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Studies of Specific Heats of Glassy $Se_{90-x}Te_5Sn_5In_x$ ($0 \le x \le 9$) System for Crystallization Region

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Abstract: Differential Scanning Calorimetry (DSC) has been used as to investigate the specific temperatures of glassy $Se_{90-x}Te_5Sn_5In_x$ ($0 \le x \le 9$) alloys in the crystallization region at various heating rates under non-isothermal conditions. This study examines specific heats of glassy Se-Te-Sn-In network for crystallization region. The observed specific heats C_{pl} (before) C_{pa} (after) and ΔC_{pc} (difference of C_{pa} and C_{pl}), for crystallization region were carried out. The study also explored the composition-dependent of glassy Se-Te-Sn-In system, variability with different concentrations of In. All specific heats change with different Indium concentrations, and most at a composition of 9 at.wt. % of In. The variations of specific heats have been explained on the basis of atomic weights and room temperature values of C_p for the elements Se and In.

Keywords: *Specific Heat; Multi-Component Chalcogenide Network; Crystallization Temperature; Average Coordination Number; Differential Scanning Calorimetry (DSC).*

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I. INTRODUCTION

Chalcogenide glass (ChGs) is an amorphous substance primarily made up of one or more main group elements like Ge, As, Sb, and others, as well as chalcogenide (Ch) elements like S, Se, and Te. Semiconductor ChGs are of great scientific interest in modern technology because of their special physical characteristics, which compose them perfect for a diversity of solid-state electronic applications [1]. Because of their high infrared transmittance, excellent moldability, and low phonon energy, these semiconducting glasses offer optical and optomechanical designers substantial benefits [2]. As a result, they are thought to be perfect materials for thermal imaging, chemical sensors, radiation shielding, amplifiers, and mid-infrared (IR) optics [3,4]. These semiconductors can be used in, optoelectronic devices photo voltaic, and photo detectors because their band gap can be modified by changing the mix of impurity in the origin surrounding substance [5].Phase-change random-access memory (PCRAM) and other nonvolatile storage systems can benefit from the rapid and reversible phase transition between crystalline and amorphous phases of Ge-Sb-Te (GST) compounds [6].Due to low optical attenuation, which is advantageous for sensing and short-range optical communication applications, semiconducting Gs have been investigated as the basic material for optical fiber transmission [7]. In glass networks, metal dopants can create new defects, alter network connections, split the Fermi level, produce carrier-type reversal, enhance the glassy surface, increase thermal stability, and increase infrared transmission.

The material's structure is improved by such chemical tailoring; make it more suitable for device production [8, 9]. ChGs must be doped with active impurities in order to customize their optical and electrical characteristics and make them appropriate for cutting-edge applications. Premeditated doping improves charge carrier concentration, transfer characteristics, and visual behavior, but unrestrained impurities can get worse material recital by creating ensnare states, boosting optical scattering, or encouraging undesirable crystallization [10].

In phase change memory applications, the impurity dopant maximizes amorphous and crystalline phases, improving, thermal stability conductivity, and band gap tuning. It also increases dependability, low power consumption and switching speeds. Because precise mixing of In and Pb results in reversal of the carrier type, that enhances mechanical properties, lowers optical losses, and strengthens structural integrity, semiconducting ChGs are more beneficial for applications in phase change memory [11]. ChGs have a number of practical electrical characteristics. Numerous uses for these materials have been proposed, ranging from the fascinating topic of memory switching and threshold to the field of xerography [12]. The Se–Te system contains alloys that are important from an economic, scientific, and technical prospective. They are widely used as optical recording devices in several fields due to their remarkable laser writing sensitivity, photographic, and recording applications such as photoreceptors in Xerox and laser printing, for infrared spectroscopy, and laser fiber methods. [13-15].

