Bull. Mater. Sci., Vol. 21, No. 2, April 1998, pp. 149–154.

Electrical and optical properties of rf-sputtered CdTe films

P C SARMAH[†] and A RAHMAN*
Department of Physics, Gauhati University, Guwahati 781 014, India
[†]Regional Research Laboratory, Jorhat 785 006, India

MS received 5 May 1997; revised 17 February 1998

Abstract. **In this paper some electrical and optical properties of *n*-type CdTe films prepared by rf sputtering at 180 W power have been reported. For doping the films a number of pellets of pure Cd placed on the CdTe target were simultaneously sputtered with the target material to get Cd-doped CdTe films. The films after doping were found *n*-type. Maximum doping concentration obtained this way was of the order of 10^{14} cm^{-3}. XRF spectra of target material and the rf-sputtered films were found to be more or less similar. All the films were found to have large number of defects indicated by profound aging effect in the initial stages of aging. The films became stable for measurements after about 8–10 days. Activation energy and band gap found from the temperature dependence of dark conductivity were 0·5 eV and 1·43 eV respectively. Photoconductivity of the films was studied and the photoconductive rise time, decay time and the decay constants were determined from the photoconductive rise and decay curves at 500 Lx and 1000 Lx of intensity of illumination.**

Keywords. **Rf-sputtered film; doping; ageing effect; activation energy; photoconductive decay.**

1. Introduction

Studies of CdTe thin films have received much attention for their various probable applications. This zinc blende type semiconductor (Rose *et al* 1987) having a direct band gap (~ 1·46 eV), is thought to be a promising candidate for thin film solar cell and other electro-optical devices. This is the only semiconductor of II–VI groups showing both types of conductivity (Zanio *et al* 1978).

Different techniques to prepare CdTe films to study their characteristics have been adopted by different workers. Some of them are vacuum deposition (Uda *et al* 1978), closed-space vapour transport and closed-space sublimation (Mitchell *et al* 1985), electrodeposition (Basol 1988), sintered films (Matsumoto *et al* 1984), spray pyrolysis (Banerjee *et al* 1989), rf-sputtering (Das and Cook 1988) etc. The main advantage of rf-sputtering is that stoichiometry of the sputtered material is retained in the deposited film (Fisher and Weber 1952), making it a suitable technique for depositing intermetallic compounds.

Many workers studied structural, electrical and optical properties of CdTe films prepared by rf-sputtering. Some of the properties studied by us have already been published earlier (Sarmah and Rahman 1990). Some unpublished works such as XRF studies, temperature dependence of resistivity, aging effect on resistivity and photoconductive rise and decay characteristics are presented in this paper.

*Author for correspondence

2. Experimental

CdTe films were prepared by rf-sputtering in an argon ion atmosphere as reported in our earlier paper (Sarmah and Rahman 1990). In order to prepare Cd rich films, pellets of cadmium were fixed on the target to sputter simultaneously along with the target material. The rf power was maintained at 180 W in preparing all the samples. Two types of samples: gap-type and sandwich type, were prepared for electrical measurements. In gap type samples, indium was vacuum deposited on the two ends of rectangular CdTe films for electrodes. Sandwich type samples were prepared by depositing indium film before and after the deposition of CdTe films. Indium was found to make ohmic contact with *n*-type CdTe film. The work function of indium has been reported to be 3·97 eV (Rhoderik 1978) and that of CdTe to be > 4 eV (Sheer and Laar 1961), which satisfy the condition for making ohmic contact between them. For compositional analysis of rf-sputtered CdTe films, XRF spectra were taken with the help of a Philips pw-1480 spectrometer. For studying different characteristics of the samples in dark and under illumination, experiments were carried out in a specially designed apparatus as shown in figure 1. The apparatus consisted of two coaxial cylinders, the inner one being supported by the outer one. The outer cylinder has a side tube fitted with an air tight window. The sample holder with the sample in it was vertically clamped to the outer surface of the inner cylinder so that the sample faced the glass window. Shielded wires from the pressure contacts to the vacuum

