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Studies of rf sputtered CdTe films prepared at different rf powers

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Abstract : In view of making solar cells, films of CdTe, a direct gap semiconductor having band gap of about 1.45 eV, have been prepared by rf sputtering. A pellet of In or Al placed on the CdTe target was simultaneously sputtered with CdTe to get In-doped or Al-doped CdTe films. Maximum doping concentrations obtained in this way were of the order of 10^{11} cm^{-3} with In and 10^{12} cm^{-3} with Al at target-substrate distance 3.8 cm. All the films were studied to see the effect of rf power on film structure, electrical and optical properties. Films prepared at rf powers above 100 watts were polycrystalline and those prepared below this power were amorphous in nature. Rate of deposition was observed to be linearly increased with rf power within about 200 watts and decreased above this. Though resistivity has been observed to increase with rf power, sheet resistance of films prepared at about 170 watts showed a minimum. Absorption coefficient has been found to decrease with increasing rf power. Photo-response has been observed to be insignificant at the doping concentrations obtained in the present case In is concluded from these studies that rf power has a profound effect on film characteristics and suitable dopant material other than Indium and Aluminium is to be found out before making photo-voltaic devices.

Keywords : rf sputtering technique, film structure, rate of deposition, sheet resistance, absorption coefficient.

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1. Introduction

In recent years, rf sputtering technique is increasingly being used for preparing different kinds of films of metals, semiconductors and insulators (Chetia *et al* 1988, Wasa 1985, Das *et al* 1984, Phahle *et al* 1976, Davidse and Maissel 1966, Sinclair and Peters 1962). In the momentum transfer mechanism of rf sputtering, stoichiometry of compounds or alloys is almost retained and as such it is specially suitable to use in preparing films of compounds and alloys. Unlike dc sputtering, the problem of charge accumulation on the target surface is absent and therefore sputter-deposition of insulating and semiconducting films are also possible.

CdTe is a II-VI group semiconducting compound of band gap energy 1.45 eV (Loferski 1956, Wysocki and Rappaport 1960). This compound being a direct gap semiconductor, can absorb photon of visible region without phonon assisted mechanism. Thus, this compound is particularly suitable to be used as solar energy absorber such as in thin film solar cells. Because of high resistivity in the undoped state, CdTe films cannot be prepared by dc sputtering due to charge accumulation on the target surface. In rf sputtering, these difficulties are absent and so it can conveniently be used in CdTe film preparation. The nature of films prepared by rf sputtering depends on several factors including rf power and gas pressure in the chamber.

In the present work, detailed studies on the effect of rf power on film characteristics have been done. In this connection, dielectric properties, sheet resistance and absorption coefficient of *n*-type CdTe films doped with In and Al atoms have been measured. Effect of rf power on the crystalline structure has also been reported here.

2. Experimental

An rf sputtering system supplied by M/s Hind High Vacuum Co. (P) Ltd., Bangalore was used for CdTe film preparation. A 2 KW rf generator operating at 13.56 MHz frequency was used whose power could be varied continuously from 0 to 2 KW. Finely controlled pure Argon gas was introduced into the bell jar for Ar ion sputtering. The system has been designed to hold 3 water-cooled targets. The substrate holder was a circular copper disc kept below the targets and could be rotated, water cooled or heated. The perpendicular distance between the target and the substrate holder was 3.8 cm which was kept fixed during all the sputtering operations. For preparation of doped CdTe films, pellet of the doping material (In or Al) of about 2 cm diameter was fixed at a place on the target surface of CdTe target. Glass substrates, thoroughly cleaned by a 10% solution of RVS-50 (Kratos Analytical, U. K.), were placed on the holder at different places to get different doping levels. In the present case, three sets of samples were obtained in a single cycle by placing substrates radially at 3 different places on the substrate holder as shown in Figure 1. Thus a set A of samples were obtained by placing substrates at a position A just below the pellet, sets B and C of samples were obtained by placing substrates at the positions B and C respectively. A 5 inch diameter disc-shaped 99.999% pure CdTe target mounted on the water cooled target holder was procured from M/s Testbourne, U. K. Detailed arrangement inside the chamber has been shown in Figure 1.

