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Study the effect of thickness and annealing temperature on the Electrical Properties of CdTe thin Films

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Abstract

The electrical properties of polycrystalline cadmium telluride thin films of different thickness (200,300,400)nm deposited by thermal evaporation onto glass substrates at room temperature and treated at different annealing temperature (373, 423, 473) K are reported. Conductivity measurements have been showed that the conductivity increases from 5.69X10^{-5} to 0.0011, 0.0001 $(\Omega.cm)^{-1}$ when the film thickness and annealing temperature increase respectively. This increasing in $\sigma_{d.c}$ due to increasing the carrier concentration which result from the excess free Te in these films.

1-Introduction:

Cadmium telluride (CdTe) is a compound semiconductor with an ideal 1.45 eV band gap for direct light to electricity conversion [1].This optimum band gap and high optical absorption coefficient and optical absorption edge for low cost terrestrial conversion of solar energy. The energy of its band gap located at the maximum of the solar energy density incident on earth's surface makes CdTe very suitable for solar cells applications [2]. Recently, the best small-area CdTe thin film cells manufactured show a conversion efficiency as high as 16% and with 90% absorption of incident light[1,3]. Polycrystalline thin films of CdTe is one of the most promising materials for the fabric-ation of semiconductor devices, such as γ and infrared (IR) detectors, optical and a cousto-optic modulators,photoconductors,spacechar-ge limited diodes and photovoltic devices, field effect transistors and solar cells.In addition, its close lattice match and chemical compatibility with $Hg_xCd_{1-x}Te$ $(0<x<1)$ make CdTe an ideal substrate for growing the variable band gap material for IR detectors. On the other hand, CdTe thin films are among the most suitable materials for passivation $Hg_xCd_{1-x}Te$ based detectors [2-4].

In the 1960, the first CdTe based solar cells with efficiencies of 4-6% were reported by Vodakov et al. [5].

Gogoi and Barua[6] have been studied the d.c conduction mechanism from currentvoltage characteristics of vacuum-deposited CdTe films as a function of film thickness (2500-13000A)at various tempera- tures (0-110^{o}C) in a vacuum of approximately 10^{-2} Torr.

In 1985 Winn and Lyons [7] were studied the structural and electrical properties of CdTe thin films prepared by compound evaporation on to glass substrates held at between 40 and 460^{o}C.They noted abrupt changes in physical properties when substrate temperature equal to 270^{o}C.Adjusting the composition of the reaction mixture and the type of substrate reported by Chu et al [8] can control the conductivity type and electrical resistivity of the film. Dawar et al [9] were produced CdTe thin films deposited by a resistive heating technique. Dc conductivity and Hall coefficient measurements were made on the films irradiate with laser pulses (20 ns) of various energy densities. Mendolia and Lemoine [10] investigated the deposition rate dependence of the electrical and optical pro-perties for CdTe thin films evaporated on cold substrate.

In 1989 Padamand and Malhotra[11]have been prepared CdTe thin films on different substrates by using the effect of dopant and ambient temperature in the range $293<T<98K$ on dc electrical conductivity and on Seebeck coefficient of CdTe were studied by Mostafa [12].

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Bayhan and Ercelebi [13] were studied the influence of post deposition treatments on the CdTe,CdS thin films electrical properties and the efficiency of CdS/CdTe heterostructures.In 2002 Al-Dhafiri[2] was studied the influence of isothermal and isochronal heat treatment on the structural and electrical properties of CdTe thin films grown by thermal evaporation technique.

Lee et al [1] were studied the strutural, electrical, and optical properties of CdTe films prepared under different growth temperatures lower than 300 ^{o}C.The effects of the growth temperature of CdTe films on the photovoltaic properties of CdS/CdTe solar cells were also investigated. Ubale et.al. [14] in 2006 have been study the structural, optical and electrical properties of CdTe films. They found that the resistivity to be of the order of $4.11X10^3$ (Ω.cm) at 523 K with an activation energy of 0.2 eV.

