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Depending the Structure and Optical Properties of Cadmium Telluride Films on the Doping Process

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Abstract

The purpose of the present paper is to study the effect of doping by different materials on the structure and the optical properties of Cadmium Telluride films which prepared by rate deposition ($4.21 \text{ nm}^n/\text{sec}$) and thickness ($\approx 200 \text{ nm}$) in vacuum by use thermal evaporation technique at a substrate temperature (300K), we are studying the effect of doping by different material (Antimony, Aluminum and Silver) on the structural¹ and optical² properties of CdTe thin films. The structural properties of these films have been studied by using X-ray diffraction methods. The optical measurements indicated that Cadmium Telluride films have a direct optical energy gap (E_g^{opt}), and it decreases when we doped this films by different materials (Sb, Al and Ag) with the same ratio doping. The optical constants refractive index (n), extinction coefficient (k), absorption coefficient (α) and dielectric constants (ϵ_r and ϵ_i) were also studied.

Keywords: CdTe, ⁴Films, ⁴Structural, Optical, Hall⁴Effect, Doping, Thermal⁴Evaporation.

الخلاصة

ان الهدف من البحث هو دراسة تأثير التطعيم بمواد مختلفة على الخواص التركيبية والبصرية لاغشية الكاديوم ترايد المحضرة بمعدل ترسيب 4.2 nm/sec وبسمك 200 nm بالفراغ باستخدام تقنية التبخير الحراري في درجة حرارة اساس 300 K , لقد تم دراسة تأثير التطعيم بمواد مختلفة هي (الانتيمون. الالمنيوم. والفضة) على الخواص التركيبية والبصرية لاغشية CdTe. لقد تم دراسة الخواص التركيبية لهذه الاغشية باستخدام طريقة حيود الاشعة السينية. ان القياسات البصرية تشير الى ان لاغشية CdTe فجوة طاقة (E_g^{opt}) مباشرة ونقل قيمتها عند تطعيمها بهذه المواد المختلفة (Sb, Al and Ag) عند معدل ترسيب متساوي. كذلك تم دراسة الثوابت البصرية: معامل الانكسار (n). معامل الخمود (k). معامل الامتصاص. وثوابت العزل (ϵ_r . ϵ_i).

Introduction

Cadmium telluride (CdTe_2) is a significant compound semiconductor belonging to cadmium chalcogenides among II–VI compounds which makes it important and quite suitable for several applications of photovoltaic semiconductor devices as it may exhibit both n- and p-types conductivity [1][2].

CdTe is one of the most promising polycrystalline materials for thin film solar cells due its physical properties, it has a direct band gap in the range (1.4 – 1.5) eV that it vary with various dopant concentrations, which is near the maximum solar energy conversion point, just

in the central of the solar spectrum, and processes high absorption coefficient (α) ($>10^4 \text{ cm}^{-1}$) for the visible solar spectrum [3].

Several deposition methods were employed for the deposition of CdTe thin films such as, spray pyrolysis [4], close space sublimation [5], sputtering [6], electron beam evaporation [7], reaction method and vacuum evaporation [8] which often favorite because it offers large possibilities to modify the deposition condition. CdTe is an important compound for laser heterostructures and photovoltaic solar cells, IR and γ detectors, field effect transistors, optical thin film filters [9].

Materials and Methodology

The samples of Cadmium Telluride doped with (Antimony, Aluminum and Silver) were prepared by thermal co-evaporation technique using coating unit in a vacuum about 2×10^{-5} Torr. A specific weight of Cadmium Telluride powder must be taken and put it in a molybdenum boat, after that we take different materials (Sb, Al and Ag) with the same ratio (0.5%) from this weight of these materials and put it in the other molybdenum boat. The rate of evaporation was ≈ 50 nm/min and the film thickness in the range of (200nm) was measured by interference method. And the substrate glass was placed directly above the source at a distance of nearly 18 cm after cleaning the glass.

The optical band gap E_g can be estimated from the following relation known as the Tauc relation [1]:

$$\alpha h\nu = B(h\nu - E_g)^n \quad (1)$$

Where B is a constant, ν is the transition frequency and the exponent n characterizes the nature of band transition. $n = 1/2, 3/2$ corresponds to direct (allowed and forbidden) and $n = 2, 3$ corresponds to indirect (allowed and forbidden) transitions, respectively. Of all the films the best straight line is obtained for n equal to $1/2$, which is expected to direct allowed transitions.

