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Electrical and Optical Properties of Vacuum Evaporated Cadmium Telluride Thin Films

J. V. DHANVIJ
Department of Physics, Smt. P. K. Kotecha Mahila Mahavidyalaya, Bhusawal-425201 Maharashtra, India

Abstract: *Cadmium Telluride thin films were prepared on a glass substrate at room temperature using thermal evaporation method under the vacuum of 10^{-5}torr. The structural properties of films were evaluated by XRD and Scanning Electron Microscopy. The quantitative analysis was done by Energy Dispersive Analysis for X – Ray to determine atomic % of the material used. The X-ray diffraction analysis confirms that films are polycrystalline in nature. The crystallite size (D) were calculated and found to be 10.9 – 13.6 nm. The optical transmission spectra were obtained in the 200 nm – 1100 nm wavelength range by UV-visible spectrophotometer. The optical band gap of the films was found to be in the range from 1.6 to 2.2 eV. The resistivity of films of different thicknesses was measured for all samples at room temperature. The plot of resistivity as a function of thickness indicates that the resistivity of films increases as thickness increases. The activation energy is also determined whose values are lies between 0.248 eV to 0.262 eV and it is found to be thickness dependent. Hall mobility, Hall coefficient and carrier concentration were also studied. The Hall coefficient shows a positive sign exhibiting P-type of semiconducting material.*
Keywords*: Thermal evaporation, Activation energy, Fermi energy, Optical band gap.*

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I. INTRODUCTION

CdTe, a direct band gap material II-VI semiconductor with band gap energy of 1.74 eV, has long been found as promising material for optoelectronic devices such as solar cells, high efficiency thin-film transistors, electron-beam pumped lasers, LED, electroluminescent devices, etc [1-5]. In addition, CdTe has large absorption coefficient to visible light. This property is useful for good theoretical conversion efficiency and has led to the investigations for obtaining efficient solar cells. There are a number of reports on the different optical and electrical properties of CdTe polycrystalline thin films prepared by various techniques such as vacuum evaporation [6-8], quasi-closed volume technique [9], electrode position [10-13], chemical bath deposition (CBD) [14-15], spray pyrolysis, sputtering [16] etc.

It is seen that different parameters of a film are structural dependent which also depend on the method of preparation, its thickness and other factors. Also the mechanical stability of the thin film is one of the major factors for designing various optoelectronic devices. The thermal evaporation method is cost effective and suitable for large area deposition. We have prepared CdTe thin films of different thicknesses by thermal evaporation method and the different micro structural parameters of these films were determined from their XRD spectra. In the present work, the effect of thickness of thermally deposited CdTe films is investigated to optimize the growth condition for a good quality film which will be suitable for optoelectronic devices.

II. EXPERIMENTAL

The CdTe compound ingots were obtained by taking appropriate amount of 99.999% pure Cd and Te in an evacuated quartz ampoule. The ampoule with the charge was then sealed under a pressure of 10^{-5} torr and was placed in rotating furnace. The temperature of the furnace was raised gradually to 970 K and left at this temperature for about 48 h. Well mixed charges were then quenched in an ice bath. The CdTe ingot was taken out from the ampoule and made into fine powder and used for film preparation. The substrate to source distance was kept 13 cm. The samples of different thicknesses in the range 1000 Å – 3000 Å were deposited at room temperature. The thickness of the films was controlled by quartz crystal thickness monitor model no. DTM-101 provided by Hind-Hi Vac. Further confirmation of thickness was estimated by Tolansky's method [17] using multiple beam Fizeau fringes. The deposition rate was maintained 5-10 Å/sec throughout sample preparation. In order to study the structural properties the films were analyzed by an X-ray diffractometer (Bruker, Germany) using CuKα radiation with wave length λ=1.5406 Å in the 2θ range from 200 to 800.

