



CONTRIBUTION OF JUNCTION AND SURFACE SPACE CHARGE ON THE GENERATION OF PHOTOVOLTAGE IN CdTe THIN FILMS

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Photovoltaic property of thin films of CdTe doped with Tellurium and Cadmium is studied. Te-doped films show higher photovoltage while the Cd-doped films show lower photovoltage than the undoped films. Tellurium segregates in the grain boundaries forming p-p⁺ junctions with higher potential barrier height. Front surface photovoltage is always found to be greater than that of the back surface. But when CdTe is deposited on substrate having thin layer of Te it shows increase of back surface photovoltage. These results are explained with the help of surface and junction photovoltage.

Introduction : Many workers (1-10) have observed photovoltaic effect in angularly deposited thin films of CdTe. Several models have been proposed (10) to explain the mechanism of photovoltaic effect. Out of them we find the p-n junction model and the model of surface photovoltage are appropriate. Here we briefly discuss them.

The p-n junction model : Starkiewicz et al (11) reporting work on Pbs anomalous photovoltaic films, concluded that the effect was due to distribution gradient of positive and negative impurity ions through the microcrystallites. This is equivalent to an array of p-n junctions and such a model has been developed for CdTe by Adriovich and Co-workers (12). But this model alone is not sufficient to explain all our observations. Hence we consider the Model of surface photovoltage :

The Surface photovoltage model :

According to this model photovoltage appears in inclined crystallite due to change of band bending near the surface under illumination.

The surface space charge gets modified because of generation of electron-hole pairs by highly absorbed radiation. If the optical absorption depth in the crystallite is less than the space charge depth there will be variation of space charge density between the two surfaces of the inclined crystallites which would give rise to photovoltage.

In the present paper we have observed how the photovoltaic effect in angularly deposited films of CdTe gets modified with doping of Te and Cd. The variation of photovoltage with intensity of light and temperature have been investigated for the films doped with Te, Cd and the undoped film.

Experimental details :- Films of CdTe are prepared by evaporation of specpure CdTe powder from a quartz crucible in a tungsten coil in a vacuum of the order of 10^{-4} pa

on properly cleaned glass substrates with a Hind Hivac Vacuum Coating unit (model 12-A4). Films are deposited onto substrates which are held at a constant angle of 30° with respect to the incident vapour direction. The substrate temperature is maintained at 230° C during deposition of CdTe. Doping with In and Cd have been carried on this film. A fixed amount of the dopant is deposited on the surface of the CdTe film. The films are then subsequently annealed in vacuum for 2 hours at a temperature of 100° C for diffusion of impurities well in the crystallites. A tungsten filament lamp is used as the source of light and the intensity of light falling on the sample is determined with the help of an Eppley thermopile. Open circuit photovoltage and shortcircuit photocurrent are measured with a Keithley Electrometer (610C). The films deposited in vacuum and exposed to the atmosphere after deposition are found to p type as determined by thermoelectric measurements.

Results and discussions:- We have reported (13) that the film deposited at an angle 30° and 230° C substrate temperature shows maximum photovoltaic effect. From the variation of photovoltage with intensity (Fig.1) it is found that photovoltage for a Te doped film increases while it decreases for a Cd doped film in comparison with the undoped film. Temperature variation of photovoltage (Fig.2) for all these films show that the photovoltage increases from low temperature and tends to saturate near the room temperature.

