CHAPTER 4

Photoconductivity studies on glasses

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PHOTOCONDUCTIVITY STUDIES ON GLASSES.

4.1 INTRODUCTION

Photoconductivity is the increase in the electrical conductivity of an insulating material caused by the light radiation incident on it. It is the phenomena when the energy of the incident photon is higher than the energy gap $E_g$, the free electron-hole pairs are produced in the solid by the absorption of light. The photoconduction is not of intrinsic kind but the impurities and imperfections also contribute to the conductivity. It is known that the imperfections in the solid introduce discrete energy levels in the forbidden energy gap, which are often called as 'traps'. The well-known examples of photoconductors are PbS, PbTe, Se, InSb, PbSe etc.

Photoconducting properties of large number of materials\textsuperscript{1-3} have been studied by many research workers. Extensive studies of photoconduction in single crystals\textsuperscript{4,5} were carried out; however, the photoconductivity study in cadmium and lead sulphide doped vanadium phosphate glasses is still at a very early stage.

The spectral dependence study of the current on exciting radiation is interesting. Generally most of the semiconductors exhibit a peak in the photoconductivity at a photon energy corresponding to the onset of interband electronic transitions. Amorphous semiconductors with a small gaps have a spectral response of photoconductivity that rises at approximately the same photon energy as the optical absorption edge and remains relatively constant at higher energies. As the fall-off on the high energy side of the edge in crystals is attributed to the increased role of surface recombination for carriers generated by strongly absorbed light, this observation presumably implies very similar rates of recombination at the surface and in the bulk.

Photoconductive effect is useful in television camera tubes, infrared detectors, light meters etc.

In this chapter the effect of light intensity, electric field and temperature on the photoelectronic and electronic properties of the $V_2O_5 - P_2O_5$, $V_2O_5 - CdS - P_2O_5$ and $V_2O_5 - PbS - P_2O_5$ glasses is studied. The spectral response is also studied.

4.2 LITERATURE REVIEW

The photoconductivity and dark conductivity of 80% CdS-20% ZnO layers fired at 700$^\circ$C for 30 minutes have been studied by Sadhana devi \textit{et al}\textsuperscript{6}. They found that, the
dark current varies linearly with voltage at lower voltage range. The photocurrent is found to be space charge limited at higher voltage range while it shows nonlinear behavior at lower voltages. The change of photocurrent-excitation intensity relationship from superlinear to sublinear nature indicates the presence of sensitizing centers near the valence band.

Yeong Jin Shin et al.\(^7\) reported the photoconductivity of CdS single crystal platelet grown by sublimation method with a two step furnace. They obtained the transmission and photocurrent spectra in the range 293 to 33 K, and found that the transmission edge and photocurrent peak positions coincide and that these peaks are due to the transition of electrons from the valence band to the conduction band. The \(\lambda_{\text{max}}\) is observed to be 4750 Å. The \(E_{\text{opt}}\) is found to be 2.58 eV.

Relaxation of stored charge carriers in the persistent-photoconductivity (PPC) mode in the CdS\(_{0.9}\)Se\(_{0.1}\) semiconductor alloy has been investigated by Dissanayke et al.\(^8\). The relaxation time constant of PPC is measured as a function of temperature, from which the recombination barrier height has been determined.

Photoconduction in sintered cadmium sulphide at elevated temperatures was reported by Das et al.\(^3\). They found that, in the sintered CdS pellets the relaxation time increases with the increase of temperature up to a certain value and then decreases drastically. Photoconductance of the order of \(5.6 \times 10^{-6}\) and dark conductance of the order of \(0.72 \times 10^{-9}\) mho.

Glew\(^9\) reports photoconductive properties of cadmium selenide sputtered films. He obtained the dark resistivity of about \(10^5 \, \Omega \text{cm}\) measured through the film compared with about \(10^7 \, \Omega \text{cm}\) measured in the plane of the film is attributed to the existence of potential barriers due to stacking faults. Illumination from the tungsten light source decreased the resistivity to \(10^3 - 10^6 \, \Omega \text{cm}\) both through and in plane of the film. Photocurrent is observed to be proportional to the square root of light intensity.

Electrical, optical and photoconductive studies of PbS-PbO crystalline films were carried out by Sameh Said et al.\(^10\). They observed that the segregated PbO microcrystallites had an increasingly profound effect on these properties. Oxygen vacancies in these crystallites produce a peck in the photoconductivity of p-type PbS-PbO films but not in n-type films. The \(\lambda_{\text{max}}\) is observed from 4800 to 5300 Å.\(^0\)

Takao Ando\(^11\) reports the preparation of infrared photoconductive layer from PbO and PbS. They found by means of X-ray diffraction, that the increasing
photoconductivity as a result of the heat treatment is accompanied with the production of PbS in the layer. It is observed that the IR sensitivity increases with % of sulphur increase, while resistivity decreases. The $\lambda_{\text{max}}$ is observed to be 6200 Å.

