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RESEARCH PAPER

Nonlinear Behavior CdS Thin Film Nanoparticles Photoresistor Sensor Changed with Annealing Temperature Preparation By a Thermal Evaporation Technique

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ABSTRACT

A study of the effect annealing on some structural, optical and electrical properties of pure CdS films on glass bases with thickness 150nm using thermal evaporation technique under pressure ($4*10^{-5}$)Torr. Structural properties were studied using X-ray diffraction technology the CdS films were shown to have a polycrystalline structure of the cube type and the preferred path [111], also increases grain size with increasing annealing temperature. In the study of Hall Effect, we observed the mobility increases with increasing annealing temperature. From the study, the relationship between bias voltage and current we observed the current increases with increased annealing temperature and the intensity of light falling on photo resistor .the current of the photo resistor is doubling with the double intensity of light falling.

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INTRODUCTION

Cadmium sulfide compound belongs to (Π-IV) groups in the periodic table .crystalline structure of cadmium sulfide (cubic) or (hexagonal) depending on how prepared the films [1]. Cadmium sulfide (CdS) has a direct energy gap about (2.42 ev) at the temperature ($300K^0$) [2]. Cadmium sulfide (CdS) semiconductor compound of n-type and can be converted to p-type by adding copper atoms (Cu) or Indium atoms (In) [3]. Photo resistor sensor made of semiconductor materials with high resistance in the dark. It arrives in several mega ohms. While in light have resistance arrives in a few hundred ohms. such cadmium sulfide (CdS) [4] making it suitable for photo electronic and electronic application [5,6].when the photons that incident on the photo resistor have enough energy, the electrons jump to conduction band as result increased conductivity and decrease resistance. The photo resistivity depending on ambient temperature, making it unsuitable for applications requiring high sensitivity to photons [7] .one common application of photo resistor sensor is streetlight control [8] there are many techniques for deposition of cadmium sulfide thin films [9, 10], one of the most important techniques used is thermal evaporation technology [11, 12, 13] because it is simple and easy to use.

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MATERIALS AND METHODS

The samples were prepared by the method of thermal evaporation of CdS with high purity (99.999%) on the glass substrates, cleaned by distilled water and alcohol then dried with filtration paper and passes a dry air current by the blower. Before deposition of the thin film, deposition electrodes from the aluminum material and using appropriate masks on the substrate using (Edward 306, coating unit) device, the samples are placed at a distance of 18cm from the boat. The thickness of the 150 nm prepared films was calculated by the approximate weight method before precipitation and according to the following Eq. 1:

$$m = 2\pi r^2 \rho t \qquad (1)$$

r^2 Is the distance between the source (boat) and the Samples ρ is the density of the material.

t: is the thickness of the film. After the preparation, the thickness was calculated by using the reflector spectrometer to confirm the thickness .then the CdS thin films were annealing to(150,300 °C) in the air for two hours .after annealing deposited electrodes from the aluminum material on the CdS films to preparation of photoresistor by using special masks under pressure(4*10-4 Torr). The photoresistor is placed within an electric circuit containing Ammeter and power supply to measure the current of darkness. The photoresistor put under the light source, then took a measurement of the current for various intensities of the light

RESULTS AND DISCUSSION

The results include x-ray diffraction of CdS thin films and results of Hall Effect measurements and some optical properties. By using X-Ray diffraction technique of prepared CdS thin films with (150) nm found that the CdS films have a polycrystalline structure of the cubic type and the dominant orientation of growth is [111]. Figs. 1-3 shows X-Ray diffraction of CdS thin films prepared by thermal evaporation method and we observe (FWHM) decreased after annealing. The grain size increases with increasing annealing temperature, this is due to improved structural properties of the films and reduction grain boundaries [14] this leads to less resistance

Hall Effect measurement was conducted at room temperature to determine the type and concentration of majority charge carriers .the measurement of the Hall coefficient shows that the films are n-type. Also measuring the effect of hall showed an increase in mobility with increasing annealing temperature as a result of improved structural properties and reduction of grain boundaries, this leads to increased conductivity after annealing. By studying the transmittance spectrum of CdS films we observe that the energy gap decreases with increasing annealing temperature as shows in Fig. 4 and increasing the absorbance of the UV- visible spectrum as shown in