The optical constant absorption coefficient (α), refractive index (n), extinction coefficient (k) and real (ϵ_r) and imaginary part (ϵ_i) of dielectric constant can be calculated from the following equation [10].

$$\alpha = 2.303 \frac{A}{t} \quad (2)$$

Where (t) is the film thickness and (A) is the optical absorbance.

$$k = \frac{\alpha \lambda}{4\pi} \quad (3)$$

Where (λ) is the wavelength of the incident radiation and (k) is the extinction.

$$\epsilon_r = n^2 - k^2 \quad (4)$$

$$\epsilon_i = 2nk \quad (5)$$

Where (n) is the refractive index was obtained from the following relation [2].

$$n = \left[\frac{4R}{(R-1)^2} - k^2 \right]^{1/2} - \frac{(R+1)}{(R-1)} \quad (6)$$

Where R is the reflection.

Hall Effect 5 measurements have been managed by Van der Pauw (Ecopia HMS -3000) to determining type of carrier, their mobility and carrier concentrations in thin films.

Result and Discussion

Figure 1 shows the XRD spectra obtained of Cadmium Telluride and doped one with different material (Antimony, Aluminum and Silver) films. The XRD pattern for CdTe and CdTe doped with 0.5% of different materials (Sb, Al and Ag) thin films shows a polycrystalline structure of all samples.

The peaks represent is cubic structure having zinc blend type with atomic prevalent growth direction peak at [111]. We notice decreases in value of intensity peak at [220], [311], while at [111] we find increases in value of intensity peak for the samples before and after doping. This may be due to improving the crystalline structure after doping with different material. This result agrees approximately with the result reported by [11] [12]. This Figure indicates According to the American standard for testing materials (ASTM) cards. The crystallite size has been estimated of the FWHM value of the (111) peak by using Scherrers equation and is observed it increased with doped this films by different materials (Sb, Al and Ag) with the same ratio doping as shows in Table 1.

Table 1: X-ray diffraction data for CdTe films before and after doping with different materials (Sb, Al and Ag).

Sample	hkl	2 θ (Deg.) Observed	d_{hkl} (Å) Observed	FWHM (Deg.)	C.S (nm)
CdTe	111	23.755	3.738		
	220	39.307	2.285	0.292	29.27
	311	46.429	1.951		
CdTe: Sb	111	23.752	3.736		
	220	39.320	2.289	0.250	33.91
	311	46.418	1.953		
CdTe: Al	111	23.758	3.745		
	220	39.322	2.286	0.210	40.37
	311	46.450	1.953		
CdTe: Ag	111	23.768	3.737		
	220	39.330	2.294	0.185	45.834
	311	46.432	1.949		