deposited electrodes and thermocouple wires were brought out of the chamber through feedthroughs. A cylindrical heater was placed inside the inner cylinder whose temperature was controlled by a temperature controller (Philips-LD 30). An X–Y recorder (Digital Electronics Ltd) was used for the purpose of measurements. For taking *I–V* curves the bias voltage was given from a variable ramp (Systronic, model 1014). For photoconductive rise and decay, a constant voltage was applied to the sample through a standard resistance and was connected to the X–Y/t recorder. The voltage applied to the sample was connected to the X-axis of the recorder and the potential drop across the standard resistance due to the current flowing through the sample was connected to the Y-axis of the recorder. The annular space between the two co-axial cylinders was evacuated to about 10^{-2} torr by a rotary pump before taking any measurement.

3. Results and discussion

We have reported XRD studies in an earlier paper (Sarmah and Rahman 1990) and showed that the CdTe films prepared at lower rf power were amorphous and those prepared at higher power polycrystalline in nature. We have also observed that when the film was doped with In or Cd during sputtering, the film became more disordered (though not amorphous) even at higher power, compared to intrinsic film prepared at the same rf power. XRF spectra of target material and the rf-sputtered films were also taken to know the compositions and quality of films. Three typical XRF spectra are shown in figure 2 for comparison.

3.1 *Aging effect*

These rf-sputtered films were always endowed with defects during deposition. With time some defects are likely to heal up due to ionic movements and as such film resistivity decreases showing aging effect. For the purpose of observing aging effect, resistivity of rf-sputtered Cd-doped films was measured at room temperature after different intervals of time. The resistivity was found to decrease rapidly in the initial stage of aging and then at slower rate approaching a saturation value after several days as shown in figure 3 for two typical samples. Such aging effect has also been reported by earlier workers (Gogoi and Barua 1982).

3.2 *Activation energy and band gap*

Temperature variation of conductivity of two typical Cd-doped CdTe films has been shown in figure 4. Both gap-type and sandwich-type samples exhibit similar behaviour except a slight shifting in conductivity value. This difference in conductivity of two types of samples may be attributed to the difference in thickness of the CdTe films. The thickness measured by interference method was taken for calculation of conductivity. But, obviously, in sandwich structure, the effective thickness was reduced due to penetration of counter electrode materials while in gap type samples thickness was not affected. However, the temperature dependence plots for both types of samples are parallel giving same activation energies.

The activation energy obtained from the slope at lower

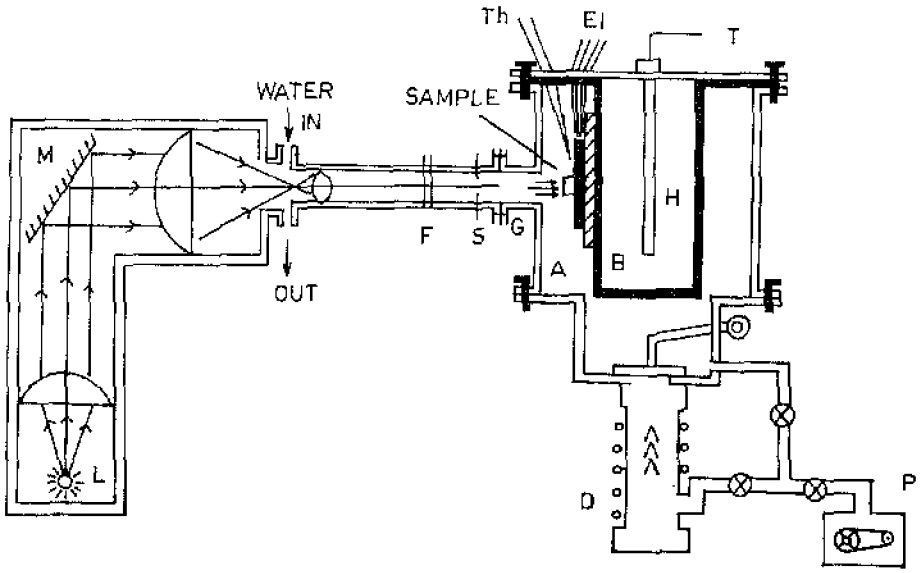

Figure 1. Experimental arrangement for different measurements (L, light source; M, mirror, A, outer cylinder; B, inner cylinder; G, glass window; S, shutter; F, arrangement for filters; Th, thermocouple; El, electrodes; H, heater; T, temperature controller; D, diffusion pump; P, rotary pump).