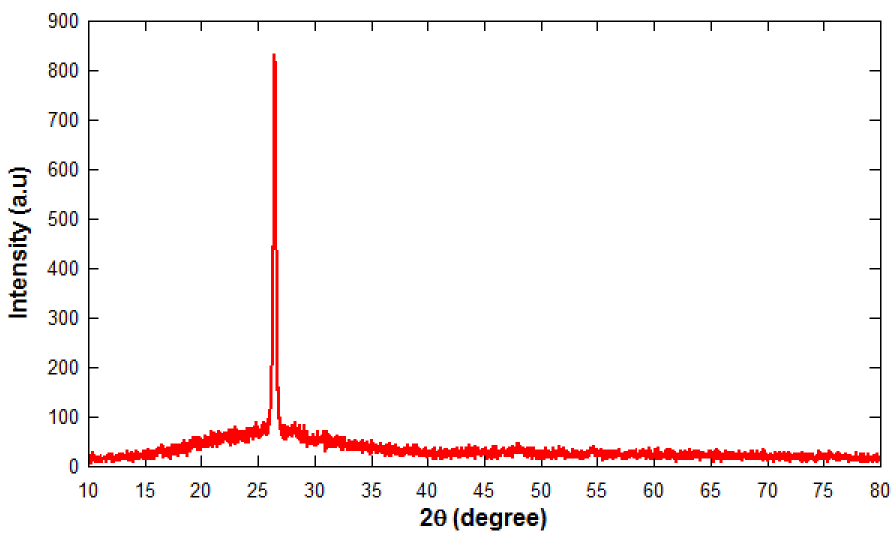

Fig. 1. X-ray diffraction of CdS films.

Fig. 5.this is due to improved structural properties after annealing where (AFM) measurement showed an increase in surface roughness rate with increasing annealing temperature ,this leads to increase scattering at surface of the CdS films , decreased transmission and increased absorption

Fig. 6 shows the relationship between current and applied voltage in the darkness and light. we observe the resistance decreases with increasing intensity of light falling on the photoresistor. If energy photons fell the largest of the energy gap of CdS. the electrons will absorb the photons and transit from the valence band to conduction band, and at the same time will generate holes in the valence band .the electron-hole pairs generated by increasing the light falling .this leads to decrease the resistance of the semiconductor material

After annealing the current increases at the same intensity as the falling light this is due to increased mobility of charge carriers which leads to increased conductivity and decreased resistance as shows in Figs. 7 and 8. From Figs. 7 and 8 we observe the current doubles when the intensity of light multiplies.

