JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 8, No. 4, August 2006, p. 1356 - 1358

Localized states in a-$Se_{98}Sb_2$ determined by thermally stimulated current measurements

V. S. KUSHWAHA, D. KUMAR[a], A. KUMAR[*]
Department of Physics, Harcourt Butler Technological Institute, Kanpur, India
[a]Department of Physics, J.S.S. Academy of Technical Education, Noida, India

Thermally stimulated current measurements were carried out on vacuum evaporated thin films of a-$Se_{98}Sb_2$ in the temperature range 293-328 K. Well defined TSC peaks are observed in this case. The peaks shift to higher temperatures as heating rate is increased. Using the single trap analysis, we have calculated the trap depth in the films.

(Received February 22, 2006; accepted July 20, 2006)

Keywords: Chalcogenide glasses, Amorphous thin films, Thermally stimulated current, Localized states

1. Introduction

In chalcogenide glasses, glassy Se has wide technical applications in electronics and optoelectronics. However, the shortcomings of pure glassy Se for its practical applications include its short lifetime, low sensitivity and thermal instability. To overcome these difficulties, certain additives are used and especially the use of Se-Te, Se-Ge and Se-Sb is of interest owing to their various properties like greater hardness, higher photosensitivity, higher conductivity and smaller ageing effects as compared to pure glassy Se. Though, the electrical, optical, dielectric and thermal properties in Se-Sb system have been reported by many workers [1-8], the measurements of thermally stimulated currents have not been reported so far in these glasses.

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.

There are various methods for the determination of localized states in semiconductors. Among them, thermally stimulated currents (TSC) is an important technique. 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.

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 [9-11]. 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 $Se_{98}Sb_2$. This material is chosen for TSC measurements on the basis of higher photosensitivity as compared to pure amorphous Se thin films.

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. [12,13]. 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. The single trap level model used for analysis of TSC is given in Fig. 1.

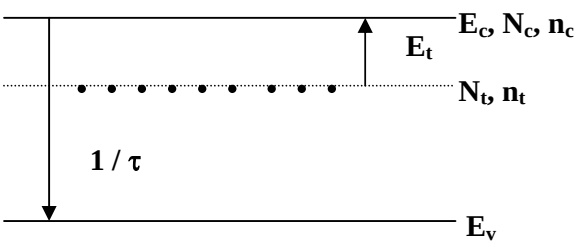

Fig. 1. Single trap level model used for the analysis of TSC in case of electrons as predominant charge carriers.

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 [14]. 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 (2)

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

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 $Se_{98}Sb_2$ was prepared by quenching technique as described elsewhere [7]. 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 30 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 330 K for one hour in a vacuum of ~ 10^{-2} Torr.

TSC measurements were made in a-$Se_{98}Sb_2$ at three heating rates (0.046 K/s, 0.063 K/s and 0.10 K/s). At each heating rate the sample was first heated from room temperature (293 K) to 328 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 328 K at the same heating rate (state B).

4. Results and discussions

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. 2 at all the three heating rates. It is clear from Fig. 2 that a maxima in TSC is observed at a particular temperature T_m. The position of TSC maxima shifts to higher temperatures as the heating rate is increased (see Fig. 2). The values of T_m and $I(T_m)$ at different heating rates are given in Table 1.

Table 1. T_m and $I(T_m)$ at different heating rates in a- $Se_{98}Sb_2$.

Heating rate β (K/s)	Peak temperature T_m (K)	$I(T_m)$ (A)
0 .046	303	1×10^{-10}
0.063	308	1.4×10^{-10}
0.100	318	2.1×10^{-10}

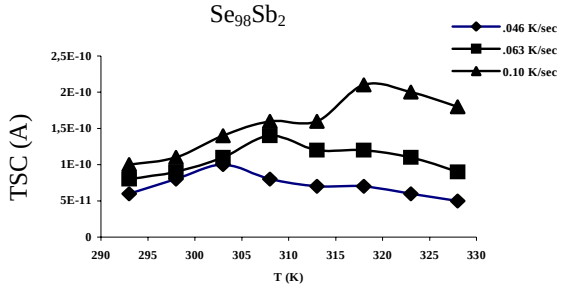

Fig. 2. Temperature dependence of TSC in a-$Se_{98}Sb_2$ at different heating rates.

