Structural, Optical and Surface Properties of CdTe Thin Films on CdS/FTO Glass Substrates

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Abstract

CdTe thin film materials were deposited on CdS/FTO glass substrate using vacuum evaporation technique The sample was characterized using X-ray diffraction (XRD), UV-VIS-NIR spectroscopy and scanning electron microscopy (SEM) techniques. XRD studies revealed that the sample was polycrystalline in nature. The SEM image showed that the sample is columnar in structure and the grains are uniform. Optical band gap of the CdTe thin film was estimated from transmittance and reflectance data and it was found 1.52 to 1.54 eV. The band gap, high absorption co-efficient, polycrystalline nature and surface image showed that thermal evaporation is suitable for deposition of CdTe absorber layer on CdS/FTO glass substrate.

1. Introduction

Power generation by solar energy can act as source of energy in the future. Thin-film solar cells are positioned to become the future of solar energy technology because of their less material usage and lower cost manufacturing processes. Cadmium telluride (CdTe) photovoltaic technology has the potential to become a leading energy producer in the coming decades in solar energy industry. The material can be used as an absorber layer for solar cells for its high absorption co-efficient and optimum band gap [1]. CdTe has favourable physical characteristics for medical applications that have been investigated in the reported paper [2]. The material is considered to be one of the most useful materials for the fabrication of X-ray and γ-ray detectors operating at room temperature due to specific properties of high average atomic number, fine charge-transport properties, high resistivity and relatively large band gap energy [3-5]. The objectives of the present work are deposition of CdTe thin film on CdS/FTO substrates and characterize the CdTe/CdS/FTO thin films to enrich knowledge about fabrication of CdTe thin film solar cell.

2. Experimental

CdTe film was prepared on CdS/FTO glass substrates at high vacuum ($\sim 10^{-6}$ Torr) by the thermal evaporation method. At the high vacuum, the substrate was heated with the help of radiant heater at a certain temperature called substrate temperature or deposition temperature. In the deposition of the thin film, the substrate temperature was 250°C and annealing temperature was 100°C for 60 minutes. The structural analysis of the film was performed using Philips X'pert PRO X-ray diffractometer. In the experiment, CuKα radiation of wavelength, $\lambda = 1.54178$ Å was used and the angle of diffraction was varied from 20° to 60°. The grain size (D) of the film was measured from Scherrer formula written below using FWHM (β) of the (111) diffraction peak [6]

$$D = \frac{0.9\lambda}{\beta \cos\theta}$$

Here, θ is the Bragg angle. The lattice parameter was calculated using the following equation

$$a = d\sqrt{h^2 + k^2 + l^2}$$

Where *h*, *k* and *l* represents the Miller indices and *d* is the inter planer spacing. The micro strain (ε) and dislocation density (ρ) of the filmwasmeasured from the following equations

$$\varepsilon = \beta_{2\theta}\cos\theta/4$$

$$\rho = 1/D^2$$

The surface image of the film was taken using Scanning Electron Microscope (SEM). The optical properties like transmittance, reflectance, and absorption co-efficient and optical band gap were analysed from UV-VIS-NIR recording spectrophotometer (shimadju, UV03100, Japan) in the photon wave length range from 400 to 2500 nm. The absorption co-efficient (α) was measured from the following formula [7]

$$\propto = -\frac{lnT}{t}$$

Where *t* is the thickness of the films and *T* is the transmittance of the films. The optical band gap energy (Eg) of CdTe was estimated using the following relation

$$(\alpha h\nu)^2 = (h\nu - Eg)$$

where, *hv* is the incident photon energy. The thickness of the film was measured by insituFTM5 quartz crystal thickness monitor (Edwards, UK). If density of the material is known, the rate of deposition, which is different for different elements, can be controlled using the monitor.

3. Results and Discussion

3.1. Structural Study of CdTe/CdS/FTO Thin Film

X-ray diffraction (XRD) patterns of CdTe thin film study of different substrates and thickness are shown in figure-1. The peaks at 2θ =23.83°, 26.69°, 30.31°, 35.40°, 39.39°, 46.50°, 50.70°, 57.02° and 62.59° are found in figure-1(a). These peaks corresponds to reflection from (111), (200), (101), (220), (311), (112), (400) and (331) planes CdTe cubic structure, respectively. The figure-1(b) and figure-1(c) showed CdTe cubic structure. The results of the structural parameters of CdTe thin films have also been tabulated in table-1. The data presented in table-1 (CdTe/CdS 1000 nm and CdTe/CdS 1300 nm) are comparable with the earlier reports[1] in table-1(CdTe 1000 nm).All peaks reflected in the XRD patterns are in good agreement with other reported paper [7-10]as well. The observed d values in figure-1 are well matches with standard d values [8, 10]. The figure-1 showed that the film CdTe/CdS 1000nm is more crystalline than CdTe 1000 nm thin film. In figure-1, the film CdTe/CdS 1000 nm showed more reflection peaks than CdTe/CdS 1300 nm thin film. The CdTe/CdS 1000 nm samples relative

