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Photoconductivity studies of $CdSe_{1-x}Te_x$ thin films as a function of doping concentration

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Abstract. Thin films of $CdSe_{1-x}Te_x$ were prepared by using electro deposition with varying doping concentrations of Te(x). Photoconductive studies as a function of applied field, time, wavelength, and intensity of incident light were carried out at room temperature between 1 and 3·5 eV. After establishing that the electrode contacts made using silver paint were ohmic, it was found that as the concentration of Te(x) increases in $CdSe_{1-x}Te_x$, the band gap of the material decreases according to the empirical relation $E_g = (2 - 1{\cdot}5x)$ eV.

Keywords. Photoconductors; doping band gap energy.

1. Introduction

The optically sensitive semiconductors are photoconductors. As the excess of electrons and holes are created in photoconductors, mainly due to optical excitation, the conductivity of the material increases accordingly. Photoconductors find many practical and essential applications (Bube 1960) in India as there is availability of solar energy all through the year. Photoconductors are compounds belonging to the II–VI groups (CdS, CdSe, CdTe, ZnS, ZnSe, etc) and III–V groups (GaAs, InP, etc). The principal advantage of II–VI compounds for terrestrial solar photovoltaics are low cost, direct band gap, and the ease of deposition of good quality films (Fahrenbruch 1977). In the present study photoconductivity of thin films of $CdSe_{1-x}Te_x$ which were prepared by electrodeposition with varying doping concentration of Te(x) has been investigated.

2. Sample preparation

The electrodeposition process was carried out with three-electrode geometry (Rajalakshmi 1990) as shown in figure 1. The working electrode or cathode is a conducting metal like titanium, graphite, silver, etc. The inert electrode which functions as a counter electrode is generally of platinum and acts as the anode. A suitable reference electrode called saturated calomel electrode (SCE) is used to measure the potential applied to the working electrode at steady state as well as fast potential scans.

Tellurium is dissolved in dilute HCl and then added to doubly distilled water containing dissolved cadmium and selenium. The electrolyte bath for the $CdSe_{1-x}Te_x$ deposition consisted of 0·2 M (mole) of $CdSO_4$ and 20 mM of SeO_2 and TeO_2 in varying concentrations dissolved in double distilled water. The pH of the solution was adjusted with H_2SO_4 and was 1·5 in all cases.

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The deposition of $CdSe_{1-x}Te_x$ as thin films was made on the titanium and silver substrates. When the concentration of TeO_2 was 5 mM, fine deposition of $CdSe_{0.8}Te_{0.2}$ was obtained under potentiostatic condition with the potential at -7.0 V. Composition of $CdSe_{0.7}Te_{0.3}$ was obtained at a potential of -0.8 V when the concentration of TeO_2 was 8·571 mM. With concentration of TeO_2 as 13·33 mM deposition of $CdSe_{0.6}Te_{0.4}$ was obtained at a potential of -7.0 V. The samples were annealed in an argon atmosphere for about 30 min and at about 200°C and slowly cooled down to room temperature. Thermal annealing of films or hot pressing of powders at adequately high temperature may cause grain growth and thereby reduce the density of grain boundary states. The main purpose of annealing is to increase the crystalline size of the semiconductor (Rajalakshmi 1990). These annealed samples were used in the photoconductive studies.

3. Experimental

The field dependence of photocurrent is shown in figure 2. The field applied was 10 V/cm. And the operating voltage selected was 1·5 V which was, as seen from the figure, ohmic.

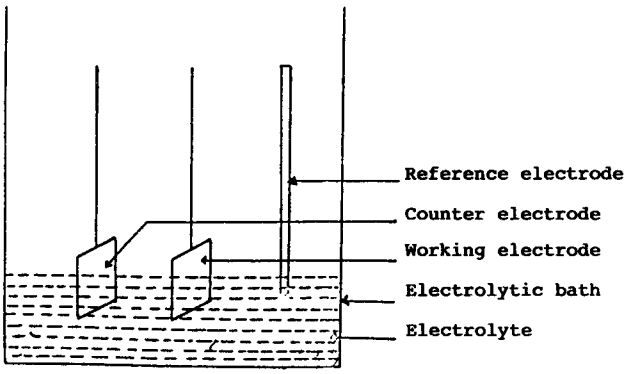

Figure 1. Schematic representation of the electrolytic cell.

