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Roughness and Surface Topography of Thermally Evaporated Cadmium-Doped Antimony Selenide Thin Films

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Abstract

In this work, thin films of $Cd_{0.9}Sb_{0.1}Se$ were successfully deposited on glass substrates by thermal evaporation method at room temperature. The $Cd_{1-x}Sb_xSe$ alloy composed of highly-pure Cd, Sb and Se samples was prepared with x=0.1 by melting method in a tube furnace at 900°C. The structural and surface characteristics of these thin films were studied by the x-ray diffraction and atomic force microscopy to determine their dependencies on film thickness. These films were amorphous and the grain size as well as the surface roughness was increasing with film thickness. The energy band gap was decreased from 2.6 to 2.15 eV with increasing film thickness from 150 to 450 nm. These structures are efficient candidates for some applications such as quantum devices.

Keywords: Ternary compound; Thermal evaporation; Thin films; Structural characteristics

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1. Introduction

Ternary compound semiconductors are essential for the development of high-frequency and high-power electronic and optoelectronic devices operating in the ultraviolet spectral region due to their wide band gap and unique electronic characteristics [1-2].

The compound semiconductors are intensively investigated due to their efficient employment in the photonics and optoelectronic applications [3-6]. The ternary compound (CdSbSe) is one of the most promising materials for some recent applications of photonics and optoelectronics, such as thin film transistors, light-emitting diodes, photodetectors, e-beam pumped lasers, electroluminescent devices and electrophotography [7-11]. Some ternary compounds were used as efficient absorbers and window layers in thin film photovoltaic and detector configurations [12].

The ternary compound CdSbSe is prepared by different methods and techniques, such as thermal evaporation, spray pyrolysis, plasma sputtering, pulsed-laser deposition and electro-deposition [13]. Among these methods, thermal evaporation is the most applicable one due to the considerable large mean free path of vapor atoms at low pressure [14]. Accordingly, sharp thin films could be deposited on various substrates with minimum impurity concentration in the film [1,4,13].

Cadmium selenide (CdSe) is one of II-VI semiconductors with direct energy band gap of about 1.74eV, high absorption coefficients, and good electrical and optical properties [15-18]. Similarly, antimony selenide (Sb_2Se_3) is considered as a very promising non-toxic absorber material for thin film photovoltaics [19]. Due to the one-dimensional crystalline structure of Sb_2Se_3, severe interfacial diffusion would be expected [19-21].

2. Experimental work

In order to prepare $Cd_{1-x}Sb_xSe$ alloy, highly-pure (99.999%) samples of Cd and Sb and Se elements with were mixed at the correct stoichiometric ratio (with x=0.1) and then sealed in quartz tube under vacuum. It was placed inside an electric furnace (type 634 HBTMN) and the temperature was raised up to 900°C by a step of 200°C. The temperature was kept constant for two hours before stepping up.

The prepared sample of $Cd_{0.9}Sb_{0.1}Se$ was cleaned with distilled water and alcohol and then placed in ultrasonic instrument. It was fixed inside deposition chamber, which was initially evacuated down to $2x10^{-5}$ mbar. An Edward E306 thermal evaporation system was used to deposit thin films of $Cd_{0.9}Sb_{0.1}Se$ on glass substrates with different thicknesses (150, 300 and 450nm).

The prepared samples were characterized by the x-ray diffraction (XRD) to introduce their crystalline structure. As the average grain size (D) of polycrystalline materials has an important role in determining the properties of material, it was determined from the full width at half maximum (FWHM) of the XRD pattern according to Scherer's formula [22]:

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

The surface roughness of the prepared films was determined by atomic force microscopy (AFM) using an AA3000 Angstrom Scanning Probe Microscope.

3. Result and Discussion

The x-ray diffraction (XRD) patterns of $Cd_{0.9}Sb_{0.1}Se$ thin films prepared in this work with different thicknesses (150, 300 and 450nm) are shown in Fig. (1). Table (1) summarizes some structural parameters obtained from the XRD patterns for the deposited films. Both figure and table depict that all as-deposited films are amorphous structure. The crystallite size was found to increase with increasing film thickness. As well, the intensity of the pattern was increasing with film thickness and this may be attributed to an enhancement in the structure of thicker films.