Amorphous Se–Te alloys show less aging effects, are more photosensitive, have a higher crystallization temperature, and are tougher than pure Se [16].As noted in prior publications have used Sn and In as adding additive since they modify the physical characteristics of the alloys [17-19]. According to A.K. Singh research on the impact of the In additive's heat capacities on the glass transition and crystallization zones of the Se-Te-Zn system, the system's heat capacities rise up to 6% of the In composition, which he explained using the chemical bond theory of solids [20]. The lowest and maximum heat capacities for endothermic and exothermic areas of Se-Zn-In glassy alloys were reported by A. K. Singh. The structural/average coordination number of ChGs may provide an explanation for the behavior of heat capacities in crystallization and glassy regions [21]. Studies of C_p for glassy Se-Te-Sn-Pb network were published by A. Sharma et al. [22]. Variations in specific heats are clarified in terms of the C_p values of Pb and Se components at ambient temperature. The calorimetric investigation of the $Se_{75}Te_{15-x}Cd_{10}In_x$($0 \leq x \leq 15$) glassy system were reported by S. Kumar et al., who observed the greatest value of specific heat at the threshold composition (5 atomic weight percent of In) [23]. In the present study I have reported the composition dependency of specific heat for $Se_{90-x}Te_5Sn_5In_x$ ($0 \leq x \leq 9$).

II. MATERIAL PREPARATION AND EXPERIMENTAL METHODOLOGY

Based on their proper atomic weight percent ratios, the remarkably pure (99.999%) basic elements Se, Te, In, and Sn were evaluated using an electronic balance equipment. The elements have been put inside quartz ampoules of size (8 cm long and 12 mm in diameter). In order to prevent the possibility of oxygen reaction of an alloy at high temperatures, the sample ampoules were sealed in a vacuum (10^{-5} torr). All ampoules were heated up to 825^0C for 10–12 hours in the furnace at a rate of 3–4 K/min. To make certain that the samples were identical in nature, they were regularly removed. For achieving the glassy behavior of the alloys, the melted samples were rapidly cooled with water (ice). X-ray diffraction patterns may be used to determine an alloy's amorphous nature [23]. Each sample's thermal behavior was examined using a Shimadzu DSC-60 Model differential scanning calorimetry (DSC) apparatus. Standard aluminum pans were used to heat 10 mg of the crushed material at different speeds (5 to 20 K/min) for the observations. A DSC was used to calculate the heat that was captured or released during phase transitions as well as the reported glass transition rates under non-isothermal conditions. High pureness standards for Sn, Pb, and In with established melting points were used to calibrate the DSC device before observations. Using the previously mentioned reference materials' well-known melting enthalpy, the complete area of their melting endotherms was measured in order to determine the instrument constant. The instrument constant was determined to be 1.5, and the temperature and enthalpy calibration findings for the standard materials contained 3% of the values reported in the literature [24]. The thermal analyzer's microcontroller can measure temperatures with an accuracy of ±0.1 K and heat runs with an accuracy of ±0.01 mW.

III. RESULT AND DISCUSSION

Figure 1 shows a typical DSC scan at 15 K/min for the glassy alloy $Se_{84}Te_5Sn_5In_6$. Endothermic and exothermic phase reversal peaks were clearly seen in the DSC trace in the glass and crystallization regions. The following correlation may be used to assess the specific heats Cpl (before), C_{pa} (after), and ΔC_{pc} (difference of C_{pa} and C_{pl}) in the crystallization area. [25]

$$C_p(T) = \left(\frac{\Delta H}{m}\right)\left(\frac{1}{\beta}\right) \qquad (1)$$

where β is denoted heating rate and ΔH shows heat exchange that occurs as a sample of mass m passes through it.

The assessed values of specific temperatures C_{pl} (before), C_{pa} (after), and ΔC_{pc} (difference of C_{pa} and C_{pl}) for the crystallization area reported in Table 1 were obtained using relation (1). The DSC thermogram's basic structure for calculating particular temperatures is shown in Figure 2.

