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Thermally stimulated current measurements in a-$(Ge_{20}Se_{80})_{94}Pb_6$

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Thermally stimulated currents (TSC's) are measured on vacuum evaporated thin films of a-$(Ge_{20}Se_{80})_{94}Pb_6$ in the temperature range 300-350 K. Well defined TSC peaks are observed at different heating rates. It is observed that the peaks shift to higher temperatures as heating rate is increased. Using the single trap analysis, we have calculated the trap depth in the present sample.

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1. Introduction

The chalcogenide glassy semiconductors are some of the widely used amorphous semiconductors for a variety of applications in optics, electronics and optoelectronics such as ultrafast optical switches, waveguides, optical memories, gratings, optical sensors, holography, infrared lasers, ionic sensors etc. These glasses generally exhibit p-type electrical conduction due to the pinning of the Fermi level arising from the trapping of the charge carriers at localized gap states [1, 2]. But in 1979, Tohge et al. [3, 4] reported for the first time p-to n-type electrical conduction in Bi doped Ge-Se glasses. In 1987, Tohge et al. [5] have observed p to n-type electrical conduction in Pb doped Ge-Se glasses also. Due to this reason, the Pb doping in Ge-Se glasses became important.

In amorphous semiconductors, the presence of localized defect states may act as traps for the charge carriers and hence affect many properties of materials. Presumably, the parameters of traps (their energy position, the character of energy distribution, trapping concentration and capture cross-section of the traps) are substantially different in different materials and these parameters determine the specific features of kinetic processes in each case.

Thermally stimulated currents (TSC) experiment is an important tool for determining the position and density of trap states in semiconductors [6, 7]. In this method, traps are filled by the photoexcitation of the semiconductor at a low enough temperature such that upon ceasing the illumination the trapped carriers cannot be freed by the thermal energy available at that temperature. The temperature is then raised at a constant rate. The liberated carriers contribute, in an applied field, to an excess current until they recombine with carriers of the opposite type or join the equilibrium carrier distribution. This excess current, measured as a function of temperature during heating, is called a TSC curve. In previous years, this technique has been extended to amorphous semiconductors. Several experiments have been carried out in hydrogenated amorphous silicon (a-Si:H) [8-10].

A TSC curve for a single trap level has one maximum whose position depends on the trap depth, the capture cross-section of the trap and the heating rate. By varying the heating rate, the trap depth and the capture cross section can be determined [11, 12]. If a discrete distribution of traps is present, the TSC curve may consist of several peaks, each originating from a distinct trap energy.

The present paper reports the TSC measurements in amorphous thin films of $(Ge_{20}Se_{80})_{94}Pb_6$. This composition is selected for TSC measurements on the basis of highest photosensitivity at this composition in a-$(Ge_{20}Se_{80})_{100-x}Pb_x$ series.

2. Theory of measurements

The simplest case is for the materials in which only one trap level is contributing to the TSC at a time. Although chalcogenide glasses may have traps distributed throughout the mobility gap, it appears justifiable to use the single trap analysis to calculate the trapping parameters of the present sample, in view of the analysis of Simmons et al. [13, 14]. We summarize the results for a single trap level, in the slow and fast re-trapping limits and shows how the trap parameters can be obtained in this case. Slow re-trapping means that the probability of recapture of thermally liberated carriers by traps is much smaller than recombination, whereas in fast re-trapping the recombination probability is small as compared to the recapture. Both cases have been treated in the literature and one finds that the TSC for a material with a single trap level in the fast as well as the slow re-trapping case is given by a general equation,

$$I(T) = A\,exp\left[-\frac{E_t}{kT} - \frac{B}{\beta}\int_{T_0}^{T} exp\left(-\frac{E_t}{kT}\right)dT\right] \qquad (1)$$

where A and B are constants whose dependence on the various trapping parameters is given below.
For fast retrapping

$$A = Q\, n_{t0}\, N_c\, \mu\, E\, C / N_t$$

$$B = N_c/\tau\, N_t$$

For slow retrapping

$$A = q\, n_{t0}\, \nu\, \tau\, \mu\, E\, C$$

$$B = \nu$$

E_t is the trap depth, β is the heating rate, T_0 is the initial temperature and k is the Boltzmann constant. At a time t after the heating has started, the temperature $T = T_0 + \beta t$.
q is the electronic charge, n_{t0} is the number of electrons in traps at t=0, N_t is the total number of traps, μ is the mobility of electrons in the conduction band, ν is the escape frequency, τ is the lifetime of the electrons, E is the electric field, C is the cross-sectional area of the sample and N_c is the effective density of states in the conduction band

