

PARAMETERS OF TRAPPING CENTERS IN AMORPHOUS $\text{Se}_{70}\text{Te}_{30-x}\text{Zn}_x$ THIN FILMS

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Thermally stimulated currents have been measured at different heating rates (β) in amorphous thin films of $\text{Se}_{70}\text{Te}_{30-x}\text{Zn}_x$ ($x = 0, 2, 4, 6, 8$). A clear TSC peak occurs at a particular temperature that shift towards higher temperatures as heating rates (β) is increased. The aim of this paper is to determine initial information about trap depth and trap concentration (N_t). The value of N_t decreases with increases in Zn concentration upto 2 % and thereafter it increases with increase in Zn concentration.

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1. Introduction

Amorphous chalcogenides have gained considerable attention due to their interesting technological applications. Their promising material science applications include photo structural, optical [1, 2], advanced I R optical fibers [3], and acoustic devices [4, 5].

Thermally stimulated conductivity (TSC) is a well known non- isothermal technique for investigating the trap level in semi conducting materials [6]. Depending on the stability of model chosen, analysis of TSC allows to estimate the trap density and the trap depth as well as other parameters. In this paper, thermally stimulated conductivity in thin films $\text{Se}_{70}\text{Te}_{30-x}\text{Zn}_x$ ($x = 0, 6, 8$) is studied at four heating rates (β). It is observed that maxima in TSC, observed at a particular temperature (T_m), shifts towards higher temperatures with increasing heating rates (β) as expected.

2. Experimental details

Thin films of $\text{Se}_{70}\text{Te}_{30-x}\text{Zn}_x$ ($x = 0, 2, 4, 6, 8$) glassy alloys having a thickness of 500 nm were prepared by vacuum evaporation techniques on glass substrates maintained at room temperature. Details of the deposition system and procedure are described in more detail in [7]. The coplanar structures are used for the present measurements (length ~ 1.2 cm and electrode separation $- 0.5$ mm)

The amorphous nature of thin films was ascertained by XRD. Before measuring the d. c. conductivity, films were annealed at 400K for one hour in a vacuum of 10^{-2} torr. Thermally stimulated conductivity was studied by mounting the films in specially designed sample holder. Temperature of the film was controlled by mounting a heater inside the sample holder and measured by a copper constantan thermocouple mounted in the vicinity of the films. For this purpose, current was measured at a particular voltage using Keithley electrometer model 614.

For measuring thermally stimulated conductivity, conductivity measurements have been made in two different states, at each heating rates. In the state I, sample is heated from room temperature 295K to 470K without any light exposure, However, in the state II, light is incident on the sample for two minutes through the transparent window at room temperature. After switching off light, the decay of the photoconductivity was allowed for 10 minute. Now, the sample is again heated at the same heating rate. The difference of conductivity in these two states is called TSC.

These measurements were also done at different heating rates. Thermally stimulated conductivity have been calculated from the relation

$$\sigma_{dc} = (1 / R) (L / A) \quad (1)$$

where, R is resistance of the sample, L is the thickness of the sample, A is the area of the cross-section of the sample.

3. Theoretical basis

Thermally stimulated current due to single trap depth E_0 , with negligible re-trapping, is given by [8].

$$I = I_0 \exp \left[\frac{-E_0}{kT} - \frac{\nu}{\beta} \int_{T_0}^T \exp \left(-\frac{E_0}{kT} \right) dt \right] \quad (2)$$

where, T_0 is the initial temperature, k is the Boltzmann constant, ν is the escape frequency, β is the warm up rate and I_0 is the pre-exponential factor which is a weak function of temperature. At low enough temperature, contribution of integral in above equation can be neglected. Under this condition, above equation can be written as

$$I = I_0 \exp \left[\frac{-E_0}{kT} \right] \quad (3)$$

A trap is characterized by the maximum in the thermally stimulated current at the temperature corresponding to this maximum T_m . The energy associated with trap is the thermal energy at T_m , which is given by,