intensity ratio of (111), (220), (311) (400) and (331) planes are 100, 57.09, 28.44, 2.66 and 4.45 and the values are comparable to the standard value of 100, 62, 28, 5 and 9 respectively. No diffraction peak corresponding to metallic Cd, Te, or other compounds was observed. The XRD analysis revealed that the all films are polycrystalline in nature and crystalinity is improved. The lattice parameter was calculated to be 6.482 Å which is very close to the standard value of 6.481Å. The calculated values are in good agreement with that the reported paper [8]. The calculated average grain size was about 23-48 nm. This was in close agreement with that of CdTe films where a smaller average grain size (24 nm) was reported [8]. The larger grain size is an important factor to increase photovoltaic efficiency.
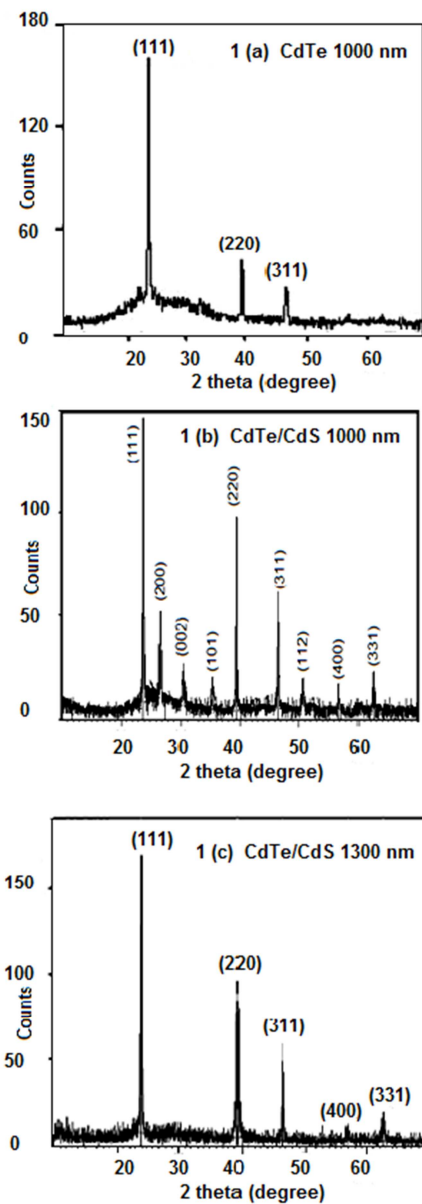

Figure 1. XRD spectra of (a) CdTe 1000 nm (b) CdTe/CdS 1000 nm (c) CdTe/CdS1300 nm.
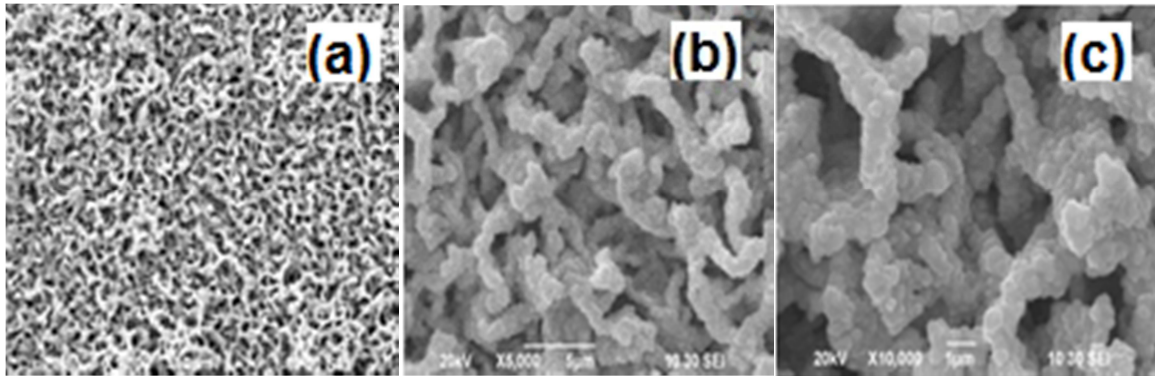
Figure 2. Surface image of CdTe film at electron acceleration voltage = 20kV magnification (a) X1000, (b) X5000, (c) X25000 on CdS/FTO glass.

