

Cadmium Telluride (CdTe) Thin Film for Photovoltaic Applications

Sekhar Chandra Ray and Kaushik Mallick

Abstract—Cadmium telluride (CdTe) thin films are prepared by the dip-coating deposition technique under atmospheric pressure at different temperature. The optical band gap obtained within the range 1.63-1.60 eV. Crystallite sizes are obtained from XRD that are dependent on composition (Cd/Te) and baking temperatures. Raman spectra confirms the presence of transverse (TO) and longitudinal (LO) optical phonons in the CdTe structure. Films are good photoconductive in nature and could be used in photovoltaic applications.

Index Terms—CdTe, optical band-gap, photoconductivity.

I. INTRODUCTION

The interest on the different properties of photonic CdTe material is of considerable, due to its practical importance in technological applications such as, integrated optics, optoelectronics, solar energy conversion, gamma ray detection, and x-ray imaging. CdTe is of low cost thin film photovoltaic cells because of its direct band gap and have high absorption coefficient. CdTe could be doped with both *n*- and *p*- type materials using a large number of preparation methods / techniques such as vacuum deposition [1], electro-deposition [2], [3], molecular beam epitaxial [4], metal-organic chemical vapour deposition [5], [6], close-space sublimation [7], [8] and screen printing [9], [10]. It is necessary to have a detailed understanding of the basic properties of the materials for the fabricating the photovoltaic applications.

In this present work we focuses on the basic and fundamental properties like optical, structural and photoconductive response of CdTe thin films grown by the dip-coating for the photovoltaic applications.

II. EXPERIMENTAL DETAILS

The dip-coating method is used to preparation of CdTe thin films on 7059 corning glasses and ITO coated glass substrates. These substrates are cleaned with detergent solution followed by water, ethanol, acetone and isopropanol respectively. In the film forming process requisite amount of

Cd (NO₃)₂·4H₂O and TeCl₄ was dissolved into ethanol solvent to make two separate solutions. After preparing two solutions they are mix-up each other to get the parent solution for the deposition of thin film by the dip-coating technique. A clean substrate was dipped into the starting solution and then withdrawn vertically at a controlled speed, under atmospheric conditions, with the help of a pulley and geared motor, when a liquid film adhered to the substrate. The substrate together with the liquid film adhering to it was immediately transferred to a furnace for baking, when the chemicals reacted to form the desired solid film. It is found that films of a very high quality films were obtainable when prepared at a baking temperature of >180°C. The thicknesses of the resulting films are several microns. Films with different compositions were obtained when films are baked at different temperature. The coating thicknesses of the film were determined from the profile of profilometry.

This work includes the results of optical band gap, x-ray diffraction, Raman spectra and electrical voltage-current relationship of the CdTe films grown by the dip-coating technique. Optical transmission, reflectance spectra were measured using UV-2501 PC SIMADZU UV-VIS recording spectrophotometer. Thin film structure was investigated using Rigaku D/MAX-IIIB X-ray diffraction with Ni-filter and Cu K_α radiation having wavelength 1.5418 Å was employed in these experiments. Energy dispersive spectroscopy (EDS) was performed using the EDAX Phoenix to determine the film composition. The Raman scattering measurements were made using Bruker FT-Raman optics model FRA-106/S. The excitation source was 30 mW with Ar⁺ laser light having wavelength 488 nm.

III. RESULTS AND DISCUSSION

The optical energy gap (E_g^{opt}) of the CdTe thin films are estimated by measuring optical density (O.D) of the films as a function of wavelength by assuming allowed direct inter-band transitions [11]. The absorption coefficient (α) as a function of photon energy was determined using function model [12], [13]. This coefficient, of the CdTe films are determined from the transmittance (T) and the reflectance R spectra, using the relation [14]:

$$\alpha = \frac{1}{d} \ln \frac{(1-R)^{1/2}}{T} \quad (1)$$

where d denotes thickness of the film. Assuming the transition probability constant near the band edge, the absorption coefficient for the allowed direct transitions may, in general, be written as a function of photon energy as [15]:

Manuscript received March 15, 2013; revised May 31, 2013. The author S.C.R. acknowledges to the Department of Science and Technology and National Research Foundation, South Africa for financial support.

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$$\alpha \propto \left(\frac{h\nu - E_g}{h\nu} \right)^{1/2} \quad (2)$$

where E_g is the band gap and $h\nu$ is the photon energy.

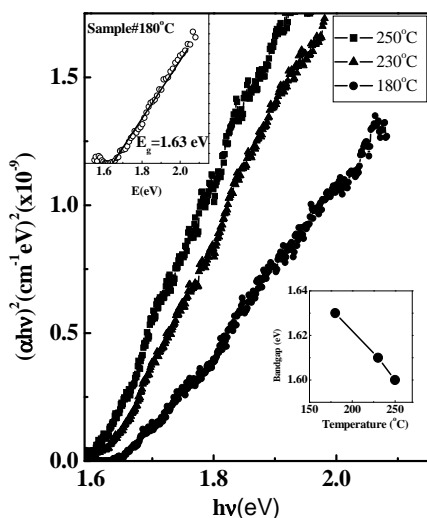


Fig. 1. $(\alpha h\nu)^2$ vs $h\nu$ characteristics of CdTe films prepared at different backing temperatures (T_B). Inset above shows the linear fitting curve ($T_B=180^\circ\text{C}$) for determination of optical direct band gap (E_g) and inset below shows the variation of E_g with (T_B).

