

# Properties of CdTe films brush plated on high temperature substrates

K.R. Murali<sup>a,\*</sup>, B. Jayasutha<sup>b</sup>

<sup>a</sup>*Electrochemical Materials Science Division, Central Electrochemical Research Institute, Karaikudi- 630006, India*

<sup>b</sup>*Department of Physics, J. J. College of Engineering and Technology, Trichy, India*

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## Abstract

CdTe thin films were brush plated on substrates maintained at temperatures in the range 30–90 °C from the precursors. The films exhibited cubic structure. Optical band gap of 1.45 eV was obtained. XPS measurements indicated the formation of CdTe. AFM studies indicated the formation of fine grains of the order of 50 nm, for the films deposited on room temperature substrates. Hot probe measurements indicated films to be n-type. A mobility in the range of 5–60 cm<sup>2</sup> V<sup>-1</sup> s<sup>-1</sup> and a carrier density of 10<sup>15</sup> cm<sup>-3</sup> was obtained.

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## 1. Introduction

CdTe is a compound semiconductor belonging to the II–VI group with an ideal band gap of 1.45 eV for direct light to electricity conversion. Large area solar cells have recently demonstrated efficiencies in excess of 10%. Several thin film techniques have been used for obtaining photovoltaic quality CdTe films. For large area deposition using other techniques which involves vacuum system may not be suitable for low cost production. One of the alternatives is the brush plating technique, which uses only a very small quantity of the electrolyte for obtaining large area thin films.

The brush plating technique also known as selective plating, differs from traditional tank or

bath plating in that the work piece is not immersed in a plating solution (electrolyte) instead, the electrolyte is brought into contact with the part and applied by a hand-held anode or stylus, which incorporates an absorbent wrapping for applying the solution in the work piece (cathode). A direct current power pack drives the electrochemical reaction, depositing the desired metal on the surface of the substrate. In practice, movement between the anode and cathode is required for optimum results when plating, stripping, activating and so on. Currently, a broad range of metals can be plated by brush plating. The key advantage of brush plating is portability. Many systems can be moved to various locations in a production facility or be transported to the job site. Selective plating is also versatile: it permits most electroplate types to be deposited onto any conductive substrate that can be touched with an electrode. Cast iron, copper, stainless steel and aluminium can be plated by this

\*Corresponding author. Tel.: +91 4565 227 550;  
fax: +91 4565 227 553.

*E-mail address:* [muraliramkrish@gmail.com](mailto:muraliramkrish@gmail.com) (K.R. Murali).

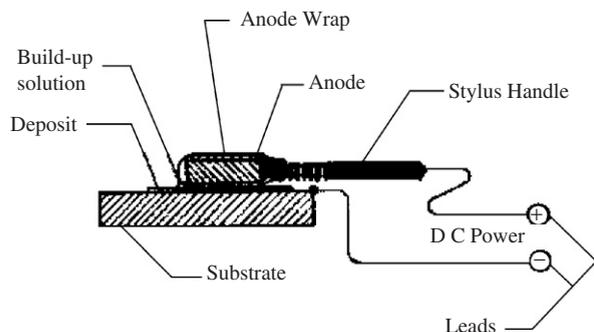


Fig. 1. Schematic of the brush plating system.

method and exhibit good adhesion. Limited adhesion can be obtained with other materials such as titanium, tungsten and tantalum.

Brush plating allows higher current densities than tank plating. This translates into higher deposition rates up to 0.0100 mm/min. In addition, inherently precise thickness control permits plate buildup or repair without the need for subsequent machining. The brush plating technique though widely used for depositing metals has been earlier employed for the deposition of CdSe films [1,2]. To our knowledge, this is the first report on CdTe films grown by the brush plating technique. In this work, results on CdTe films brush plated on titanium and conducting glass substrates maintained at high temperatures are reported. The schematic of the brush plating system is shown in Fig. 1.

## 2. Experimental methods

CdTe films were brush plated on to titanium and conducting glass substrates maintained at different temperatures in the range 30–90 °C. The precursors used were 3 ml of 0.5 M CdSO<sub>4</sub> and 0.5 ml of 0.1 M TeO<sub>2</sub>. A current density of 100 mA cm<sup>-2</sup> was employed and the plating time was 10 min. The cotton wrapped graphite anode was soaked in the precursor solution and brushed on the cathode at the rate of 2 cm/min. Uniform pressure was applied on the cathode surface while moving the anode, this resulted in uniform thickness. Thickness of the films was measured by the weight difference method. The thickness was found to vary in the range of 3.0–5.0 μm as the substrate temperature increased. The films were characterized by X-ray diffraction technique using Philips X-ray diffractometer with Cu Kα radiation. Optical absorption measurements were made on the films using Hitachi UV–VIS–NIR

spectrophotometer. XPS studies were made on the films using ESCALAB. EDAX measurements were also made. Surface morphology of the films were studied by AFM.