The efficiency of CdTe thin film devices is strongly affected by the electrical characteristics of these films. So that, in this article, combined studies of dc conductivity and Hall effect under varying annealing temperature with different thickness of thin CdTe polycrystalline films are presented.

2-Experimental:

The alloy of CdTe was prepared from their elements, cadmium and tellurium (99.999% pure, obtained from Balzers, Switzerland). The films were deposited onto glass substrates at room temperature from a molybdenum boat by thermal evaporation technique with different thickness (200,300,400 nm) in a vacuum of about $2x\ 10^{-5}$ Torr.Thermal evaporation in vacuum is also often used because it offers many possibilities to modify the deposition conditions.The sours to substrate distance was 15cm and the deposition rate was fixed at 2nm/sec.Then the films were provided with suitable masks to deposit the aluminum electrodes after annealing treatments at (373,423,473K)in air for one hour. The electrical contacts were made by fine copper wires soldered to the electrodes by indium using low power soldering iron (30 watt). The d.c conductivity of CdTe films as function of temperature are studied in the range of temperature (300-473K).d.c power supply type PE-1540) and digital electrometer Keithley (616) were used. Hall effect was carried out by using d.c power supply (0-40 volt), and two digital electrometer (Keithley) to measure the passing current (I) and Hall voltage (V_H)that emerge after applied constant transverse magnetic field (B=0.25 Tesla).The Hall coefficient, concentration and mobility of the carrier for films have been determined by using the following equations respectively.

$$R_H = \frac{V_H . t}{I.B} ....(1)$$

$$n = \frac{1}{e.R_H} ....(2)$$

$$\mu_H = \frac{\sigma}{e.n} ....(3)$$

Where t thickness of the sample which is determined using optical interference fringes (fizeau fringes).

3-Results and discussion:

It is well known that the electronic transport properties of the polycrystalline thin films strongly depend on their structure where the x-ray analysis showed that CdTe alloy and thin films prepared at room temperature are polycrystalline and have the cubic zinc blende structure [15]. The study of the temperature dependence of electrical conductivity of such films offers a lot of information on the electrical conduction mechanism in respective films in correlation with their structure.

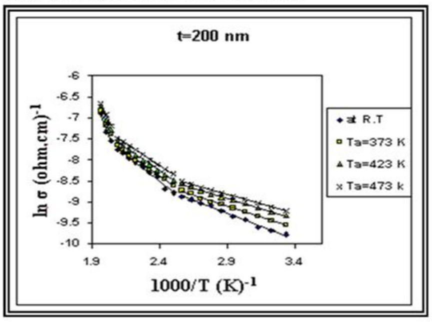
3-1 D.C conductivity:

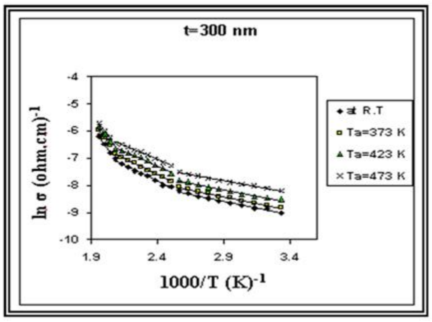
In Fig.(1) the temperature dependence of electrical conductivity are presented within the temperature range (300-473)K,for as deposited and annealing films at different annealing temperature (373,423,473)K for various thickness (200,300,400) nm.From this figure we can note that the plot can not be fitted by a single straight line, this means that the carriers are not simply activated to above conduction edge or states, i.e.,there are three activation energies E_{a1},E_{a2} and E_{a3}.The values of E_a that are calculated from Arrhenius equation $\sigma = \sigma_o \exp(-E_a / k_B T)$

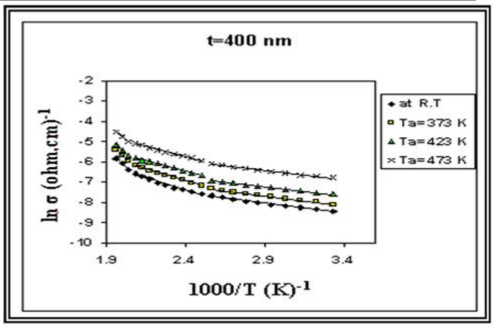
E_a denotes the thermal activation energy of electrical conduction (σ_o) is a parameter depending on the semiconductor nature, and k_B is Boltzman's constant.

