

Pulse plated cadmium telluride films and their characteristics

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Abstract Cadmium telluride thin films were deposited on conducting glass and titanium substrates by the pulse plating technique at different duty cycles in the range 10–50%. The films were characterised by X-ray diffraction and were found to possess single phase cubic structure. Optical studies indicated a direct band gap of 1.45 eV. Surface morphology of the films indicated that the crystallite size increases with increase of duty cycle. X-ray photoelectron spectroscopy studies confirmed the formation of CdTe. Electron-dispersive X-ray studies were made to estimate the composition. Cross-plane resistivity measurements indicated that the resistivity decreases with increase of duty cycle.

Keywords CdTe · II–VI · Electrodeposition · Pulse plating

Introduction

The unique properties of CdTe make it an ideal material for several applications: photovoltaic cells, nuclear detectors, high-performance electro-optic modulators and photorefrac-

tive devices. It can exhibit both n and p types of conductivity, which makes diode technology [1] and field effect transistors [2] possible, and it can exhibit a semi-insulating state as well [3]. CdTe-based semi-magnets, like CdMnTe, display extremely exciting properties, which have not so far been completely exploited [4]. CdTe polycrystalline films can be prepared by several techniques [5–15]. In the present work, CdTe thin films were deposited by the pulse plating technique, and their characteristics were studied.

Experimental methods

CdTe films were deposited on titanium and conducting glass substrates at room temperature using 0.25 M cadmium sulphate and 0.01 M TeO₂ dissolved in sodium hydroxide. The pH of the bath was adjusted to 2.0 by adding sulphuric acid. The conducting glass and titanium substrates were cleaned prior to deposition. The duty cycle was varied in the range of 10–50%. The deposition time was 60 min in all the cases. Thickness of the films estimated from gravimetry was 2.0 μm. The films were characterised by X-ray diffraction using a PANalytical X-ray diffractometer. Optical absorption measurements were made on the films deposited on conducting glass substrates using Hitachi U3400 UV/vis–NIR spectrophotometer. Surface morphology studies were made using Molecular Imaging Systems atomic force microscope. Electron-dispersive X-ray (EDAX) measurements were made on the films using a JEOL SEM fitted with EDAX attachment. X-ray photoelectron spectroscopy (XPS) studies were made using MK III VG ESCA system. Some earlier studies of pulsed electrochemical growth of CdTe were made with potential pulses, which are closely related to direct current electrodeposition [16, 17]. Pulsed electrodeposition is the advanced form of electrodeposition which offers better

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control over deposit properties by controlling the interfacial electrochemical reaction for the formation of CdTe. A number of variables like pulse waveform, cathodic/anodic pulses, ON/OFF pulse time or duty cycle, applied and mean current density, etc. [18] offer effective ways to control macroscopic properties such as morphology, porosity and adhesion, electronic properties through crystallinity in elemental composition and its electrical conductivity. A recent paper on CdTe pulse electrodeposition [19] discusses the effect of ON time, OFF time, pulse current density and mean current, but the duty cycles, used in this study were in the range of 6–13%. In contrast to the direct current electrodeposition where only current or voltage can be controlled, in pulse current electrodeposition, ON time, OFF time and peak current density can be independently varied. This can be judiciously employed to create a mass transport situation and promote electro-crystallization of the film through adsorption and desorption effects [20–22] which determine

the crystalline, compositional and optical properties of the film. In this work, the CdTe films were deposited at duty cycles higher than 10% and in the range 10–50%.

Results and discussion

The as-deposited films exhibited cubic structure irrespective of the duty cycle. The full-width at half-maximum of the peaks were found to decrease with increase of duty cycle. Figure 1 shows the XRD pattern of the CdTe film deposited at different duty cycles. The data show that the CdTe thin films have a zinc-blende structure. Strong (111) preferred orientation was observed for the films deposited at lower duty cycles; as the duty cycle increases from 10% to 30%, the intensity of the (111) peak increases. Further increase of duty cycle from 30% to 50% results in the increase of (111) peak intensity; in addition, peaks corresponding to (220) and (311) also appear in the XRD pattern. The lattice parameter “*a*” evaluated from the XRD pattern is 0.649 nm.

