Chapter VII

Photoconduction Studies
7.1. Introduction

Photoconductivity is an important property of semiconductors by means of which the bulk conductivity of the sample changes due to the incident radiation. The operation of almost all optoelectronic devices is based on the creation or annihilation of electron-hole pairs. Pair formation essentially involves raising an electron in energy from the valence band to the conduction band, thereby leaving a hole behind in the valence band. In principle, any energetic particle incident on a semiconductor, which can impart energy at least equal to the band gap energy to a valence band electron, will create pairs. The simplest way to create electron-hole pair is to irradiate the semiconductor [1]. When an insulator or a semiconductor is irradiated with light of sufficiently short wavelength often an increase in its conductivity is observed and this phenomenon is known as photoconductivity. Although this effect occurs in many materials both inorganic and organic the combination of different parameters such as spectral response, dark resistance, rise and decay time of photoconductivity etc. makes only a few materials to be useful for practical uses. Photoconductivity involves response time measurements or thermally stimulated conductivity which can be very useful probes for deducing the transport parameters of semiconductor films [2,3]. Information about traps is obtained from the intensity dependence of photocurrent and decay time. Thermal and optical quenching of photoconductivity yields ionization energies for impurities. Spectral response also yields information about trap levels. CdTe thin films have been proposed as a feasible candidate for optoelectronics device applications especially for photovoltaic applications based on their special characteristics. The transient photoconductivity in polycrystalline CdSe and CdTe films deposited on SiO₂ substrates has been investigated by Vaitkus et al [4] and reported as the recombination centers located in the intercrystalline and surface regions control the photoconductivity until the non-equilibrium carrier concentration
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reaches $10^{18}$ cm$^3$. The defect generation in photoconduction in semiconductors has been reported by Margulis et al [5], Spanulescee et al [6] and Johnson et al [7]. Photoconduction properties of the CdTe thin film layers have been studied by Sharma et al. [8], P.K. Naik et al [9], and Walter Huber et al [10]. Several workers [11-16] have reported the barrier-modulated photoconductivity on semiconductor thin films.

Polycrystalline CdTe thin films contain some inherent native defects irrespective of the deposition methods and conditions. These defects act as traps or recombination centers that influence the photoelectronic properties of the films. Moreover it is necessary to study photoconductive measurements of CdTe thin films in order to obtain useful information such as material properties and the development of device technologies. This chapter deals with the results of present work on photoconductive effects in CdTe thin films prepared at room temperature by thermal evaporation technique.

7.2. Theory

The description of photoconductivity phenomena focuses on the definitions of three basic quantities: the photosensitivity, the spectral response, and the speed of response.

In a semiconductor with free electrons and/or free holes, the electrical conductivity in the dark is given by

$$\sigma_0 = q(n_0 \mu_{n_0} + p_0 \mu_{p_0})$$  \hspace{1cm} (7.1)

In the light, this conductivity is increased by the photoconductivity $\Delta \sigma$

$$\sigma_L = \sigma_0 + \Delta \sigma$$  \hspace{1cm} (7.2)

Consider the case of one-carrier transport for simplicity. Then in the dark $\sigma_0=n_0q\mu_0$ and in the light