The temperature dependence of C_p for glassy $Se_{90-x}Te_5Sn_5In_x$ ($0 \leq x \leq 9$) alloy at a constant heating rate of 15 K/min is shown in Figure 3(a-d). These figures make it evident that, prior to the crystalline area, C_p is slightly temperature dependent. However, when the temperature rises close to the crystallization zone, its value climbs dramatically and reaches its most at the crystallization temperature. The value of C_p achieves a stable value beyond the crystallization region that is slightly larger than that of C_p before to the crystallization regions as structural rearrangement and nucleation expansion increase energy absorption. As shown in Table 1, specific heat values in the crystallization area initial drop and reach their lowest value at 6 atomic weight percent of In. Specific heat is increased by further indium additive insertion, reaching a maximum at 9 atomic weight percent of

In. Table 1 makes it evident that the ternary $Se_{90}Te_5Sn_5$ alloy's specific temperatures, C_{pl} (before) and C_{pa} (after), are significantly reduced with the addition of In. The atomic weights and room temperature values of C_p for the elements Se and In may help to partially explain this. Specific heat (0.32 J/g-K) of Se is greater than C_p (0.23 J/g-K) of In at the room temperature. After (In) was added to the ternary $Se_{90}Te_5Sn_5$ alloy and reached a minimum at 6 atomic weight percent of In, this might be the cause for the lesser C_{pl} and C_{pa} values in quaternary alloys compare to the $Se_{90}Te_5Sn_5$ternary alloy.

As more indium (In) is added to the ternary $Se_{90}Te_5Sn_5$ alloy, specific heat values increase. Since Se has a lower atomic weight (78.96 g mol^{-1}) than Indium (114.82 g mol^{-1}), extra specific heat is essential to reflect a high order crystallization rate when the mean atomic weights of quaternary alloys rise relative to other alloys in this system. Similar behavior was observed by A. Sharma et al. in another glassy system [22].

To determine the average coordination numbers<Z> for different glasses under study, the following relation was used [26]:

$$< Z >= \frac{(pZ_{Se} + qZ_{Te} + rZ_{Sn} + sZ_{In})}{(p+q+r+s)} \quad \text{.......} (2)$$

The literature states that Zse = 2, Z_{Te} = 2, Z_{Sn} = 4, and Z_{In} = 3 are the coordination numbers of Se, Te, Sn, and In, respectively. The atomic weight percentages of the elements in the glassy matrix are denoted by the symbols p, q, r, and s. For glassy systems with In = 0, 3, 6, and 9, the average coordination number may be obtained using equation (2), yielding 2.1, 2.13, 2.16, and 2.19, respectively [23].

Figure 4 shows the variability of specific temperatures with average coordination number for the current glassy Se-Te-Sn-In system. From the figure the values C_{pl} (before) C_{pa} (after) and $\Delta C_{pc}$are minimum at <Z>= 2.16[27]. The specific heats attain a minimum and a maximum, values for 6 and 9 at. wt.% of In respectively. At 6 at. wt. % of In, which corresponds to an average coordination number <Z>= 2.16 shows minimum specific heats due to atomic arrangement become more rigid but still amorphous, resulting in lower energy fluctuations and gives minimal energy glassy alloys moves closer to crystalline material and also Se-Te-Sn-In system could go into an over constrained or heterogeneous domain and additional low-frequency excitations may emerge, all specific heats experience a slightly increase for 9 at. wt. % of In because amorphous network begins to develop local regions of order, increasing heat capacity due to higher atomic mobility. Additionally, all specific heats values are maximum at 9 at. wt.% of Indium due to formation of rings and chains [28].

IV. CONCLUSIONS

Calorimetric studies have been done in glassy $Se_{90-x}Te_5Sn_5In_x$ ($0 \leq x \leq 9$) alloys using DSC under non-isothermal conditions for crystallization region. The results show variation of specific heats for different compositions and minimum at 6 at. wt.% of In. Higher value of specific heatfor$Se_{81}Te_5Sn_5In_9$ glass has been explained on the basis of mean atomic weights of quaternary alloys increase, more heat is needed for structural rearrangements.

