PHOTOELECTRICAL PROPERTIES IN THIN FILMS OF $(Ge_{20}Se_{80})_{0.98}Sn_{0.02}$ GLASSY ALLOY

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Electrical measurements have been made in thin films $(Ge_{20}Se_{80})_{0.98}Sn_{0.02}$ glassy alloy as a function of temperature and intensity. Dark conductivity (σ_d) and photoconductivity (σ_{ph}) measurements show that the conduction in this glassy alloy is an activated process having single activation energy in the measured temperature range (289 K to 333 K). Intensity dependence of photoconductivity (σ_{ph}) follows a power law with intensity (F), $\sigma_{ph} \propto F^{\gamma}$. The value of γ has been found nearly 0.5, suggesting bimolecular recombination. Rise and decay of photocurrent at different temperatures, intensities and illumination times show that photocurrent rises monotonically to the steady state value and the decay of photocurrent is quite slow. Analysis of photoconductive decay shows that the recombination within localized states may be predominant recombination mechanism in this glassy system.

1. Introduction

Chalcogenide glasses have recently drawn great attention due to their potential use in various solid state devices [1-4]. The common feature of these materials is the presence of localized states in the mobility gap [5] due to the absence of long range order as well as various inherent defects. As the photocurrent behaviour is controlled by carrier localization and delocalization processes [6], this method may be used to determine the energy distribution of various species of gap states which influence carrier mobility and life time in these materials, under the assumption that the response is controlled by multi-trapping processes. So, photoconductivity technique is a valuable diagnostic tool for the material quality.

Work on steady state and transient photoconductivity in chalcogenide glasses have been reported by many authors [7-11]. These measurements have been interpreted as revealing a broad featureless exponential tail of states above the valence band mobility edge [11], or in contrast, a fairly well defined set of recombination centres in the gap [7]. In this paper the authors have made measurements on the steady state and transient photoconductivity measurements in the amorphous thin film of $(Ge_{20}Se_{80})_{0.98}Sn_{0.02}$ as a function of temperature (289 K to 333 K) and intensity (3 Lux to 1035 Lux). The transient photoconductivity measurements have also been made at various times of illumination to see the recombination mechanism in this material. The results of temperature dependence of dark conductivity have also been included in the paper.

Section 2 describes the experimental details of the sample preparation and photoconductivity measurements. The results are presented and discussed in section 3. The last section deals with the conclusions from the present work.

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2. Experimental method

A glassy alloy of $(Ge_{20}Se_{80})_{0.98}Sn_{0.02}$ is prepared by quenching technique. Materials of 5N purity are weighed according to their atomic percentages and are sealed in a quartz ampoule (length $\approx$ 14 cm, internal diameter $\approx$ 8 mm) with a vacuum $\approx 2 \times 10^{-5}$ Torr. The ampoules are kept inside a furnace where the temperature is raised to 1000 ^oC at the rate of 3-4 ^0C/min. The ampoule is frequently rocked for 24 hrs at the maximum temperature to make the melt homogenous. Quenching is done in ice water. Thin films of the alloy are prepared by a vacuum evaporation technique keeping substrate at room temperature and at base pressure of $\approx 10^{-5}$ Torr which had predeposited thick indium electrodes. The thickness of amorphous film is $\approx$ 5000 A^0. These films are kept inside the deposition chamber for more than 24 hrs to attain thermodynamic equilibrium as stressed by Abkowitz et al. [12] in chalcogenide glasses.

For photoconductivity measurements, the sample is mounted inside a specially designed metallic sample holder with a transparent quartz window which allows light to shine on the sample. A vacuum of $\approx 10^{-3}$ Torr is maintained throughout the experiments. The coplanar geometry (length $\approx$1.82 cm and electrode gap $\approx$ 0.8 mm) is used for electrical measurements. Photoconductivity measurements have been done using a heat filtered white light by a 200 W tungsten lamp as a light source. Light intensity is measured by a digital Luxmeter (Testron, Model 1332). To measure the decay of photocurrent, light is shone on the sample until the steady state is reached. The light is then turned off and the current is measured with time by a $3^1/_2$ - digit digital picoammeter [Model DPM-111]. The photocurrent I_{ph} is obtained after subtracting the dark current (I_d) from the current measured in the presence of light.