Transmission spectra were obtained in the wavelength range of 200 nm – 1100 nm by Shimadzu 1601 UV-Visible model of the spectrophotometer at room temperature. Resistivity of the samples was measured by four probe technique using model No.DEP-02 "Scientific Equipment Roorkee", as function

of thickness and temperature. A small oven had been provided to facilitate measurements at various temperatures ranging from room temperature 303 K to 473K. A highly regulated constant current generator was specifically designed to provide the required varying current. (0 to 20 mA with resolution 10 μA) had been provided for the purpose. In the present work, Hall voltage (VH) of a semiconducting crystal can be measured under different magnetic field strength (B) and varying magnitude of current (I) using model No.HEX-21C,SES "Scientific Equipment Roorkee". A modified Hall probe had been used for thin films to evaluate the mobility and carrier concentration of the semi conducting material. The sample for the measurement was kept in a known magnetic field produced by electromagnet**.**

III. RESULTS AND DISCUSSION

3.1 Structural Characterization

Fig.1 and Fig.2 illustrates the XRD pattern of CdTe thin film prepared at substrate temperature of 303K. The 2θ peaks observed at 24.914^0, 37.316^0 and 43.582^0, exhibit the formation of the cubic phase of CdTe which is correspond to the (111), (200) and (220)) planes of reflections. The inter-planar distances as indicated in the XRD result were found to be 3.5711 Å, 2.4078 Å, and 2.0750 Å. The presence of large number of peaks indicates that the films are polycrystalline in nature. From the results shown below, the strongest peak for the grown films occurred at 2θ=24.914° with d = 3.5711 Å which is correspond to (111) plane. The lattice parameters in the prepared thin films have been determined as a= 4.57Å and c=7.48Å. The average particle size of Cadmium Telluride thin films was determined using Debye–Sherrer's equation [18] and found to be 10.9 – 13.6 nm.

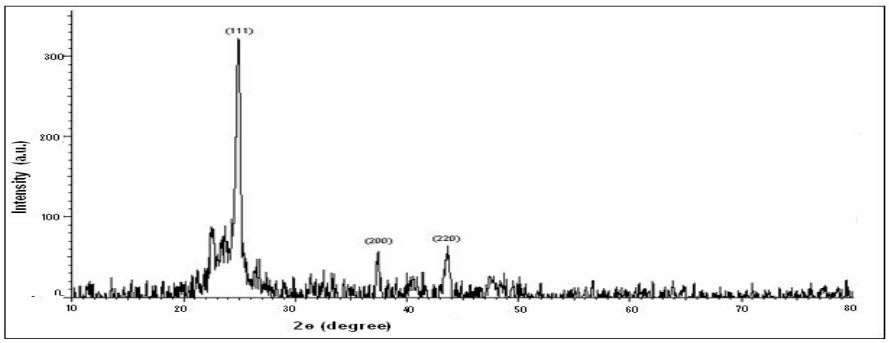

Figure1: XRD of CdTe of thickness 1500Å

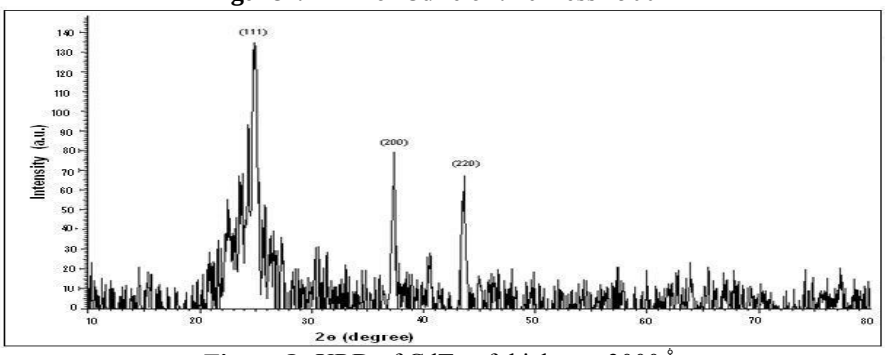

Figure 2: XRD of CdTe of thickness 3000Å

3.2 Optical Property

The optical transmittance spectra of CdTe films in the present studies were recorded using the UV-Visible spectrophotometer (Shimadzu 2450) in the range 300nm to 1100nm wavelength at room temperature. Fig.3 shows transmission spectra of a typical CdTe film deposited at room temperature before and after annealing for one hour in vacuum. On heat treatment the transmittance is found to be slightly increased. The band gap energy (*E*g) was estimated on the basis of the recorded optical spectra using the following Tauc relation, $\alpha h\nu = A\,(h\nu - Eg)^n$