The optical band gap values of the films were obtained from transmission measurements and by plotting $(\alpha h\nu)^2$ vs $h\nu$. Figure 2 show these data near the band edge for CdTe films deposited at different duty cycles. The extrapolated values of the optical energy gap, E_g , are 1.49, 1.46 and 1.46 eV for films deposited at 10%, 30% and 50% duty cycles, respectively. As can be seen from these data, the trend is movement of the absorption edge towards lower energies appropriate for single crystal CdTe with increasing duty cycle.

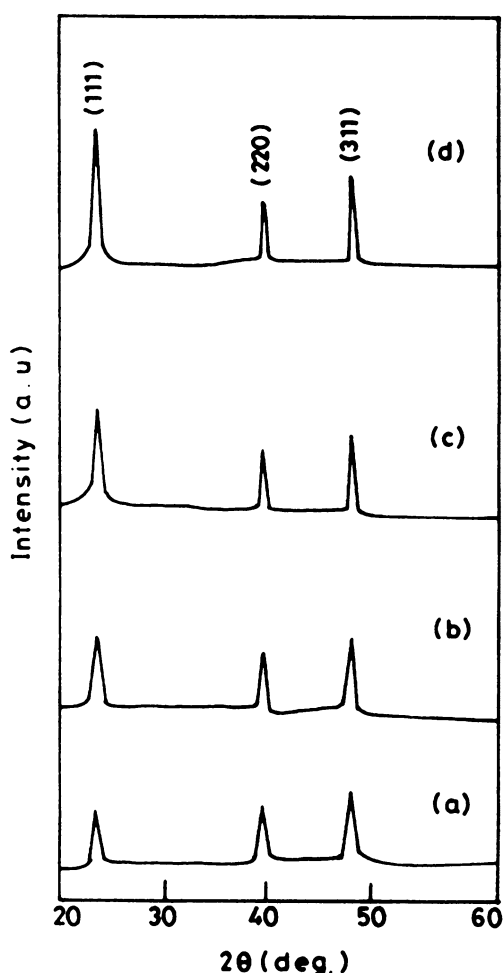


Fig. 1 X-ray diffraction pattern of the CdTe films deposited at different duty cycles: **a** 10%, **b** 15%, **c** 30%, **d** 50%

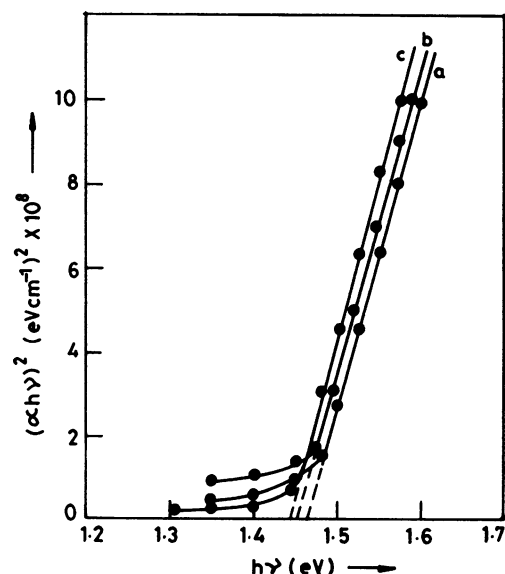


Fig. 2 $(\alpha h\nu)^2$ vs $h\nu$ plot of the CdTe films deposited at different duty cycles: **a** 10%, **b** 30%, **c** 50%