3. Results and discussion

Fig. 1 shows the temperature dependence of dark conductivity (σ_d) and photoconductivity (σ_{ph}) for amorphous thin film of $(Ge_{20}Se_{80})_{0.98}Sn_{0.02}$. The plot of $\ln\sigma_d$ vs. 1000/T is a straight line indicating that conduction is an activated process having single activation energy in the temperature range 289 K to 333 K. σ_d can, therefore, be expressed by the usual relation

$$\sigma_d = \sigma_o \exp\left(\frac{-\Delta E}{kT}\right) \qquad (1)$$

where ΔE is the activation energy for dc conduction and k is the Boltzmann's constant. The value of σ_d (297 K) = $6.54 \times 10^{-9}\,\Omega^{-1}cm^{-1}$ and activation energy, $\Delta E_d = 0.93$ eV.
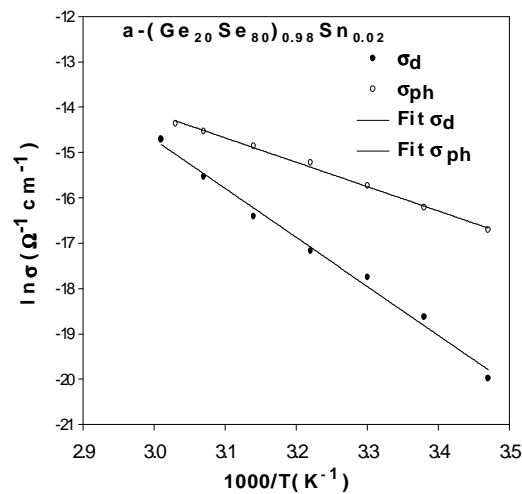

Fig. 1. Temperature dependence of dark conductivity, σ_d and photoconductivity, σ_{ph} .

Fig. 1 also contains the plot of photocurrent vs. 1000/T. It is clear from the figure that the photoconductivity is an activated process and the activation energy (ΔE_{ph}) for photoconduction is much smaller than the dark conduction. The value of σ_{ph} (297 K) = 9.66×10^{-8} $\Omega^{-1}cm^{-1}$ and $\Delta E_{ph} = 0.46$ eV. No maximum in photocurrent is observed at the operating temperature range. Similar results have been reported [13-15] in various other chalcogenide glasses also. Intensity dependence of steady state photoconductivity has also been studied to see the nature of recombination process (result not shown here). The plots of lnI_{ph} vs. lnF are straight lines at all temperatures which indicate that the photoconductivity (σ_{ph}) follows a power law with intensity (F) i.e.

$$\sigma_{ph} \propto F^{\gamma} \tag{2}$$

where the power γ lies between 0.5 and 1.0 ($\approx$0.6). According to Rose [16] the value of γ between 0.5 and 1.0 can not be understood by assuming a set of discrete trap levels but consisting the existence of continuous distribution of trap levels in the band gap. In our case also, the value of γ lies between 0.5 and 1.0 which indicates that a continuous distribution of localized states exists in the mobility gap and the resulting recombination mechanism will be bimolecular [17] where the recombination rate of electrons is proportional to the number of holes. In non-equilibrium condition, most of the electrons and holes generated after light shining and located at D^o centres and these centres decrease by recombination process [2 $D^o \rightarrow D^+ + D^-$] when the illumination is stopped.
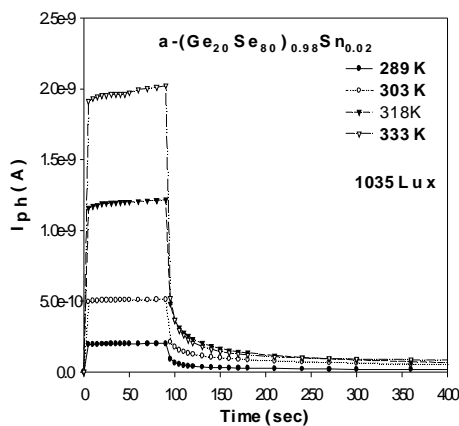

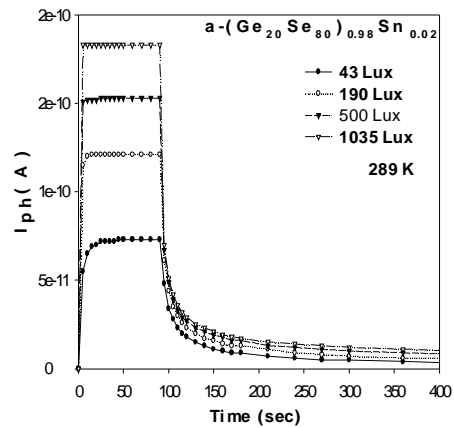Fig. 2. Rise and decay of I_{ph} at various temperatures.