In the sequence of rf sputtering, at first, the chamber was routinely pumped down to 5×10^{-6} torr after which pure Ar gas was introduced to raise the chamber

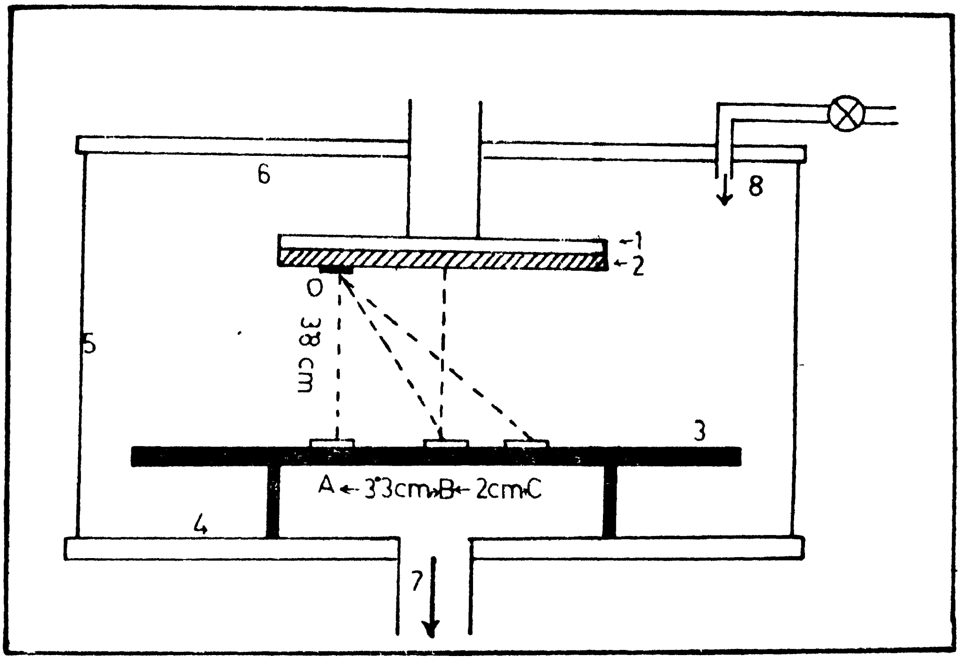

Figure 1. Schematic of arrangement inside the vacuum chamber : (1) target holder ; (2) CdTe target ; (3) substrate holder ; (4) Base plate ; (5) Bell jar ; (6) Top plate ; (7) To pump ; (8) Ar gas inlet
A, *B*, *C*, positions of glass substrates , *O*, pellet for doping.

pressure upto 1.5×10^{-8} torr. The rf power was switched on after this pressure was steady. The films were prepared at different rf powers. In a single cycle, rf power was maintained constant. In all the cycles substrates were water cooled.

The different thicknesses of the rf sputtered films were measured by interference method (Tolansky 1948). CdTe films were deposited on vacuum deposited Indium films on glass substrate. Counter-electrodes of In were vacuum deposited onto In-doped CdTe films and Ni counter-electrodes were deposited onto Al-doped CdTe films. Capacitance was measured at 1 KHz using digital LCR-Q meter (model 4910) procured from M/s Aplab, Bombay. The resistivity ρ and sheet resistance $\rho_\square$ were calculated by measuring electrical resistanee R using the same LCR-Q meter. For measuring absorption coefficient, monochromatic light of 6000 Å obtained from mercury lamp using a filter was focussed on the sample. The transmitted light was seen by a PMT (model RCA 931), the output of which was read in a digital picoammeter (Scientific Equipment, Roorkee). The absorption coefficient α was calculated from the relation $I = I_0 e^{-\alpha t}$ where I_0 is the incident light intensity, I is the transmitted light intensity and t is the film thickness (Streetman 1986). Response of the PMT has been proportional to the light intensity in this part of the spectrum. *I-V* characteristics were taken both in dark and under illumination for Al-doped CdTe samples. The samples were illuminated with white light from a projector lamp of 500 watts. X-ray diffraction curves were taken for different samples using Philips X-ray diffractometer (model PW-1710).