3.2. Surface Study of CdTe/CdS/FTO Thin Film

The surface morphology of CdTe thin film deposited on a glass substrate observed under a scanning electron microscope is shown in figure-2. The crystallites of these films are regularly spiral shaped with a typical size of about 700 nm. It is clear that the layer is not uniform and does not completely cover on the FTO substrate. As resolution (X 25000) increases a very few pinholes are observed clearly in the film. Individual grain boundary is not specifically visible rather grains are connected to one another like rope. This substrate characteristic is in agreement with the reported work [8]. The surface image suggested that CdS nucleates at these points and grow as columns normal to the substrate. The grains of the film are entangled due to deposit on top of CdS/FTO glass substrate and formed wide grain boundaries. This situation can be changed to a certain extent by using either thick CdS or CdTe layers or deposition of a buffer layer.

Table 1. Structural parameters of CdTe thin films.

| Sample Name	Observed 2θ (degree)	Observed FWHM(°2θ)	Observed (d) (nm)	Standard (d) (nm)	Relative intensity	Plane (hkl)
CdTe/CdS 1000 nm	23.8338	0.1378	0.3734	0.3742	100	(111)
	26.6871	0.1574	0.3340	0.3355	22.96	(200)
	30.3131	0.4723	0.2949	0.2906	7.52	(002)
	35.3960	0.2362	0.2536	0.2514	6.09	(101)
	39.3840	0.1968	0.2288	0.2290	57.09	(220)
	46.5042	0.2362	0.1953	0.1954	28.44	(311)
	50.7031	0.4723	0.1801	0.1812	4.92	(112)
	57.0181	0.9446	0.1615	0.1619	2.66	(400)
	62.5877	0.5760	0.1483	0.1488	4.45	(331)
CdTe 1000 nm [1]	23.8525	0.1771	0.3731	0.3742	100	(111)
	39.3353	0.2165	0.2291	0.2290	23.33	(220)
	46.4827	0.3840	0.1952	0.1954	13.38	(311)
CdTe/CdS 1300 nm	23.819	0.0984	3.735	0.3742	100	(111)
	39.351	0.2362	2.290	0.2290	44.98	(220)
	46.488	0.2755	1.953	0.1954	24.08	(311)
	56.857	0.4723	1.619	0.1619	2.89	(400)
	62.403	0.3840	1.487	0.1488	6.47	(331)
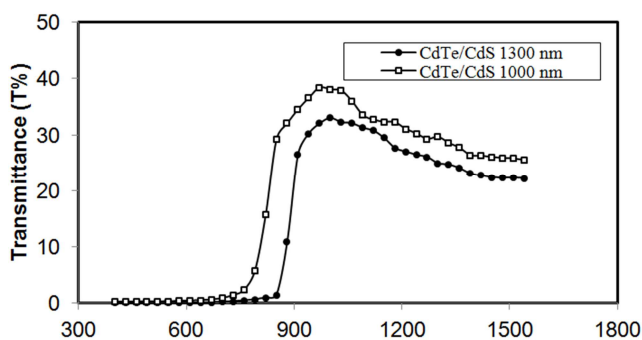
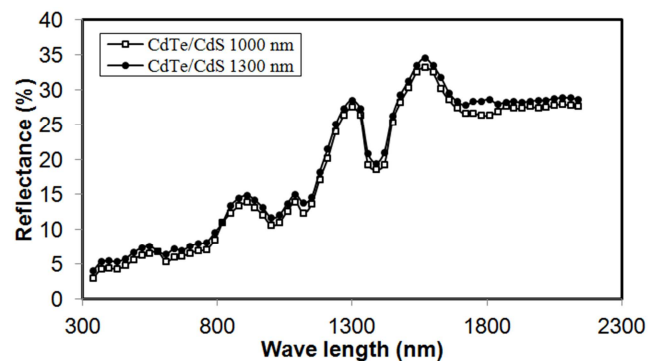*Figure 3. Transmittance variation of CdTe thin films with wavelength.*

Figure 4. Reflectance variation of CdTe thin films.