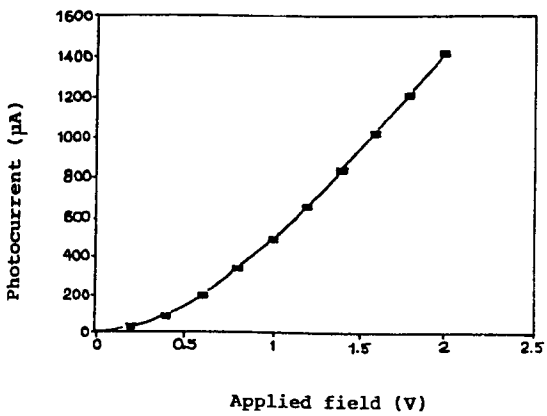

Figure 2. Photocurrent of $CdSe_{0.8}Te_{0.2}$ vs applied field.

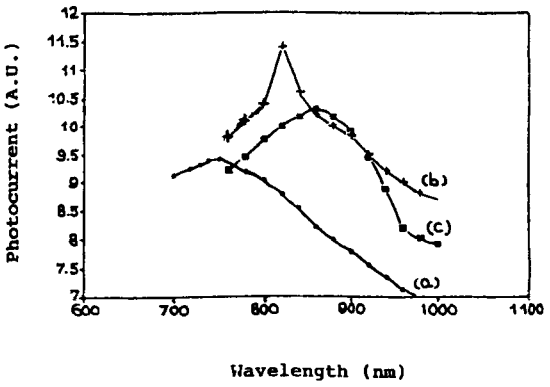

Figure 3. Spectral dependence of photoconductivity of $CdSe_{1-x}Te_x$ with $x = 0{\cdot}2$ (**a**), 0·3 (**b**) and 0·4 (**c**).

Table 1. Photocurrent maxima of $CdSe_{1-x}Te_x$.

Sample	Maxima (nm)	Band gap (eV)
$CdSe_{0{\cdot}8}Te_{0{\cdot}2}$ (a)	745	1·67
$CdSe_{0{\cdot}7}Te_{0{\cdot}3}$ (b)	825	1·51
$CdSe_{0{\cdot}6}Te_{0{\cdot}4}$ (c)	860	1·45

The photocurrent of the samples were studied as a function of (i) wavelength, (ii) time and (iii) intensity of the incident light.

3.1 *Spectral dependence of photocurrent*

The wavelength dependence of the photocurrent was measured by scanning the output of the monochromator (Thermo Jarrell Ash) between 700 nm and 1000 nm by means of a stepping motor drive. A constant potential was applied to the sample between silver pasted electrodes. The photocurrent was measured by means of an electrometer (Keithley 614), the output of which was recorded on a strip chart recorder (Cole Parmer). The wavelength responses of the samples for Te concentration of 0·2, 0·3, 0·4 are shown in figure 3. The maxima of photocurrent occurs at 745 nm, 825 nm and 860 nm for the Te concentration of 0·2, 0·3, 0·4 respectively. Since the photoconductivity maxima correspond to band gaps, the corresponding band gaps were calculated to be 1·67 eV, 1·51 eV and 1·45 eV as indicated in table 1. There was a sudden rise in photocurrent around 825 nm (figure 3) for Te concentration of 0·3. This could be ascribed to the sharp transition at the critical point of band gap which was 1·51 eV.

It is seen that as the concentration of Te increases the band gap decreases and the relation between the concentration and the band gap is near-linear according to the expression (Saidin 1990)

$$E_g = (2 - 1{\cdot}5x)\,\text{eV},$$

with E_g, band gap energy and x, concentration of Te.

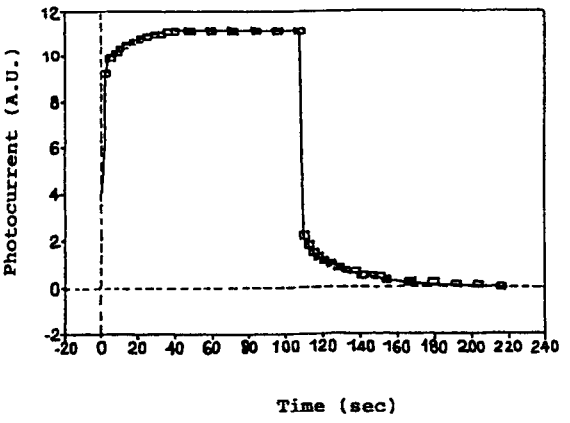

Figure 4. Response curve of $CdSe_{0.8}Te_{0.2}$.