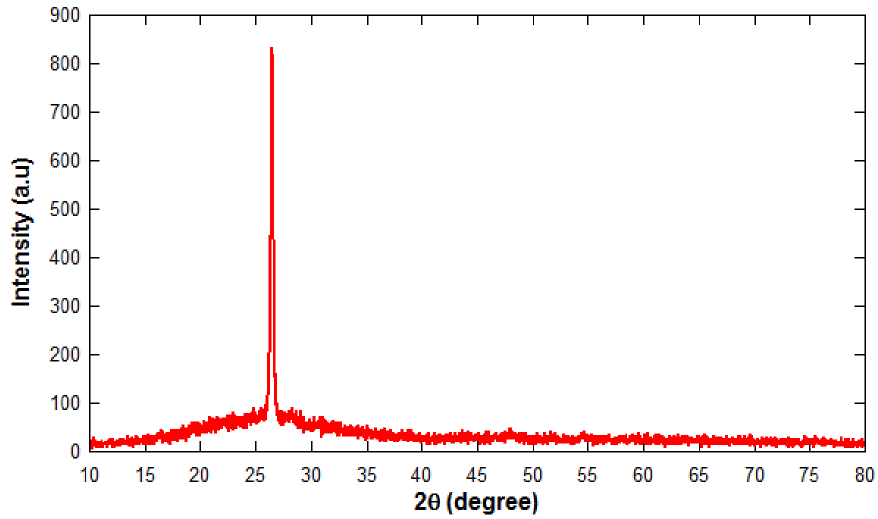

Fig. 2. X-ray diffraction of CdS films at (150°C) annealing

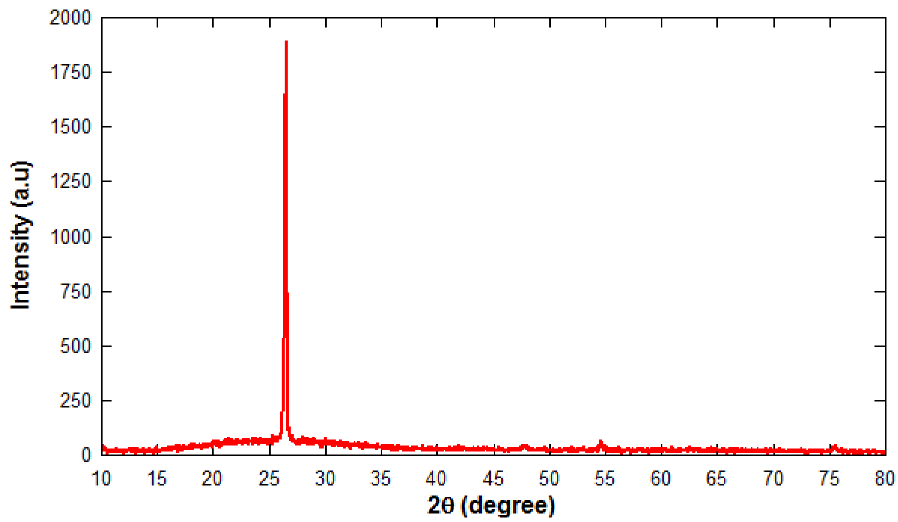

Fig. 3. X-ray diffraction of CdS films at annealing (300 °C)