Where, *A* is constant, α is the absorption coefficient, *h*υ is photon energy, and *n* depends on the nature of the transition. For direct transitions *n* =1/2 or 3/2, while for the indirect case *n* = 2 or 3, depending on whether they are allowed or forbidden, respectively. The best fit to the experimental data was obtained for *n* = 0.5. This is in agreement with the literature data according to which CdTe is a semi-conducting material with a direct band gap. Figure 4 shows $(\alpha h\nu)^2$ versus *hv* for CdTe thin films. The plot of $(\alpha hv)^2$ versus *hv* has direct transition with direct band gap energies. The observed trend at absorption edge towards lower photon energies for the increasing film thickness could be attributed to the change in the grain size and the stoichiometry. The

straight line portion is extrapolated to cut the x-axis, which gives the energy gap. All graphs show straight line portions supporting the interpretation of direct band gap for all the films. The estimated band gap values were obtained near about 1.6 to 2.2 eV which is in good agreement with the earlier investigation of CdTe [19-21]. Hence the CdTe can be used in development of efficient photovoltaic applications.

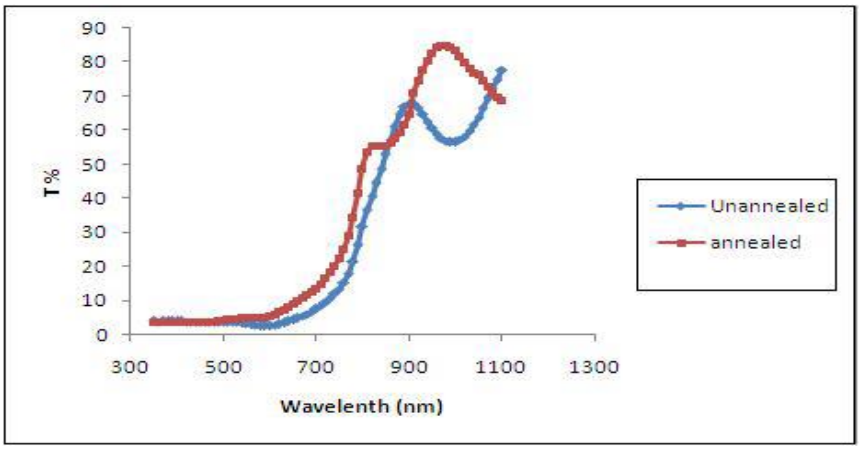

Figure3: The transmission spectra

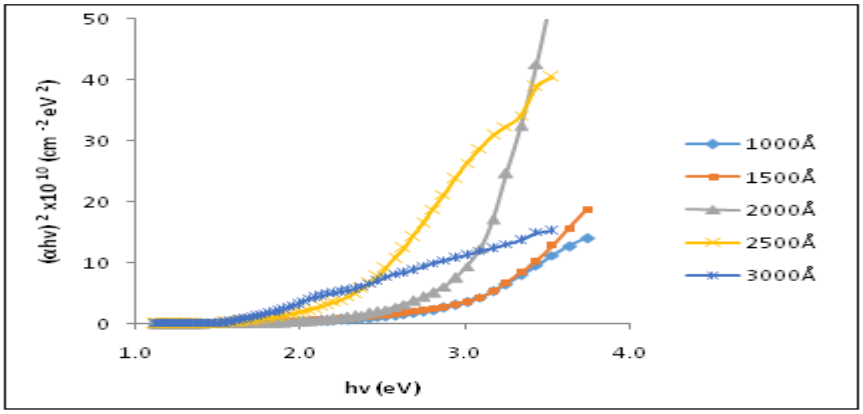

Figure 4: plot of $(\alpha h\nu)^2$ Verses hν of CdTe Thin Film

3.3 Electrical Properties

3.3.1 Resistivity Measurement of CdTe Thin Films by Four Probe Method

The resistivity of CdTe thin films of different thicknesses 1000 -3000 Å was measured by four-probe set up. Resistivity for all samples was measured at room temperature. The graphical representation of probe voltage verses probe current for different thickness is as shown in Fig.5 (a).The plot of resistivity as a function of thickness indicates that the resistivity of films increases as thickness increases. The plots of ρ against 1/d and ρd against d, which represent straight line graph following Sondheimer relations,

$$\rho = \rho_0 \left[d + \frac{3\lambda}{8}(1-p) \right]$$

$$\rho = \rho_0 \left[1 + \frac{3\lambda}{8d}(1-p) \right]$$

Where, ρ_0 and pare the bulk resistivity and specular reflection coefficient respectively at the surface of thin film. Surface scattering assumed entirely non-specular so that p = 0, the mean free path λ_0 and bulk resistivity ρ_0 may be computed from the observed slope and intercept [Fig.5(c)]. It is found that $\rho_0 = 1.25\ x\ 10^{-4}\Omega cm\ \ and\ \lambda_0 = 2.688\ x\ 10^{-4} cm$. Using these values in the relation (Chopra 1966), charge carrier concentration is estimated as n = 3.493x10^7 /cm^3.