Electrical domain formation in the dark after interrupting photoexitation in photoconductive CdS and (Cd, Zn)S thin films has been investigated by Osamu Yoshie\textsuperscript{12}. Atakulov \textit{et al}\textsuperscript{13} reports the results of an investigation of change in the properties of PbS films heated in vacuum and in air at various temperatures and suggested the mechanism for the processes that occurs in the case. The conductivity of the order of 2.6 (Ω-cm)$^{-1}$ is observed.

Study on long-term relaxation of the conductivity due to photostimulated diffusion of oxygen along grain boundaries in cadmium sulfide films was reported by Panov \textit{et al}\textsuperscript{14}.

Watton R\textsuperscript{15} reports the study on induced pyroelectricity in sputtered lead scandium tantalite films. Electrical characterization has been performed to assess the merit of the films for use in IR detection.

Photoconductors based on evaporated Zn$_x$Cd$_{1-x}$S and CdSe$_{1-y}$S$_y$ thin films, with a novel multilayer structure, were fabricated and characterized by Torres\textsuperscript{16}, through spectral response measurement. The influence of the preparation conditions, number of layers and electrode configuration on the performance of the Photoconductors was determined. Photoconductors with a detection range between 400 and 750 nm were developed.

A new structure for the PbS based photoresistor was proposed by Pentilie \textit{et al}\textsuperscript{17}. They found that the shape of the spectral distribution remains the same but the amplitude of the signal depends on the value and on the polarity of the applied voltage. An improvement of about 40% was obtained for the PbS Photoconductive signal compared with the situation when the gate electrode is in air.

Microstructure of thin film Photoconductors and its correlation with optical and electronic properties was reported by Klement\textsuperscript{18}, with an intention to find a material to replace amorphous hydrogenated silicon used as photosensitive part in the retina of an electronic eye.

Photoelectric properties of the thin polycrystal PbS films prepared by a new spray method have been investigated by Alyoshin \textit{et al}\textsuperscript{19}. Large scale temperature dependencies of dark and photocurrents, volt-watt and volt-ampere characteristics, electron beam microscopy of film surface were investigated.
Ristova et al\textsuperscript{20} reports the silver doping of thin CdS films by an ion exchange process. They found that the increase of the dark conductivity and simultaneous decrease of the photoconductivity were related to the Ag increase in the compound.

Several physical properties, photoluminescence spectra and optical absorption of Er\textsuperscript{3+} doped PbO-Al\textsubscript{2}O\textsubscript{3}-B\textsubscript{2}O\textsubscript{3} glasses have been studied\textsuperscript{24}. S S Yawale et al\textsuperscript{25} reported he infrared spectral investigations of some Borate glasses in the frequency range 200 to 4000 cm\textsuperscript{-1}.

4.3 THEORETICAL CONSIDERATIONS

When a photon is absorbed, an electron and a hole are created. They attract each other and particularly at low temperatures may recombine, having made no contribution to the current. Let, G, the number per cubic centimeter of free charge carriers produced by the radiation, can be equated to the number of quanta or photon absorbed. We define ip as the excess current per unit volume produced by the radiation. For simplicity let us consider that the current is due to single type of charge carriers, that is either by electrons or by holes. The analysis can be generalized to the case when both contribute. Then two situations are of interest. In the first, electrons and holes are trapped and do not escape and they recombine from those traps, which are from states fairly near the fermi level. In this case the photocurrent i\textsubscript{p} is proportional to G. In the second case the recombination rate of the electron is proportional to the number of holes (trapped or otherwise) In such a case the photocurrent i\textsubscript{p} is proportional to G\textsuperscript{1/2}, where i\textsubscript{d} being the dark current.