## 3. Results and discussion

XRD patterns of the films deposited at different substrate temperatures are shown in Fig. 2. The prominent peaks corresponding to (111), (220), (311), (400), (331), (422) and (511) of the cubic CdTe phase are observed in all cases. It is observed that as the substrate temperature increases, the intensity of the peaks also increases and the width of the peak decreases due to improved crystallinity. The crystallite size calculated using the Debye Scherrer equation [3] is found to increase with increase of substrate temperature (Table 1).

To examine the chemical composition of the films, the XPS spectra of the CdTe films grown at

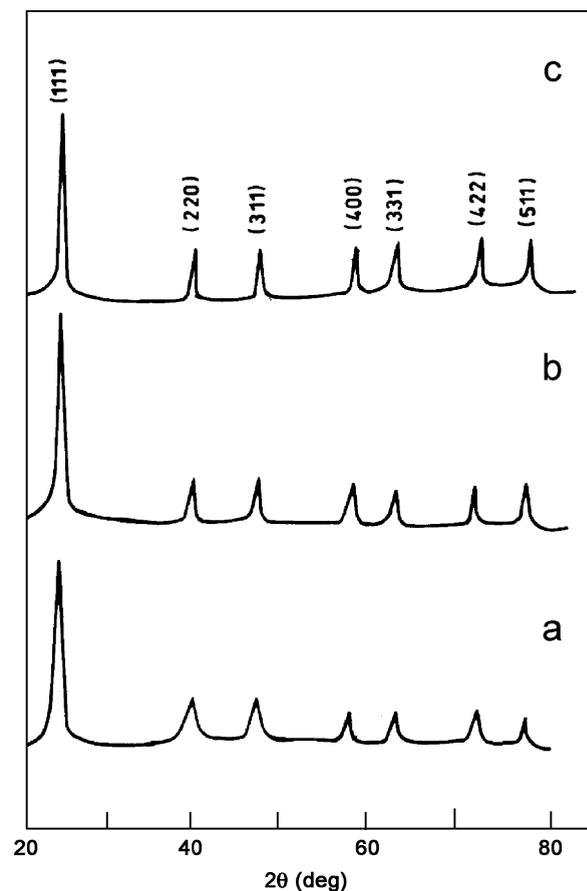


Fig. 2. X-ray diffraction pattern of CdTe films plated at different substrate temperatures: (a) 30 °C; (b) 50 °C; and (c) 90 °C.

Table 1  
Variation of crystallite size with substrate temperature

Substrate temperature (°C)	Crystallite size(nm)
30	50
50	70
70	90
80	105
90	120

different bath temperatures were measured and are indicated in Fig. 3. The XPS spectra of the CdTe films deposited at 90 °C is shown 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 [4]. These findings are characteristic of the Cd in CdTe and are in good agreement with the literature [5,6]. 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. There is no evidence of shifting of the energy levels to higher binding energies corresponding to  $\text{TeO}_2$  formation.

EDAX measurements indicated Cd (50.2%) and Te (49.8%) for the films deposited on room temperature substrates, as the substrate temperature increased to 90 °C, the selenium concentration increased slightly (Cd—49.8% and Te—50.2%). Hot probe measurements indicated n-type behaviour, similar to earlier reports on electrodeposited CdTe films [7–10].

Optical absorption measurements were made at room temperature by placing an uncoated identical conducting glass substrate in the reference beam. A plot of  $(\alpha h\nu)^2$  versus  $h\nu$  for the films deposited at a substrate temperature of 90 °C is shown in Fig. 4. The plot is linear indicating the direct band gap nature of the films. Extrapolation of the line to the  $h\nu$  axis indicated a direct band gap of 1.45 eV.

AFM images were taken on the films deposited at different temperature in order to study the surface topography. Fig. 5 shows the AFM images ( $1 \times 1 \mu\text{m}$ ) of the CdTe films deposited at different substrate temperature. These images show that the grain size of the films increase as the substrate temperature rises, which is consistent with the XRD results. Investigation of the AFM images demonstrates that for low temperatures, the grain sizes are small (Fig. 5(a)). By increasing the substrate temperature, these small grains gradually combine