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REFERENCES

[1]. Singh, K., Mehta, N., Sharma, S. K., & Kumar, A. (2016). Crystallization kinetics of glassy $Se_{90}In_{10-x}Ag_x$ alloys: Observation of Meyer–Neldel rule. *Processing and Application of Ceramics*, *10*(3), 137–142.

[2]. Zhang, X.-H., & Bellec, Y. (2003). Production of complex chalcogenide glass optics by molding for thermal imaging. *Journal of Non-Crystalline Solids*, *326*, 519–523.

[3]. Ravagli, A., Craig, C., Lincoln, J., & Hewak, D. W. (2017). Ga–La–S–Se glass for visible and thermal imaging. *Advanced Optical Technologies*, *6*, 131–136.

[4]. Saraswat, K., Pal, S. K., Khattari, Z. Y., Dahshan, A., & Mehta, N. (2024). A comprehensive study of radiation shielding parameters of chalcogen-rich quaternary alloys for nuclear waste management. *Optical Materials*, *157*, 116253.

[5]. Milochova, M., Kassem, M., & Bychkov, E. (2012). Chalcogenide glass chemical sensor for cadmium detection in industrial environment. *ECS Transactions*, *50*, 357–362.

[6]. Anjali, B., Patial, S., & Bhardwaj, S. (2017). On the AC conductivity mechanism in nano-crystalline $Se_{79-x}Te_{15}In_6Pb_x$ alloys. *Physica B: Condensed Matter*, *523*, 52–61.

[7]. Chen, H., Ran, M., Wei, W., Wu, X., Lin, H., & Zhu, Q. (2022). A comprehensive review on metal chalcogenides with three-dimensional frameworks for infrared nonlinear optical applications. *Coordination Chemistry Reviews*, *470*, 214706.

[8]. Snopatin, G. E., Shiryaev, V. S., Plotichenko, V., Dianov, E., & Churbanov, M. F. (2009). High-purity chalcogenide glasses for fiber optics. *Inorganic Materials*, *45*, 1439–1460.

[9]. Šiljegović, M. V., Sekulić, D. S. L., Lukić-Petrović, S. R., & Petrović, D. (2016). Correlation between microstructure and electrical properties of Bi–As_2S_3 quasibinary chalcogenides using AC impedance spectroscopy. *Journal of Materials Science: Materials in Electronics, 27*, 1655–1661.

[10]. Raoux, A. J. S., Welnic, W., & Ielmini, D. (2010). Phase-change materials and their application to nonvolatile memories. *Chemical Reviews, 110*, 240–267.

[11]. Sedeek, K. K., Adam, A., Churbakov, L. M. F., Wahab, A., & Hafez, F. M. (2004). Dielectric relaxation in $Ge_{1-x}Se_2Pb_x$ nano-crystalline systems. *Materials Chemistry and Physics, 85*, 20–26.

[12]. Shoab, M., Aslam, Z., Ali, J., & Zulfequar, M. (2023). Crystallization kinetics and electrical properties of indium-incorporated Se–Te–Sb–In chalcogenide glasses. *Journal of Materials Science: Materials in Electronics, 34*, 1399.

[13]. Abdel-Rahim, M. A. (1997). Calorimetric studies of glassy alloys in the Ge–Se–Te system. *Physica B: Condensed Matter, 239*, 238–242.

[14]. Horie, M., Ohno, T., Nobukuni, N., Kioyo, K., & Hashizume, T. (2001). Optical disk system technologies. *Technical Digest, ODS 2001*, MC1, 37.

[15]. Akiyama, T., Uno, M., Kitahara, H., Narumi, K., Nishiuchi, K., & Yamada, N. (2001). Rewritable dual-layer phase-change optical disk utilizing a blue-violet laser. *Japanese Journal of Applied Physics, 40*, 1598.

[16]. Ohta, T. (2001). Phase-change optical memory promotes DVD optical disk. *Journal of Optoelectronics and Advanced Materials, 3*, 609.