Supposing that a majority carrier combines with trapped carriers from a discrete or band-edge localized state in its vicinity. Mott, Davis\textsuperscript{23} introduce two possibilities. The first is a low temperature regime in which the recombination always occurs before the majority carrier hops away from the recombination center. If W is the activation energy for hopping and Po the probability of recombination per unit time, this occurs if

\[ P_0 > v_{ph} \exp (-W/kT) \]  

(4.1)

In this case

\[ b = a^3 v_{ph} \exp (-W/kT) \]  

(4.2)

Where 'b' can be defined as b = vA , v is the thermal velocity of the carriers and A is a capture cross section. In such a case b, ( bN is the chance per unit time that a majority carrier recombines when there are bN minority carriers per unit volume) is not
independent of \( T \), and 'a' is spatial extent of the state. In the high temperature regime, the carriers normally hop away before recombination. In this case,
\[
b = P_0 a^3.
\] (4.3)

In non-crystalline materials various theoretical discussions of the exciton have been given 23.

Suppose that an electron is excited to energy \( \Delta E \) above the bottom of the conduction band. If the electron looses one phonon quantum \( \hbar \omega \) per time \( 1/\omega \), it will diffuse a distance \( r_0 \) given by
\[
r_0 = \frac{1}{\hbar \omega^2} \left[ \frac{\Delta E + e^2}{k r_0 D} \right]
\] (4.4)

before it is thermalized ; \( D \) is here the diffusion coefficient. If the particles will not escape, then they will come together and form an exciton. If the recombination takes place, the quantum efficiency is,
\[
\eta = \left[ 1 + \exp(E_c / kT) \right]^{-1}
\] (4.5)

with
\[
E_c = \frac{e^2}{k} \left[ \frac{1}{r_e} - \frac{1}{r_0} \right]
\] (4.6)

It is interesting to consider the spectral dependence of photoconductivity in relation to that of the absorption coefficient . The structure in \( \alpha \) is evident in all the photoconductivity curves. The ordinate is derived from the equation for the photocurrent.
\[
i_p = \frac{eN_0 (1 - R)}{t_t} \left[ 1 - \exp(-\alpha d) \right]\eta \tau
\] (4.7)

Where \( N_0 \) is the number of incident photons per second, \( R \) the reflectivity, \( d \) the thickness of the sample, \( \tau \) the recombination lifetime, and \( t_t \) the carrier transit time.

*Photoconductivity variation with temperature:*

The photoconductivity is expressed as,
\[
\sigma = N_e e \mu \exp (-E_F / kT)
\] (4.8)

Where \( E_F \) is the fermi energy or activation energy.
\( \mu \) is the mobility and 

\( N_e \) is the concentration of energy levels present in the lowest \( kT \) wide part of conduction band which is of the order of \( 10^{19} \) at room temperature and \( T \) is the absolute temperature.

**Trap depth**

The rise time \( (\tau_R) \) is the exact time required to reach \( 1/2 I_{p_{\text{max}}} \) after illumination is switched on.

The decay time \( (\tau_D) \) is the time required for the photocurrent to decay to \( 1/2 I_{p_{\text{max}}} \) after illumination is switched off.

The current at any instant of time \( (t) \) is given by,

\[
I = I_0 \exp (- p t)
\]

Where \( I_0 \) is the current at the moment light is interrupted and 

\( p \) is the probability of an electron escaping from a trap.

The trap depth at different temperatures is given by

\[
E = kT \left( \log S - \log \frac{I}{I_0} \right)
\]

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4.4 **EXPERIMENTAL PROCEDURE**

**Photoconductivity measurement**

Glass samples under investigation were prepared by mixing appropriate amount of of \( V_2O_5 \), CdS, PbS and \( P_2O_5 \) (AR-grade) corresponding to formula \( X V_2O_5 - (100-X) P_2O_5 \), \( X V_2O_5 - (90 - X) \)CdS-10 \( P_2O_5 \) and \( XV_2O_5 - (90 - X) \)PbS-10 \( P_2O_5 \) respectively. The detailed procedure of preparation of glass is given in chapter 1. Prior to the measurement, the flat surfaces of the specimen were coated with silver paint.

The sample was mounted in a dark chamber with a slit, where from the light was allowed to fall over the sample. The illumination was provided by a halogen lamp (1000-Watt). The intensity over the sample was varied by changing the distance. Different excitation wavelengths were obtained by filters. The light intensity was measured with a digital luxmeter (model no. LX 101, Lutron-Taiwan make, having spectral sensitivity for 400 - 700 nm). The photocurrent was measured with a digital picoammeter (model PM 01, RSI Roorkee make). The samples were left in the dark for a period of greater than 100 minute before dark current measurements were taken. A
small furnace is prepared in which sample holder is placed. The furnace is kept in a chamber. The photocurrent is measured at different temperatures ranging from RT (room temperature 303 K to 473 K). The temperature of the sample was measured by digital temperature indicator.