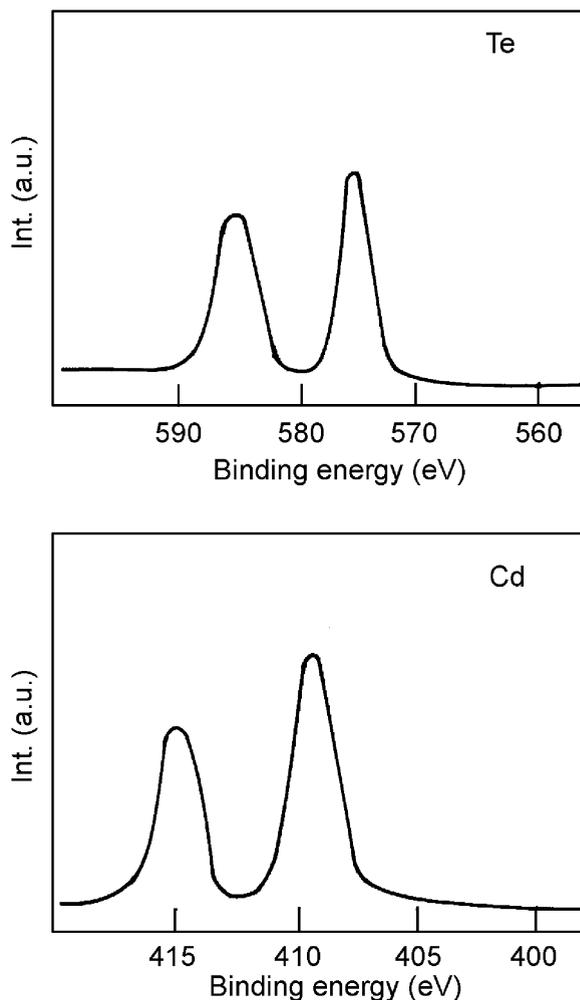


Fig. 3. XPS spectra of CdTe films deposited at a substrate temperature of 90 °C.

and make bigger grains (Fig. 5(b)). With increasing the substrate temperature further, the grains become bigger (Fig. 5(c) and (d)). The samples roughness also increases as the substrate temperature increases. The surface roughness increases from 50 to 150 Å as the substrate temperature increases from 30 to 90 °C. The increase of grain size with substrate temperature may be due to the fact that the increase of thermal energy facilitates recrystallization and hence the increase of the crystallite size.

Hall measurements were made on the films adopting the procedure reported earlier [11]. In this method the CdTe layer is mechanically transferred from the conducting substrate onto a non-conducting epoxy resin without the formation of cracks [12,13]. The electrical properties of the CdTe layers were examined at room temperature by resistivity

and Hall measurements using Van der Pauw method. The value of the resistivity determined from Van der Pauw method varied from  $10^3$  to

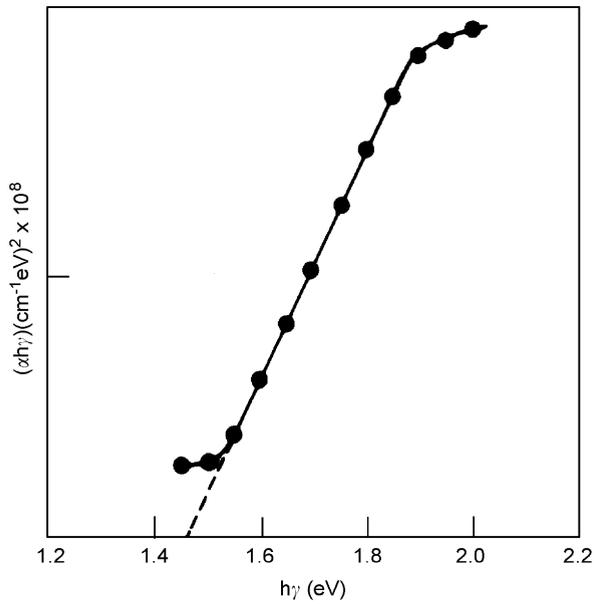


Fig. 4.  $(\alpha hv)^2$  versus  $h\nu$  plot of CdTe films deposited at a substrate temperature of  $90^\circ\text{C}$ .

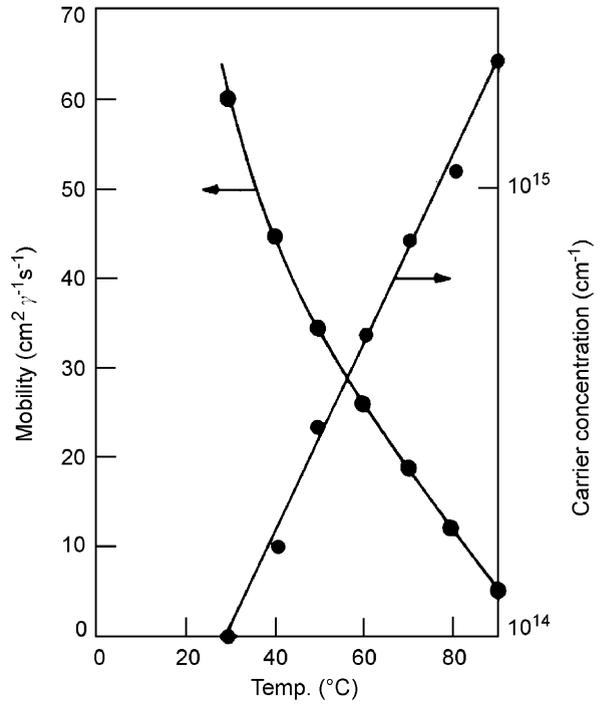


Fig. 6. Variation of carrier density and mobility with substrate temperature.