[17]. Kasap, S. O., Wagner, T., Aiyah, V., Krylouk, O., Bekirov, A., & Tichy, L. (1999). Thermal and mechanical properties of amorphous chalcogenide Se–Te–P semiconducting alloys. *Journal of Materials Science, 34*, 3779–3786.

[18]. Twaddell, V. A., Lacourse, W. C., & Mackenzie, J. D. (1972). Impurity effects on the structure and electrical properties of non-crystalline selenium. *Journal of Non-Crystalline Solids, 8–10*, 83–90.

[19]. Fernandes, B. J., Sridharan, K., Munga, P., Ramesh, K., & Udayashankar, N. K. (2016). Memory-type switching behavior of ternary Ge–Te–Sn chalcogenide compounds. *Journal of Physics D: Applied Physics, 49*, 295104.

[20]. Nagels, P., Rotti, M., & Vikhrov, S. (1981). Doping of chalcogenide glasses in the Ge–Se and Ge–Te systems. *Journal de Physique Colloques, 42*, C4-907–C4-910.

[21]. Singh, A. K. (2011). Effect of indium additive on heat capacities of Se–Zn–Te multicomponent chalcogenide glasses. *Chalcogenide Letters, 8*(2), 123–128.

[22]. Singh, A. K. (2011). Effect of indium additive on the heat capacity of Se–Zn chalcogenide glasses. *European Physical Journal: Applied Physics, 55*, 11103.

[23]. Sharma, A., Kumar, H., & Mehta, N. (2012). Determination of specific heat in Se–Te–Sn–Pb chalcogenide glasses using modulated DSC. *Materials Letters, 86*, 54–57.

[24]. Kumar, S., & Singh, K. (2012). Glass transition, thermal stability, and glass-forming tendency of Se–Te–Sn–In chalcogenide glasses. *Thermochimica Acta, 528*, 32–37.

[25]. Touloukian, Y. S. (1970). *Thermophysical properties of matter: Volume 5 – Specific heat*. New York: Plenum Press.

[26]. Joraid, A. A., Abu-Sehly, A. A., Abu El-Oyoun, M., & Mohamed, A. H. (2013). Advanced kinetics modeling and modulated DSC of Se–Te–Sn glasses. *Chalcogenide Letters, 10*, 303–317.

[27]. Tanaka, K. (1989). Structural phase transitions in chalcogenide glasses. *Physical Review B, 39*, 1270–1279.

[28]. Thorpe, M. F. (1983). Continuous deformations in random networks. *Journal of Non-Crystalline Solids, 57*, 355–370.

[29]. Eisenberg, A. (1963). Glass transition temperatures in amorphous selenium. *Polymer Letters, 1*, 177–179.

Table 1. Computed Values of Specific Heat C_{pl} C_{pa}, and ΔC_{pc} in Crystallization Region for Multi-Components Chalcogenide Glassy $Se_{90-x}Te_5Sn_5In_x$ (x = 0, 3, 6, and 9) Network.

Composition	$\langle z \rangle$	C_{pl}	C_{pa}	ΔC_{pc}
$x = 0$	2.10	0.796	0.627	0.169
$x = 3$	2.13	0.760	0.622	0.138
$x = 6$	2.16	0.745	0.619	0.125
$x = 9$	2.19	0.919	0.731	0.187

