Study the Structural/Microstructural and Electrical Properties of CdTe:Sb Thin Films Deposited by Flash Evaporation

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Abstract

in this research studied the structure and electrical properties of the Pure CdTe and metal Sb-doped CdTe thin films with 0.5, 1, and 1.5 wt.%, respectively. They deposited on glass substrates using flash evaporation technique. It was found that the prepared films had a cubic structure and a strong preferred <111> crystal orientation. Atomic force microscopy (AFM) results showed that the film surface doped Sb was more compact and uniform and also the root mean squared (RMS) roughness increased with Sb contents. The electrical properties were investigated as function of Sb wt.% doping. The results showed that the electrical conductivity (σ) increasing trend with increasing the wt.% of dopant , while the activation energies (E_{a1}, E_{a2}) showed an opposite trend, where the activation energies decreased with dopant.

1. Introduction

Thin films of II–VI semiconductors are widely used in many semiconductor devices such as photo electrochemical cells, field effect transistors, IR detectors, photodiodes, photo conductors and photovoltaic solar cells[1, 2]. CdTe has long been identified as a candidate for the absorber layer in low cost thin film photovoltaic solar cells because of its direct bandgap, high absorption coefficient and the possibility of a variety of preparation techniques such as close spaced sublimation (CSS)[3], vacuum deposition [4], electrodeposition [5], and RF sputtering[6], close spaced vapor transport [7]. In this present work we focused attention on the prominent techniques for the deposition of thin films of multicomponent alloys whose constituents have different vapor pressures. Thin films of CdTe have been prepared under suitable growth conditions by a simple flash evaporation (FE) technique. This technique requires only one boat maintained at sufficiently high temperature to evaporate the least volatile component of the alloy. The main advantage of (FE) is that it does not require maintaining the critical vapor pressures of the components and temperatures of the boats unlike multisource thermal evaporation[8] .

CdTe thin film still has many defects, such as it has extremely high resistivity. To solve this issue, the implying of the technique Sb-doped CdTe film to change electrical properties [9]. In this work deposited Sb-doped CdTe films using the mixed powder of

Sb and CdTe by flash evaporation technique at room temperature to study the effect of the doping element Sb on the structure and electrical properties of CdTe .

2. Experimental

Thin films of CdTe are deposited by flash evaporation technique onto cleaned glass substrates kept at room temperature .The evaporation of films was done by using a vacuum system model (Edward 306A). High purity CdTe and High purity Sb powder are used as a source material for thin films evaporated from a molybdenum boat.

Before the deposition on glass substrates, they cleaned ultrasonically with acetone, deionized water, and finally dried by air blower.

The powder was dropped into a heated boat from the feed, passing through a guide funnel by manual vibrating handmade system. The boat heated up to the temperature about 1500K appropriate to evaporate the CdTe:Sb powder at pressure of less than 10^{-5} Torr at ambient temperature in vacuum chamber. The source to substrate distance was approximately 15 cm. After deposition, the films were removed from the coating chamber and exposed to the ambient atmosphere.

3. Results and Discussion

3.1 Structural properties

Figure (1) shows the x-ray diffraction patterns of pure CdTe and Sb-CdTe with various Sb concentration (0.5 – 1.5 wt.%). The peaks of X-ray diffraction indicate that all obtained films were polycrystalline and the major diffraction peak was oriented along (111) plane which reflects the zinc blende structure of the CdTe thin films.

The degree of preferred orientation increased with increasing the doping concentration. Thus, the film with the highest doped percentage concentrations had a better crystalline quality, as indicated from its XRD spectra.