The condition of maxima in TSC (i.e., a peak in TSC) can be obtained by using the condition

$$\left.\frac{dI(T)}{dT}\right|_{T=T_m} = 0 \qquad (2)$$

Therefore we conclude that

$$exp\left[\frac{E_t}{kT_m}\right] = \frac{B}{\beta}\frac{kT_m^2}{E_t} \qquad (3)$$

Equation (3) predicts that the TSC maxima temperature (T_m) will shift towards higher temperature with the increase in β. Moreover, a plot of ln (T_m^2/β) versus $1/T_m$ should be a straight line whose slope is related to E_t. Also, for temperatures close to T_m, the equation (1) can be approximated as [14]

$$I(T_m) = A\,exp\left[-\frac{E_t}{kT} - 1\right] \qquad (4)$$

From equation (4), if $E_t / kT_m >> 1$, a plot of ln $I(T_m)$ versus $1/T_m$ is a straight line for different heating rates whose slope is related to E_t.

3. Experimental

Glassy alloy of $(Ge_{20}Se_{80})_{94}Pb_6$ was prepared by quenching technique. Thin films of this glassy material were prepared by vacuum evaporation technique keeping glass substrates at room temperature. Vacuum evaporated indium electrodes at bottom are used for the electrical contact. The thickness of the films is ~ 500 nm. The co-planar structure (length ~ 1.2 cm and electrode separation ~ 0.5 mm) was used for the present measurements.

For TSC measurements, thin films were mounted in a specially designed sample holder, which has a transparent window to shine light. A vacuum ~10^{-2} Torr is maintained throughout the measurements. The temperature of the films is controlled by mounting a heater inside the sample holder and measured by a calibrated copper- constantan thermocouple mounted very near to the films. A voltage of 10 V is applied across the films and the resulting current is measured by a digital Pico-Ammeter. Before measurements, the films were first annealed at 350 K for one hour in a vacuum ~ 10^{-2} Torr.

TSC measurements were made in a-$(Ge_{20}Se_{80})_{94}Pb_6$ at three different heating rates (0.046 K/Sec, 0.063 K/Sec and 0.10 K/Sec). At each heating rate the sample was first heated from room temperature 300 K to 350 K without shining light (state A). Thereafter, the sample was cooled down to room temperature again and light from a 200 W tungsten lamp is shone on the sample through a transparent window for 2 minutes. Proper care was taken for the increase of temperature during light shining. After switching off the light, the photoconductivity was allowed to decay for 10 minutes. Then, the sample was heated again to 350 K at the same heating rate (state B).

4. Results and discussion

From the above measurements, we have found that the current in state B is higher than in state A. The difference of currents in these two states is called thermally stimulated current (TSC). The temperature dependence of TSC is plotted in Fig. 1 at all the three heating rates. It is clear from Fig. 1 that a maxima in TSC is observed at a particular temperature T_m and the position of TSC maxima shifts to higher temperatures as the heating rate is increased. The values of T_m and $I(T_m)$ at different heating rates are given in Table 1.

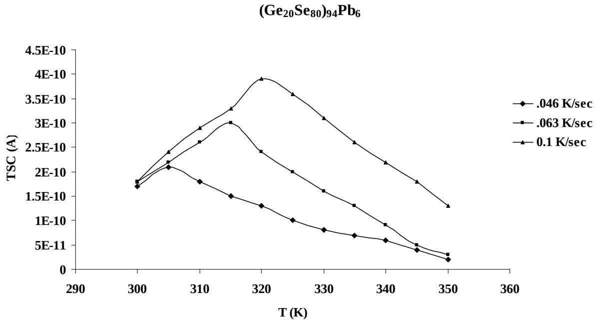

Fig. 1.Temperature dependence of TSC in a-$(Ge_{20}Se_{80})_{94}Pb_6$ at different heating rates.

Table.1.

Heating rate (β) (K/s)	Peak Temperature (T_m) (K)	$I(T_m)$ (A)
0 .046	305	2.1×10^{-10}
0.063	315	3.0×10^{-10}
0.100	320	3.9×10^{-10}

As evident from equation 3, in case of TSC, ln $(T_m)^2 / \beta$ vs $1 / T_m$ should be a straight line whose slope will give the value E_t / k. Our experimental results also show a straight line curve between ln $(T_m)^2 / \beta$ and $1 / T_m$

(see Fig. 2). From the slope of this curve the trap depth E_t is calculated and found to be 0.35 eV.

Equation 4 shows that in case of TSC, ln $I(T_m)$ vs $1/T_m$ curve should be straight line whose slope will be E_t/k. Here, $I(T_m)$ is the current at the temperature where TSC maxima occurs. Fig. 3 shows that ln $I(T_m)$ vs $1 / T_m$ curve is a straight line. From the slope of this curve E_t comes out to be 0.34 eV, which is very close to the value obtained from $\ln(T_m)^2 / \beta$ vs $1 / T_m$ curve (Fig. 2).