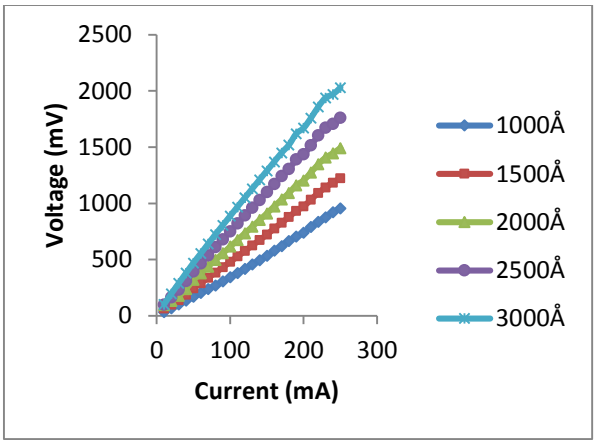

Figure 5(a): Plot of Probe Voltage vs Probe Current

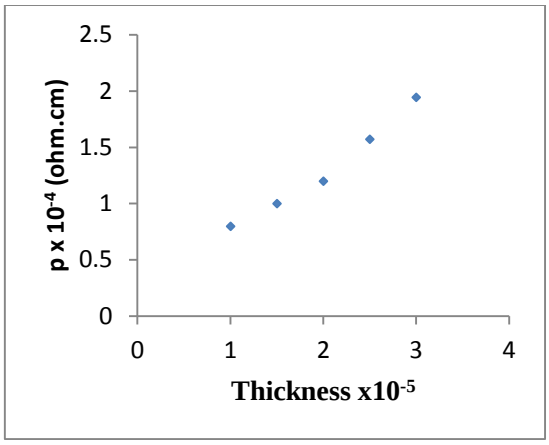

Figure 5(b): Plot of Resistivity vs Thickness

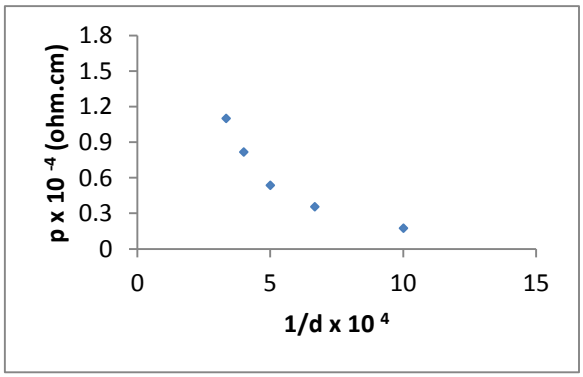

Figure5(c) : Plot of Resistivity versus 1 / Thickness

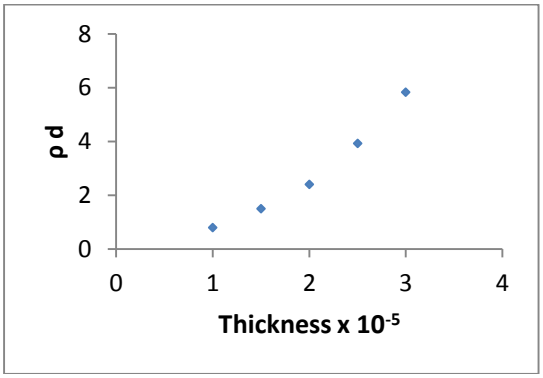

Figure 5(d): Plot of ρd versus Thickness

3.3.2 High temperature (303 to 473K) in plane resistivity measurement by four-probe method

Using high temperature four-probe resistivity set up, the resistivity of CdTe (thickness – 1000 - 3000 Å) thin films were measured in the temperature range 303 to 473K.The graphical variation of log ρ versus 1/T for each case is represented in Figure6.