Fig. 1 shows the variation of $(\alpha h\nu)^2$ against photon energy ($h\nu$) obtained from the optical spectra of CdTe thin films at different backing temperature. The optical band-gaps (E_g^{opt}) are calculated by extrapolating the linear portion of the $(\alpha h\nu)^2 = 0$ as inserted in Fig. 1 (left-above). The calculated optical direct band-gap values are also plotted and inserted in fig.1 (right – below). The values are varied between 1.63 to 1.60 eV for the samples deposited within the baking temperature 180-250°C are in good agreement with those found in the literature data for CdTe band-gap. The lower values of E_g^{opt} obtained for samples deposited at higher temperature could be attributed to the change in the grain size and the stoichiometry due to loss of Te resulting formation of shallow acceptor levels [16], [17]. The high concentration of the acceptor states introduced by these free Cd atoms gives rise to the density of the states tails extending into the forbidden band. Consequently, the effective band-gap width will be reduced [15]. The band gap values found to be in good agreement with those published in the literature of CdTe [18], [19].

Fig. 2 shows the X-ray diffraction pattern of CdTe thin films prepared at different temperature with corresponding five different compositions as mention in the figure. X-ray diffraction spectra clearly indicate the formation of hexagonal structure of CdTe film. The peak positions are in good agreement with JCPDS data file19-0193 of x-ray powder data for hexagonal-phase features of CdTe. The (hkl) reflection is the closed-packing direction of the zincblende substrate and this type of ordering is often observed in polycrystalline CdTe thin films. Peak positions, relative intensity, their d -values are listed in table 1 and compared with the JCPDS data file. Few peaks marked by * are not identified and may be the metallic oxide impurities arises from the film structure. The XRD spectra had a large peak at

$2\theta \approx 15^\circ$, which corresponds to the (102) crystallographic plane. This shows that the CdTe films predominately (102) orientation. Considering this peak position and plane, average crystalline size of the CdTe in (102) orientations were evaluated for all samples using the following relation [20]:

$$D = \left(\frac{0.9\lambda}{\beta \cos \theta} \right) \quad (3)$$

where D is the average crystalline size in normal direction to the reflection plane, θ –the Bragg angle and β –the full width at half maximum (FWHM). The evaluated values of crystalline size D are 40-50 nm and changes with backing temperature and Cd content presence in the film structure as shown in figure 2b. The compositional analyses were performed by the EDS measurements and it shows the Cd/Te at% is increases with backing temperature due to removal of Te from the film surface (see Fig. 2b).

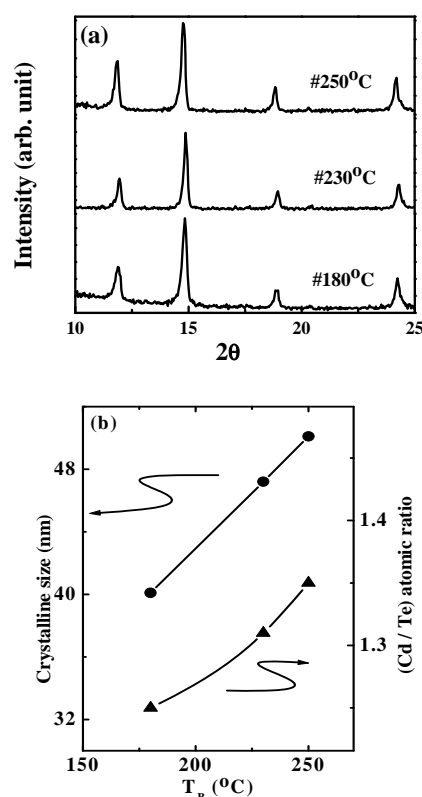


Fig. 2. (a) X-ray diffraction spectra of CdTe films prepared at different backing temperatures (T_B). (b) Variation of crystallite sizes and Cd/Te atomic ratio with (T_B).