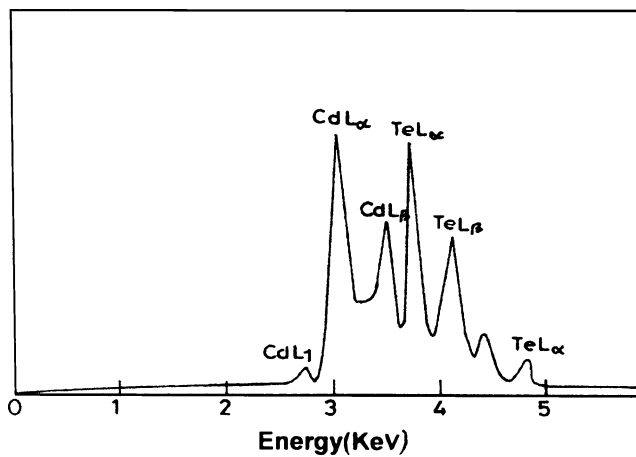


Fig. 3 EDAX spectrum of CdTe films deposited at 50% duty cycle

The compositional analysis for the CdTe films was carried out by EDAX technique. A typical EDAX spectrum recorded in the binding energy region of 0–10 keV is shown in Fig. 3. The spectrum peak reveals the presence of Cd and Te in the film. The compositions for CdTe thin films deposited at different duty cycles are indicated in Table 1. EDAX study shows that the Cd to Te ratio is 1.1 for the films deposited at 50% duty cycle and 1.05 for the films deposited at 10% duty cycle. Hot probe measurements indicated the films to be n-type.

To examine the chemical composition of the films, the XPS spectra of the CdTe films deposited at different duty cycles were measured and are indicated in Fig. 4. The XPS spectra of the CdTe films deposited at 50% duty cycle are shown as a representative in the figure for the binding energies of the Cd (3d_{5/2} and 3d_{3/2}) and Te (3d_{5/2} and 3d_{3/2}) level. As shown in the figure, the peak energy levels associated with Cd (3d_{5/2} and 3d_{3/2}) appeared at 405 and 411.7 eV, respectively, which are in good agreement with the literature [23]. These findings are characteristic of the

Table 1 Composition by EDAX for the films deposited at different duty cycles

Duty cycle (%)	Element composition (at.%)	
	Cd	Te
10	52.63	47.37
20	51.86	48.14
30	51.08	48.92
40	50.74	49.26
50	50.03	49.97