From X-ray diffraction analysis particle size has been calculated using Scherrer formula (13) and is found to be about 530nm. Therefore the average number of grain boundaries per cm of the film can be taken to be 2×10^6 . If we consider this

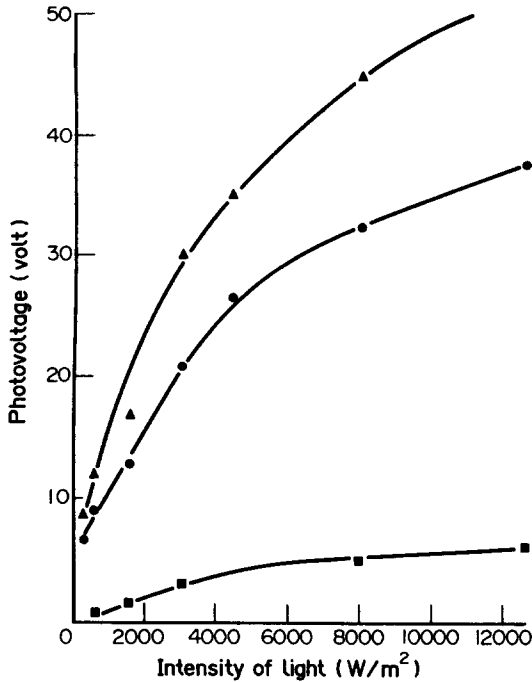


Fig. 1. Plot of Photovoltage with Intensity of light

- ▲ - Tellurium doped film
- - Undoped film
- - Cadmium doped film

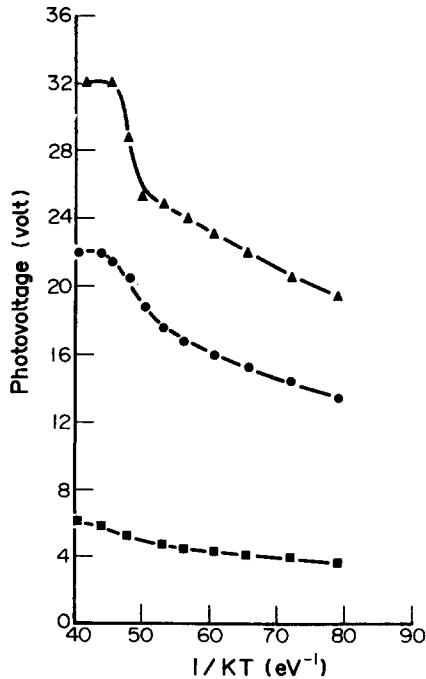


Fig. 2. Plot of Photovoltage with $\frac{1}{KT}$

- ▲ - Te doped
- - Undoped
- - Cd doped

grainboundary to be some type of junction i.e. p-p⁺ or p-n then there will be on the average same number of junction per cm length of the film. Photovoltage observed for the undoped film at room temperature and with 3000 W/m² intensity of illumination is 21 Volt. Hence the voltage drop per junction will be of the order of 10⁻⁵ Volt. The current voltage characteristics of an illuminated photovoltaic junction is given by

$$I = I_0(e^{qV/KT} - 1) - I_L \dots\dots\dots(1)$$

When we measure the open circuit photovoltage, I is to be zero. It is quite reasonable here to assume

$$\frac{-qV}{KT} \ll 1$$

Therefore the photovoltage per junction can be expressed as

$$V = \frac{KT}{q} \ln \frac{I_0}{I_L} \dots\dots(2), \text{ where}$$

$I_{SC} = I_L =$ Illuminated Short Circuit Current

$I_0 =$ Reverse saturation current, $K =$ Boltzman's Constant, $q =$ Charge of an electron.

Now the total photovoltage per cm length of the film can be written as,

$$V_T = n \frac{KT}{q} \ln \frac{I_0}{I_L} \dots\dots(3), \text{ where } n \text{ is the}$$

number of junction per cm length of the film. With illumination (Fig.3) it is observed that I_0/n remains constant for all these films. This indicates that both n & I_0 remains constant. With illumination within the range of observation it is also observed that if sample is doped with Te the value of I_0/n is less compared to undoped film. This indicates that I_0 decreases with such doping which is possible only with the increase of junction barrier height. Excess Tellurium which acts as an acceptor impurity segregates in the grain boundary and causes the formation of p-p⁺ junction with higher potential barrier height. It is expected that the higher potential barrier will contribute more to the photovoltage.