3. Results and discussions

The linearity of deposition rate has been obseived in our case at low power below about 200 watts (Figure 2). At higher rf power, this linearity has been deviated. The growth rate has been observed to decrease with increase in rf

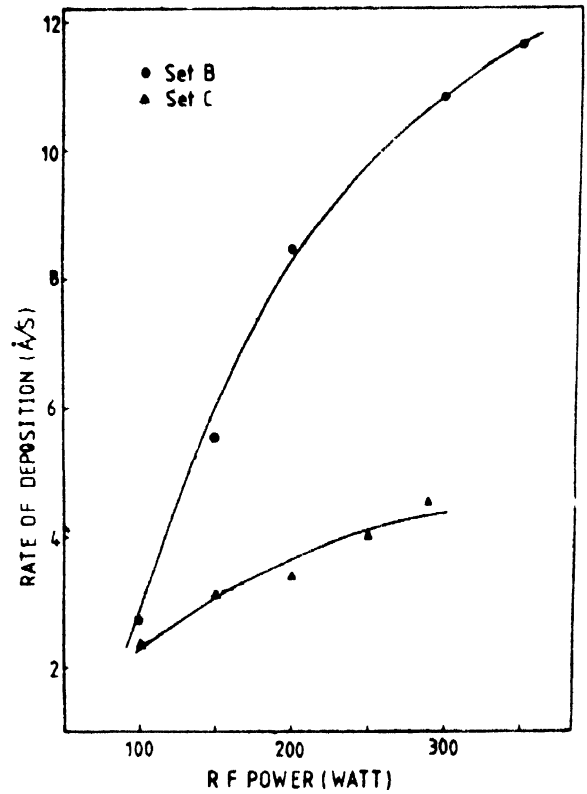

Figure 2. Varition of deposition rate of CdTe films with sputtering *rf* power.

power. The possible cause of this deviation may be due to increase of substrate temperature. Higher K.E. carried by the sputtered ions at higher rf power, is released to the lattice of the deposited film increasing thereby its temperature. Higher substrate temperature enhances the mobility of the deposited atoms increasing probability of their reflection without getting bonded to the film thus decreasing the deposition rate. From Figure 2, it is evident that growth rate is higher for films deposited on substrate placed below the centre of the target (**B** series of the samples).

Sheet resistance of different samples prepared at different rf powers have been found to vary significantly with rf power (Figure 3). Sheet resistance has been observed to be minimum in the film prepared at about 170 watts rf power. The possible cause of this minimum may be due to the exact amount of energy carried by the deposited atoms/molecules at this rf power. This energy was sufficient for the atoms/molecules to move to the lattice sites after sputter deposition.