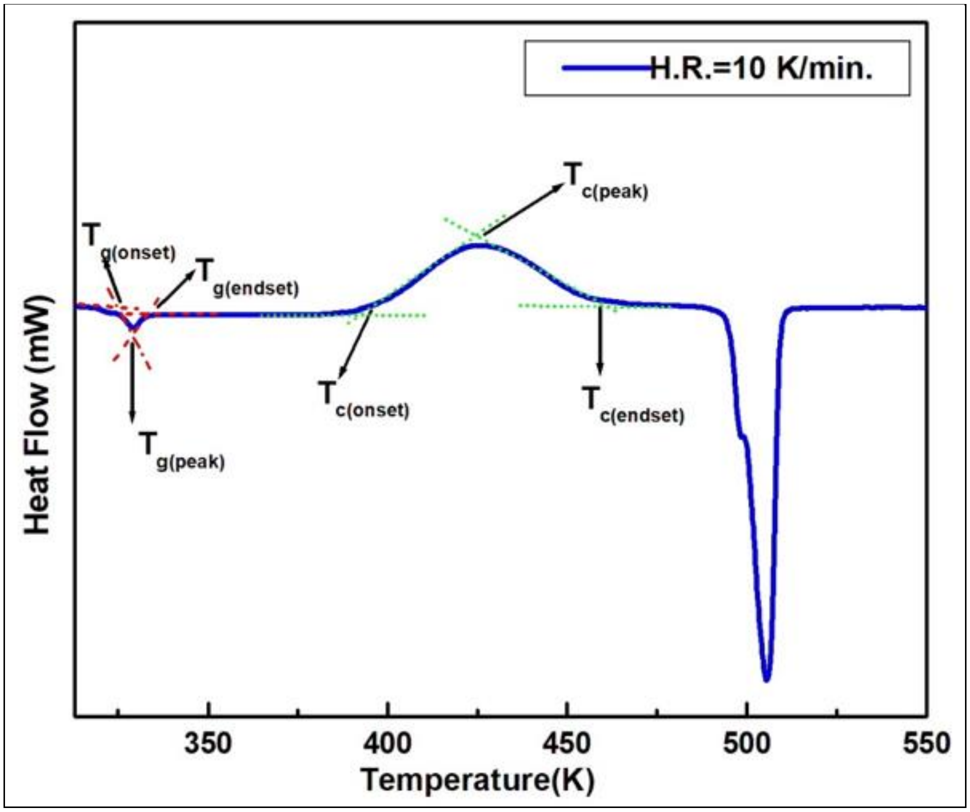

Fig 1. DSC Thermogram, of $Se_{84}Te_5Sn_5In_6$ Chalcogenide Glass at 10 K/min. Heating Rate.