Fig. 3 shows first-order Raman spectra of CdTe thin films. There are three main Raman active modes are observed at $\sim 84 \text{ cm}^{-1}$, $\sim 121 \pm 0.5 \text{ cm}^{-1}$ and $\sim 140 \pm 0.5 \text{ cm}^{-1}$. A very week peak at 175 cm^{-1} is also observed and its peak intensity becomes quite prominent when CdTe thin film is prepared at baking temperature of 250°C . The features in this figure can be understood on the basis of the positions and selection rules for transverse (TO) and longitudinal (LO) optical phonons of CdTe. The TO and LO modes of CdTe have been found to occur at $140 \pm 0.5 \text{ cm}^{-1}$ and 175 cm^{-1} respectively [21]-[23]. The feature observed at $121 \pm 0.5 \text{ cm}^{-1}$ is corresponds to the LO mode of the CdTe [24] while the peak at 84 cm^{-1} originate from phonons with an E (Te) symmetry. One interesting fact

is that our observed Raman lines at 84 cm^{-1} and 175 cm^{-1} are approximately 5 cm^{-1} lower and higher in energy respectively than those reported earlier [25], [26] and it may be due to non-stoichiometric compositions in the film forming network or due to dispersive phenomena of laser light that used (in this case 488 nm) during Raman spectra measurements.

TABLE I: D-SPACING (\AA) OF CdTe SAMPLE DEPOSITED AT FIVE DIFFERENT BACKING TEMPERATURES (T_B) SHOWN IN FIG. 2 COMPARED WITH JCPDS 19-013 OF WURTZITE CdTe.

Reflections	Sample $T_B=180^\circ\text{C}$	Sample $T_B=230^\circ\text{C}$	Sample $T_B=250^\circ\text{C}$	JCPDS 19-013
(101)	7.43	7.43	7.45	7.64
(102)	5.96	5.95	5.99	5.93
(103)	4.71	4.68	4.71	4.59
(202)	3.67	3.67	3.68	3.73
(203)	3.39	3.40	3.40	3.37

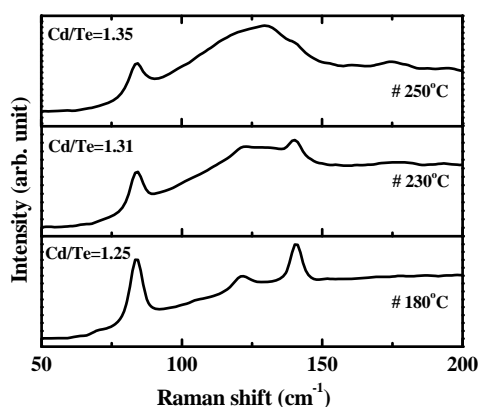


Fig. 3. Raman spectra of CdTe films prepared at different backing temperatures (T_B).

The current-voltage (I - V^2) characteristic of device consisting of ITO/CdTe/Au of two films prepared at two different backing temperatures are shown in Fig. 4(a). ITO is used as a positively biased terminal with respect to the Au. This device is used up to 100 V as a bias-voltage and the corresponding dark current shows a very few mA. The film deposited at 250°C temperature is slightly higher current than the film prepared at 180°C and it may be due to better crystallinity of the film. The photocurrent is measured using a light source having power of 100 watt white bulb for the films deposited at 250°C baking temperature as shown in Fig. 4(b). It's clearly shows that CdTe films have photoconductive character, although the photocurrent is not so high with compare to dark current. However, the current flow through device may be limited by space charge effects within the film thickness or carrier tunneling through a barrier not associated within the films. It is easy to perceive that the photo-absorption process will generate electron-hole pairs within CdTe cluster with very low efficiency. The voltage current (I - V^2) shows an increased linearity that indicates the continuous increase of voltage, the current increases exponentially as $I \sim V^x$ ($x=2$) in the entire region. Therefore, the space-charge limited current (SCLC) dominates the carrier transport process.

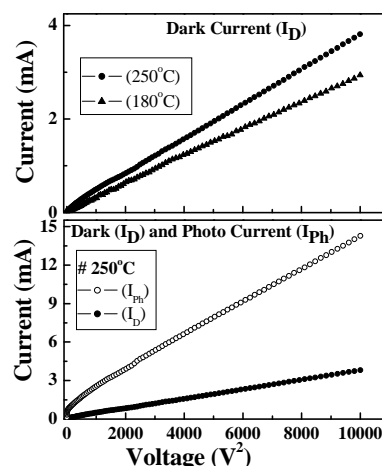


Fig. 4. (a) Voltage-Current (V^2 - I) relationship (dark current) of CdTe films prepared at $T_B=180^\circ\text{C}$ & 250°C ; (b) Dark (I_D) and photocurrent (I_{ph}) of the CdTe film prepared at $T_B=250^\circ\text{C}$ temperature.

IV. CONCLUSION

CdTe films with cadmium-rich and nearly stoichiometric compositions were prepared by cost effective spin-coating technique. Films were grown under atmospheric pressure at different baking temperature. Optical band gap were obtained within the range 1.60 - 1.63 eV . XRD analysis of the films confirms the formation of hexagonal structure and predominately (102) orientation films. Raman spectra confirm the presence of transverse (TO) and longitudinal (LO) optical phonons of CdTe in the film forming structure. The films have photocurrent response that could be used for photovoltaic devices.

ACKNOWLEDGMENT

The author (S.C.R.) thank to the Department of Science and Technology (DST) and the National Research Foundation (NRF), South Africa, for financial support for the work.

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