$$E_0 = \alpha f \left[\beta, T_m, T' \right] k T_m \quad (4)$$

in the above equation, α is a dimensionless model constant. The variable T' is the temperature at half of the maximum current value on the low temperature side of the current peak. Assuming, Grossweiner model [9], the constant α and function is given as $\alpha = 1.51$:

$$f \left[\beta, T_m, T' \right] = \left[\frac{T_m}{T'} - 1 \right]^{-1} \quad (5)$$

and attempt frequency is given by,

$$\nu = 3 \left(\frac{\beta}{T_m} \right) f \left(\beta, T_m, T' \right) \exp \left[\frac{E_0}{kT} \right] \quad (6)$$

This method has been employed for slow enough heating rates. In our case minimum heating rates is about 3 K / m. This is why we have calculated activation energy of traps by other methods.

3.1 Initial rise method

This method is valid for all type of recombination kinetics [10], proposed by Garlic and Gibson [11] which states that in the rising part of the TSC curve the current is proportional to $\exp(-E_0/kT)$. Therefore, the plot of the logarithmic of the current as a function of $1 / kT$, gives

directly a straight line of slope E_0 . The progressive shifting from linear behavior at high currents is likely due to the overcoming of the critical temperature T_c [12], above which the Garlic-Gibson are not more valid. The advantage of this method lies essentially in the fact that it is independent of recombination kinetics. i. e. in this method only rising part of the TSC curve has to be considered.

3.2 Variable heating rate method

In this method the traps are emptied at different heating rates while all other parameters are kept constant. The equation relating heating rate to the temperature maximum of the current peak is given by [13]

$$\ln(T_m^2 / \beta) = (E_0 / k T_m) - \ln(w \cdot k / E_0) \quad (7)$$

with $w = N_c \cdot \sigma \cdot V_{th}$

where, T_m is the temperature of the current peak maximum, β is the heating rate, k is Boltzmann's constant, E_0 is the thermal energy of trap, w is the escape attempt frequency, N_c is the effective density of state in the conduction band, σ be the trapping cross section area, and V_{th} is thermal velocity.

As the heating rate increases from one measurement to another, the centroid of current peak associated with trap, shifts to higher temperature. Using different heating rates, $\beta_1, \beta_2, \beta_3$ one gets temperature maximums, T_1, T_2, T_3 respectively. Plotting $\ln(T_m^2/\beta)$ versus $1000 / T_m$ results, in straight line with a slope equal to trap thermal energy (E_0). Also it is an important to consider the possibility of re-trapping in which the freed charge carriers undergoes re-trapping by empty deep levels. This effect will lead to increase of the magnitude of the measured deep trap current peak relative to the shallow trap's current peak, which in turns lead to a change of the concentration of trapped charge

3.4 Trap concentration

The concentration of the traps has been estimated using the relation [14]

$$N_t = \frac{Q}{ALeG} \quad (8)$$

Here, Q is the quantity of the charge released during a TSC experiment and can be calculated from the area under the TSC peak, A and L are the area and thickness of the sample respectively, e is the electronic charge and G is the photoconductivity gain.

The latter was calculated using the expression [15]

$$G = \tau / t_{tr} \quad (9)$$

where, τ is the carrier life time and t_{tr} is the carrier transit time between electrodes.

4. Results and discussion

It is clear from Figs 1- 4 that current in state II is higher than in state I at each heating rate in case of amorphous thin films of $Se_{70}Te_{30}$, the difference of current in these two states is called TSC. Similar results were observed for other composition also (results are not shown here).