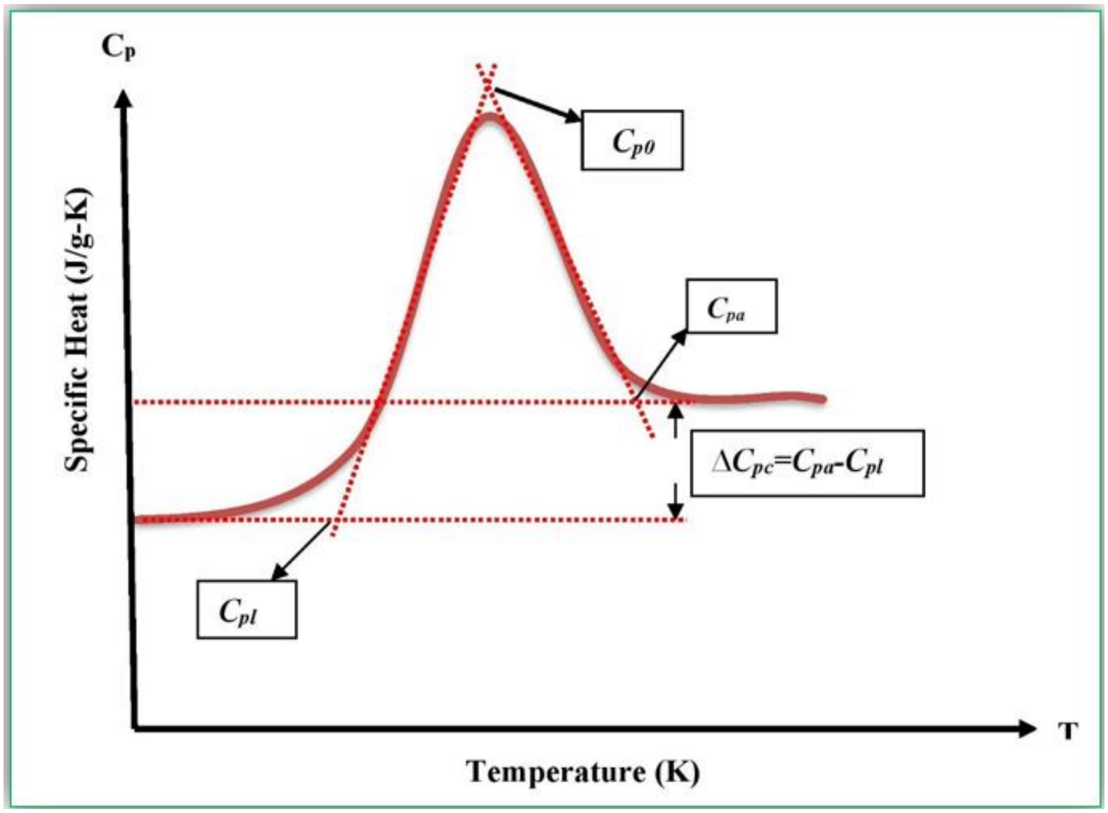

Fig. 2: A Schematic Framework of a DSC Thermogram that Shows Specific Heat as a Function of Temperature.