$$\sigma_0 + \Delta \sigma = (n_0 + \Delta n)q(\mu_0 + \Delta \mu)$$  \hspace{1cm} (7.3)
allowing for the possibility that photoexcitation may change both the carrier density \( \Delta n \) and carrier mobility \( \Delta \mu \). Then
\[
\Delta \sigma = q \mu_n \Delta n + (n_0 + \Delta n)q \Delta \mu \quad (7.4)
\]
Now it is generally true that
\[
\Delta n = G \tau_n \quad (7.5)
\]
where \( G \) is the photoexcitation rate \( \left( \text{m}^3\text{s}^{-1} \right) \) and \( \tau_n \) is the electron lifetime, so that
\[
\Delta \sigma = q \mu_n G \tau_n + nq \Delta \mu \quad (7.6)
\]
One additional complexity arises from the fact that the lifetime \( \tau_n \) may itself be a function of excitation rate \( \tau_n(G) \). There are therefore three types of effects that may manifest themselves in eqn. (7.6). The first step is increase in carrier density with constant lifetime \( \tau_n \), so that
\[
\Delta \sigma = q \mu_n \tau_n G \quad (7.7)
\]
The photoconductivity is proportional to \( G \) so that a log-log plot of \( \Delta \sigma \) vs \( G \) shows a slope of 1. The second step is increase in carrier density with lifetime \( \tau_n \) a function of photoexcitation intensity, so that
\[
\Delta \sigma = q \mu_n \tau_n(G) G \quad (7.8)
\]
If \( \tau_n \) varies as \( G^{(y-1)} \), the \( \Delta \sigma \) varies as \( G^y \). If \( y<1 \), the lifetime decreases with increasing excitation rate; the behaviour is said to be ‘sublinear’. If \( y>1 \), the behaviour is said to be ‘supralinear’. The third step is increase in carrier mobility, so that
\[
\Delta \sigma = nq \Delta \mu \quad (7.9)
\]
A number of possible mechanisms may give rise to this kind of behaviour:

Scattering by charged impurities may change under photoexcitation either through a change in the density of charged impurities or through a change in the scattering cross section of such impurities. If the material is polycrystalline and contains intergrain potential barriers, photoexcitation can reduce the height of these

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barriers as well as the depletion width in the grains adjacent, giving rise to an increase in carrier mobility. Photoexcitation may excite a carrier from a band characterized by one mobility to a band characterized by a different mobility.

In the case of insulators at reasonably high photoexcitation rates, $\Delta n \gg n_0, \Delta p \gg p_0$, and

$$\Delta \sigma = Gq \left( \tau_n \mu_n + \tau_p \mu_p \right)$$  \hspace{1cm} (7.10)

We may define a ‘figure of merit’ for a single-carrier photoconductor as

$$\Delta \sigma / Gq = \tau \mu$$  \hspace{1cm} (7.11)

Thus the ‘lifetime-mobility’ product is a measure of the photoconductor’s sensitivity to photoexcitation [17].

7.3. Measurements

CdTe thin films were deposited at room temperature onto well-cleaned glass substrates by thermal evaporation technique. All the Ohmic contacts were made using silver paste and fine copper wires were soldered to the contacts. Steady current from a regulated power supply was applied to the samples. The dark currents as well as photocurrents have been measured using a multifunctional optical power meter (ORIEL-70310). An ELH lamp was used for white light and a series of VIS-NIR interference filters were used for monochromatic light. The incident light intensity was measured in mW/cm² by placing a Suryamapi at the position of the sample.

7.4. Results and Discussion

7.4.1. Photoconductivity as a function of light intensity

The figure 7.1 shows the variation of photocurrent with applied voltage for different light intensities. The observed photocurrent increases with increase in applied voltage as well as light intensity. The increase in photocurrent with light intensity may be mainly due to the reduction in barrier height ($E_b$) rather than the
increase in the majority carriers. The decrease in $E_b$ will result in the increase in minority carriers, which flow down the barrier to neutralize the trap states at the grain boundaries. The figure 7.2 shows the variation of photocurrent with applied voltage for different film thicknesses for 100W/m² light intensity. The photocurrent shows the oscillatory nature but does not show significant change with film thickness. This shows that the photocurrent does not rely on film thickness. The photocurrent is drastically increased in the applied voltage range 6V-9V and it has been shown in the figure 7.2 in the rounded portion.

**Figure 7.1:** Variation of photocurrent with applied voltage for different illuminations.
Figure 7.2: Variation of Photocurrent with applied voltage for films of different thicknesses.

