditions depending upon the crystal structure and the thickness of the film. The minimum value was recorded for the film deposited with deposition temperature ( $90C^\circ$ ) which reaches (1) and the same value was recorded for the film deposited with [PH] value of 11.9. This value may be attributed to the remaining of hydroxide phase within the structure of these films. It can be observed from Figure (12) that the curves behaviors for all deposition conditions were similar to the behavior of all curves of refractive index (according to relation (9)). This is due to the depending of the value of real part on dielectric constant to the values of refractive index more than to that dependence on the values of extinction coefficient because of being the values of (K) very small compared with of refractive index. The curves of Figure (13) show similar behavior of those curves of extension coefficient due to the depending the values of ( $\epsilon_i$ ) on the concept of (K).

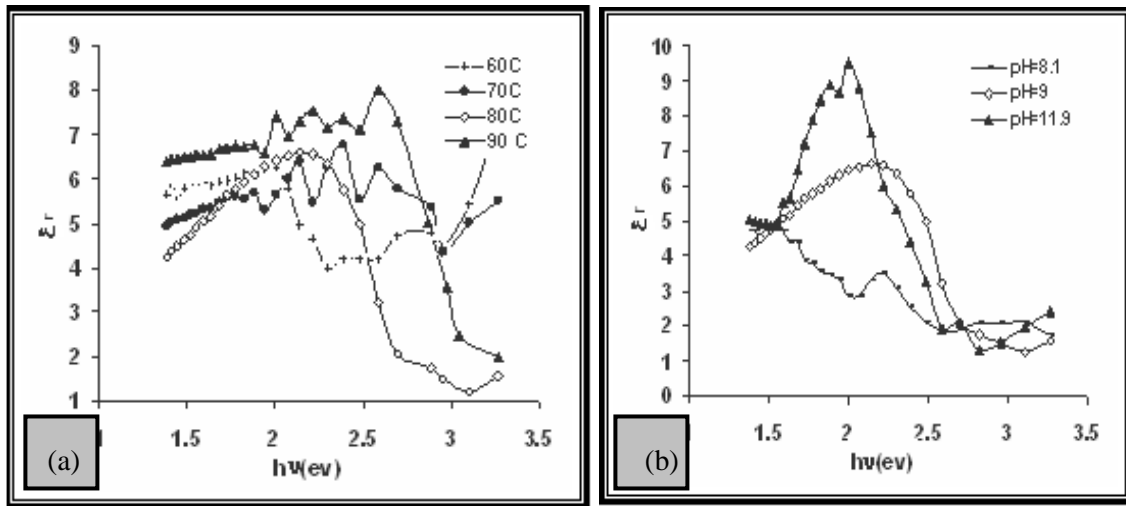
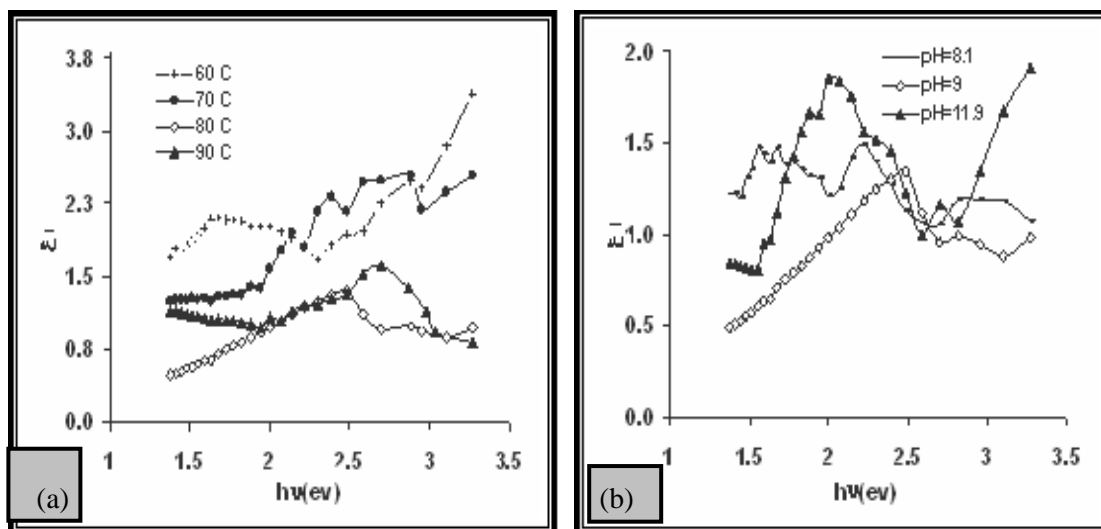


Figure (13) :Variation of real part of dielectric constant as a function of photon energy of CdO films for different deposition conditions (a)deposition temperatures, and (b)[pH] values .



**Figure (14) :Variation of imaginary part of dielectric constant as a function of photon energy of CdO films for different deposition conditions (a)deposition temperatures, and (b)[pH] values .**

For all deposition conditions, it can be found that the films which were deposited with molarity of 0.2 have small amount of losing energy of about (0.7) at range of photon energy (2.9 – 3.4eV) and the same minimum value of ( $\epsilon_i$ ) was recorded for the films deposited at deposition temperature of 80°C and with pH value of 9.

### CONCLUSIONS

Chemical bath deposition is a simple and suitable method of obtaining adherent, specular, homogeneous and stoichiometric CdO thin films. The optimum condition for deposition of CdO films by using cadmium nitrate  $Cd(NO_3)_2$  salt as a source of  $Cd^{2+}$  ion were 80°C and pH of 9. The high conductivity and high visible transmission (> 80%) make the films suitable for use in the transparent electrodes.

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