As evident from equation 3, in case of TSC, ln $(T_m)^2$ / β 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 between ln $(T_m)^2$ / β and $1/T_m$ (see Fig. 3). From the slope of this curve the trap depth E_t is calculated and found to be 0.41 eV.

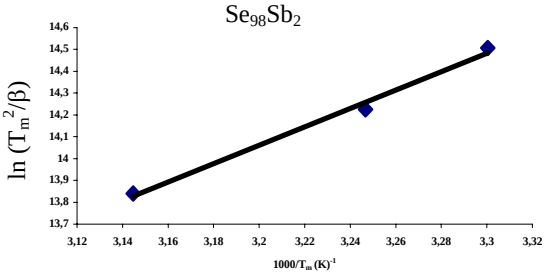

Fig. 3. $ln(T_m^2/\beta)$ vs $1000/T_m$ curve in a- $Se_{98}Sb_2$ for three different heating rates.

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. Our experimental results also show a straight line between ln I (T_m) and 1 / T_m (see Fig.4). From the slope of this curve E_t comes out to be 0.40 eV, which is very close to the value obtained from ln $(T_m)^2$ / β vs 1 / T_m curve (Fig. 3).

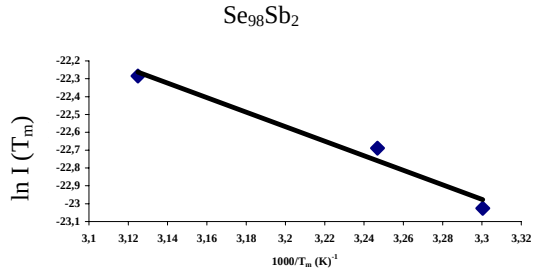

Fig. 4. ln $I(T_m)$ vs $1000/T_m$ in a- $Se_{98}Sb_2$ for three different heating rates.

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 a earlier study [16] also, TSC measurements are reported and trap level is found to be at 0.27 eV.

5. Conclusion

Thermally stimulated current measurements have been made to characterize traps in glassy $Se_{98}Sb_2$. 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 0.40 eV in this case.

References

[1] V. I. Mikla, I. P. Mikhalko, V. V. Mikla, Mater. Sci. Engin. B **83,** 74 (2001).
[2] M. Singh, D. R. Goyal, A. S. Maan, J. Phys. Chem. Sol. **60,** 877 (1999).
[3] M. A. Majeed Khan, M. Zulfequar, S. Kumar, M. Husain, J. Modern Opt. **50(2),** 251 (2003).
[4] S. Jayakumar, C. Balasubramanian, S. K. Narayandas, D. Mangalaraj, C. P. Girija Vallabhan, Thin Solid Films **266**, 62 (1995).
[5] D. Dimitrov, D. Tzocheva, D. Kovacheva, Thin Solid Films **79,** 323 (1998).
[6] N. Choudhary, A. Kumar, Turk. J. Phys. **29,** 119 (2005).
[7] V. S. Kushwaha, S. Kumar, A. Kumar, Turk. J. Phys. **29,** 349 (2005).
[8] R. S. Tiwari, N. Mehta, R. K. Shukla, A. Kumar, Turk. J. Phys. **29,** 233 (2005).
[9] D. S. Misra, A. Kumar, S. C. Agarwal, Phil. Mag. B **49,** L 69 (1984).
[10] D. S. Misra, A. Kumar, S. C. Agarwal, Phys. Rev. B **32,** 4052 (1985).
[11] D. S. Misra, V. A. Singh, S. C. Agrawal, Solid Stat. Comm. **55**, 147 (1985).
[12] J. G. Simmons, G. W. Taylor, Phys. Rev. B **4,** 502 (1971).
[13] J. G. Simmons, G. W. Taylor, M. C. Tam, Phys. Rev. B **7**, 3715 (1973).
[14] G. A. Dussel, R. H. Bube, Phys. Rev. **155,** 764 (1967).
[15] E. Hernandez, L. Duranl, C. A. Durante Richon, G. Aranguren, C. Guerrero, J. Naranjo, Cryst. Res. Technol **37,** 1227 (2002).
[16] D. Kumar, S. Kumar, J. Optoelectron. Adv. Mater. **6,** 413 (2004).

*Corresponding author: dr_ashok_kumar@yahoo.com