7.4.2. Spectral Dependence

The figure 7.3 shows the variation of photocurrent with wavelength for CdTe films of 3000Å at different applied voltages. From the figure 7.3 it is observed that the photocurrent exhibits maxima and minima peaks. The figure 7.4 shows the variation of photocurrent and optical absorption with wavelength of the light for the film of 3000Å thickness. The inset of the figure shows the optical absorption spectrum. The nature of the photocurrent curve is similar to optical absorption spectrum. From the photoconductive spectrum the band gap of the films has been evaluated as 1.55 eV, which is in agreement with the band gap determined from the optical absorption measurements in the chapter 4. The experimental conditions of the surface cells must be taken in to account in order to correlate the photoconduction and absorption of the material. In surface cells, parallel photoconduction and absorption spectra can be measured uninfluenced by the direction of irradiation only with very thin layers. According to the relation \( I_A = I_0 (1 - 10^{-\alpha d}) \), layer of thickness...
3000Å with an extinction modulus of $10^3\text{cm}^{-1}$ absorbs 70% of the incident photons and well demonstrated in the figure 7.4. This means that strongly absorbed light (with in an absorption band) will hardly induce a detectable photo effect. The light absorbed at high extinction modulus ($m_0$) in a thin surface layer produces a high concentration of mobile carriers, while the light that penetrates more deeply can produce a relatively low carrier concentration.

**Figure 7.3:** Variation of photocurrent with wavelength for different applied voltages ($t = 3000\text{Å}$)
Figure 7.4: (a) Photoconduction spectral response curve for CdTe thin film of 3000Å thickness. (b) Illustrative comparison of the shape of the photoconductivity spectral response and the absorption of the material, defining three characteristics regions.
The spectral responses of the photoconductivity curves are given in figure 7.4a. The general shape of these curves is pictured in the figure 7.4b. In the high absorption region I, the photoconductivity is controlled by the surface lifetime. In the intermediate range of region II, there is still strong absorption and the photoconductivity is controlled by the bulk lifetime. In the low absorption region III, the photoconductivity is also controlled by the bulk lifetime, but decreases with increasing wavelength as the absorption decreases.

### 7.4.3. Photocurrent – Voltage characteristics

Figure 7.3 shows dependence of photocurrent on wavelength for different applied voltage. It is observed that the photocurrent increases with increase in applied voltage ($\leq 3V$) and further increases rapidly at higher voltages ($>3V$) for all wavelengths studied. When irradiated in the range of intrinsic absorption the observed current-voltage behaviour is the result of a superposition of dark current and photocurrent. The carriers produced by light ($n_{\text{opt}}$) contribute to the carriers injected by the contact ($n_i$) and thermally produced carriers ($n_{\text{therm}}$) and this changes the carrier distribution in energy bands and traps, which is decisive for the current. As long as the light induced carrier concentration (per unit time) exceeds the concentration of injected carriers, the current voltage characteristics remains linear. Figure 7.1 shows the characteristics, which are super linear in the dark, can therefore become linear in light illumination ($n_{\text{opt}} + n_{\text{therm}} > n_i$). This causes the reduction of light intensity, however, can give rise to a transition from linear to super linear characteristics ($n_{\text{opt}} + n_{\text{therm}} < n_i$)[18].

### 7.4.4. Photosensitivity

The photosensitivity of the material, i.e., the change in conductivity from optical excitation divided by the excitation intensity, is often increased by incorporating centres which capture minority carriers rapidly, but have a much
smaller probability of capturing majority carriers to bring about recombination. The photosensitivity is given by the expression as

\[
\text{Photosensitivity} = \frac{\Delta \sigma}{\sigma} = \frac{I_L - I_D}{I_D}
\]  

(7.12)

Where \(I_L\) and \(I_D\) stand for current under illumination and dark respectively. The variation of photosensitivity is shown in figure 7.5. From the figure it is observed that the photosensitivity decreases with increase in incident light wavelength.

**Figure 7.5:** Variation of photosensitivity of various wavelengths for CdTe thin films.

### 7.5. Conclusion

The Photocurrent-Voltage characteristics of CdTe thin films explain the Ohmic as well as space charge limited current conduction. The photocurrent increases with increase in illumination intensity as well as applied voltage. The estimated maximum photocurrent was found to be 190nA. The non linear dependence of photocurrent with voltage indicates that the CdTe thin films having traps. Imperfections, which act as trapping centers will enhance the photosensitivity.
but decrease the speed of response. The recombination centres, on the other hand, will decrease the photosensitivity. The maximum photoconductivity centered around 1.5 to 1.7 eV energy gap, which is desirable for solar cell applications.
References