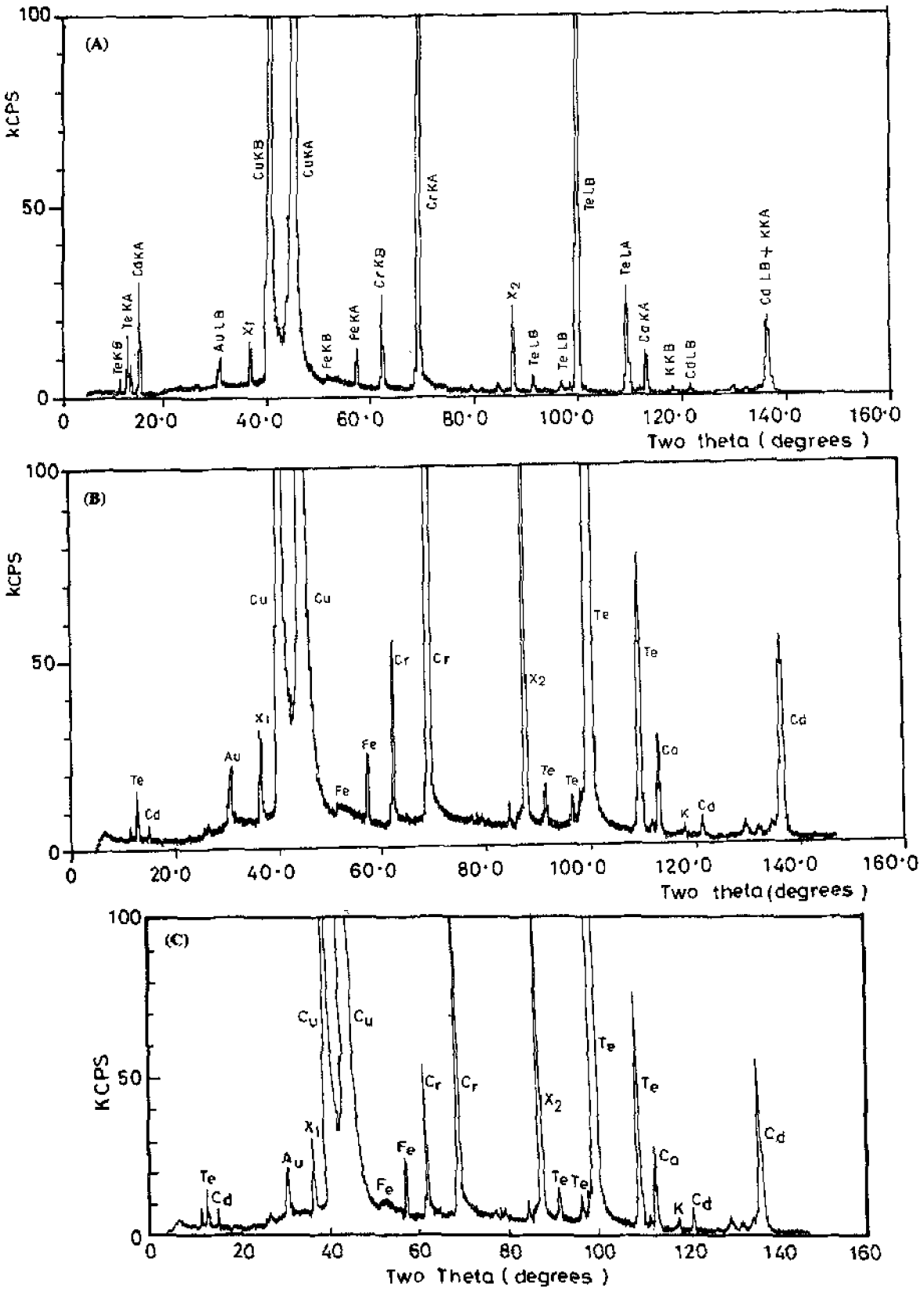

Figure 2. XRF spectra of CdTe films: (A) target material; (B) rf-sputtered film and (C) Cd-doped rf-sputtered film (Cr and Au from X-ray tube; Cu line from mask; Ca, X_1 and X_2 may be instrumental errors).