4.5: RESULTS AND DISCUSSION:

Fig. 4.1 (a) shows the actual photograph of the photoconductivity measurement set up. and Fig 4.1 (b) shows schematic diagram of set up. Fig 4.1 (c) shows the photograph of LDR made from V$_2$O$_5$ –P$_2$O$_5$, V$_2$O$_5$ –CdS-P$_2$O$_5$ and V$_2$O$_5$ –PbS-P$_2$O$_5$ which works as photosensor. The results are summarized in Table 4.1 (a), (b) and (c).

\[ V_2O_5 – P_2O_5 \]

Field dependence: The current-voltage characteristics of sample 80V$_2$O$_5$ –20P$_2$O$_5$ under different intensities of illumination and in the dark are shown in figure 4.2(a1). Similar graphs for another compositions of the series are shown in Fig’s 4.2 a2 to 4.2 a4. (See Appendix 1) The log I versus log V curves are straight lines giving slopes ‘r’ and can be represented by \( I \propto V^r \). The dependence is found to be \( I \propto V^{1.5} \).

Intensity dependence: The variation of photocurrent (I) with light intensity (L) is
Fig 4.1 (b) Schematic representation of the photoconductivity measurement set-up.

Fig 4.1 (c) shows the photograph of LDR made from $V_2O_5 - P_2O_5$, $V_2O_5 - CdS - P_2O_5$ and $V_2O_5 - PbS - P_2O_5$.
shown in Fig. 4.3(a). At lower intensities (< 1000 lux) the photocurrent increases slowly and at higher intensities the increase is more. The explanation of such type of change may be given in terms of various imperfection centres. Fig 4.3(d) shows the plot of photocurrent versus molar percentage of V₂O₅, CdS and PbS.

<table>
<thead>
<tr>
<th>Sr no</th>
<th>% Composition</th>
<th>Rise time (τ₁) Sec</th>
<th>Decay time (τ₂) Sec</th>
<th>Trap depth (eV)</th>
<th>P × 10⁸</th>
<th>E_f (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>V₂O₅·P₂O₅</td>
<td>80-20</td>
<td>96</td>
<td>120</td>
<td>0.20</td>
<td>0.075</td>
</tr>
<tr>
<td>V2</td>
<td>V₂O₅·P₂O₅</td>
<td>70-30</td>
<td>118</td>
<td>120</td>
<td>0.22</td>
<td>0.070</td>
</tr>
<tr>
<td>V3</td>
<td>V₂O₅·P₂O₅</td>
<td>60-40</td>
<td>120</td>
<td>180</td>
<td>0.23</td>
<td>0.065</td>
</tr>
<tr>
<td>V4</td>
<td>V₂O₅·P₂O₅</td>
<td>50-50</td>
<td>120</td>
<td>180</td>
<td>0.27</td>
<td>0.060</td>
</tr>
</tbody>
</table>

Fig 4.2(a) Variation of dark current and photocurrent for 80V₂O₅-20P₂O₅ glasses at room temperature (303K).
- dark  - - - 100lux  - - - 1000lux  - - - 10000lux

Spectral studies: The spectral region chosen is from 3500 to 7000 Å, because it encompasses the fundamental optical absorption edge of bulk V₂O₅. The spectral range is kept same for all the samples. The different wavelengths are obtained from a halogen lamp using filters and the measurements were made for a fixed incident photoflux.

The dependence of photocurrent on the excitation energy of light is shown in Fig. 4.4(a), shows four spectral curves corresponding to the four different compositions of V₂O₅-P₂O₅ glass system. The peak is observed at 6540 Å for 80V₂O₅. The peak of
Fig 4.3(a) Variation of photocurrent with intensity of illumination at room temp (303 K) for $V_2O_5$-$P_2O_5$ glasses.

- $50V_2O_5$
- $60V_2O_5$
- $70V_2O_5$
- $80V_2O_5$

Fig 4.3(d) Plot of Photocurrent versus mol % of CdS, PbS and $V_2O_5$.

- $V_2O_5$
- CdS
- PbS
Fig 4.4(a) Spectral response characteristics of V$_2$O$_5$-P$_2$O$_5$ glasses at room temperature (303K).

- 80V$_2$O$_5$ ■ 70V$_2$O$_5$ ▲ 60V$_2$O$_5$ × 50V$_2$O$_5$

Fig 4.4 (d) Plot of $\gamma_{\text{max}}$ versus mol % of CdS, PbS and P$_2$O$_5$.

- CdS ■ PbS ▲ P$_2$O$_5$
Fig. 4.5(a) - Variation of log $\sigma$ with reciprocal temperature for V$_2$O$_5$-P$_2$O$_5$ glasses at different illuminations.