3.3. Optical Study of CdTe/CdS/FTO Thin Film

Figure-3 shows the variation of transmittance of CdTe thin film of thickness 1000 nm deposited on Chemical Bath Deposited-CdS with photon wavelength varying in the range between 300 nm and 1500 nm.
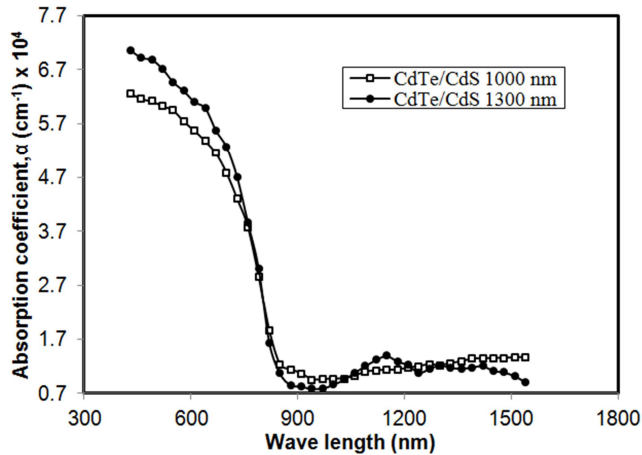

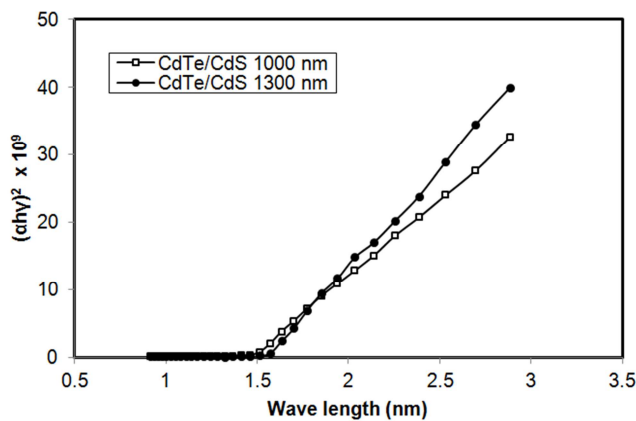**Figure 5.** *Absorption coefficient variation of CdTe thin films.*

Figure 6. *(αhν)²vs. photon energy (hν) plot of CdS/CdTe thin films.*

The figure showed consistent optical transparency in the spectral region between 1200 nm to 1500 nm. High transmittance in a higher wavelength region and a sharp absorption edge is observed in the films. The absorption edge is interrelated to the optical band gap which agrees with reported work [10]. The transmittance falls steeply with decreasing wavelength from 900 nm to about 800 nm. The decrease in transmission could arise due to the increase in absorbance associated with change in surface microstructure as reported by Chandramohanet. al. [12]. Figure-4 shows the variation of reflectance with photon wavelength in the range 300nm to 1500nm. From figure-4, it is observed that reflectance falls with decreasing wavelength (300-880 nm). The variation of absorption co-efficient (α) with wavelength in the range varying between 300nm-1500nm of CdTe thin films is shown in figure-5. From figure-5, it is seen that in the shorter wavelength the absorption co-efficient exhibits higher values, these values of ($\alpha > 10^4$) means there is a large probability of the allowed direct transition which agrees with

the work of Mottet. al. [13]. The absorption co-efficient values decrease steeply with increase in wavelength and remain consistent at higher wavelength. The low absorption co-efficient makes CdTe films useful for optical components in high laser window and multispectral applications, providing good imaging characteristic. In figure-6, $(\alpha h\nu)^2$ is plotted against photon energy ($h\nu$) to find the band gap energy of CdTe thin film. The linear dependence showed by $(\alpha h\nu)^2$ with photon energy($h\nu$)indicates that the transmission is direct. The direct band gap energies of the films are determined by extrapolating the straight portion to the energy axis. Band gap is found 1.53±0.1eV by extrapolation of data point which is very close to standard value of 1.5eV. Absorption coefficient is used to describe the reduction in intensity of light in a medium as a function of distance. The energy gap in a semiconductor is responsible for the fundamental optical absorption edge. The fundamental absorption process is one in which a photon is absorbed and an electron is excited from an occupied valence band state to an unoccupied conduction band state, if photon energy is less than the gap energy, then the electron will not be absorbed. Such inter band absorption process is possible only if the photon energy is higher than the band gap energy.

4. Conclusion

CdTe thin film was successfully deposited on CdS/FTO substrate using thermal evaporation method. The structural study of the film showed that the film is polycrystalline in nature and crystalinity is improved due to CdS/FTO layer. The surface image of the film concluded that the charge carrier mobilities along these columnar type materials have highest possible values and the grain boundary scattering becomes minimal during PV activity across the device structure. The films showed 42% transparency, 32% reflectance and high absorption co-efficient ($\alpha > 10^4$). The optical band gap of the film was found 1.53 eV. These result revealed that CdTe layer could be suitable as absorber layer for CdTe/CdS heterojunction solar cell structure.

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