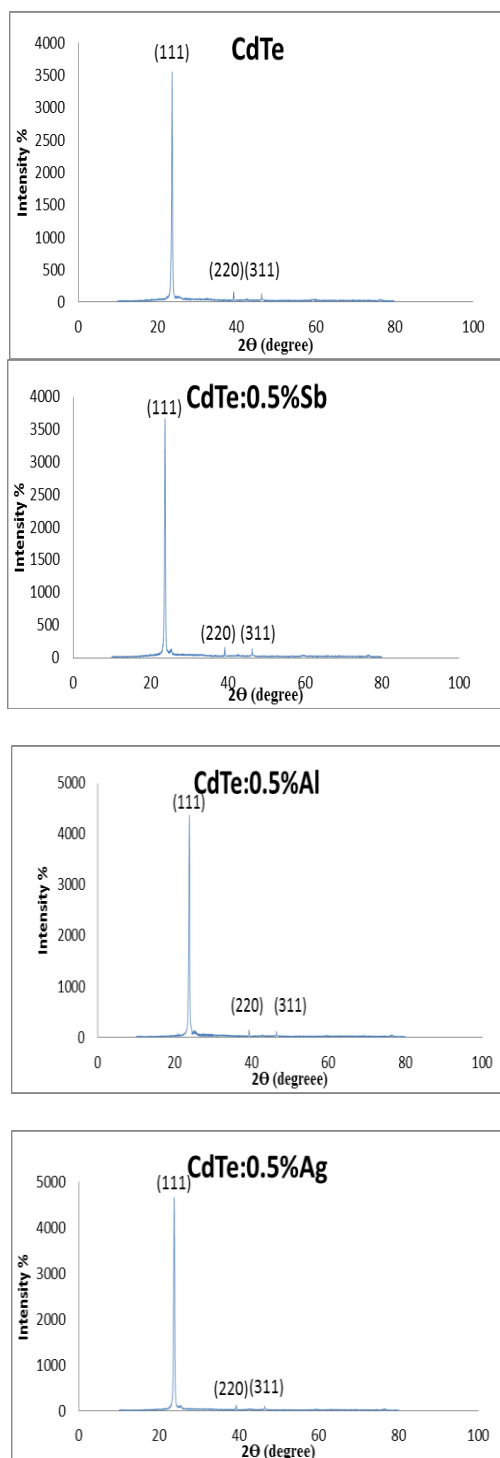


Figure 1: XRD patterns of CdTe thin films before and After doping by different materials (Sb, Al and Ag).

Figure 2 shows the AFM images of three-dimensional (3D) surface morphology of CdTe and doped one with different material (Antimony, Aluminum and Silver) thin films. The values of surface roughness⁶ and the grain siz-

es¹ are calculated. The grain³ size has been observed (88, 104, 120 and 140) for pure CdTe thin films and doped with different materials (Sb, Al and Ag) respectively¹ as shown in Table 2. This is also supported by the X-ray diffraction data. Therefore, the average diameter of CdTe:Ag thin film⁷ (see Figure 2) is larger⁹ than the other thin³ film.

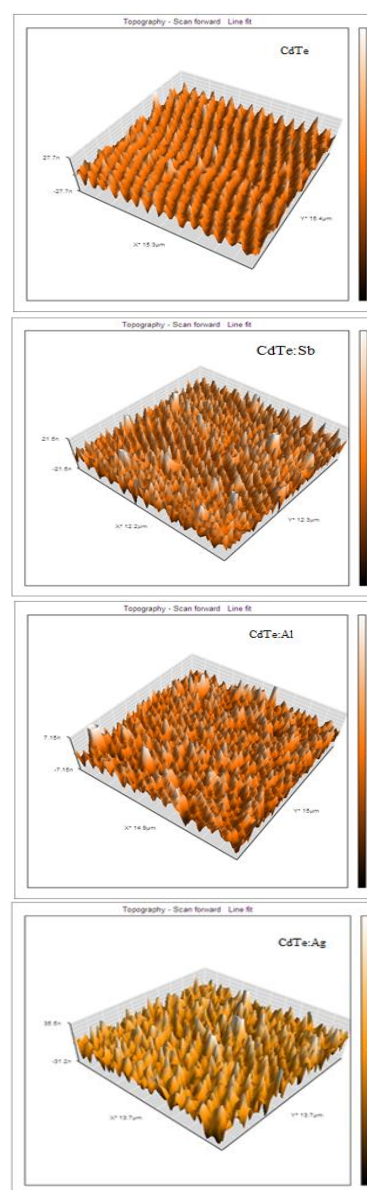


Figure 2: 3D Atomic force microscopy (AFM) of CdTe thin films before and after doping by different materials (Sb, Al and Ag)

Table 2: The average grain size (G.S) and the roughness of CdTe films before and after doping with different materials (Sb, Al and Ag)

Sample	Grain size (G.S) (nm)	Roughness average (nm)	r.m.s (nm)
CdTe	88	6.70	8.75
CdTe:Sb	104	8.19	10.31
CdTe:Al	120	9.55	12.04
CdTe:Ag	140	11.78	15.95

The optical energy gap values (E_g) for all samples doped and un doped of Cadmium Telluride films have been determined. A plot of $(\alpha h\nu)^2$ versus photon energy for CdTe films at different doping materials (as prepared, Antimony, Aluminum and Silver) is shown in Figure 3 and Table 3. The plot is linear, indicating as the direct band gap nature of the film. Extrapolation of the line to the photon energy axis gives the band gap. The values of the optical energy gap for CdTe films have the value (1.58, 1.56, 1.55, 1.52) eV when we change the doping materials (un doped, Sb, Al and Ag), respectively. This is due to the increase of the density of localized states in the E_g , which causes a shift to lower values. This result agrees approximately with the result reported by [13] [14] [15].

Table 3: The optical properties parameters of CdTe films before and after doping with different materials (Sb,Al and Ag) when $\lambda=700$ nm.