temperature region was about 0·5 eV. This corresponds to impurity conduction due to excess cadmium. As the temperature is raised, the impurity levels are exhausted and the conduction becomes intrinsic in nature. The band gap obtained from the slope at higher temperature region was about 1·43 eV.

3.3 *Photoconductivity in CdTe films*

The variation of photocurrent with light intensity was recorded at room temperature. Photocurrent was observed to increase with light intensity showing saturation at higher light intensity as shown in figure 5 for two typical samples. The increase of photocurrent and decrease of resistivity with light intensity is due to generation of extra carriers upon illumination. At lower intensities the concentration of available recombination centres is very much larger than the concentration of free electrons, most of the excited electrons have been trapped. Under this condition, the photocurrent varies linearly with light intensity. However, at higher illumination, generation of carriers are controlled by the recombination processes (Bube 1960).

The photoconductive rise and decay characteristics of Cd-doped films at room temperature were recorded with an X–Y/t recorder. Figure 6 shows the rise and decay

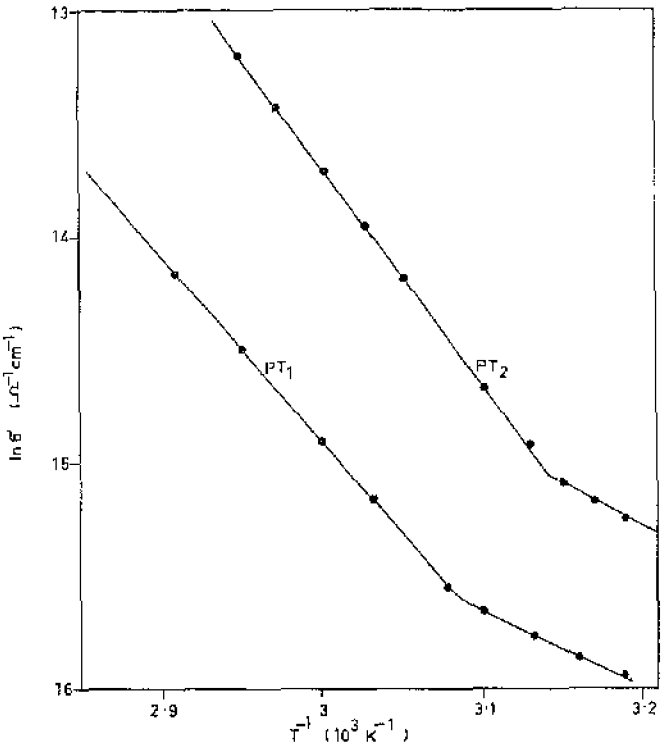

Figure 4. $\ln\sigma$ vs T^{-1} plots for two typical Cd-doped CdTe films prepared at 180 W. Sample PT1, gap type, doping conc. 6×10^{14} cm^{-3}; thickness 11,000 Å, gap area $7{\cdot}8\times10^{-2}$ cm^2; sample PT2 sandwich type, doping conc. 3×10^{14} cm^{-3}; thickness 10,500 Å; electrode area $9{\cdot}5\times10^{-2}$ cm^2.