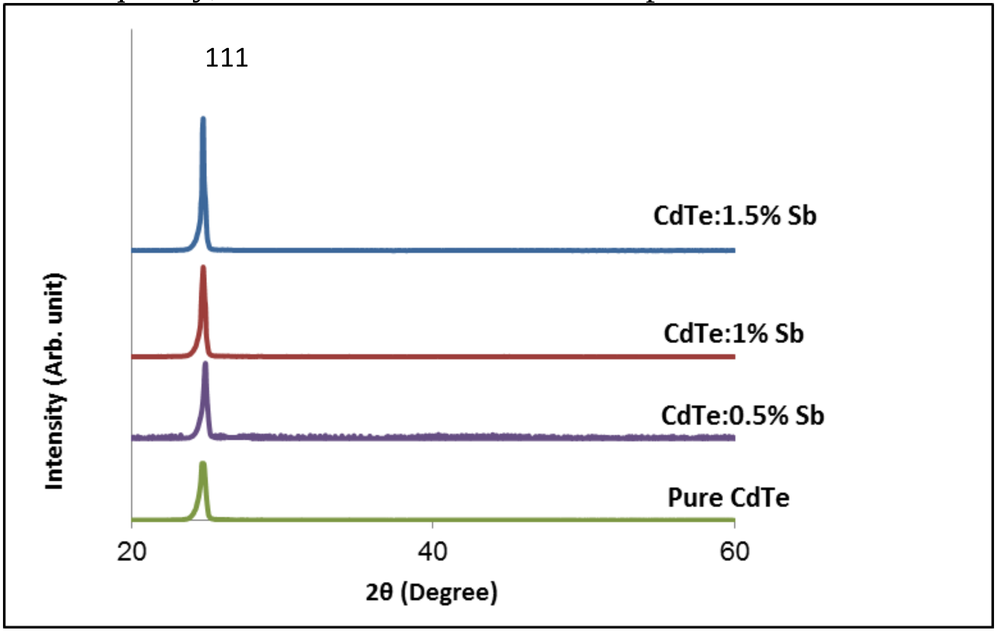


Figure 1:X-ray diffraction pattern of CdTe:Sb films for different concentrations.

The average grain size was calculated from the Scherrer formulae, which involved the width of the X-ray diffraction line [10]:

$$D = \frac{0.9\lambda}{\beta \cos\theta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where θ is the diffraction angle, λ is the wavelength of the X-ray source and β is measured in radians as full-width at half maximum (FWHM) of the diffraction line.

The micro strain (ε) and the dislocation density (δ) of the films were estimated using the equations[11]:

$$\varepsilon = \frac{\beta Cos\theta}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\delta = \frac{1}{D^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The crystallite size (D), Strain (ε), dislocation density (δ) and lattice spacing were calculated and presented in Table (1). As-deposited films showed crystalline structure with 14.2 nm grain size. With the increase in doping concentration the grain size started increasing. Similar behavior was reported in literature for Sb-doped CdTe thin films deposited using thermal evaporation technique [9]. This was because more and more Sb atoms diffused CdTe and reduced the dislocations of CdTe film. All the Sb atoms settle in the film dislocations and hence stress reduced with increase in doping concentrations.

Table 1. XRD analysis of CdTe:Sb thin films

Sample	Grain size D (nm)	Dislocation density $\delta * 10^{-4}$ line/ nm ^{2}	Strain $\varepsilon_t * 10^{-3}$
Pure CdTe	14.2	51.0	9.36
0.5 % CdTe:Sb	16.4	37.2	5.81
1 % CdTe:Sb	18.9	29.9	5.08
1.5 % CdTe:Sb	30.6	10.7	4.79

3.2 Morphology

The Atomic Force Microscopy (AFM) images for pure CdTe and Sb doped CdTe thin films deposited by flash evaporation technique at substrate at room temperature are shown in Figure 2. These AFM images showed that the films surface doped Sb was more compact and uniformed. The particle size shown by AFM was higher as compared with that calculated from the XRD results. This was because of the fact that the XRD gave the average mean crystallite size while AFM showed agglomeration of the particles.