Fig. 3. Rise and decay of I_{ph} at various illumination levels.

Fig. 2 shows the rise and decay of photocurrent at different temperatures. It is clear from the figure that the photocurrent rises monotonically to the steady state value and the decay of photocurrent is quite slow. A persistent photocurrent is observed at all temperatures which is a common feature of other chalcogenide glasses [18-19]. Fig. 3 shows the rise and decay of photocurrent at room temperature (289 K) for different illumination levels. It is clear from figure that decay of photocurrent is quite slow. The persistent photocurrent is observed at all levels of illuminations. The decay of photocurrent has also been studied as a function of illumination times (results not shown here) and it is observed that the decay is quite slow and the persistent photocurrent is found at all illumination times.

From above observations, it is clear that the persistent photocurrent is observed at all temperatures, intensities and illumination times and it is believed that persistent photocurrent may not be simply due to carriers trapped in the localized states [18]. So, for simplifying the analysis, the persistent photocurrent is subtracted from the measured photocurrent. The plots between lnI_{ph} vs. time curves are not straight lines (results not shown here) shows that the decay is non-exponential at all

temperatures, intensities and illumination times. In amorphous materials, having traps in the mobility gap, the recombination time of carriers is same as the carrier life time when the free carrier density is more than the trapped carrier density [19]. If the free carrier density is much less than the trapped carriers, the recombination process is dominated by the rate of trap emptying and is much larger than the carrier life time, resulting in a slow decay.

To study the decay rate analysis quantitatively at various temperatures, intensities and illumination times, we have defined the decay time constant as [20].

$$\tau_d = -\left[\frac{1}{I_{ph}}\left(\frac{dI_{ph}}{dt}\right)\right]^{-1} \tag{3}$$

Fig. 4 shows the time dependence of τ_d for decay curve of Fig. 2. It is clear from the figure that the decay constant increases as the time increases which confirms the non-exponential decay of photocurrent. For exponential decay, the decay constant should not vary with time. Figs. 5-6 shows the values of τ_d (t = 15 sec) at different temperatures and intensities. It is clear from figure that the value of τ_d decreases as the temperature is increased (Fig. 5) and increases as the intensity (Fig. 6) is increased.
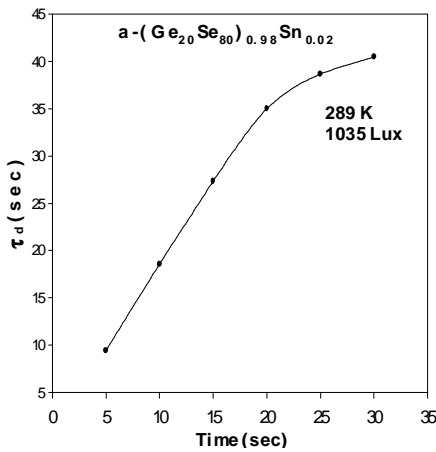

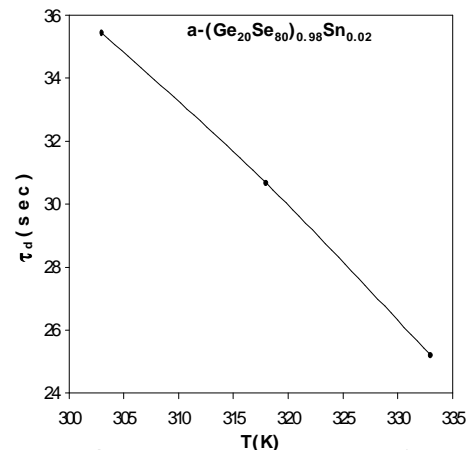Fig. 4. Time dependence of τ_d for the decay curve .