- dark
- 100Lux
- 1000Lux
- 10000Lux

Fig 4.7(a): Plot of Activation energy versus illumination for V$_2$O$_5$-P$_2$O$_5$ glasses. The plot is for room temperature.
the spectral curve shifts to lower wavelength with decrease of the mol. % of vanadium pentoxide. Peak I is located at 6540 A° and peak IV at about 6200A°. It is found that the sensitivity of the samples increases with increasing amount of vanadium oxide. (Fig. 4.4. d)

It is common for spectral response curves of photoconductivity to show a fairly sharp maximum at a wavelength slightly longer than that corresponding to the absorption edge. For wavelengths longer than the maximum, the excitation decreases simply because the absorption producing free carriers are decreasing. For wavelengths shorter than the maximum, the radiation is being strongly absorbed and produces excitation only near the surface. The surface imperfections are characterized by rapid non-radiative recombination, the excitation of photoconductivity being less when limited to the surface.

It is reported that the transmission edge energy corresponds to photocurrent peak energy.

*Temperature dependence:* The temperature dependence of dark current and photocurrent has been studied for all the systems.

The variation of log $\sigma$ versus $1/T$ for $80V_2O_5$ sample under different illuminations is shown in Fig.4.5(a1). Similar graphs for another compositions of the series are shown in Fig's 4.5 a2 to 4.5 a4. (See Appendix I) The activation energies calculated from the slopes of log $\sigma$ versus $1/T$ curves are shown in Fig 4.7(a) for dark and illuminated conditions respectively for $V_2O_5$ - $P_2O_5$ glasses. The increase in the conductivity with temperature is attributed to the presence of large number of deep traps.

$V_2O_5$ - $CdS$ - $P_2O_5$.

*Field dependence:* The current - voltage characteristics of 10CdS glass sample under different intensities of illumination and in the dark are shown in Fig 4.2(b1) Similar graphs for another compositions of the series are shown in Fig's 4.2 b2 to 4.2 b5. (See Appendix I) The current - voltage curves are found to be approximately ohmic for all the five samples($I \propto V^{1.14}$), but for highest intensity the dependence is $I \propto V^{1.18}$. The current-voltage characteristic reported for cadmium selenide sputtered thin films show saturation only when the photoconductor is illuminated. For dark current there is no
saturation. The current-voltage characteristics of SnO$_2$-CdS shows some asymmetric behavior.$^{21}$

**Intensity dependence:** The variation of photocurrent (I) with light intensity (L) for five samples is shown in Fig.4.3(b). At lower intensities (<1000 lux) the photocurrent increases slowly and at higher intensities the increase is more. The reported$^2$ intensity dependence of CdS-ZnO solid solutions, shows approximately same behavior as observed in their study. They report that, at lower and higher intensities the slopes of the lines are different.

**Table 4.1(b) Values of Rise time, Decay time, Probability (p), Trap depth and Thermal activation energies ($E_a$), corresponding to different compositions for $V_2O_3$-CdS-P$_2$O$_5$ glasses.**

<table>
<thead>
<tr>
<th>Sr no</th>
<th>% Composition</th>
<th>Rise time ($\tau_R$) Sec</th>
<th>Decay time ($\tau_D$) Sec</th>
<th>Trap depth (eV)</th>
<th>P $\times 10^6$</th>
<th>$E_a$ (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VX1</td>
<td>80-10-10</td>
<td>120</td>
<td>210</td>
<td>0.34</td>
<td>0.062</td>
<td>0.349</td>
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<tr>
<td>VX2</td>
<td>70-20-10</td>
<td>132</td>
<td>138</td>
<td>0.35</td>
<td>0.062</td>
<td>0.408</td>
</tr>
<tr>
<td>VX3</td>
<td>60-30-10</td>
<td>126</td>
<td>150</td>
<td>0.36</td>
<td>0.061</td>
<td>0.281</td>
</tr>
<tr>
<td>VX4</td>
<td>50-40-10</td>
<td>120</td>
<td>180</td>
<td>0.38</td>
<td>0.061</td>
<td>0.272</td>
</tr>
<tr>
<td>VX5</td>
<td>40-50-10</td>
<td>85</td>
<td>180</td>
<td>0.39</td>
<td>0.060</td>
<td>0.197</td>
</tr>
</tbody>
</table>

**Fig.4.2(b) Variation of dark current and photocurrent for 80V$_2$O$_3$-10CdS-10P$_2$O$_5$ glasse at room temperature(303K).**

- - dark 
- - 100lux
- - 1000lux
- - 10000lux
Spectral studies: The dependence of photocurrent on the excitation energy of light is shown in Fig. 4.4(b). The photocurrent increases with wavelength until 5500 Å after which it drops. The sample responds up to 5500 Å. The change in sensitivity with composition is not remarkable. The maximum wavelength $\lambda_{\text{max}}$ increases with mol % of CdS as shown in Fig. 4.4 (d).