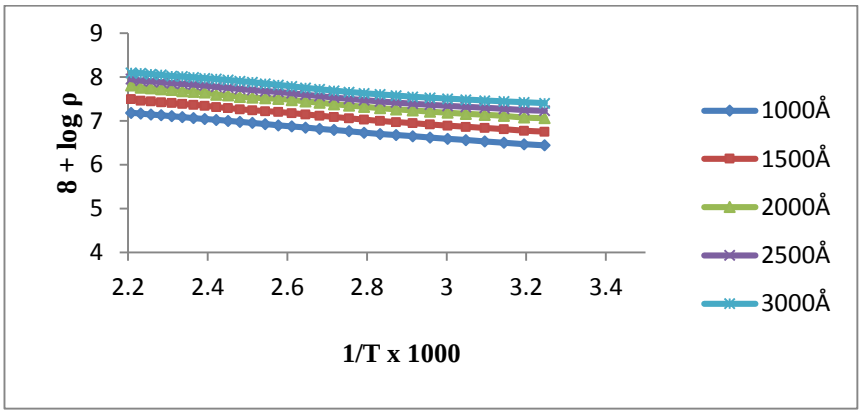

Figure 6: Plot of log of Resistivity verses Reciprocal of Temperature

The calculated activation energy of CdTe thin films is as shown in Table 1 and whose values are varied between 0.24 to 0.26eV. From this observation it is clear that activation energy is thickness dependent, as thickness increases activation energy increases.

Table 1: The evaluated values of electrical resistivity and activation energy of CdTe films

Thickness (Å)	Resistivity (10^{-4} Ω cm)	Activation energy(eV)
1000	0.1744	0.248
1500	0.3469	0.252
2000	0.5354	0.256

2500	0.8221	0.260
3000	1.1011	0.262

3.3.3 Hall Measurement of CdTe Thin Films

Hall measurement provides a sensitive method for evaluating the type, Hall mobility, Hall Coefficient and Carrier Concentration of CdTe thin films. Author has carried out the Hall measurement for different thickness (1000 - 3000 Å) using Hall set up. The graphical representation of Hall voltage versus Probe current at constant Magnetic Field 4KGauss for different thicknesses is shown in Figure7.The plot indicates Hall Mobility, Hall Coefficient and Carrier Concentrations are thickness dependant and the deposited films are of P- type semiconducting in nature. All the evaluated values are as shown in Table 2.

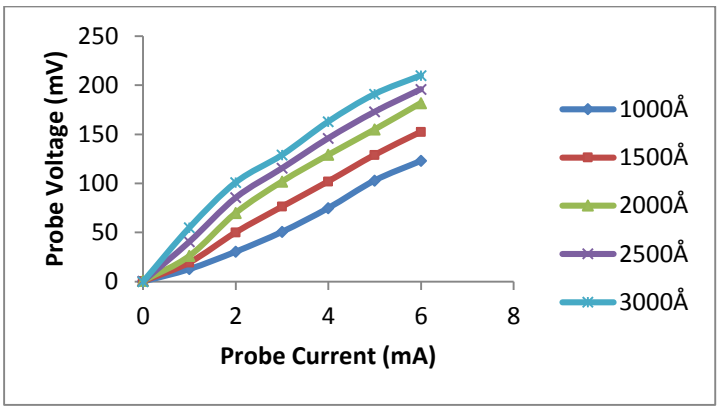

Figure7: Plot of Probe voltage verses probe current

Table 2: Estimated Parameters

Thickness (Å)	**Constant Magnetic Field (4KGauss)**		
	Hall Mobility (10^{-8}) cm^2/volt.sec	**Hall Coefficient cm^3/coulomb**	**Carrier Concentration (10^{18}) Per cm^3**
1000	5.303	0.925	0.675
1500	4.049	1.212	0.546
2000	2.801	1.500	0.416
2500	2.951	2.450	0.312
3000	3.086	3.399	0.183

IV. CONCLUSIONS

CdTe thin films of different thicknesses had been deposited successfully on glass substrate. XRD confirms that the structure of the film is polycrystalline in nature. The values of the optical band gap energy, calculated from the transmission spectra, ranged between 1.6 to 2.2 eV. The plot of resistivity, as the function of thickness, indicates that the resistivity of films increases as thickness increases. Activation energy is also determined whose values lie between 0.24 to 0.26eV and it is found to be thickness dependent. The mean free path λ_0 and bulk resistivity ρ_0 was computed. It is found that $\rho_0 = 1.25\ x\ 10^{-4}\Omega cm\ and\ \lambda_0 = 2.688\ x\ 10^{-4} cm$. The Hall measurement of CdTe films indicates that Hall mobility, Hall- coefficient and carrier concentration are thickness dependent and the deposited films are of P- type semiconducting in nature.

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