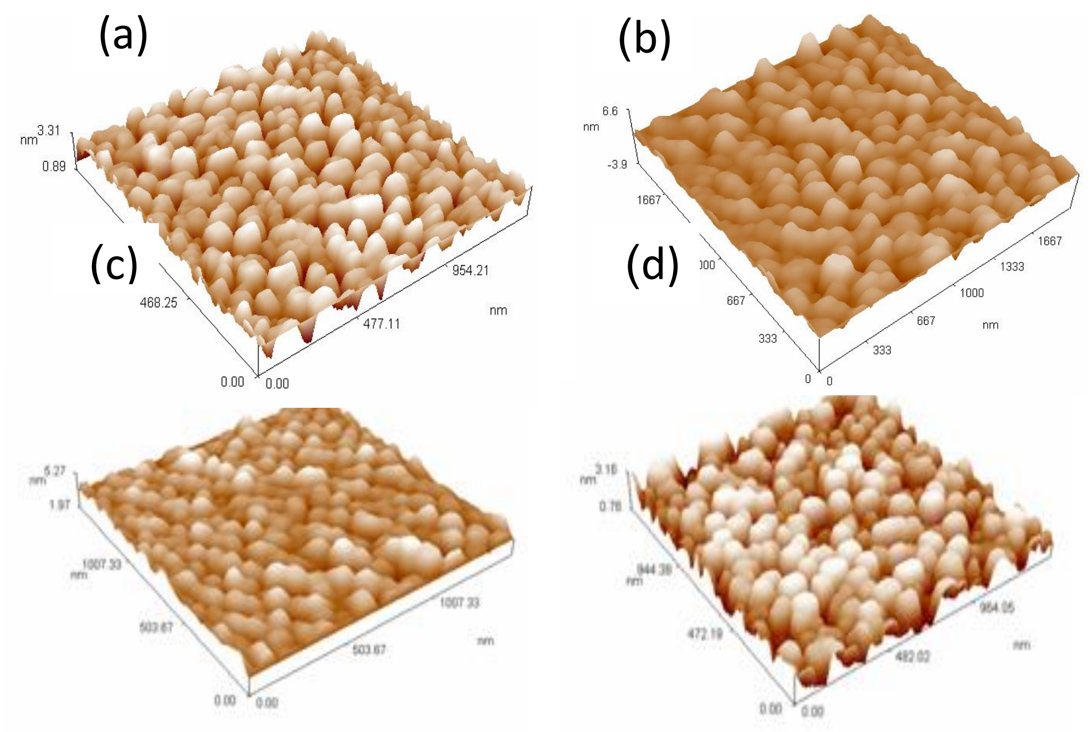


Figure 2: (a)pure CdTe(b) 0.5wt% concentration of Sb, c) 1 wt% concentration of Sb, d) 1.5wt% concentration of Sb

The root mean square value of the surface roughness (rms roughness) calculated from the AFM images increases with increase in concentration see figure (3). The increase in roughness may be due to the different kinetics of the dopant atoms and the host atoms on the film surface at a particular temperature. Increasing content of Sb may increase the crystallite size and hence in the increase in the roughness of the films and hence significant modifications in the surface topographies have been observed. Similar behaviors were reported by Abbas Shah [12] for CdTe doped with Ag. These characteristics were very well supported by the XRD results.