Temperature dependence: The variation of log $\sigma$ versus 1/T for the sample 10CdS under different illuminations is shown in Fig. 4.5(b1). Similar graphs for another compositions of the series are shown in Fig's 4.5 b2 to 4.5 b5. (See Appendix I) The activation energies calculated from the slopes of log $\sigma$ versus 1/T curves are shown in Fig 4.7(b) for dark and maximum illumination (10000 lux) conditions for 80V$_2$O$_5$–10CdS–10P$_2$O$_5$ glass. Das et al. reported the activation energy of 0.9 eV, calculated from the slopes of ln dark conductance versus 1/T curves, for sintered CdS pellets. The temperature dependence of photocurrent CdS-ZnO solid solutions show two straight line sections in different temperature regions, indicating activation energy of 0.433 eV in higher temperature region and 0.045 eV in the lower temperature region.
Fig 4.4 (b) Spectral response characteristics of photocurrent for $V_xO_{3-x}$-CdS-$P_xO_y$ glasses at room temperature (303K).

- 10CdS  
- 20CdS  
- 30CdS  
- 40CdS  
- 50CdS

Fig 4.5(b) - Variation of $\log \sigma$ with reciprocal temperature for $V_xO_{3-x}$-10CdS-$10P_xO_y$ glass at different illumination.

- dark  
- 100Lux  
- 1000Lux  
- 10000Lux

Fig 4.7(b): Plot of Activation energy versus illumination for $V_xO_{3-x}$-CdS-$P_xO_y$ glasses. The plot is for room temperature.

80
\(V_2O_5-PbS-P_2O_5\)

Field dependence: The current - voltage characteristics of 10PbS sample under different intensities of illumination and in the dark are shown in Fig. 4.2(c1). Similar graphs for another compositions of the series are shown in Fig's 4.2 e2 to 4.2 e5. (See Appendix 1) The current - voltage curves are found to be ohmic for all the six samples.

Intensity dependence The variation of photocurrent (I) with light intensity (L) for four samples is shown in Fig.4.3(c). At lower intensities (< 1000 lux) the photocurrent increases slowly and at higher intensities the increase is more.

Spectral studies The variation of photocurrent on the excitation energy of light is shown in Fig.4.4(c). The peak of the spectral response curve is observed at 6200 Å. The reported spectral response for infrared photoconductive layer prepared from PbO and S shows the peak at 6000 Å. They found that the infrared sensitivity of the layer increases with increasing amount of sulfur, while resistivity of the layer decreases. The \(\lambda_{\text{max}}\) increases with mol % of PbS as shown in Fig. 4.4 (d).

Table 4.1(c) Values of Rise time, Decay time, Probability (p), Trap depth and Thermal activation energies (E), corresponding to different compositions for \(V_2O_5-PbS-P_2O_5\) glasses.

<table>
<thead>
<tr>
<th>Sr no</th>
<th>% Composition (V_2O_5-PbS-P_2O_5)</th>
<th>Rise time ((r_b)) Sec</th>
<th>Decay time ((r_p)) Sec</th>
<th>Trap depth (eV)</th>
<th>(P \times 10^6)</th>
<th>(E) (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VY1</td>
<td>80-10-10</td>
<td>132</td>
<td>180</td>
<td>0.48</td>
<td>0.038</td>
<td>0.259</td>
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<td>VY2</td>
<td>70-20-10</td>
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<td>180</td>
<td>0.48</td>
<td>0.058</td>
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<td>VY3</td>
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<td>VY4</td>
<td>50-40-10</td>
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<td>VY5</td>
<td>40-50-10</td>
<td>96</td>
<td>180</td>
<td>0.53</td>
<td>0.056</td>
<td>0.335</td>
</tr>
</tbody>
</table>

Fig 4.2 (c4) Variation of dark current and photocurrent for \(80V_2O_5-10PbS-10P_2O_5\) glasses at room temperature (303K).

- - - - - - - - dark __________ 100lux ______ 1000lux ________10000lux
Fig 4.3 (c) Variation of photocurrent with intensity of illumination at room temperature (303K) for V$_2$O$_5$-PbS-P$_2$O$_5$ glasses.