Sample	E_g (eV)	$\alpha \times 10^4$ (cm ⁻¹)	n	k	ϵ_r	ϵ_i
CdTe	1.58	7.292	9.47	0.40	89.6	7.698
			0	6	22	
CdTe:Sb	1.56	8.321	9.30	0.47	86.4	8.840
			7	4	04	
CdTe:Al	1.55	9.595	8.88	0.53	78.6	9.504
			6	4	83	
CdTe:Ag	1.52	10.670	8.32	0.59	68.9	9.900
			4	4	37	

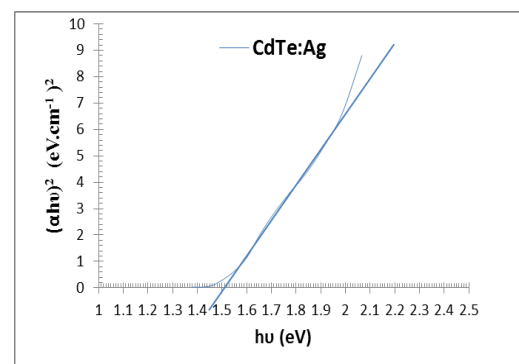
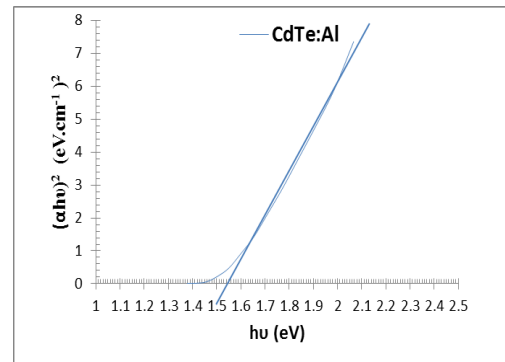
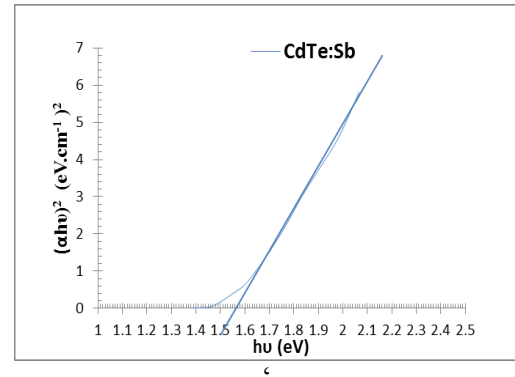
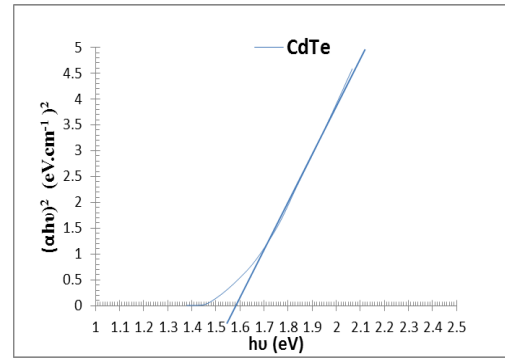


Figure 3: Variation of energy gap of CdTe thin films before and after doping by different materials (Sb, Al and Ag)

Figure 4 refers to the transmission for (CdTe, CdTe:Sb, CdTe:Al and CdTe:Ag) films in the range between (300-1000) nm. The transmittance spectra show a decrease when we change

the doping materials (un doped, Sb, Al and Ag), respectively because of the effect of impurity atoms, which is working on the composition of localized levels in the energy gap. This result similar to the result described by [15].

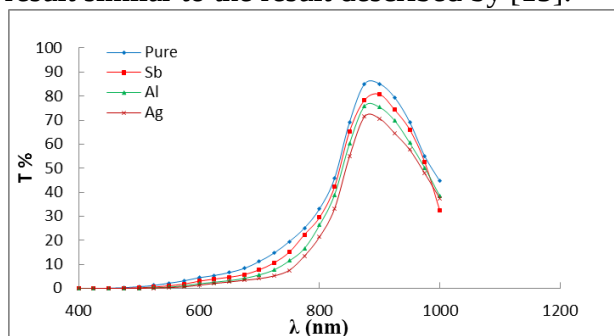


Figure 4: The optical transmission of CdTe thin films before and after doping by different materials (Sb, Al and Ag)

The absorbance spectrum of CdTe films before and after doping is shown in Figures 5. The absorbance spectrum shifts to longer wavelengths with use several of doping materials for all the samples and the absorbance increases after doping with several materials (Sb, Al and Ag), respectively, and this may be due to improving the crystallite size and decreasing the transmittance, which agree with the results obtained from [15].