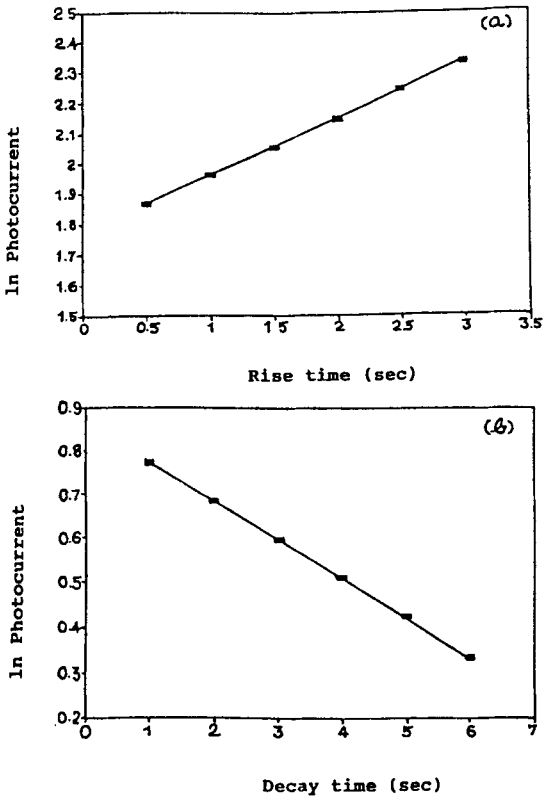

Figure 5. (**a**) $\ln I_{ph}$ vs rise time and (**b**) $\ln I_{ph}$ vs decay time of $CdSe_{1-x}Te_x$ ($x = 0{\cdot}2$).

Table 2. Response curve of $CdSe_{1-x}Te_x$.

Sample	Rise time (sec)	Decay time (sec)
$CdSe_{0.8}Te_{0.2}$	14·4	10·8
$CdSe_{0.7}Te_{0.3}$	12·0	9·6
$CdSe_{0.6}Te_{0.4}$	10·8	9·6

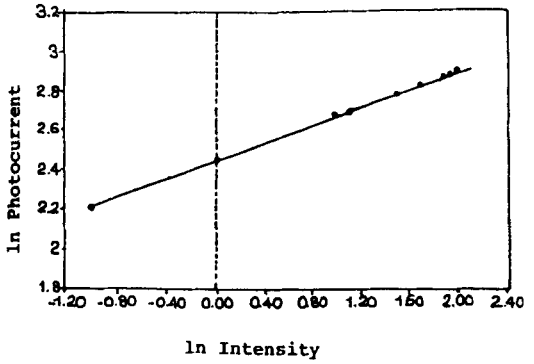

Figure 6. ln I_{ph} vs ln intensity of $CdSe_{0.8}Te_{0.2}$.

Table 3. Variation of slope ln I_{ph} vs ln intensity as a function of Te concentration.

Sample	Slope
$CdSe_{0.8}Te_{0.2}$	0·23
$CdSe_{0.7}Te_{0.3}$	0·14
$CdSe_{0.6}Te_{0.4}$	0·12

3.2 *Time dependence of photocurrent*

A representative plot of the time dependence of photoconduction in $CdSe_{0.8}Te_{0.2}$ under illumination of 100 W halogen lamp is shown in figure 4. The rise curve and the decay curve are exponential in nature. The response time $CdSe_{1-x}Te_x$ for various values of x are indicated in table 2.

The response curves for $CdSe_{1-x}Te_x$ have single exponential with single time constant as shown in figure 5 (for $x = 0{\cdot}2$). The single exponential curve indicates that the transition is a direct band–to–band transition. As the concentration of x increases due to doping, the charge carriers also increase, since photoconductivity is the change in resistance of the material due to optical generation of extra charge carriers.

3.3 *Intensity dependence of photocurrent*

Using neutral density filters the photocurrent as a function of intensity was studied. The logarithm of photocurrent of $CdSe_{1-x}Te_x$ varied linearly with logarithm of intensity and the slope of the intensity curves are indicated in figure 6. As the concentration of Te(x) increases the slope of ln I_{ph} vs ln intensity decreases. In the photoconductors the rate of charge carriers will increase steadily with the increasing incident light intensity since the rate of creation of free charge carriers will be greater. And in the presence of doping, efficiency of the photocurrent is enhanced. Thus doping makes the photosensitive more sensitive as well as more efficient as a photoconductor.

4. Conclusions

From the above mentioned investigations we conclude that (i) The photoabsorption in $CdSe_{1-x}Te_x$ is due to direct band–to–band transition and the presence of doping material (Te) enhances the photoconductivity making it more efficient; and (ii) as the concentration of Te(x) increases in $CdSe_{1-x}Te_x$, the band gap of the material decreases according to the empirical relation

$$E_g = (2 - 1{\cdot}5x)\,\text{eV},$$

with E_g the band gap and x the concentration of Te ($x = 0{\cdot}2, 0{\cdot}3, 0{\cdot}4$).

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