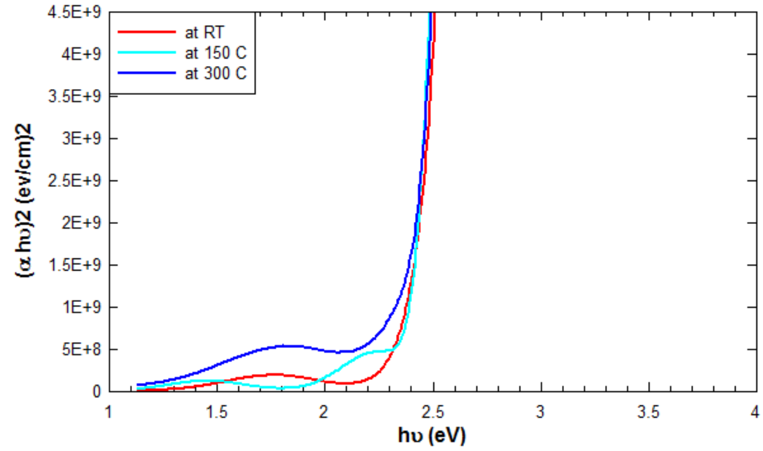

Fig. 4. Energy gap of CdS films

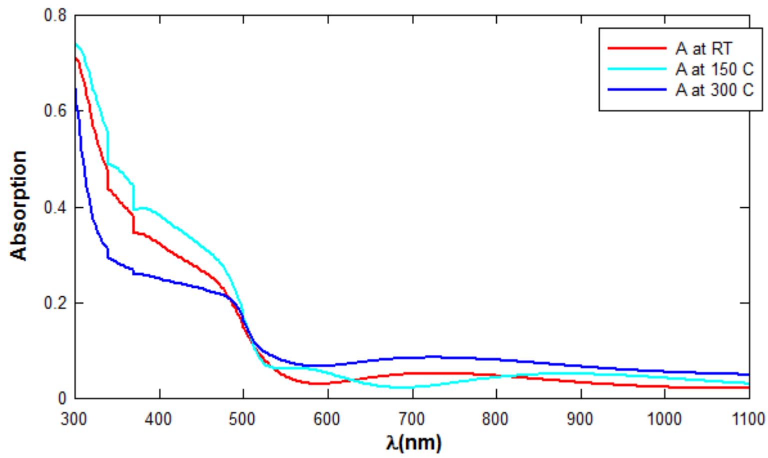

Fig. 5. Absorbance of CdS

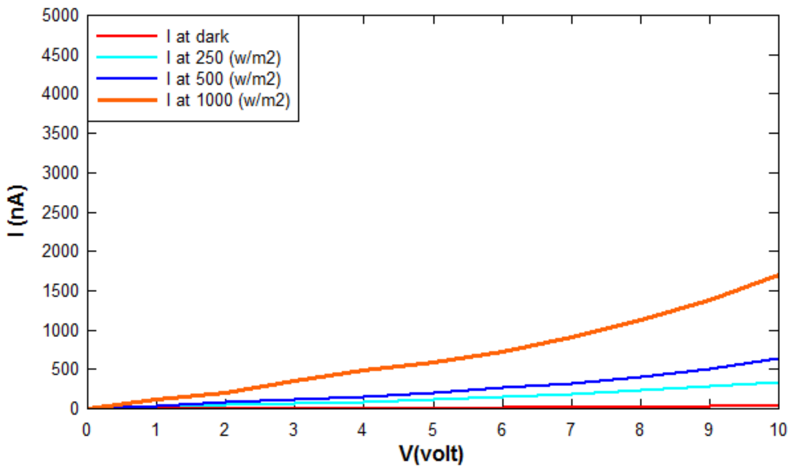

Fig. 6. Relationship between applied voltage and current

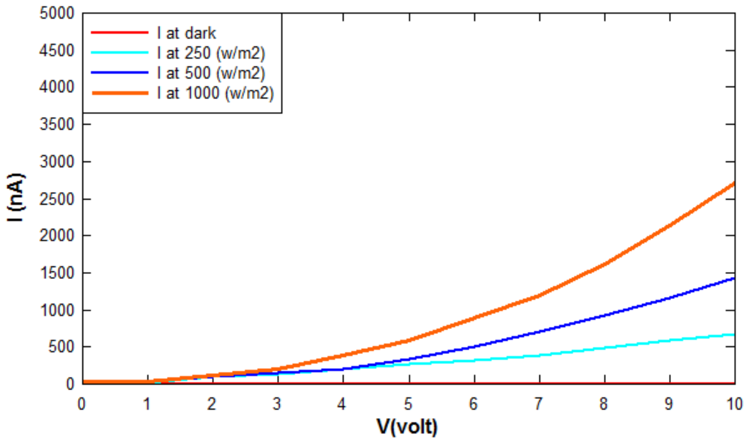

Fig. 7. Relationship between voltage and current at annealing (150 °C)

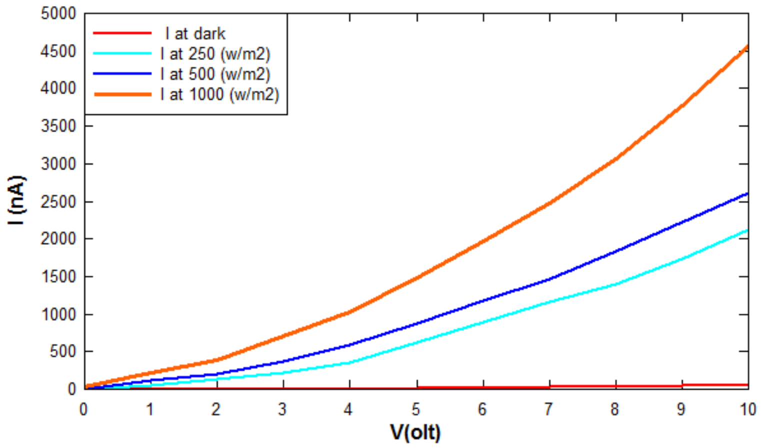

Fig. 8. Relationship between voltage and current at annealing (300 °C)

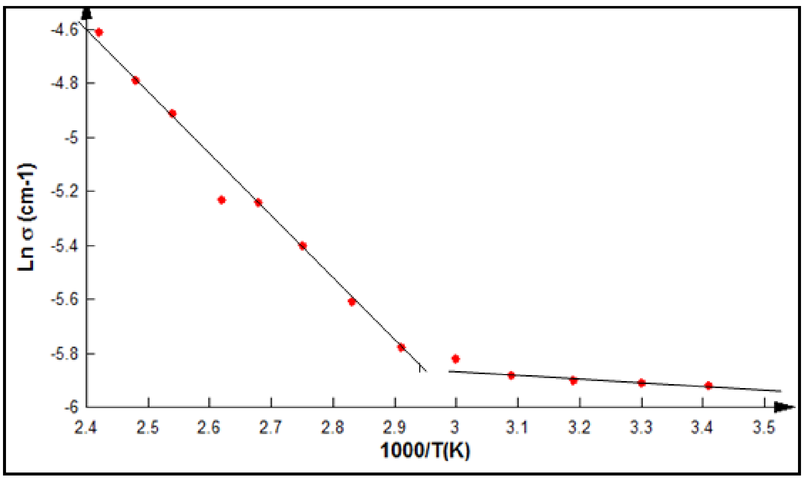

Fig. 9. Change (Lnϭ) with (1000/T) of CdS thin film at (R.T)

Electric properties

D.C electric conductivity

The continuous conductivity of CdS films was measured by changing the resistance with the temperature to obtain information on the nature of the mechanism of the conductivity of the CdS films within the thermal range (293-433k) and calculate the activation energy. Fig. 9 shows the relationship between the $\ln\sigma_{d.c}$ of reverse temperature (1000/T), increase continuous electrical conductivity with increasing temperature and this is one of the most important characteristics of semiconductors[5,6]. It is clear from the figure that there are two energies of activation that corresponds to the results of X-ray tests, that is, the films have polycrystalline

Table 1. Activation energy of CdS thin film for various annealing temperatures

Sample	Annealing Temperature	E_{a1} ev	Range K	E_{a2} ev	Range K	σ_{RT} $\Omega^{-1}.cm^{-1}$
	R.T	0.0107	273-323	0.188	333-433	4.34 E-3
CdS	150 °C	0.013	273-323	0.288	333-433	0.138
	300 °C	0.039	273-323	0.208	333-433	0.31