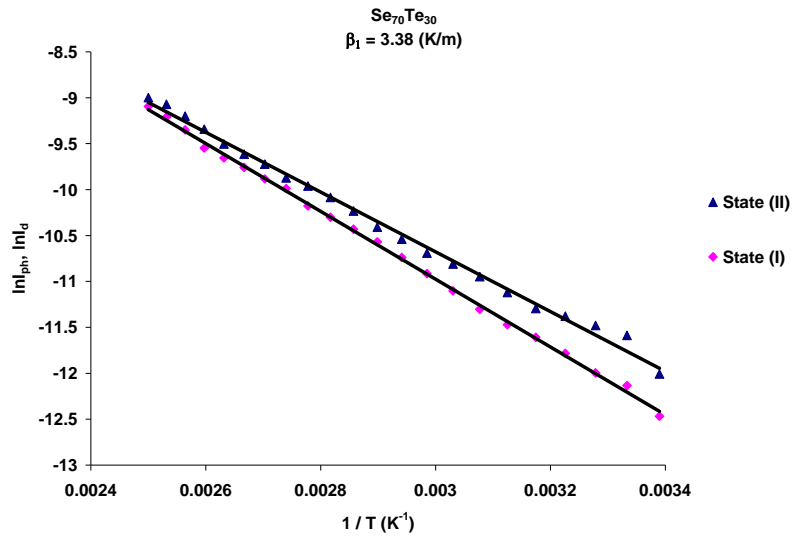


Fig. 1 Temperature dependence of current at heating rates 3.38 (K/m) of Se₇₀Te₃₀ thin films

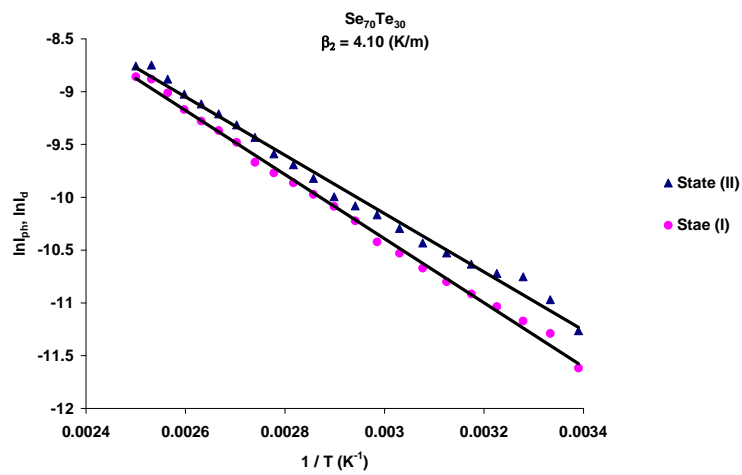


Fig. 2 Temperature dependence of current at heating rates 4.10 (K/m) of Se₇₀Te₃₀ thin films

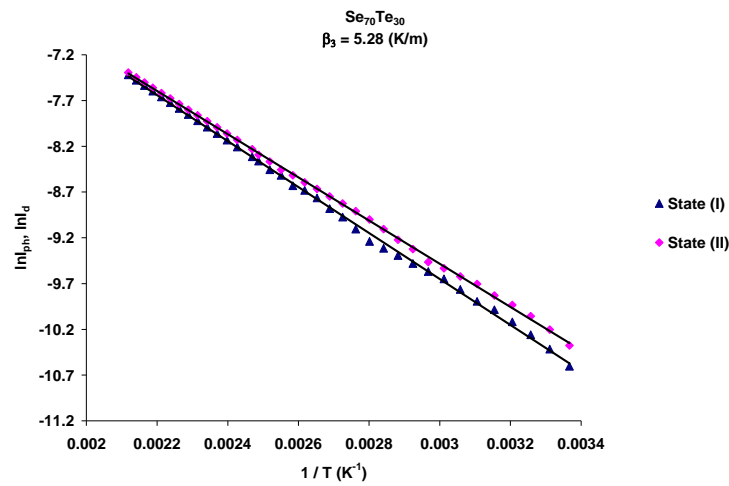


Fig. 3 Temperature dependence of current at heating rates 5.28 (K/m) of $\text{Se}_{70}\text{Te}_{30}$ thin films