The conductivity increase from5.69 X10^{-5}to0.0001,0.0011$(\Omega.cm)^{-1}$with increasing the annealing temperature and thickness respectively.The irreversible temperature dependence of the electrical conductivity for respective films is supposed to be due to the changes in film structure during the annealing process.The annealing films contain a large a mount of free Te atoms not bonded in the CdTe lattice.These free Te atoms trap electrons on their available chemical bond and create acceptor states. In this way, the charge carrier density in these films is greater in comparison with that of the stoichiometric sample.Consequently, the electrical conductivity of the respective films will be greater, fact that explains the greater value obtained for their σ [16].

Fig.(1) The plots of ln σ vs. 1000/T for CdTe films of different thickness and at different annealing temperature.







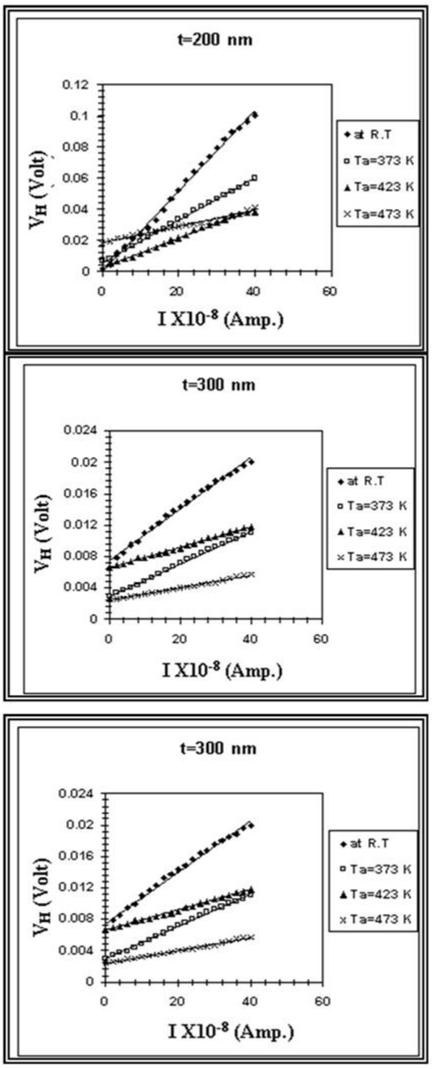
This result coincides with the results of Al-Dhafiri [2] how found that the increase σ with annealing temperature due to increase the excess Te atoms which are usually not bonded in the CdTe lattice. This leads to an enhancement on the density of Te- vacanceies in the CdTe film and, hence of the free carrier concentration. A similar result was reported by Bayhan and Ercelebi[13] have been found that the resistivity of the CdTe films consistently decreases as the annealing temperature and time increasr. Bayhan [5] found that the As-grown CdTe layers were slightly p-type, but highly resistive. Air heat treated layers were p-type and slightly less resistive than as-grown layers.Winn and Lyons [7] found the change in resistivity was attributed to the presence of a conductive tellurium phase for films deposited with T_s<230C.While the increase in conductivity with increasing the film thickness attributed to increase the carrier concentration which led to increase the conductivity.The value of conductivity and activation energy are listed in table (1).

3-2 Hall Effect:

The type of charge carriers of the semiconductor material,concentration and their mobilities have been estimated from Hall measurements.Figs.(2a,b&c)illustrate the relation between Hall voltage (V_H) and the current (I)for CdTe films were deposited on glass substrate at R.T with different thickness (200,300,400)nm and treated at different annealing temperature(373,423,473)K.The type of carrier can be predict from the single Hall coefficient (R_H), since R_H is negative for n-type and positive for p-type.The type of carrier in CdTe films are p-type, i.e.,the holes are predominant in the conduction process.