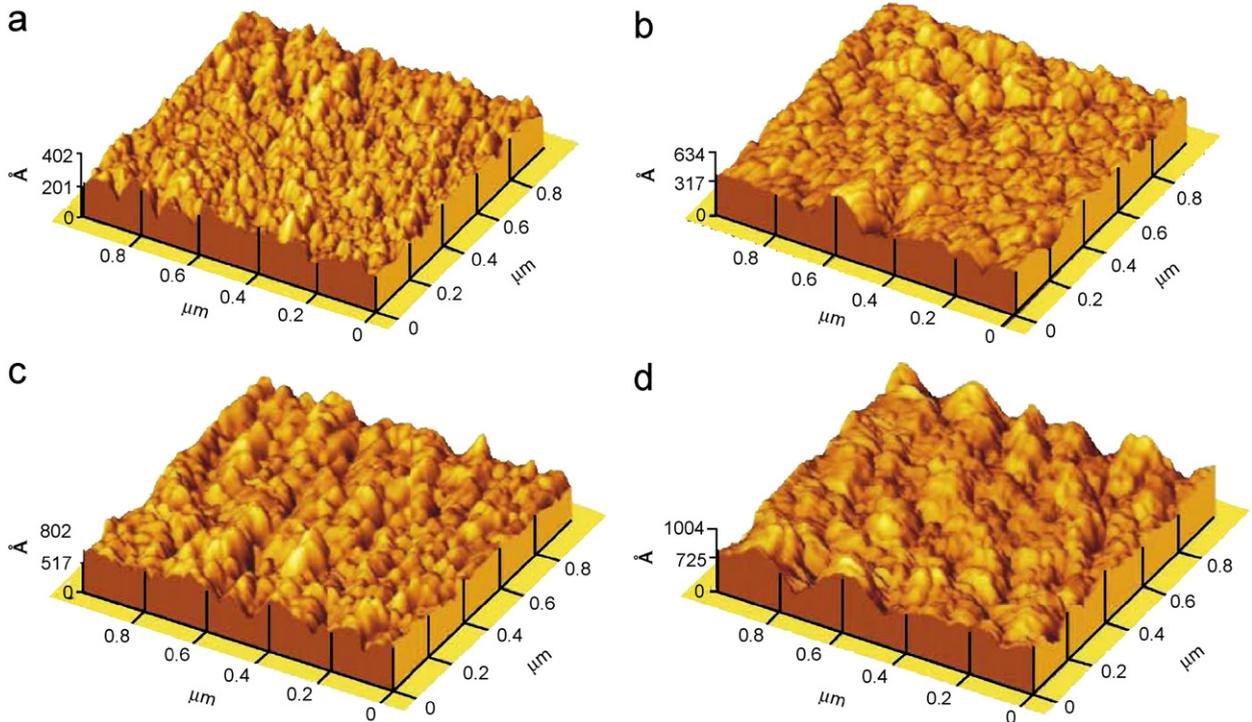


Fig. 5. Atomic force micrographs of CdTe films deposited at: (a)  $50^\circ\text{C}$ ; (b)  $60^\circ\text{C}$ ; (c)  $70^\circ\text{C}$ ; and (d)  $90^\circ\text{C}$ .

$10^4 \Omega \text{cm}$  similar to earlier reports [7,9,14]. Hall measurements indicated the films to be n-type. Fig. 6 indicates the variation of mobility and carrier concentration with substrate temperature. The carrier concentration is found to vary from  $10^{14}$  to  $10^{15} \text{cm}^{-3}$  with increase of substrate temperature. The mobility is found to vary from 5 to  $60 \text{cm}^2 \text{V}^{-1} \text{s}^{-1}$ . These results are similar to earlier reports [15]. The electrical conductivity in CdTe is mainly associated with the tellurium vacancy, which is responsible for the n-type conductivity.

#### 4. Conclusions

A cost effective and simple method of obtaining CdTe films of reasonable resistivity, carrier concentration and mobility has been demonstrated. The resistivity varied from  $10^3$  to  $10^4 \Omega \text{cm}$ , carrier concentration varied from  $10^{14}$  to  $10^{15} \text{cm}^{-3}$ , the electron mobility varied from 5 to  $60 \text{cm}^2 \text{V}^{-1} \text{s}^{-1}$  as the substrate temperature increases. Steps are underway to deposit large area films for photovoltaic cell applications, which can be used for commercial production.

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