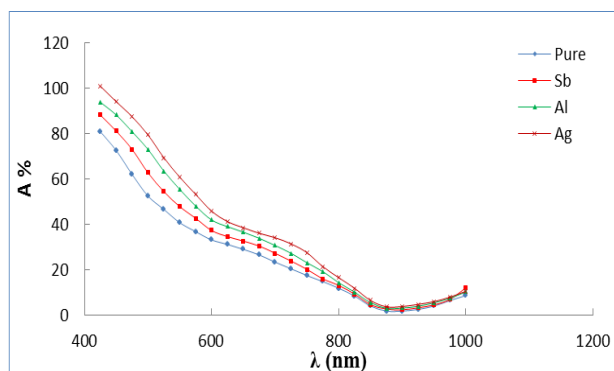


Figure 5: The absorbance spectrum of CdTe thin films before and after doping by different materials (Sb, Al and Ag)

From Figure 6 we can see the behavior reflectance spectrum of Cadmium Telluride films doped with different materials (Sb, Al and Ag) as a function of wavelength. From this figure we can observe increasing of reflectance with as a function of the wavelength of short wave-

length, but at long wavelength we can see decreasing reflectance with increases the wavelength. This result similar to that reported in reference [15].

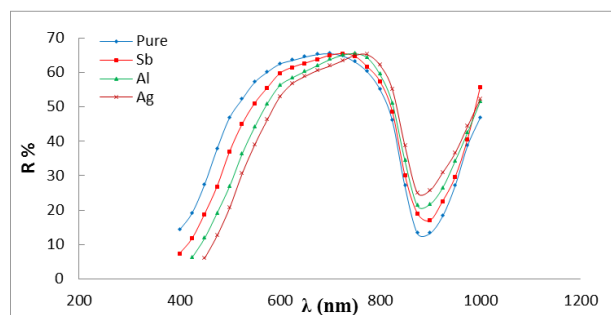


Figure 6: The reflectance spectrum of CdTe thin films before and after doping by different materials (Sb, Al and Ag)

We can notice that the absorption coefficient (α) for (CdTe, CdTe:Sb, CdTe:Al and CdTe:Ag) films in general increases after doping with the used materials (Sb, Al and Ag), respectively. This behavior is presented in Figures 7 and this result agrees with that obtained from [15].

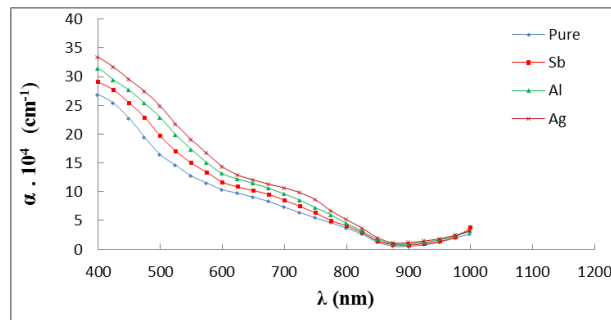


Figure 7: The absorption coefficient of CdTe thin films before and after doping by different materials (Sb, Al and Ag)

Figure 8 shows the variations in refractive index (n) as a function of wavelength for all samples. The refractive index increases after doping with several materials (Sb, Al and Ag), respectively because increase the energy level in forbidden gap and this result agree with the results obtained from [15].

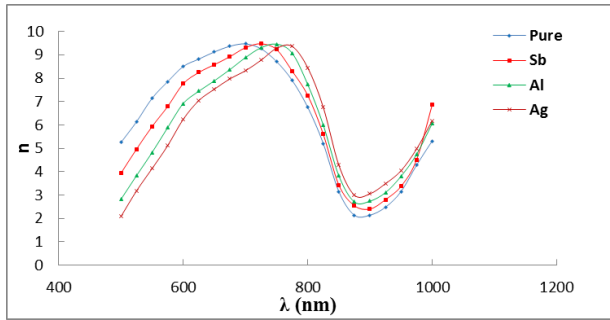


Figure 8: The variations in refractive index of CdTe thin films before and after doping by different materials (Sb,Al and Ag)

The extinction coefficient (k) increases with the various doped elements (Antimony, Aluminum and Silver) respectively as shown in Figure 9 and this may be due to increasing the absorption coefficient which shown in Figure 7.