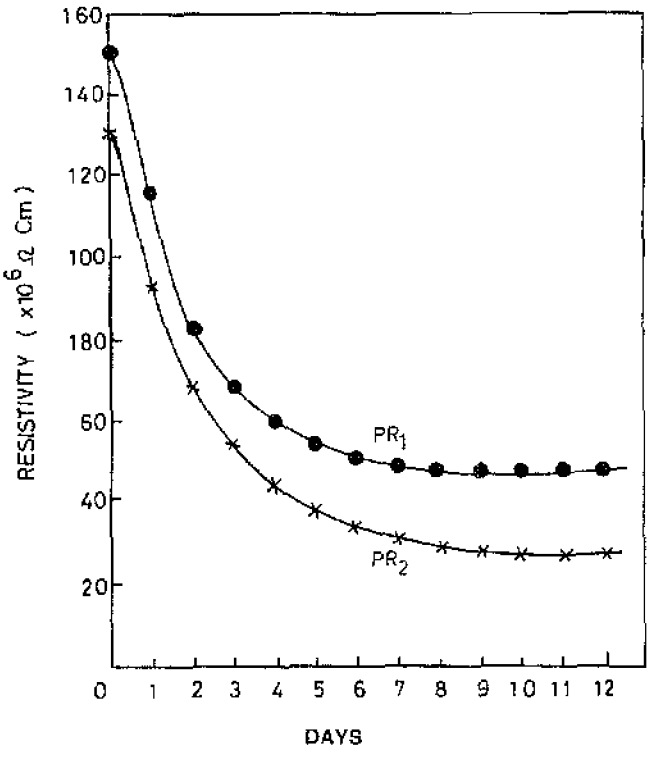

Figure 3. Ageing effect on resistivity of two typical Cd-doped CdTe films prepared at 180 W, doping concentration $2{\cdot}6\times10^{14}$ cm^{-3} and gap area between electrodes $2{\cdot}6\times10^{-2}$ cm^2; thickness 9500 Å (sample no. PR1) and 10,000 Å (sample no. PR2).

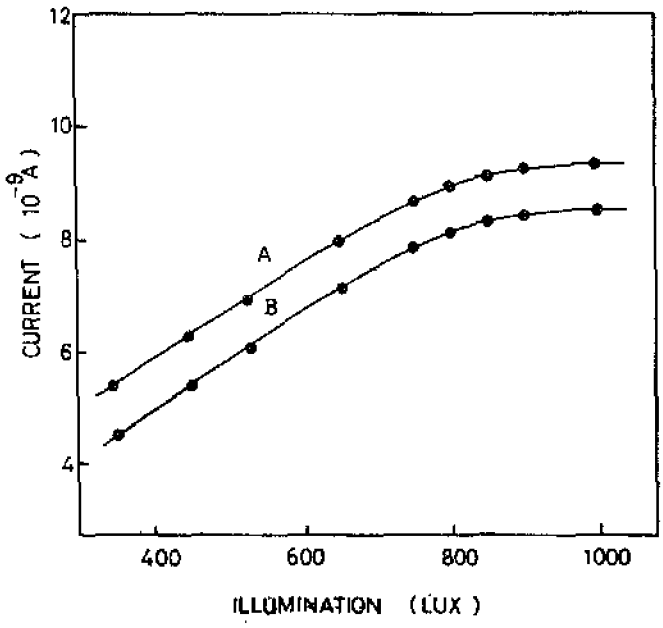

Figure 5. Variation of photocurrent with intensity of illumination for two typical films prepared at 180 W; sample A, doping conc. $1{\cdot}5\times10^{14}$ cm^{-3}; thickness 12,500 Å; sample B, doping conc. 6×10^{13} cm^{-3}; thickness 10,200 Å.