Table 2. Measurement of the Hall effect of the CdS thin film for various annealing temperatures

Sample	Annealing Temperature	R_{H} cm2/c	N_{H} $(cm)^{-3}$	$\sigma_{(\Omega.cm)^{-1}}$	type	μ_{H} $cm^{2}/v.sec$
CdS	RT	-6.636 E+1	-9.406 E+16	9.854 E-1	n	6.539 E+1
	150 (°C)	-3.295E+4	-1.895E+14	2.235E-3	n	7.363E+1
	300 (°C)	-1.352E+7	-4.616E+11	3.000E-5	n	4.056E+2

Table 3. Measurements of the atomic force microscope

Sample	Annealing Temperature	Average Diameter nm	RMS Roughness Nm	Ave Roughness nm
CdS	RT	40.61	2.68	2.22
	150 °C	50.83	6.19	5.27
	300 °C	60.03	6.95	5.7

structure calculated the activation energy from the following Eq. 2 [7]:

$$\sigma_{d.c}=\sigma_0 \exp(-E_a/k_BT) \quad (2)$$

From the conductivity measurement, we observe the continuous conductivity increases with increasing annealing temperature as shows in Table 1.

Hall Effect

Hall Effect measurements were performed at room temperature for pure CdS thin films to determine the type, concentration, and mobility of the majority charge carriers of these films. The test showed that the pure CdS films are N-type, indicating that the majority charge carriers are the electrons and the minority charge carriers are the holes. The reason may be due to the density of the Cd atoms that act as a donor a larger than density S voids. From the measurement of the Hall Effect we observe the Mobility increases with increasing annealing temperature as shows in Table 2. This is due to increase the grain size and thus decrease the grain boundaries.

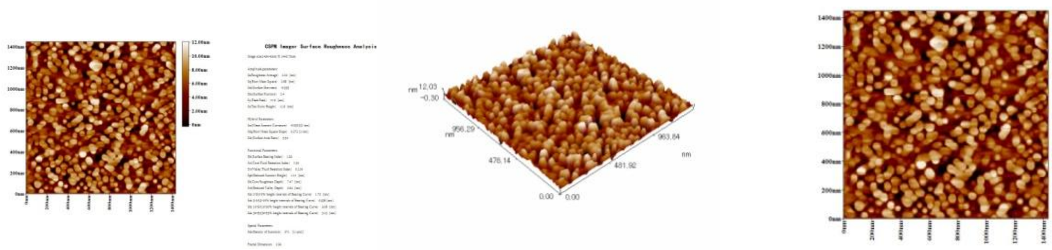

Fig. 10. AFM photos with two dimensions and three dimensions.

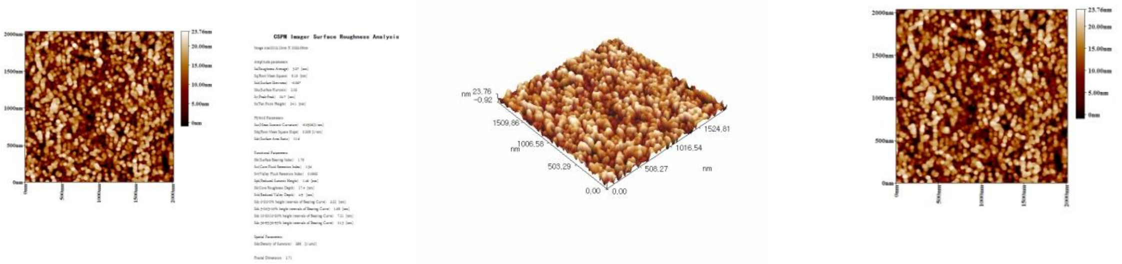

Fig. 11. AFM photos with two dimensions and three dimensions at annealing 150 °C.

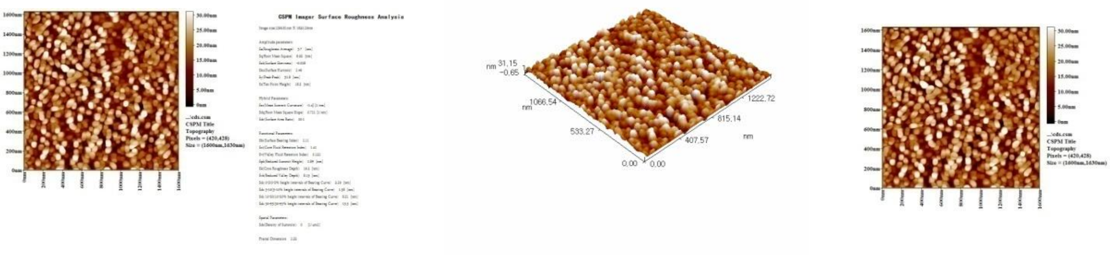

Fig. 12. AFM photos with two dimensions and three dimensions at annealing 300 °C.