The carrier concentration which is found from the relation(2)increase with incr-easing the annealing temperature and thick-ness of the films as illustrated in Table (1).

Fig.(2) Hall voltage as a function of current for CdTe films of different thickness and at different annealing temperature.



This can be explained by the role played by the free Te atoms in CdTe lattice like the acceptor impurities in p-type semiconductor. An increase of the Te amount will determine an increase of carrier concen-tration and, consequently an increase of the electrical conductivity of the film [17].

This result is in agreement with the result of Al-Dhafiri [2] and in contrast with the result of pautral et al [18] whom found that the electrical and optical properties of CdTe crystals generally inhomogeneous after annea-ling due to the redistribution of preexisting impurities.The mobility was found to decre-ase with increasing the thickness and annea-ling temperature,this decreasing is probably due to scattering of the electrical carriers at the twins and low-angle grain boundaries present in the films.The annealing of such films leads to an improvement of the arrang-ement of Cd and Te atoms in the film crys-tallites. At the same time, the tellurium excess forms precipitate at intergrain boundaries[19]. Table(1) summaries the values of all electrical parameters conductivity,activation energy ,carrier conce-ntration, mobility of carriers at room temperature.

Table (1) The electrical parameters of CdTe films obtain from D.C and Hall effect measurements.

T (nm)	T_a(K)	$\sigma X10^{-5}$ $(\Omega.cm)^{-1}$	E_{a1} (eV)	E_{a2} (eV)	E_{a3} (eV)	R_H (cm^3/C)	$n_H X10^{14}$ (cm^{-3})	μ_H $(cm^2/V.s)$
200	300	5.69	0.690	0.215	0.106	208000	0.30	11.8
	373	7.12	0.607	0.194	0.090	112000	0.55	7.97
	423	8.96	0.602	0.191	0.082	80000	0.78	7.17
	473	10.0	0.581	0.178	0.077	40000	1.56	4.00
300	300	12.2	0.668	0.212	0.087	36000	1.74	4.39
	373	14.8	0.604	0.206	0.086	24000	2.60	3.55
	423	19.9	0.592	0.188	0.082	12000	5.21	2.39
	473	27.5	0.570	0.174	0.076	9600	6.51	2.64
400	300	21.4	0.614	0.211	0.085	8000	7.81	1.71
	373	30.4	0.603	0.202	0.084	6400	9.77	1.94
	423	50	0.549	0.183	0.078	4800	13.00	2.40
	473	115.9	0.528	0.172	0.076	3200	19.50	3.71

4-Conclusion:

This study showed that there are three transport mechanisms of charge carriers through the heating temperature range, the D.C conductivity increased with increasing film thickness and annealing temperature while the Hall measurement showed that all the films are p-type and the carrier concen-tration increased when the films treated at different annealing temperature and with increasing the film thickness.

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دراسة تأثير السمك ودرجة حرارة التلدين على الخصائص الكهربائية لأغشية CdTe

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الخلاصة:

لقد بحثت الخصائص الكهربائية لأغشية تلوريد الكادميوم المتعددة البلورات ذات الأسماك المختلفة(200,300,400nm) المرسبة بالتبخير الحراري على أرضيات من الزجاج في درجة حرارة الغرفة والمعاملة عند درجات حرارة تلدين مختلفة (373,423,473 K) . قياسات التوصيلية أظهرت زيادة التوصيلية من $5.69X10^{-5}$ الى $0.0001,0.0011(\Omega.cm)^{-1}$ عند زيادة سمك الغشاء ودرجة حرارة التلدين على التوالي ، أن الزيادة بقيمة $\sigma_{d.c}$ تعزى الى زيادة تركيز الحاملات والذي ينتج من زيادة Te الحر في هذه الأغشية.