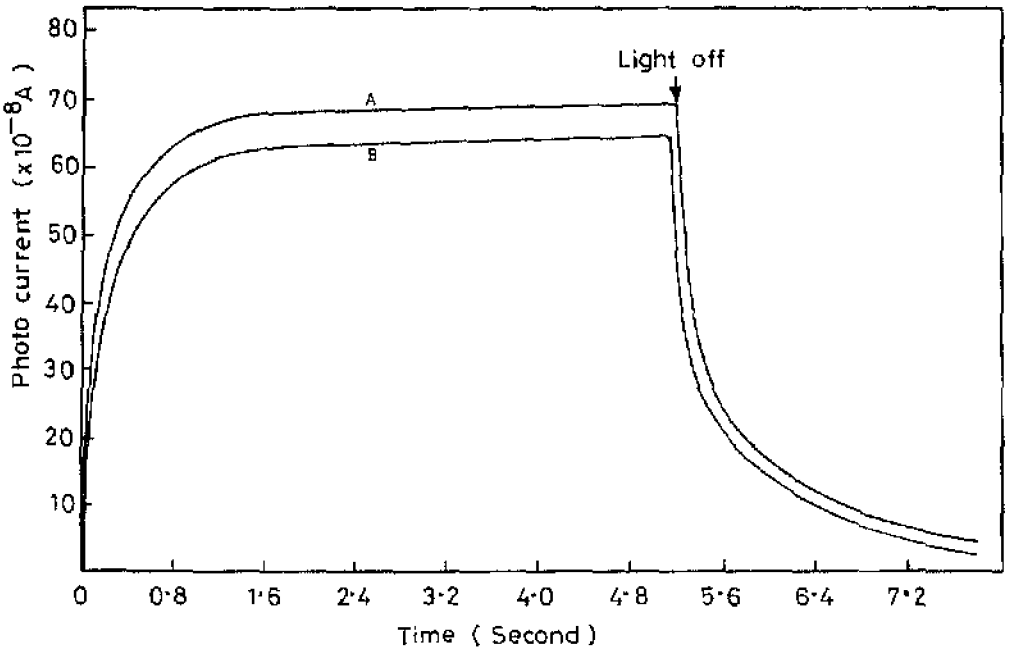

Figure 6. Rise and decay of photocurrent with time at 300 K for a typical Cd-doped film. A, 500 Lx; B, 1000 Lx (rf power 180 W; doping conc. $2{\cdot}5 \times 10^{14}$ cm^{-3}; gap area $2{\cdot}5 \times 10^{-2}$ cm^2).

curves of a typical sample. The rise and decay processes are characterized by initial fast rise and slower decay. The rise and decay curves can be explained on the basis of release of electrons and holes under the influence of light accompanied by their recombination. The current reaches a steady value when the rate of recombination becomes equal to the rate of generation of new carriers and the concentration of carriers reach a steady value. When light is switched off, the initial rapid drop of photocurrent is controlled by recombination mechanism alone and depends on the life time of the majority carriers. However, at higher illumination the number of free carriers are higher than the trapped carriers and recombination takes place without involving trapping process (Bube 1960).

The photoconductive rise time t_r and decay time t_d were determined from the tangents to the rise and decay curves. The values have been observed to decrease with increase of illumination. The photoconductive decay curve has been found to fit the expression

$$I_{pt} = I_0 t^{-b},$$

where I_0 is the initial photocurrent at $t = 0$ and I_{pt} the photocurrent after time t and b the decay constant.

Two plots of log photocurrent vs log time of photoconductive decay at two intensities of illumination for a typical sample is shown in figure 7. For each illumination two linear regions are obtained giving two decay