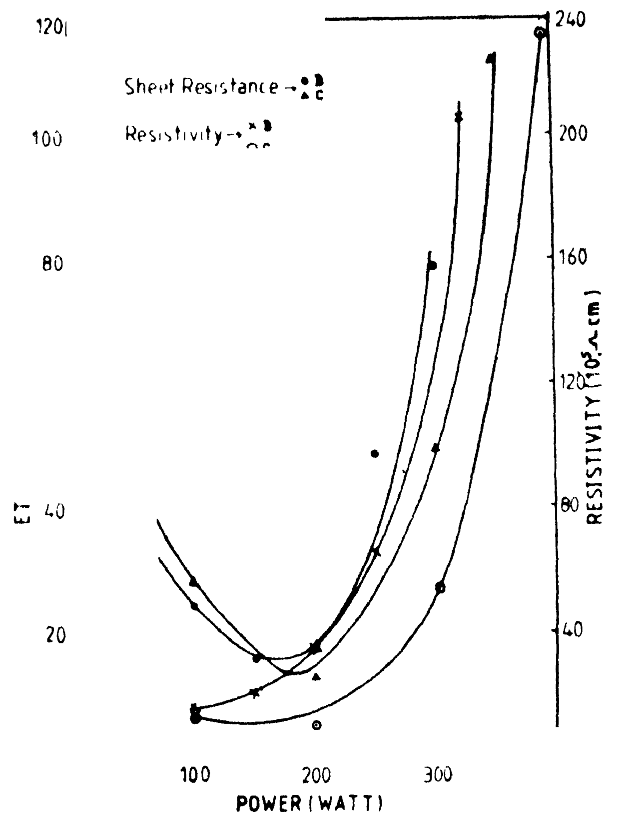

Figure 3. Resistivity (ρ) and sheet resistance ($\rho\square$) variation of CdTe films prepared at different *rf* powers.

Below this power, the deposited atoms/molecules cannot move long distances to occupy lattice sites, thus resulting in higher resistivity. Above minimum, the film may have some defect structures due to high energy carried by the deposited atoms/molecules.

X-ray diffraction studies showed that the CdTe films are mainly polycrystalline in structure. Below 100 W amorphous films were produced on water cooled glass substrates. As the rf power increased film structure changes from amorphous to polycrystalline nature (Figure 4).

Effect of bias voltages on capacitance were studied with increasing bias. Capacitance values of many samples increased suddenly to higher values and then

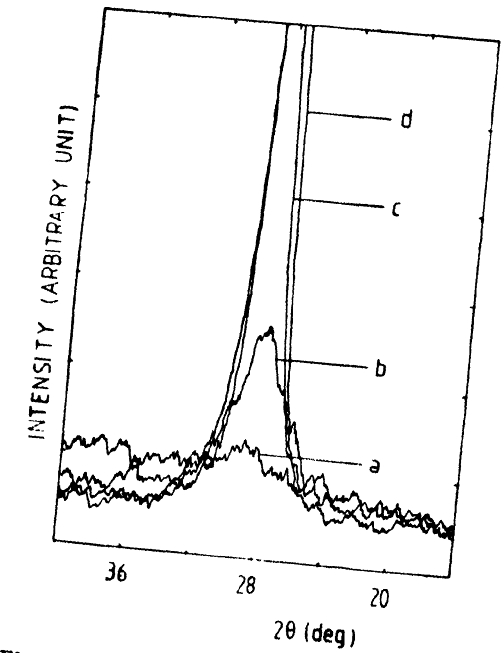

Figure 4. X-ray diffractograms of CdTe films prepared at different *rf* powers : Curve (a) 100 W ; (b) 200 W ; (c) 300 W ; (d) 350 W.

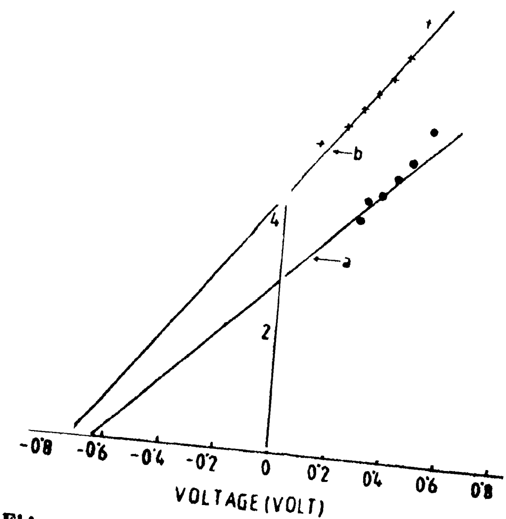

Figure 5. $C^{-2}-V$ characteristics of two Al-doped samples : (a) 150 W , (b) 200 W.

got short circuited. This is not possibly due to dielectric breakdown, but may be due to migration of conducting electrode materials into the bulk of the sample through holes and vacant sites present in the films. C-V plots of two typical Al-doped CdTe samples have been shown in Figure 5. Doping concentration was calculated from the slope using relation (SZe 1969).

$$\eta = 2C_0^2 V_D / e\epsilon A$$

where ϵ is dielectric constant, e is the electronic charge, A is the contact area and V_D is the diffusion potential. C_0 is the capacitance at zero bias condition. The doping concentrations found from the two C-V plots were of the order of 10^{12} cm^{-3}. In case of In-doped films the highest concentration found was of the order of 10^{11} cm^{-3}. Hall effect could not be performed on these films as the resistivity values were quite high to send any appreciable current through the samples.