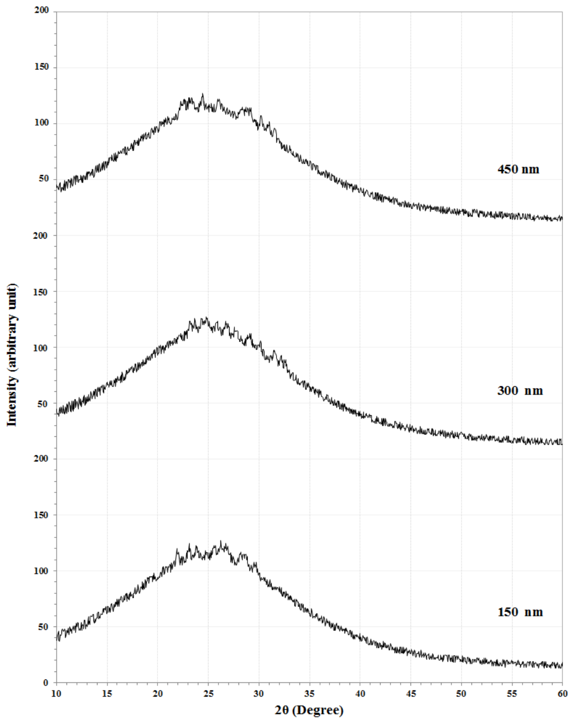
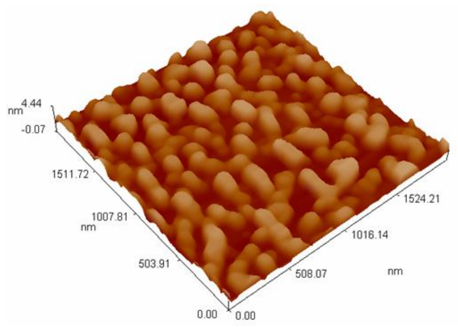


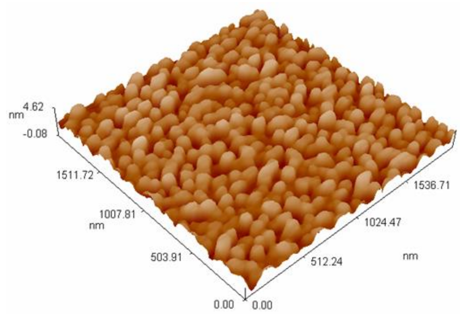
Fig (1) The XRD patterns for $Cd_{0.9}Sb_{0.1}Se$ thin film samples of different thicknesses (150, 300 and 450nm)

Obviously, thin films deposited by thermal evaporation from multi-elements alloys exhibit amorphous structures and most attempts in the last two decades to produce thin films of crystalline structures from such alloys by thermal evaporation method have failed. Such disadvantage of thermal evaporation method can be compensated by the low cost and large scale production of thin films for various applications.

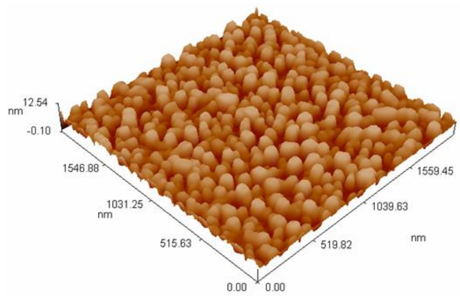
The grain size and average roughness of the prepared $Cd_{0.9}Sb_{0.1}Se$ thin films were determined by AFM analysis, as shown in Fig. (2) and Table (2). It is obvious that the average grain size increases with increasing film thickness from 150 to 450 nm. This was also observed from the XRD results as the intensities of the preferred orientations become higher than others with increasing film thickness. The average roughness of the film surface was slightly increased while the film thickness was increased from 150 to 300nm, while a reasonable increase in the average roughness was observed with the further increase in film thickness up to 450nm. This feature makes is very applicable in gas sensing and photonic detection devices.



(a) 150nm



(b) 300nm



(c) 450nm

Fig. (2) The AFM images for $Cd_{0.9}Sb_{0.1}Se$ thin film samples of different thicknesses

In order to introduce the effect of increasing film thickness on the energy band gap of the prepared