AFM Microscopy

The study of the morphology of the surface of the film is a matter to be studied because of its influence on the efficiency of the solar cell manufactured this test gives information

On the rate of granular size and surface roughness and the rate of square root roughness for different annealing temperature as in Table 3 well as giving images in two dimensions and three dimensions as in Figs. 10-12. We observe from the analysis of AFM the grain size, RMS, and average roughness increase with increasing annealing temperature.

Optical properties

The transmittance and absorbance of CdS film was recorded within the wavelength (300-1100nm) The Fig. 13 shows the transmittance as a function of the wavelength where it increases by increasing the wavelength, pure CdS films show good transparency in the visible and near-ultraviolet region where the transmittance is about 80%.but the transmittance decreases with increasing annealing temperature. As shown in Fig. 13.

Fig. 14 shows that absorption decreases with increasing wavelength for different annealing

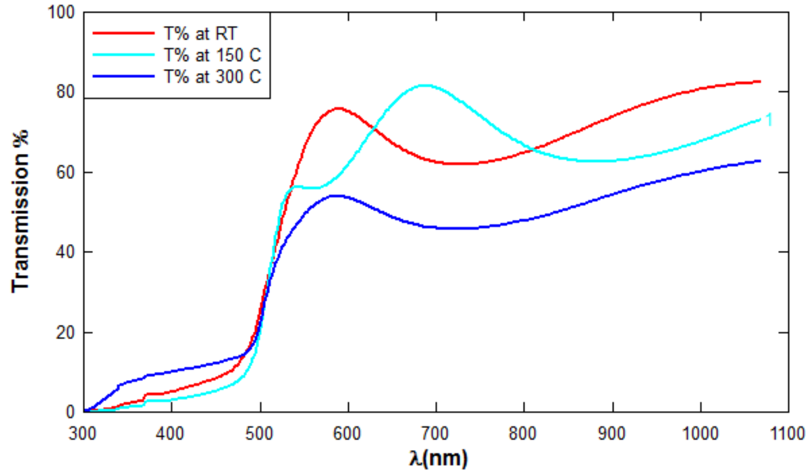

Fig. 13. Transmission of CdS film.

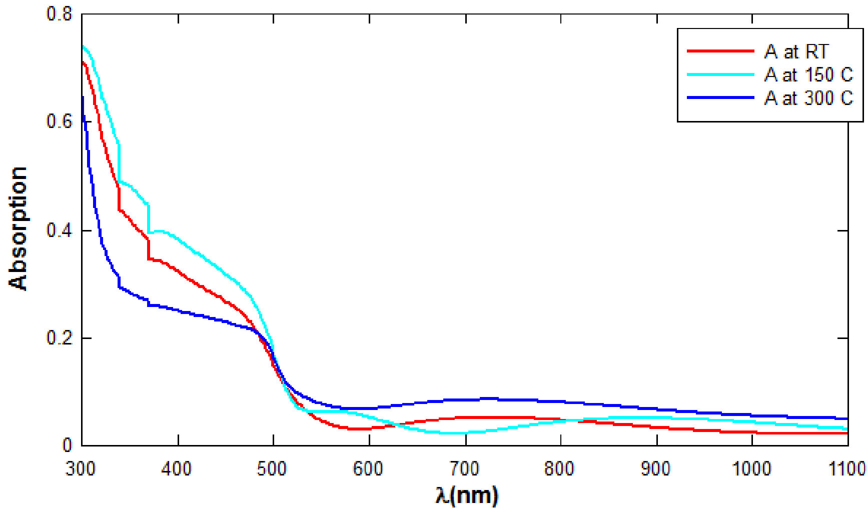

Fig. 14. The Absorption as a function of the wavelength.

temperature. This is due to the low energy of falling photons and their inability to promote the electron from the valance band to the conduction band [9].

The absorption coefficient was calculated from the following Eq. 3 [10]:

$$\alpha = \frac{2.303A}{t} \quad (3)$$

A: is the Absorbance, t: thickness

It is noted from the Fig. 15 That the CdS films have a high absorption coefficient and this indicates direct electronic transitions [11]

The energy gap is one of the most important optical constants that depend on the physics of semiconductors to manufacture electronic devices such as solar cells, optical detector, optical diodes and others .The energy gap of pure CdS films was calculated by plotting the relationship betwee $(\alpha h\upsilon)^2$ and $h\upsilon$ as in Fig. 16 and from the straight line extension of the curve and its intersection with the x-axis we obtain the energy gap of the CdS films, the energy gap was found to be equal to (2.4) ev at room temperature .The creases to (150, 300 °C) respectively. This value is close to that of a previous study [1energy gap of CdS thin film decreases to (2.38, 2.32ev) when the annealing temperature in [2].