In general it is observed that when the upper surface of the film is exposed to light the magnitude of photovoltage observed is always greater than the lower surface when back surface is illuminated. As the film is exposed to air the upper surface is expected to form an accumulation layer due to absorption of oxygen. Hence it seems that the observed photovoltage would be an algebraic sum of junction and surface photovoltage. The lower surface which is in contact with the substrate seems to be of different nature. It may be that at the substrate film interface depletion layer have been formed. So the resultant photovoltage with lower surface is reduced because of less contribution from the surface photovoltage.

If tellurium is deposited on the upper surface it will form more accumulation layer with more surface potential. The observed larger photovoltage on the front surface than the back surface may be due to significantly large contribution to the photovoltage from both surface and grain boundaries. It is also observed if Te is deposited on the glass substrate and then CdTe is deposited on it the photovoltage on the back surface is greater than the front surface. This clearly shows Te is forming an efficient

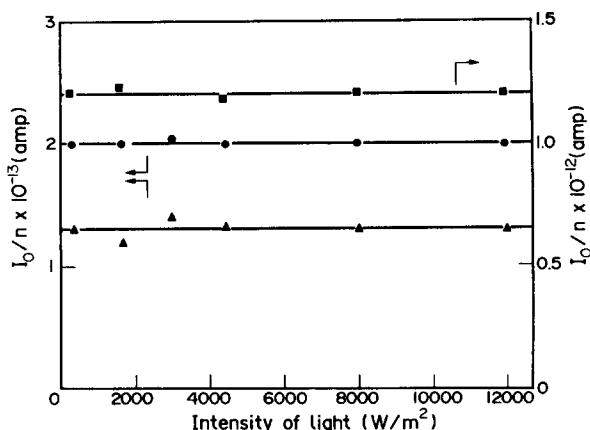


Fig. 3. Plot of I_0/n with Intensity of light
 ▲ - Te doped
 ● - Undoped
 ■ - Cd doped

accumulation layer with CdTe film surface as far as photovoltaic effect is concerned. If cadmium is doped the value of I_0/n is higher compared to the undoped film. This indicates that I_0 increases with such doping which is possible only with the decrease of the

junction barrier height. Cadmium acts as a donor impurity and reduces the barrier height. As a result we observe the magnitude of the photovoltage is less compared to the undoped film.

With increase of temperature (Fig.2) photovoltage for all the films are found to increase which is in accordance with equation(3). Hence the number of junction either increases or remains constant with the increase of temperature. But in any case the

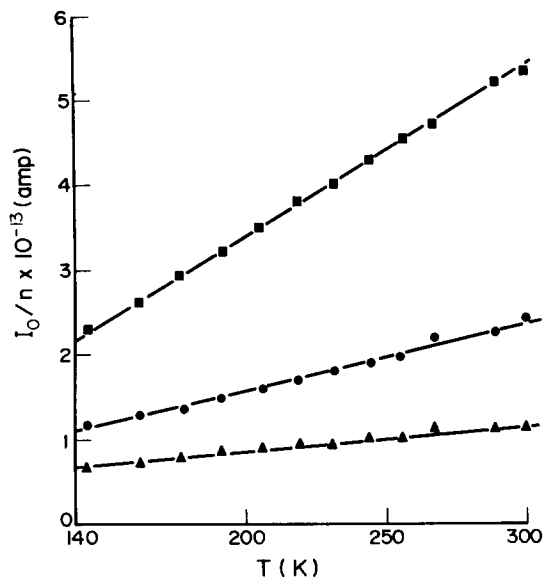


Fig. 4. Plot of I_0/n with Temperature
 ▲ - Te doped
 ● - Undoped
 ■ - Cd doped

increase of n with temperature is less probable so n can be taken to remain constant throughout the range of temperature studied. It is also (Fig.4) observed that I_0/n increases slowly with the increase of temperature for undoped and Te-doped film while increases sharply for Cd-doped film. Hence with the increase of temperature I_0 increases while n almost remains constant.

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