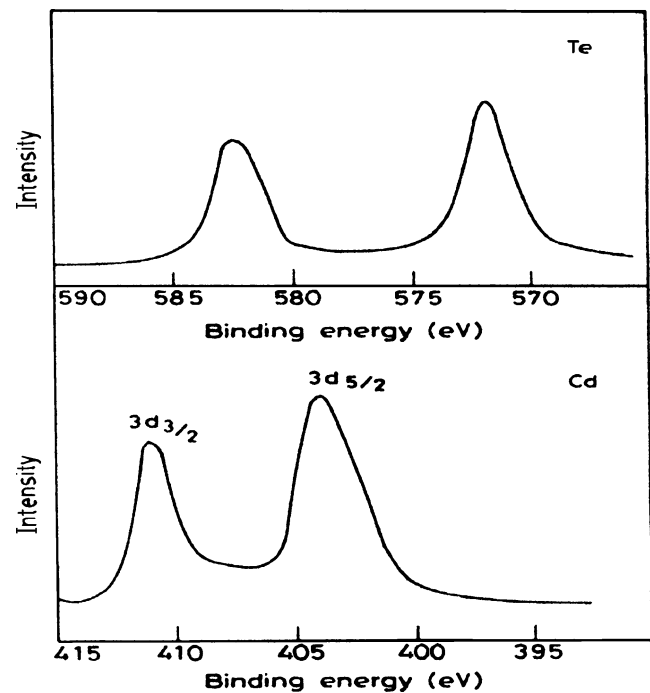


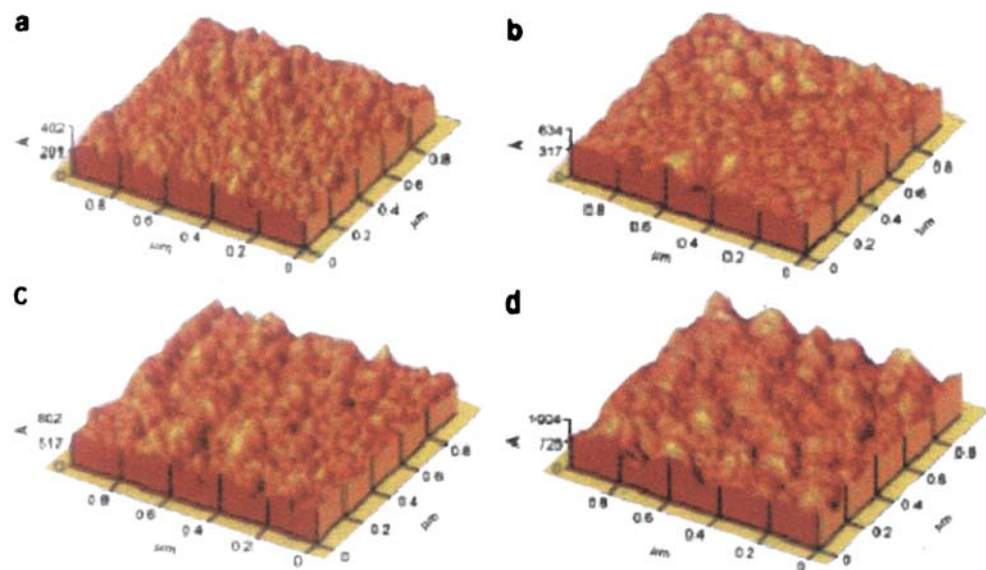
Fig. 4 XPS spectra of the CdTe films deposited at 50% duty cycle

Cd in CdTe and are in good agreement with the literature [24–25]. The figure also shows the binding energies of the Te (3d_{5/2} and 3d_{3/2}) levels at 575.2 and 584.2 eV, respectively.

Atomic force microscopy (AFM) images were taken on the films deposited at different duty cycles in order to study the surface topography. Figure 5 shows the AFM images (1×1 μm) of the CdTe films deposited at different duty cycles. These images show that the grain size of the films increase as the duty cycle increases, which is consistent with the XRD results. Investigation of the AFM images demonstrates that for low duty cycles, the grain sizes are small (Fig. 5a). By increasing the duty cycle, these small grains gradually combine and form bigger grains (Fig. 5b). When the duty cycle was increased further, the grains become bigger (Fig. 5c, d). The roughness of the films also increases as the duty cycle increases. The surface roughness increases from 50 to 150 Å as the duty cycle increases from 10% to 50%. The increase of grain size with duty cycle can be understood from the fact that at higher duty cycles, the ON time is high and the flux of ions available for deposition is high, resulting in higher nucleation rates and higher thickness compared to lower duty cycles.

The cross-plane resistivity of the films was measured by providing In point contact on the top surface of the film; titanium substrate served as the other contact. The resistivity was measured for the films deposited at different duty

Fig. 5 AFM images of the CdTe films deposited at different duty cycles: **a** Z-201 Angstroms/div, **b** Z-317 Angstroms/div, **c** Z-517 Angstroms/div, **d** Z-725 Angstroms/div



Scan Area – 1.0 μm x 1.0 μm

a - Z – 201 Angstroms/div, b – Z – 317 Angstroms/div

c – Z – 517 Angstroms/div, d – Z – 725 Angstroms/div

cycles. Table 2 shows the values of resistivity of the films deposited at different duty cycles. It is observed that the resistivity decreases from 450 to 80 Ω cm as the duty cycle increases from 10% to 50%. This may be due to the fact that the scattering of the carriers is low for the films deposited at higher duty cycles because of the large crystallite size. In addition, thickness of the films deposited at higher duty cycles is higher than the thickness of films deposited at lower duty cycles.

Conclusion

A cost-effective and simple method of obtaining single-phase cubic CdTe films of reasonable resistivity and crystallite size suitable for photovoltaic cells has been demonstrated. The process can be scaled up for commercial exploitation.

Table 2 Variation of resistivity with duty cycle

Duty cycle (%)	Thickness (μm)	Resistivity (Ω cm)
10	1.0	450
20	1.2	345
30	1.4	260
40	1.7	130
50	2.0	80

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