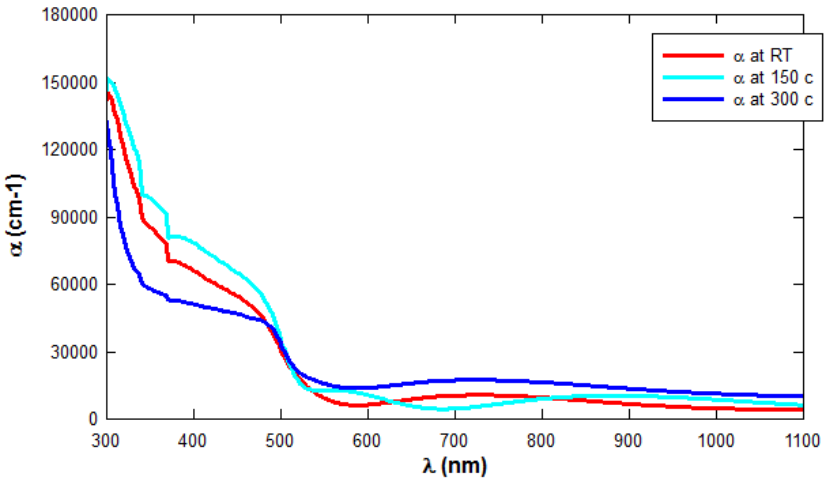

Fig. 15. The absorption coefficient as function wavelength

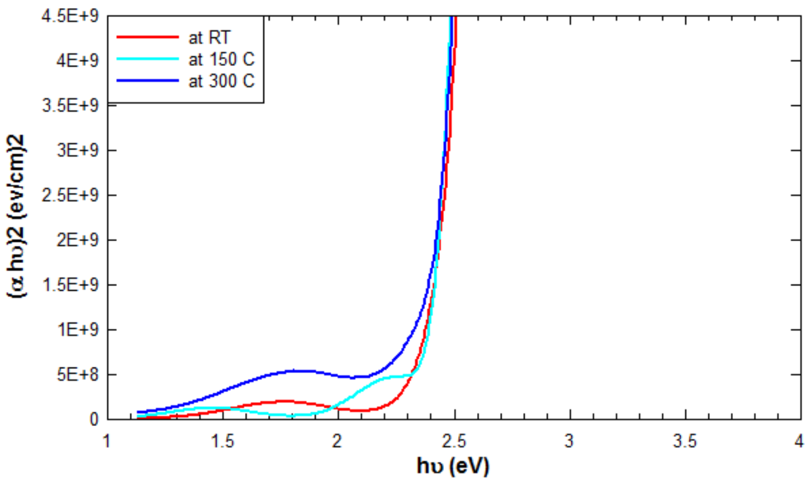

Fig. 16. Relationship between $(\alpha h\upsilon)^2$ and $h\upsilon$.

The equation (4) shows that the coefficient of extinction is related to the absorption coefficient. Through equation, the coefficient of extinction of the CdS films can be calculated:

$$k = \frac{\alpha\lambda}{4\pi} \tag{4}$$

Fig. 17 shows the change in the coefficient of extinction as a function of wavelength.

The refractive index was calculated from equation (5). We observe that the refractive index is associated with the coefficient of extinction and reflectivity, Note from the Fig. 18 that the refractive index increases with increasing annealing temperature.

$$n = [(\frac{4R}{(R-1)^2})^{1/2} - k^2 - \frac{(R+1)}{(R-1)}] \tag{5}$$

The interaction between light and medium charges is due to the process of absorption of energy in the material and then the polarization process of the charges of that medium. This polarization is usually described as the complex dielectric constant of the medium [13]The real