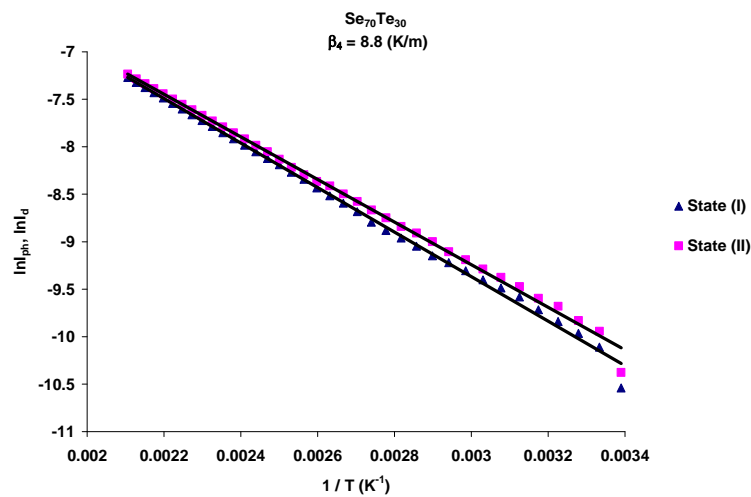


Fig. 4 Temperature dependence of current at heating rates 8.8 (K/m) of $\text{Se}_{70}\text{Te}_{30}$ thin films

Fig.5. shows experimental TSC (A) curves for amorphous $\text{Se}_{70}\text{Te}_{30}$ thin films at different heating rates. It is clear from this plot that as the heating rates increases from one measurement to another, the centroid of current peak associated with trap shifts to higher temperatures respectively. Similar results were observed for other compositions also (results are not shown here)

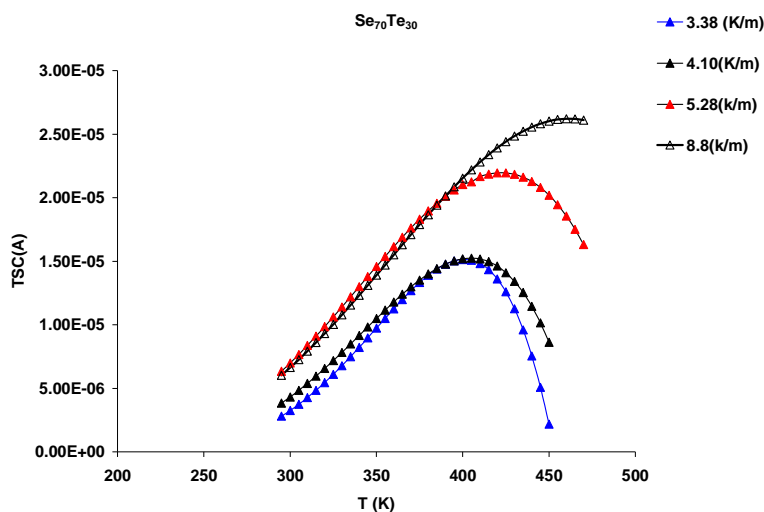


Fig. 5 Experimental TSC (A) curves for $Se_{70}Te_{30}$ thin films measured at four different heating rates

Fig. 6. shows a plot of \ln logarithm of thermally stimulated current as function of $1000 / T$ for initial rise part of TSC peak of amorphous $Se_{70}Te_{30}$ thin films. A linear dependence is observed in this case whose slope gives (E_0) . It may be pointed out here that initial rise method is applied only for one heating rate only. Similar calculations were done in other alloys and the results are given in Table 1.