- 50PbS - 40PbS - 30PbS - 20PbS - 10PbS

Fig 4.4 (c) Spectral response characteristics of V$_2$O$_5$-PbS-P$_2$O$_5$ glasses at room temperature (303K).

- 10PbS - 20PbS - 30PbS - 40PbS - 50PbS
Fig 4.5 (c): Variation of $\log(\sigma)$ with reciprocal temperature for $80\text{V}_2\text{O}_5-10\text{PbS}-10\text{P}_2\text{O}_5$ glass at different illuminations.
- dark
- 100Lux
- 1000Lux
- 10000Lux

Fig 4.7 (c): Plot of Activation energy versus illumination for $\text{V}_2\text{O}_5$-$\text{PbS}$-$\text{P}_2\text{O}_5$ glasses. The plot is for room temperature.
Temperature dependence: The variation of log $\sigma$ versus $1/T$ for the sample 10PbS, under different illuminations is shown are Fig.4.5(c1). Similar graphs for another compositions of the series are shown in Fig's 4.5 c2 to 4.5 c5. (See Appendix 1) The activation energies calculated from the slopes of log $\sigma$ versus $1/T$ curves are shown in Fig 4.7(c). for dark and illuminated conditions respectively.

Growth and decay curves:
The rise and decay of photocurrents at different compositions are shown are Fig 4.6(a) $\text{V}_2\text{O}_5$-$\text{P}_2\text{O}_5$, Fig 4.6(b) $\text{V}_2\text{O}_5$ -CdS-$\text{P}_2\text{O}_5$ and Fig 4.6(c) $\text{V}_2\text{O}_5$ -PbS-$\text{P}_2\text{O}_5$. Measurement have been made for a fixed intensity (10000 Lux). It is seen that the value of the photocurrent changes with composition. The various parameters such as rise time, decay time, probability trap depth and thermal activation energies are calculated from these curves and reported in Table 4.1(a), (b) and (c) respectively for $\text{V}_2\text{O}_5$-$\text{P}_2\text{O}_5$, $\text{V}_2\text{O}_5$ -CdS-$\text{P}_2\text{O}_5$ and $\text{V}_2\text{O}_5$ -PbS-$\text{P}_2\text{O}_5$ glasses. It is observed that the trap depth and thermal activation energy increases with mol % of $\text{V}_2\text{O}_5$-$\text{P}_2\text{O}_5$ in this system. Similarly the trap depth increases for other two systems with CdS and PbS mol %. The thermal activation energy increases with PbS mol% whereas it decreases with CdS mol%.

![Graph showing rise and decay curves for $\text{V}_2\text{O}_5$-$\text{P}_2\text{O}_5$ glasses.]

Fig 4.6(a) Rise and decay curves for $\text{V}_2\text{O}_5$-$\text{P}_2\text{O}_5$ glasses. (Light intensity = $10^4$ Lux, Voltage = 1 Volt)

$\bullet$ 80$\text{V}_2\text{O}_5$ = 70$\text{V}_2\text{O}_5$ $\bullet$ 60$\text{V}_2\text{O}_5$ $\times$ 50$\text{V}_2\text{O}_5$
Fig 4.6(b) Rise and decay curves for $V_2O_5$-CdS-$P_2O_5$ glasses. (Light intensity $=10^4$ Lux, Voltage = 1 Volt)

- 50CdS
- 40CdS
- 30CdS
- 20CdS
- 10CdS

Fig 4.6(c) Rise and decay curves for $V_2O_5$-PbS-$P_2O_5$ glasses. (Light intensity $=10^4$ Lux, Voltage = 1 Volt)

- 50PbS
- 40PbS
- 30PbS
- 20PbS
- 10PbS
4.6 CONCLUSIONS

The field dependence in these glasses is $I \propto V^r$ in nature. The photocurrent increases as the intensity of the illumination is increased. The spectral response in these glasses has also been found sensitive to the composition. The transmission edges are corresponding to the photocurrent peak positions, and these peaks are due to the transition of electron from the valence band to the conduction band. Temperature dependence study shows that the glasses are semiconducting in nature.
REFERENCES

APPENDIX 1

The current - voltage characteristics of $V_2O_5 - P_2O_5$ series under different intensities of illumination and in the dark.

Fig 4.2(a2) Variation of dark current and photocurrent for 70$V_2O_5$-30$P_2O_5$ glasses at room temperature (303K).

- 10000lux
- 1000lux
- 100lux
- dark

Fig 4.2(a4) Variation of dark current and photocurrent for 50$V_2O_5$-50$P_2O_5$ glasses at room temperature (303K).