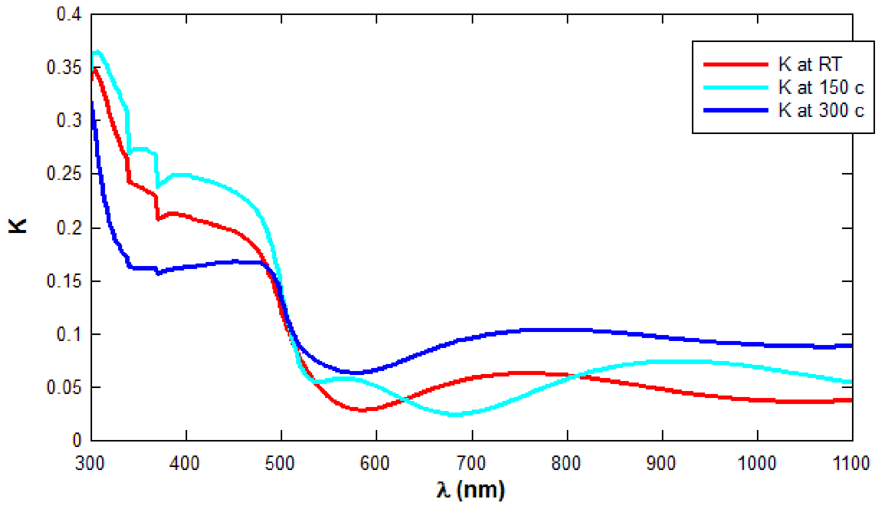

Fig. 17. The extinction coefficient as a function of the wavelength.

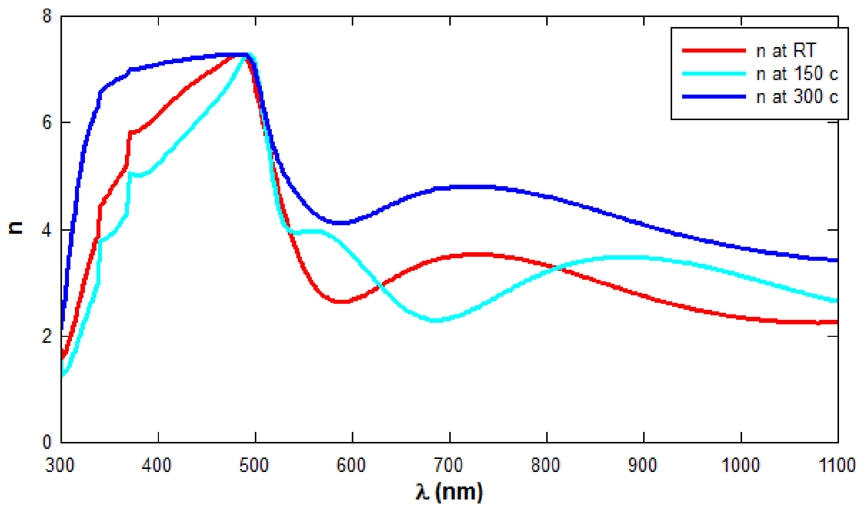

Fig. 18. The refractive index as a function of the wavelength.

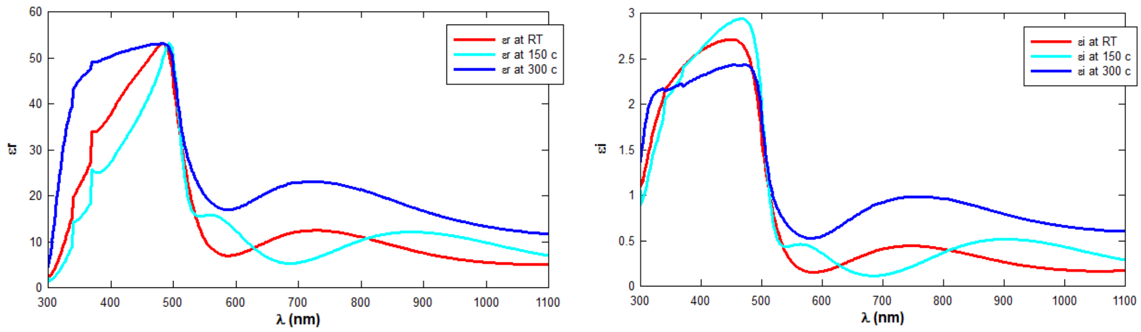

Fig. 19. (a): The real dielectric constant as a function of the wavelength,(b): The imaginary dielectric constant as a function of the wavelength

and imaginary dielectric constant of the CdS films was calculated by Eqs.6 and 7):

$$\varepsilon_r = n^2 - k^2 \quad (6)$$

$$\varepsilon_i = 2nk \quad (7)$$

We observe from Figs. 19 a and b general indication that the dielectric constant in real and imaginary parts decreases with increasing wavelength

CONCLUSION

In this research was reached the most important the following conclusions

1-The pure CdS film is prepared by thermal evaporation in a vacuum Polycrystalline is a cubic type and the dominant orientation of growth is [111].

2-CdS films have high resistance decreases with increased intensity of light falling on the photoresistor.

3-The resistance of CdS films decreases with increasing annealing temperature.

4-The annealing temperature leads to an improvement in the properties of the photoresistor sensor.

5-The current of photoresistor is doubled with doubling the intensity of the falling light.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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