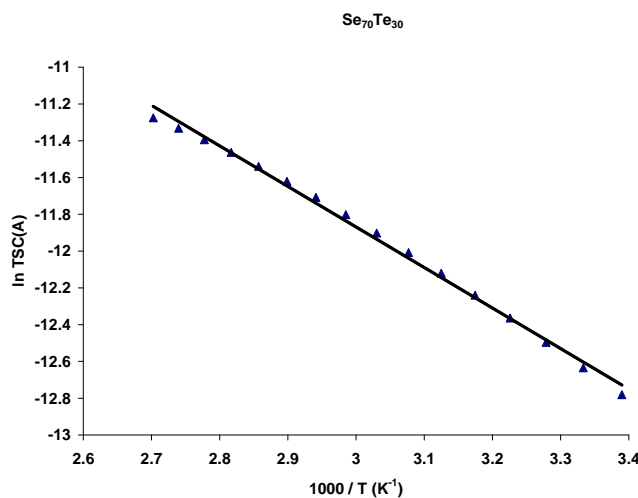


Fig. 6. \ln TSC (A) versus $1000/T$ plot for initial rise part of TSC peak for $Se_{70}Te_{30}$ thin films

Table. 1

| Sample | Value of E_0 (eV) | |
|----------------------|---------------------|-------------------------------|
| | Initial Rise method | Variable Heating rates Method |
| $Se_{70}Te_{30}$ | 0.18 | 0.17 |
| $Se_{70}Te_{28}Zn_2$ | 0.20 | 0.22 |
| $Se_{70}Te_{26}Zn_4$ | 0.21 | 0.54 |
| $Se_{70}Te_{24}Zn_6$ | 0.14 | 0.34 |
| $Se_{70}Te_{22}Zn_8$ | 0.19 | 0.37 |

An alternative approach is to plot $\ln(T_m^2/\beta)$ versus $1000/T_m$ for various heating rates. This is known as variable heating rate method. Plotting $\ln(T_m^2/\beta)$ versus $1000/T_m$ result in straight line with a slope equal to E_0 . The advantage of this method is that activation energy is independent of the kinetic process present in sample. Fig.7. shows such plots for amorphous $Se_{70}Te_{30}$ thin films where the slope yields the value of E_0 little higher that obtained from initial rise method. Similar plots were obtained in case of other glasses also and the results are given in Table 1.