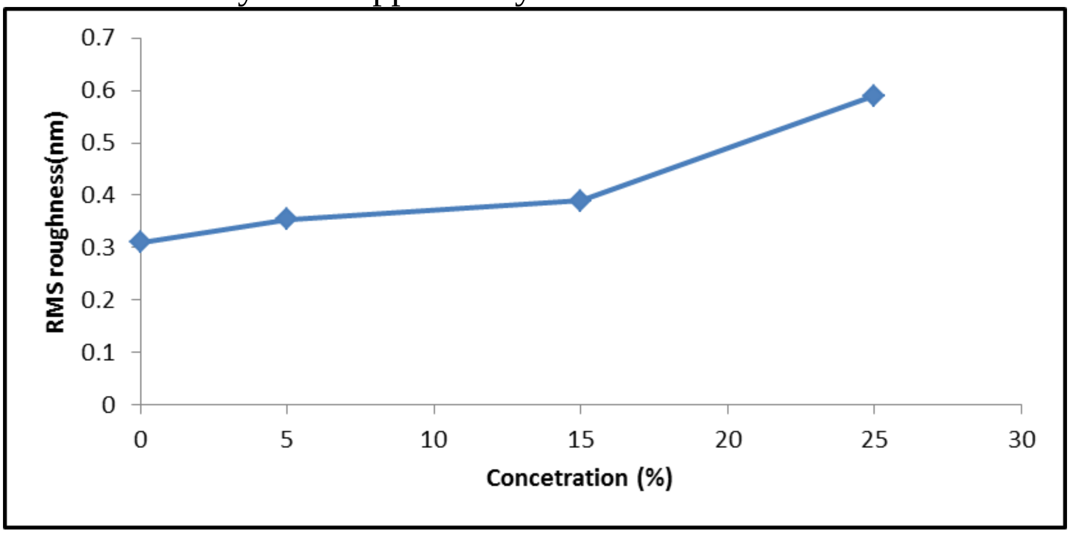


Figure 3. Surface roughness of CdTe:Sb films for different concentrations.

3.3 Electrical properties

The variation logarithm of the conductivity (lnσ)with 1000/T for pure and dopant CdTe thin films with (0.5,1,1.5)% Sb in the range (303-503) K deposited at room temperture, are shown in Figure (4). It is clear from this figure that there are two transport mechanisms, giving rise to two activation energies (E_{a1}) and (E_{a2}). At higher temperatures range (380-503) K, the conduction mechanism is due to carriers excited into the extended states beyond the mobility edge and at lower temperatures range (303-380) K, the conduction mechanism is due to carriers excited into the localized states at the edge of the band [13].

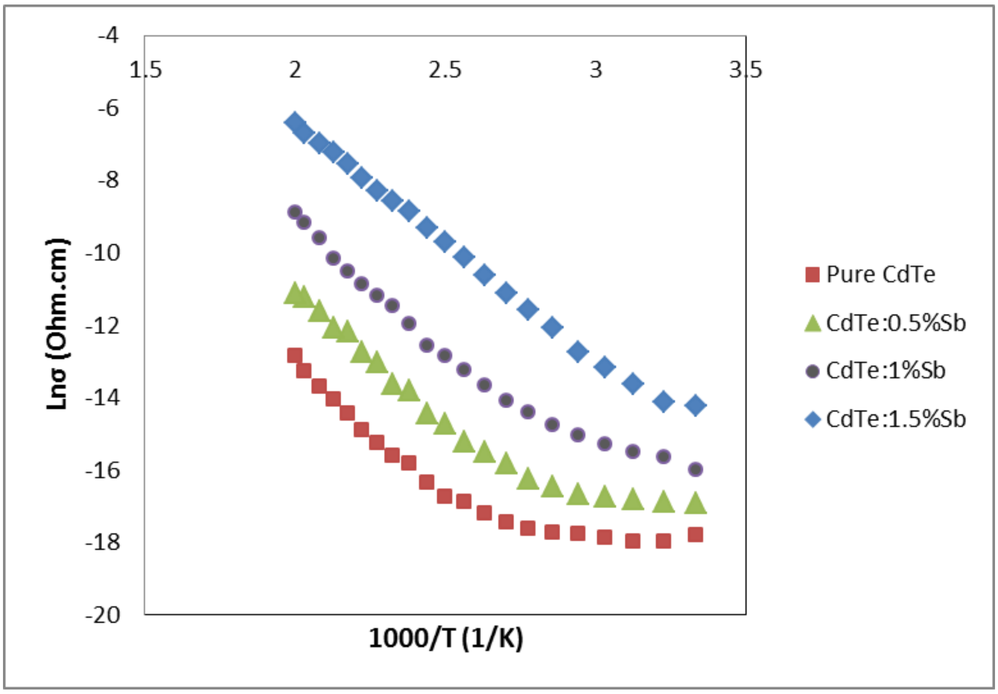
The D.C .conductivity was determined according to the relation [14]:

$$\sigma_{d.c} = L \backslash R.A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where, R is the resistance, A is the area of the film (W.t),W is the width of the electrode, t is the films thickness, L is the distance between the electrodes, and also the activation energy (E_{a1},E_{a2}) are determined according to relation[13]:

$$\sigma_{d.c} = \sigma_o \exp(-Ea / k_B T) \ldots\ldots\ldots\ldots (5)$$

Where σ_o is constant, but changes slowly with temperature, K_B is Boltzman's constant, T is absolute temperature in Kelvin.