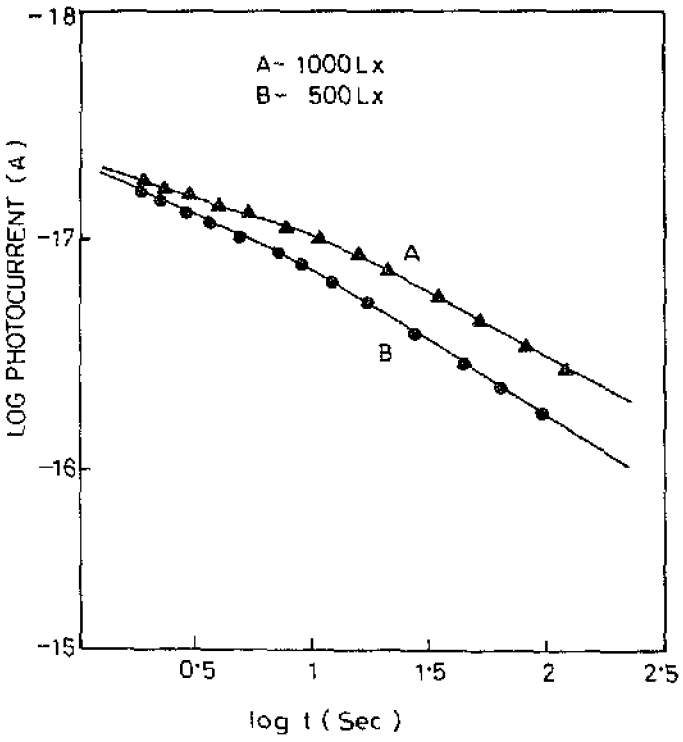

Figure 7. ln photocurrent vs ln time plots for photoconductive decay of a typical Cd-doped CdTe film prepared at rf power 180 W; doping conc. 2×10^{14} cm^{-3}; thickness 10,500 Å; gap area $2{\cdot}5 \times 10^{-2}$ cm^2.

Table 1. Values of photoconductive rise and decay times and decay constants of a Cd-doped sample at two intensities of illumination.

Intensity of illumination (Lx)	Rise time t_r(s)	Decay time t_d(s)	Decay constants b_1	b_2
500	0·12	0·20	0·37	0·58
1000	0·08	0·16	0·56	0·68

Sample no. PO6, thickness 11,500 Å, rf power 180 W, gap area $2{\cdot}5 \times 10^{-2}$ cm^2, doping concentration 12×10^{14} cm^{-3}.

constants. They are observed to increase with illumination. The values of photoconductive rise time, decay time and the decay constants are given in table 1. The photoconductive response has been observed to be slightly lower in sandwich-type sample than in gap-type sample. This is possibly due to interception of illuminated light by indium electrode in sandwich-type sample.

4. Conclusions

Some properties of rf-sputtered Cd-doped CdTe films have been presented here. Doping of CdTe films by Cd from a number of pellets on the CdTe target during sputtering, can be achieved up to 10^{14} cm^{-3}. The films are found *n*-type and endowed with defects as indicated by the aging effect on resistivity. The resistivity of the films decreases very fast initially after the preparation of the samples and then slowly attaining a constant value after about 8 days. Temperature dependence of dark conductivity shows that conduction between room temperature to 338 K is mainly due to impurity levels, activation energy being about 0·5 eV. At higher temperature beyond 338 K the conduction becomes intrinsic showing a band gap of about 1·43 eV. The photocurrent has been observed to increase rapidly with illumination at lower values and tends towards saturation at higher values. The photoconductive rise and decay curves have been found to decrease while decay constants increase with illumination.

Acknowledgement

The authors wish to thank the Department of Science and Technology, New Delhi, for using the equipments procured for a different project funded by them.

References

Bube R H 1960 *Photoconductivity of solids* (New York: John Wiley and Sons, Inc.)
Banerjee A, Saha H and Guha R 1989 *Indian J. Phys.* **A63** 326
Basol B M 1988 *Solar Cells* **23** 69
Das S R and Cook J G 1988 *Thin Solid Films* **163** 409
Fisher T F and Weber C E 1952 *J. Appl. Phys.* **23** 181
Gogoi S and Barua K 1982 *Thin Solid Films* **92** 227
Matsumoto H, Kuribayashi K, Uda H, Komatsu Y, Nakano A and Ikegami S 1984 *Solar Cells* **11** 367
Mitchell K W, Eberspacher C, Cohen F, Avery J, Duran G and Bottenberg W 1985 *Proc 18th IEEE PVSC Las Vegas, NV* (New York: IEEE) p. 1359
Rhoderik E H 1978 *Metal–semiconductor contacts* (Oxford: Clarendon Press) p. 54
Rose M R, Lowrence A S and Wulf J 1987 *Electronic properties of matter* (New Delhi: Wiley Eastern Ltd.) p. 144
Sarmah P C and Rahman A 1990 *Indian J. Phys.* **A64** 21
Sheer J J and Van Laar J 1961 *Phillips Res. Rep.* **16** 323
Uda H, Taniguchi H, Yoshida M and Yamashita T 1978 *Jap. J. Appl. Phys.* **17** 585
Zanio K, Willardson R F and Beer A C (eds) 1978 *Semiconductors and semimetals* (New York: Academic Press) **13** 164