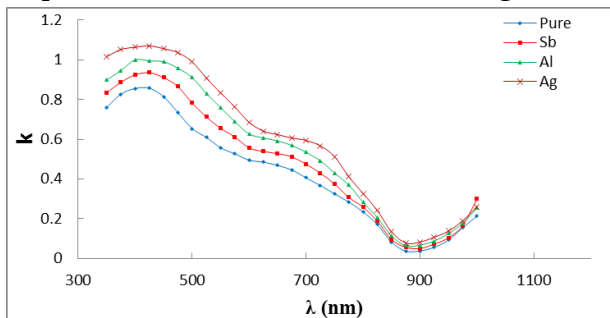


Figure 9: The extinction coefficient of CdTe thin films before and after doping by different materials (Sb,Al and Ag)

The dielectric constant real part (ϵ_r) and imaginary part (ϵ_i) of Cadmium Telluride doped with several materials (Antimony, Aluminum and Silver) films respectively are shown in Figure 10 and in Figure 11 corresponds. We can notice the increasing of both dielectric constant real part and imaginary part when we change the materials of doping (Antimony, Aluminum and Silver) corresponds for the films. This increasing for the real part (ϵ_r) attributed to the same reason mentioned previously in the refractive index, while the increases of imaginary part (ϵ_i) due to the similar interpretation discussed previously for the extinction coefficient.

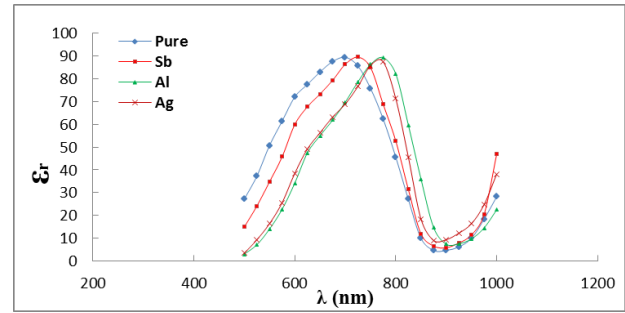


Figure 10: The dielectric constant real part of CdTe thin films before and after doping by different materials (Sb,Al and Ag)

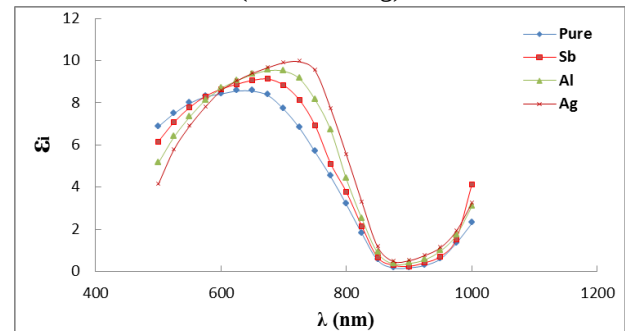


Figure 11: The imaginary part real part of CdTe thin films before and after doping by different materials (Sb,Al and Ag)

The films were electrically characterized using Hall Effect measurements. All films showed n-type conductivity during the Hall Effect measurement and this indicates that the charge carriers are electrons. The results of Hall Effect measurements are summarized in Table 4. The obtained values of mobility are interestingly lower than the reported values [16] while electron concentrations the values are comparable.

Table 4: Hall parameters for CdTe films before and after doping with different materials (Sb, Al and Ag).

Sample	$R_{(H)}$	$\mu_{(H)}(\text{cm}^2/\text{V.S})$	$N_D(\text{cm}^{-3})$
CdTe	-1066553	9.695935	5.86E+12
CdTe:Sb	-815926.9	10.4606	7.66E+12
CdTe:Al	-320512.8	10.68376	1.95E+13
CdTe:Ag	-96153.85	54.01901	6.5E+13

Conclusions

The effect of change doping material on the structure and optical properties of CdTe thin films deposited by thermal evaporation technique were studied. The structure of all films at

different doping ratio is cubic structure having a zinc blend type, the films show a direct optical energy gap (E_gopt), and it decreases when we change doping materials. All films exhibit high transmittance. The transmittance spectra and show a decrease after doping with several materials (Sb, Al and Ag), respectively, while absorbance spectrum, the absorption coefficient, the refractive index, the extinction coefficient, dielectric constant real part (ϵ_r) and imaginary part (ϵ_i) increases when we use different materials (Sb, Al and Ag), respectively. From Hall Effect all films showed n-type conductivity. So we can use CdTe: (Sb, Al and Ag) films as solar cells or IR window.

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