Fig. 5. Temperature dependence of τ_d (t = 15 sec).
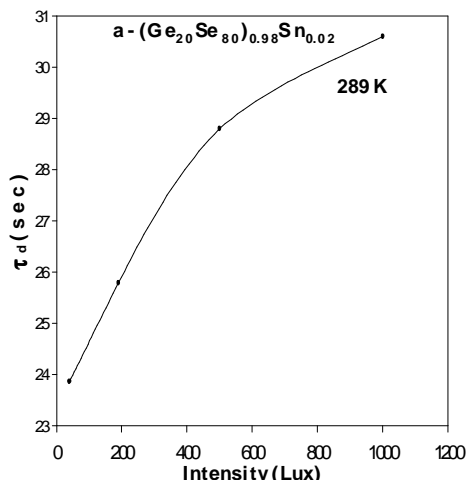

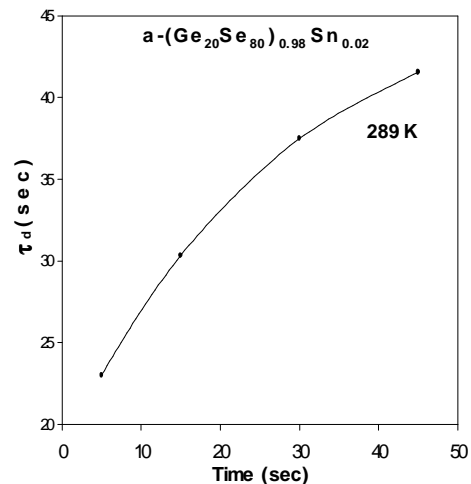Fig. 6. Intensity dependence of τ_d (t = 15 sec).

Fig. 7. Illumination time dependence of τ_d (t = 15 sec).

According to Fuhs and Meyer [20] where the recombination with in the localized states is considered to be the predominant recombination mechanism at all temperatures and intensities and when I_{ph} increases with temperature, the excess charge carrier density is given by

$$\Delta p = \frac{N_v}{N} \sqrt{\frac{g_o}{a_1}} \exp\left[-\frac{E_{tp}}{kT} \right] \tag{4}$$

where N= concentration of hole traps (in this case), N_v= density of states in the valence band, E_{tp}= energetic depth of hole traps, g_o= excess carrier generation rate, a_1= recombination rate.

From equation 4 it is clear that steady state photoconductivity should increase exponentially with the temperature and square root of intensity. In our case also, we have observed the same type of behaviour.

Fuhs and Meyer [20] have also shown that

$$\frac{\Delta p(t)}{\Delta p(0)} = \frac{1}{\left(1 + \dfrac{t}{\tau}\right)} \tag{5}$$

$$\text{where } \tau = \sqrt{a_1 g_o} \tag{6}$$

From equation 6 it is clear that the decay constant τ should increase as the intensity of illumination is increased.

In our case τ_d increases as the intensity of illumination increases (see Fig. 6). They have also shown that in the temperature range where I_{ph} decrease with the increase in temperature, τ_d may decrease even the case of the recombination with in the localized states. We have also observed a decrease in τ_d as the temperature is increased (see Fig. 5). This type of behaviour of τ_d has also been reported by Moustakas et al. [21] and Main et al. [22] and it has been attributed to the presence of gap states near the mobility edge. In the presence of these gap states, the calculated τ_d will be longer than the decay time of mobile carriers, if the carriers recombine via these states. Fig. 7 shows the illumination time dependence of τ_d (t = 15 sec) at a temperature 289 K. It is clear from the figure that τ_d increases as the illumination time is increased. Similar type of behaviour has also been observed by Igalson [18] and he explained these results on the assumption that the recombination takes place within charged defect states present in these material.

4. Conclusions

Steady state and transient photoconductivity measurements have been done in amorphous thin film of $(Ge_{20}Se_{80})_{0.98}Sn_{0.02}$ as a function of temperature, intensity and illumination times. Intensity dependence of photoconductivity follows a power law. Temperature dependence of photoconductivity indicates that the conduction is through an activated process with a single activation of energy in the temperature range. The present result of τ_d as a function of temperature, intensity and illumination times can be explained if recombination within localized states taken into account as suggested by Fuhs and Meyer.

Acknowledgements

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