- 10000lux
- 1000lux
- 100lux
- dark
The current - voltage characteristics of V$_2$O$_5$-CdS-P$_2$O$_5$ series under different intensities of illumination and in the dark

Fig 4.2(b2) Variation of dark current and photocurrent for 70V$_2$O$_5$-20CdS-10P$_2$O$_5$
- dark - 100lux - 1000lux --- 10000lux

Fig 4.2(b3) Variation of dark current and photocurrent for 60V$_2$O$_5$-30CdS-10P$_2$O$_5$
- dark - 100lux - 1000lux --- 10000lux

Fig 4.2(b3) Variation of dark current and photocurrent for 50V$_2$O$_5$-40CdS-10P$_2$O$_5$
glass at room temperature(303K).
- dark - 100lux - 1000lux --- 10000lux

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The current-voltage characteristics of V$_2$O$_5$-PbS-P$_2$O$_5$ series under different intensities of illumination and in the dark.

**Fig 4.2 (c2)** Variation of dark current and photocurrent for 70V$_2$O$_5$-20PbS-10P$_2$O$_5$ glasses at room temperature (303K).
- dark
- 100lux
- 1000lux
- 10000lux

**Fig 4.2 (c3)** Variation of dark current and photocurrent for 60V$_2$O$_5$-30PbS-10P$_2$O$_5$ glasses at room temperature (303K).
- dark
- 100lux
- 1000lux
- 10000lux

**Fig 4.2 (c4)** Variation of dark current and photocurrent for 50V$_2$O$_5$-40PbS-10P$_2$O$_5$ glasses at room temperature (303K).
- dark
- 100lux
- 1000lux
- 10000lux
The variation of log $\sigma$ versus $1/T$ for $V_2O_5 - P_2O_5$ series under different illuminations

Fig. 4.3(a2) - Variation of log $\sigma$ with reciprocal temperature for $70V_2O_5 - 30P_2O_5$ glasses at different illuminations.

- $\bullet$ 10000lux
- $\times$ 1000lux
- $\triangle$ 100lux
- $\blacksquare$ dark

Fig. 4.3(a3) - Variation of log $\sigma$ with reciprocal temperature for $60V_2O_5 - 40P_2O_5$ glasses at different illuminations.

- $\bullet$ 10000lux
- $\times$ 1000lux
- $\triangle$ 100lux
- $\blacksquare$ dark

Fig. 4.3(a4) - Variation of log $\sigma$ with reciprocal temperature for $50V_2O_5 - 50P_2O_5$ glasses at different illuminations.

- $\bullet$ 10000lux
- $\times$ 1000lux
- $\triangle$ 100lux
- $\blacksquare$ dark
The variation of log $\sigma$ versus 1/T for V$_2$O$_5$-CdS-P$_2$O$_5$ series under different illuminations

Fig 4.5(b2) - Variation of log $\sigma$ with reciprocal temperature for 70V$_2$O$_5$-20CdS-10P$_2$O$_5$ glass at different illumination.

- dark
- 100lux
- 1000lux
- 2000lux
- 10000lux

Fig 4.5(b3) - Variation of log $\sigma$ with reciprocal temperature for 60V$_2$O$_5$-30CdS-10P$_2$O$_5$

glass at different illumination.

- dark
- 100lux
- 1000lux
- 10000lux

Fig 4.5(b4) - Variation of log $\sigma$ with reciprocal temperature for 50V$_2$O$_5$-40CdS-10P$_2$O$_5$

glass at different illumination.

- dark
- 100lux
- 1000lux
- 10000lux

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The variation of $\log \sigma$ versus $1/T$ for $V_2O_3$–PbS–P$_2$O$_5$ series under different illuminations

**Fig. 4.5 (c1)** Variation of $\log \sigma$ with reciprocal temperature for 70$V_2O_3$-20PbS-10P$_2$O$_5$ glass at different illuminations.
- dark ■ 100lux ▲ 1000lux ■ 10000lux

**Fig. 4.5 (c2)** Variation of $\log \sigma$ with reciprocal temperature for 60$V_2O_3$-30PbS-10P$_2$O$_5$ glass at different illuminations.
- dark ■ 100lux ▲ 1000lux ■ 10000lux

**Fig. 4.5 (c3)** Variation of $\log \sigma$ with reciprocal temperature for 50$V_2O_3$-40PbS-10P$_2$O$_5$ glass at different illuminations.
- dark ■ 100lux ▲ 1000lux ■ 10000lux