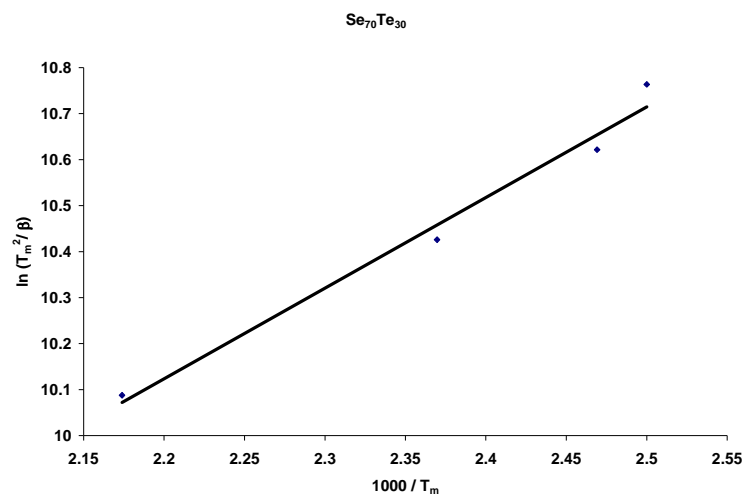


Fig.7. $\ln(T_m^2/\beta)$ versus $1000/T_m$ for $Se_{70}Te_{30}$ thin films

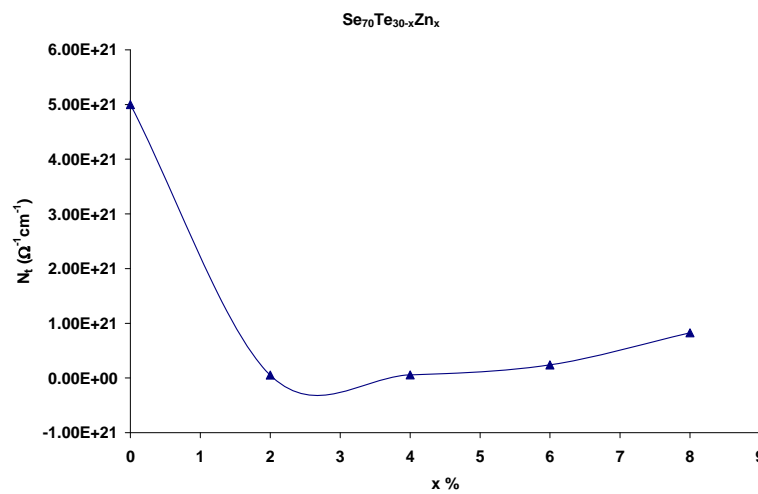


Fig. 8. Composition dependence of Trap density (N_t) for $Se_{70}Te_{30-x}Zn_x$ thin films.

Table 2. the values of trap density (N_t) for $Se_{70}Te_{30-x}Zn_x$ thin films.

| Composition at x % | Concentration of trap (N_t) |
|--------------------|---------------------------------|
| 0 | 5.00×10^{21} |
| 2 | 5.24×10^{19} |
| 4 | 5.60×10^{19} |
| 6 | 2.38×10^{20} |
| 8 | 8.12×10^{20} |

The trap density in each alloy was calculated by the method discussed in section 3.4. Here N_t are calculated by using $G = 1$, because it is not possible to measure G under the same TSC conditions with the necessary accuracy.

Composition dependence of trap concentration is shown in Fig 8. It is clear from this figure that N_t first decreases on increasing Zn concentration and then increases on further increase in Zn concentration.

5. Conclusions

The present paper reports thermally stimulated conductivity in amorphous thin films of $\text{Se}_{70}\text{Te}_{30-x}\text{Zn}_x$ ($x = 0, 2, 4, 6, 8$). A maximum in TSC curve has been observed at a temperature (T_m) that shifts towards higher temperatures on increasing heating rates β . Trap depth is calculated in each glassy alloy using initial rise method as well as variable heating rate method. Trap density is also calculated from the area of TSC peak in each glassy alloy. Composition dependence of trap density shows that on adding Zn as third element in binary Se-Te system the trap density (N_t) decreases upto 2 % of Zn. However, on further incorporation of Zn, the trap density increases.

References

- [1] V. Kolobov, J. Tomoniya, J. Optoelectron. Adv. Mater. **4**, 679 (2002).
- [2] T. Ohta, J. Optoelectron, Adv. Mater. **3**, (2001) 609.
- [3] I. D. Agarwal, J. S. Sanghera, J. Optoelectron, Adv. Mater. **4**, 665 (2002).
- [4] M. Lain, A. B. Seddon, J. Non-Crys. Solids. **184**, 30 (1995).
- [5] A. B. Seddon, J. Non-Crys. Solids. **184**, 44 (1995).
- [6] R. H. Bube, Photoconductivity of solids, Wiley Newyork, 292 (1960)
- [7] R. K. Pal, A. Kumar, Journal of Ovonic Research **4**, 113 (2008).
- [8] T. A. Cowell, J. Woods, Br. J. Appl. Phys. **18**, 1045 (1976).
- [9] L. I. Grossweiner, J. Appl.Phys. **24**, 1306 (1953).
- [10] R.Chen, Y. Krish, Analysis of Thermally Stimulated Process, Prgamon Press, Oxford(1981)8
- [11] G. F. J. Garlick, A. F. Proc.Phy.Soc. **81**, 141 (1948).
- [12] C.H. Haake, J. Opt. Soc. America **47**, 649 (1957)
- [13] R. H. Bube, Photoelectronic Properties of Semiconductors, Cambridge, Press, Cambridge, 149 (1992)
- [14] C. Manfredotti, R.Murri, A. Quirini, L. Vasanelli, Phys, Stat. Sol. **38**, 685 (1976).
- [15] R. H. Bube, Photoelectronic Properties of Semiconductors, Cambridge, Press, Cambridge, 20 (1992)