Figure(4):Plot of ln σ versus 1000/T of CdTe:Sb films for different concentrations.

From Table (2), the electrical conductivity(**$\sigma_{d.c}$**) is found to increase from 1.83x10-8 $(\Omega.cm)^{-1}$ to 6.66x10-7 $(\Omega.cm)^{-1}$, while the activation energy (E_{a2}) is found to dcrease from 0.6٤٦٨ eV to 0.523eV for pure and doped CdTe thin film 1.5% Sb respectively. This behavior of $\sigma_{d.c}$ and E_{a2} with doping percentages can be attributed to the increase in grain size of CdTe:Sb films can lead to decreasing in the scattering of carriers by the grain boundaries . Similar behaviors were reported by Song et al.[8

]and Al-Douri et al.[15] for CdTe doped with Sb films deposited using thermal evaporation.

Table 2, Value of σ_{RT}, E_{a1} and E_{a2} of CdTe:Sb films for different concentrations

Sample	σ_{RT} $(\Omega.cm)^{-1}$ at R.T	E_{a1} (eV)	Temp. range (K)	E_{a2} (eV)	Temp. range (K)
Pure CdTe	1.83×10^{-8}	0.2371	303-380	0.6٤٦٨	380-503
CdTe:0.5%Sb	4.44×10^{-8}	0.2156	303-380	0.575	380-503
CdTe:1%Sb	1.14×10^{-7}	0.207	303-380	0.547	380-503
CdTe:1.5% Sb	6.66×10^{-7}	0.201	303-380	0.523	380-503

4. Conclusion

Thin films of CdTe and Sb-doped CdTe with 0.5, 1, and 1.5 wt.%, respectively have fabricated successfully by flash evaporation technique on glass substrate. By analysis of X- ray diffraction it is found that all CdTe films exhibit a polycrystalline structure with apreferential orientation along the (111) plane. Atomic force microscopy (AFM) reveals that the films present a compact surface and root mean squared (RMS) roughness increased with Sb contents. The influence of impurity percentages (0.5,1, and 1.5) %Sb is investigated on the electrical properties for CdTe films. The electrical conductivity of Sb doped CdTe films are calculated. Upon increasing the Sb concentration, the electrical conductivity of the films is found to increase from 1.83×10^{-8} $(\Omega.cm)^{-1}$ to 6.66×10^{-7} $(\Omega.cm)^{-1}$.Finally, it should be mentioned that there are two transport mechanisms of the charge carriers over the range of 303-503K,and activation energies (E_{a1}, E_{a2}) show decreased with dopant.

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دراسة الخصائص التركيبية/ المجهرية والكهربائية لأغشية CdTe:Sb الرقيقة والمرسبة بالتبخير الوميضي

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الخلاصة

لقد تم في هذا البحث دراسة الخواص التركيبية و الكهربائية لأعشيه CdTe النقية والمطعمة بمعدن Sb بنسب 0.5، 1، و ١,٥ ٪، على التوالي، أودعت على ركائز الزجاج باستخدام تقنية التبخير بالوميض .وقد تبين أن هذه الأفلام لديها بنية مكعبة والتوجه المفضل <111>. ان مِجهر القوة الذرىة (AFM) يكشف عن أن سطح الأغشية أصبح أكثر اندماجا وانتظاما عند تطعيمه ب Sb وجذر متوسط التربيع (RMS) اظهر زيادة في خشونة السطح مع زيادة محتوى Sb.ولقد تم تفسير الخواص الكهربائية كدالة لنسبة التطعيم . وأظهرت النتائج أن التوصيلة الكهربائية (σ) تزداد مع زيادة نسبة التطعيم ، في حين أظهرت طاقات التنشيط (E_{a1})، (E_{a2}) اتجاها معاكسا، حيث انخفضت الطاقات مع زيادة التطعيم.