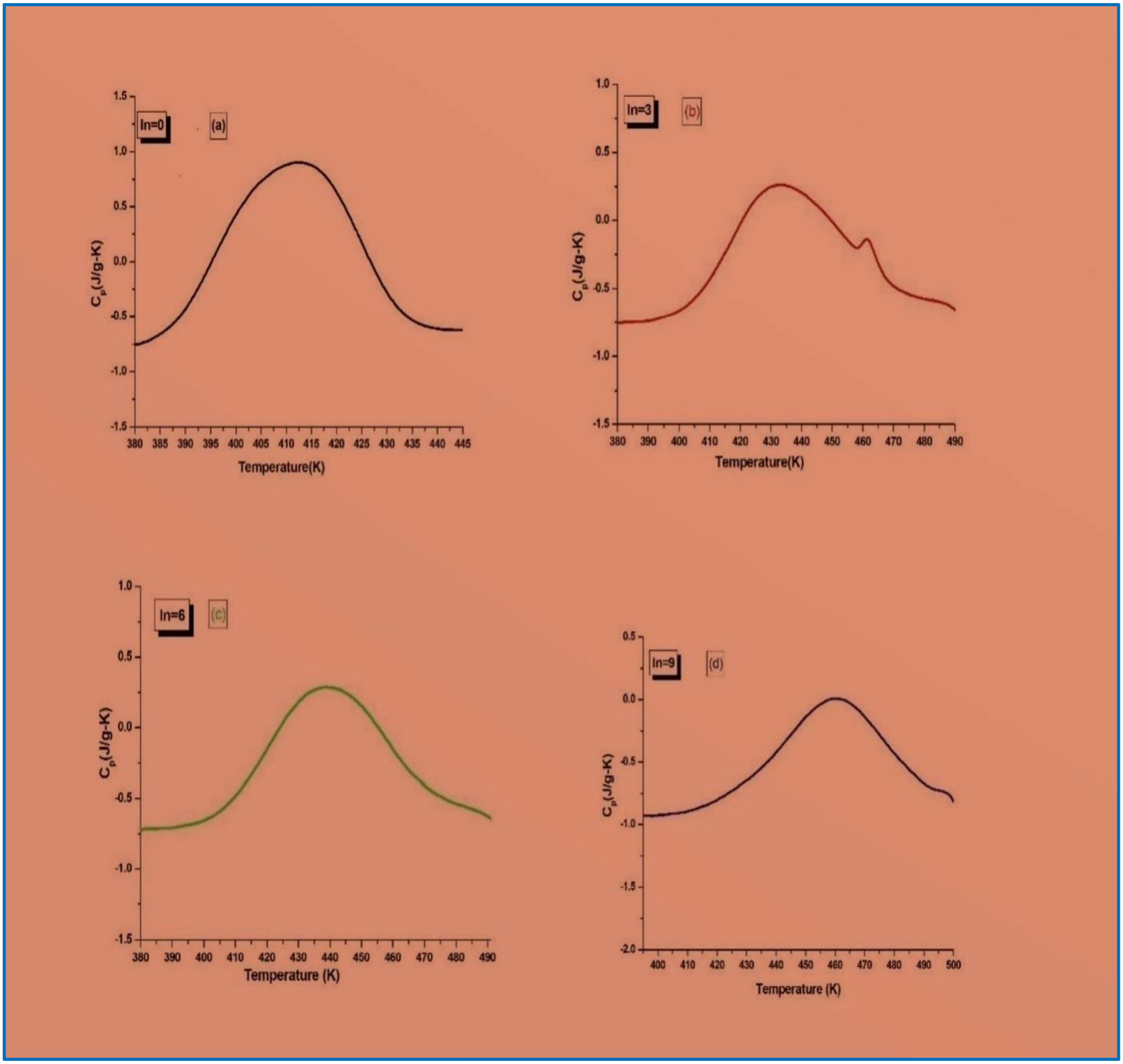

Fig. 3(a-d). A Graphical Illustration of Temperature-Dependent Specific Heat in Glass Transition Region for Glassy Se-Te-Sn-In Network at Heating Rate 15 K/min.

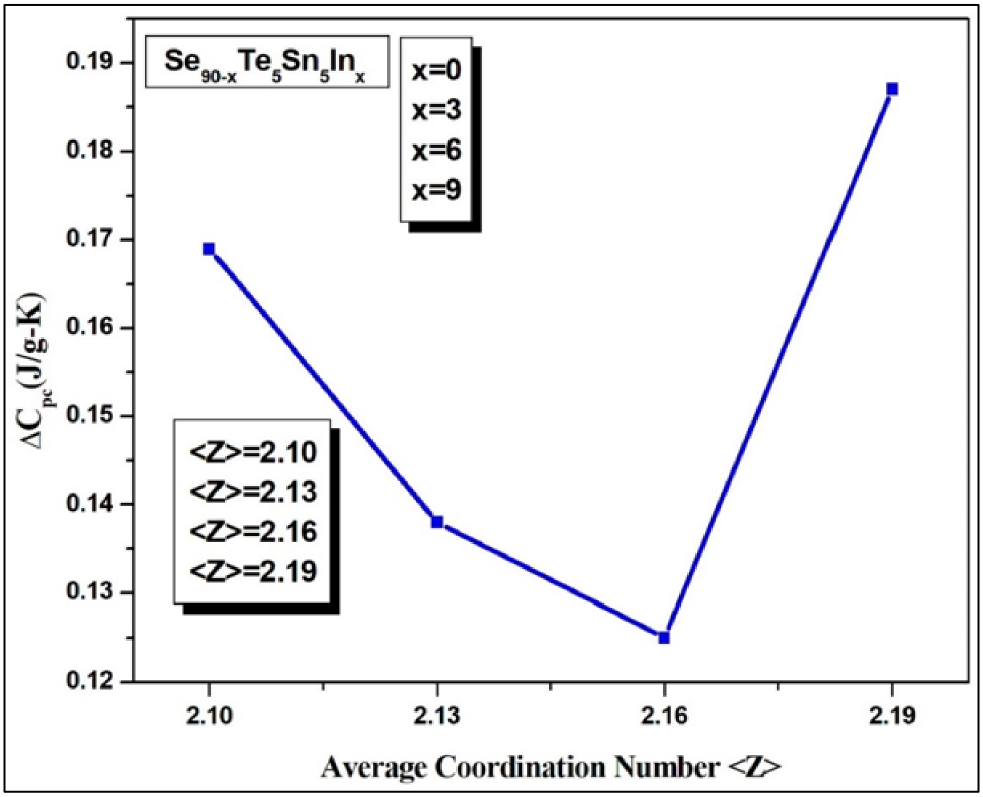

Fig 4: Variation of Specific Heat at Peak Glass Transition Temperature with <Z> for Multi-Components Chalcogenide Glassy Se-Te-Sn-In Network.