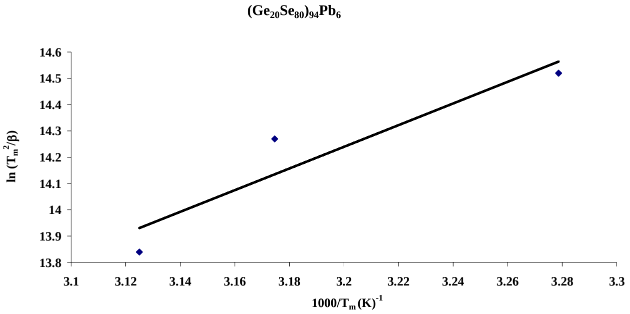

Fig. 2. ln(T_m^2/β) vs 1000/T_m curve in a- $(Ge_{20}Se_{80})_{94}Pb_6$.

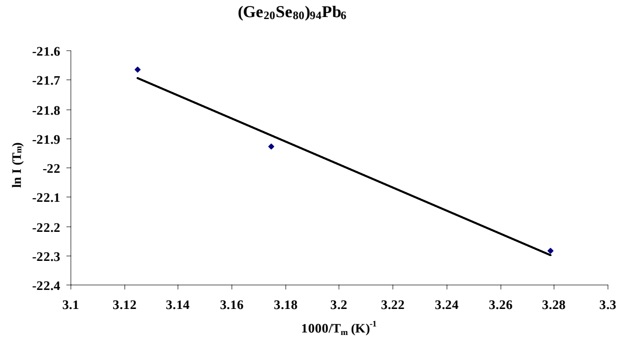

Fig. 3. ln $I(T_m)$ vs 1000/T_m curve in a- $(Ge_{20}Se_{80})_{94}Pb_6$.

Hernandez et. al. [15] have also reported thermally stimulated currents in glassy $CuIn_5Se_8$ sample and analyzed their data by the single trap level theory as used in the present paper. They found deep levels at 0.55 eV and 0.79 eV in their sample. In our earlier study [16] also, TSC measurements are reported and trap level at 0.40 eV is found.

5. Conclusion

Thermally stimulated current measurements have been made to characterize traps in glassy $(Ge_{20}Se_{80})_{94}Pb_6$. It is observed that TSC peaks shift to higher temperatures as heating rate is increased. From the heating rate dependence of peak temperature and also from the heating rate dependence of current at the peak temperature, the trap depth is calculated which comes out to be approximately 0.34 eV in this case.

References

[1] R. A. Street, N. F. Mott, Phys. Rev. Lett. **35,** 1293 (1975).
[2] A. I. Gubanov, Sov.Phys.Solid State **3**, 1964 (1962).
[3] N. Tohge, Y. Yamamoto, T. Minami, M. Tanaka, Appl. Phys. Lett.**34,** 640 (1979).
[4] N. Tohge, T. Minami, M. Tanaka, J. Non-Cryst. Solids, **37,** 23 (1980).
[5] N. Tohge, M.Matsuo, T. Minami, J. Non-Cryst. Solids, **95-96**, 809 (1987).
[6] R. H. Bube, photoconductivity of solids, John Wiley and Sons (1980).
[7] R. R. Haering, E. N. Adams, Phys. Rev. **117**, 451 (1960).
[8] W. Fuhs, M. Milleville, Phys. Status Solidi B **98,** K29 (1980).
[9] D. S. Misra, V. A. Singh, S. C. Agarwal, Solid Stat. Comm. **55**, 147 (1985).
[10] M. Yamaguchi, J. Non- Cryst. Solids, **59-60,** 425 (1983).
[11] D. S. Misra, A. Kumar, S.C. Agarwal, Phil. Mag. B **49**, L 69 (1984).
[12] D. S. Misra, A. Kumar, S. C. Agarwal, Phys. Rev. B **31**, 1047 (1985).
[13] J. G. Simmons, G. W. Taylor, Phys. Rev. B **4**, 502 (1971).
[14] J. G. Simmons, G. W. Taylor, M. C. Tam, Phys. Rev. B **7**, 3715 (1973).
[15] E. Hernandez, L. Duranl, C. A. Durante Richon, G. Aranguren, C. Guerrero, J. Naranjo, Cryst. Res. Technol **37**, 1227 (2002).
[16] V. S. Kushwaha, D. Kumar, A. Kumar, J. Optoelectron. Adv. Mater. **8,** 1356 (2006).

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