Absorption coefficient α has been found to vary with rf power for all the samples. Effect of rf power on α has been shown in Figure 6 for In-doped CdTe

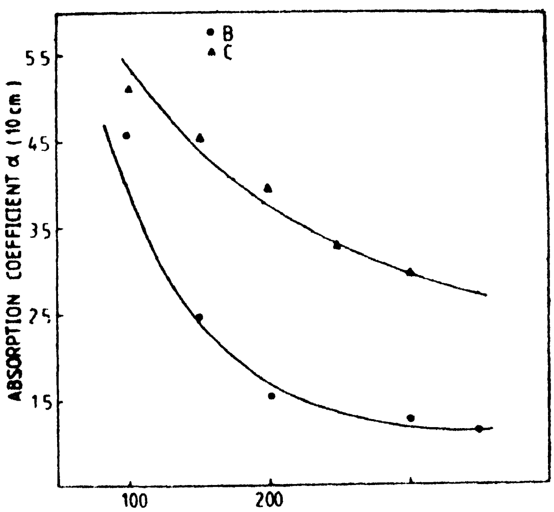

Figure 6. Absorption coefficient variation with *rf* poer of a few In-doped CdTe films.

films. Its variation with rf power may be due to the variation of defect concentration which also caused resistivity variation with rf power as already has been discussed.

Photo-response of these structures was very low. Typical I/V curves of a sample with Al-doped CdTe film have been shown in Figure 7. The I/V curve of the sample under illumination was taken at 500 lx light intensity. The nature of the illuminated curve shows that series resistance of the device is very high. It needs further improvement for using as an efficient photovoltaic device.

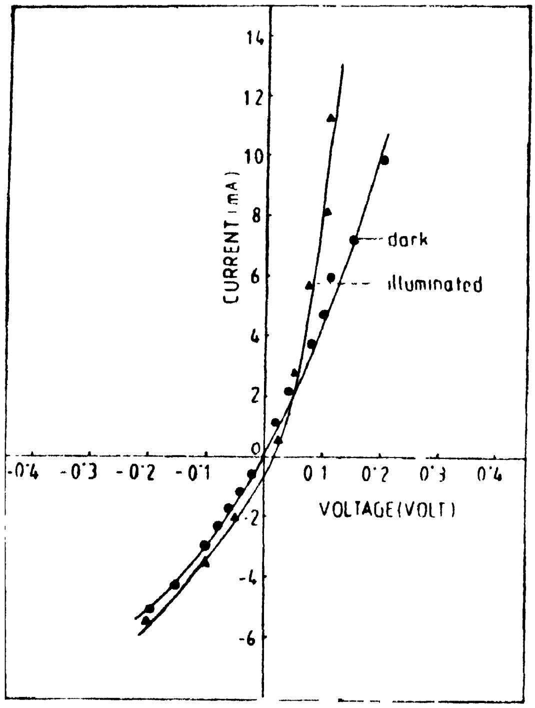

Figure 7. *I/V* characteristics of an Al-doped CdTe film in dark and at 500 lx intensity of illumination (Area 6.79×10^{-2} sq. cm).

4. Conclusions

Some properties of rf sputtered CdTe films have been studied in the present case. Doping of CdTe films by In or Al from a pellet on the CdTe target during sputtering, could be achieved upto 10^{11} cm^{-3} or 10^{12} cm^{-3}. There has been profound effect of rf power on deposition rate, structure, film resistivity and absorption coefficient. A minimum sheet resistance has been obtained in the films prepared at about 170 watts rf power. This power may be suitable to prepare CdTe films for solar cell application. Photo-response of these films was not significant enough at these doping concentrations for using them in PV devices. Further work are in progress in our laboratory.

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