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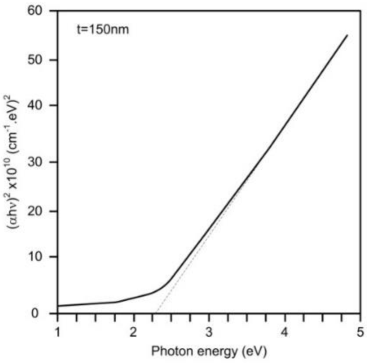
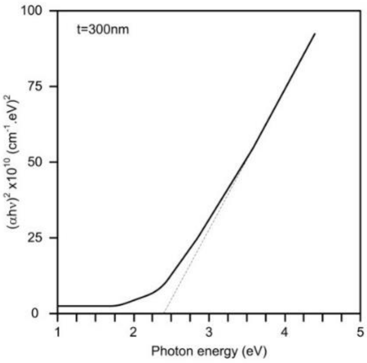
$Cd_{0.9}Sb_{0.1}Se$ thin film, the relation of $(\alpha h\nu)^2$ with the incident photon energy $(h\nu)$ was plotted for three different samples with film thickness of 150, 300 and 450nm, as shown in Fig. (3). The incorporation of Sb impurities in the CdSe structure leads to decrease the energy difference between covalence and conduction bands of the direct type. Moreover, increasing film thickness leads to increase the volumetric concentration of impurities available within the structure of the film.

Table (2) indicate the average grain size and the average roughness for $Cd_{0.9}Sb_{0.1}Se$ thin film samples of different thicknesses

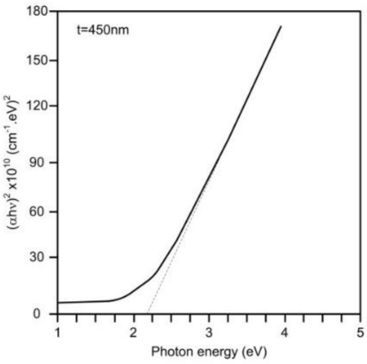
Thickness (nm)	Ave. Grain Size (nm)	Ave. Roughness (nm)
150	0.58	0.508
300	0.61	0.513
450	1.78	1.53



(a)



(b)



(c)

Fig. (3) The relation of $(\alpha h\nu)^2$ with the photon energy $(h\nu)$ for $Cd_{0.9}Sb_{0.1}Se$ thin film samples of different thicknesses (a) E_g=2.6eV, (b) E_g=2.4eV and (c) E_g=2.15eV

4. Conclusion

Thin $Cd_{0.9}Sb_{0.1}Se$ films were thermally deposited on glass substrates from an alloy target. The structural characteristics of these films, such as crystalline orientations, surface roughness and energy band gap were investigated. All prepared films were amorphous. The effects of increasing film thickness on the grain size, surface roughness and energy band gap were determined. The thermal evaporation method used to prepare the $Cd_{0.9}Sb_{0.1}Se$ thin films from multi-elements alloy can be described as a low-cost and reliable deposition method.

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Table (1) Structural parameters of $Cd_{0.9}Sb_{0.1}Se$ thin films of different thicknesses (150, 300 and 450nm)

2θ (Deg.)	FWHM (Deg.)	d_{hkl} (Å)	(*hkl*)	Phase	d_{hkl} Std. (Å)	G.S. (nm)	Card No.
15.060	0.282	5.878	(020)	Sb_2Se_3	5.885	28.4	900-7438
16.860	0.400	5.254	(120)	Sb_2Se_3	5.2501	20.1	900-7438
23.300	0.653	3.815	(100)	CdSe	3.7226	12.4	901-16665
26.620	0.259	3.346	(002)	CdSe	3.5076	31.5	901-16665
26.900	0.282	3.312	(101)	CdSe	3.2883	29.0	901-16665
28.220	0.506	3.160	(211)	Sb_2Se_3	3.1537	16.2	900-7438
30.580	0.612	2.921	(221)	Sb_2Se_3	2.8606	13.5	900-7438
33.560	0.447	2.668	(240)	Sb_2Se_3	2.625	18.6	900-7438
35.000	0.500	2.562	(012)	CdSe	2.5529	16.7	901-16665
37.500	0.700	2.396	(041)	Sb_2Se_3	2.3623	12.0	900-7438
39.500	0.500	2.280	(150)	Sb_2Se_3	2.3071	16.9	900-7438
41.300	0.376	2.184	(110)	CdSe	2.1493	22.6	901-16665
44.236	0.647	2.046	(440)	Sb_2Se_3	2.0673	13.3	900-7438
49.160	0.376	1.852	(112)	CdSe	1.8326	23.2	901-16665
51.300	0.706	1.780	(531)	Sb_2Se_3	1.7851	12.5	900-7438
53.700	0.500	1.706	(232)	Sb_2Se_3	1.6917	17.8	900-7438
57.300	0.500	1.607	(720)	Sb_2Se_3	1.5977	18.1	900-7438
59.000	0.500	1.564	(422)	Sb_2Se_3	1.5768	18.3	900-7438

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