Physical Properties and Structural Characterization of Thermally Evaporated Ge\(_{25}\), Ga\(_x\)Se\(_{75}\) System

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ABSTRACT

The effect on the physical properties viz. average coordination number "Z", number of constraints "N\(_{con}\)", mean bond energy <E>, glass transition temperature "T\(_g\)", density "p", with the variation in Gallium content has been studied theoretically in the present article for Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) [x=5 to 20 at %] system. Mean bond energy is proportional to the transition temperature. It has been found that almost all the parameters, studied here, and the parameter “R” were increased with the increase in “Ga” content. This confirms the suitability of structural topological model to explain the compositional dependencies of the physical parameters, not only for bulk but also for thin films evaporated from them. Stoichiometric bulk ingot materials of the ternary mixture Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) were prepared by direct fusion of the constituent elements in vacuum sealed silica tubes. X-ray diffraction studies indicate that the investigated sample exhibited a hexagonal structure. Thin films were deposited by thermal evaporation from the pre-synthesised ingot material, onto glass substrates. The dependence of the crystalline temperature “T\(_c\)” and the peak temperature of crystallization “T\(_p\)” on the composition has been studied in the present work. X-ray and electron diffraction studies on the as-deposited and annealed films revealed an amorphous-to-crystalline phase transition at T\(_c\) ≈ 300 °C. EDX studies on the prepared films show that the as-deposited films are nearly stoichiometric. This analysis helps in finding the suitability of an alloy to be used in phase transition optical memories / switches.

Key words: Thin films, thermal evaporation, X-ray diffraction, scanning electron microscopy.

Introduction

During the recent past, the chalcogenide glasses are studied by a number of researchers as they are very interesting materials for reversible phase change optical recording devices. Ever since the reversible switching phenomenon in certain types of chalcogenide glasses was first reported, a lot of attention has been given to characterization and improvement of the properties of chalcogenide glasses in particular the materials exhibiting the switching phenomenon. It is well known that the phase change can be reversibly switched between the amorphous and crystalline state and find applications in rewritable optical recording (Gupta et al., 2011 and Saxena et al., 2012).

The investigation of composition dependence of various properties of chalcogenide glasses has been increased during last decade. As selenium exhibits the unique property of reversible phase transformation and also applications like photocells, memory switching etc., it seems attractive, but pure selenium has disadvantage like short life time and low photo sensitivity. To overcome this problem, some impurity atoms like Ge, In, Bi, Te, Ga, Sb, Ag, etc. can be used to make alloys with Se, which may enhance sensitivity, crystallization temperature and reduce ageing effects (Saxena and Bhatnager, 2003 and Zakery and Elliot, 2003).

Many approaches have been proposed to explain the compositional dependence of various physical properties of chalcogenide network glasses. One of these approaches is the so-called chemically ordered network model [CONM], in which the formation of heteropolar bonds is favoured over the formation of homopolar bonds. Also called the tie line or stoichiometric compositions at which the glass structure is made up of cross- linked structural units consisting of heteropolar bonds only. Other approaches are the so-called topological models which are based on the constraints theory and on the structural dimensionality considerations. In these models, the properties can be discussed in terms of the average coordination number “Z”, which is indiscriminate of the species or valence bond (Wakkad et al., 2000).

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There are some research on physical and optical properties of Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\). Only very few reports on the structure and electrical properties of the thermally deposited Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) thin films. The fact that there is a lack of literature data concerning physical properties and structural characterization of Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) thin films. Thus the objective of the present work is to present detailed information pertaining to the physical and structural properties of Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) thin films on “x” in the allowable composition range 5 ≤ x ≤ 20.

**Experimental Techniques:**

Bulk ingot materials of the ternary Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\), [5 ≤ x ≤ 20] were prepared by the direct fusion of high-purity “5N” elements Ge, Se and Ga, in the appropriate weight proportion. The mixture was contained in a precleaned silica tubes, sealed under vacuum at pressure ~10\(^{-3}\) Pa. The sealed tubes were baked in a high temperature furnace at 1200K for about 48 h.

Thin films of Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) were deposited at room temperature by thermal evaporation technique under vacuum of ~5 × 10\(^{-3}\) Pa. The deposition process was carried out on precleaned glass substrates and carbon stub. The film thickness and the deposition rate were controlled during evaporation process via quartz crystal thickness monitor [Type Edwards, FTM4]. Several trials were conducted to adjust the evaporation conditions in order to avoid the material spillage or decomposition by overheating during evaporation process.

The crystal structure of the prepared ingot materials and the corresponding deposited films were examined using a Diano Corporation X-ray diffractometer. CoK\(_{\alpha}\) radiation [\(\lambda = 1.7093\) A\(^{-}\)] was used with normal focus. Differential scanning calorimetry [DSC] of the prepared Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) powder (x = 5, 10, 15 and 20) has been carried out using Shimadzu DTA-50 apparatus to investigate transition temperature, \(T_g\), crystallization temperature, \(T_c\), and the temperature of crystallization, \(T_p\). Transmission electron microscope [Type JEOL-JMS 1240] was used to investigate the microstructure of the deposited films. The elemental composition and surface morphology of Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) thin film deposited on carbon stub was examined using energy-dispersive analysis of X-ray, interfaced with the scanning electron microscopy [Type JEOL-JSM 840A].

**Results and Discussion**

**Physical properties:**

The average coordination number and bonding constrains:

For the composition Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\), the average coordination number “Z” was calculated by using the standard method (Wakkad et al., 2000; Saxena et al., 2012 and Saxena et al., 2012).

\[
Z = \frac{aN_{Ge} + bN_{Ga} + cN_{Se}}{a + b + c} \tag{1}
\]

where a, b and c are the at % of Ge, Ga and Se respectively and \(N_{Ge}=4\), \(N_{Ga}=2\), \(N_{Se}=2\) are their respective coordination number. The calculated values of average coordination number for Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) [x=5 to 20 at. %] system are listed in table 1. It is clear from figure 1 that values of “Z” increase from 2.47 to 2.54, with increase in concentration of “Ga” from 5 to 20.

Detarmination of average coordination number “Z” allows the estimation of the total number of constraints is given by (Saxena et al., 2012 and Saxena et al., 2012).

\[
N_{con} = N_{c} + N_{p} \tag{2}
\]

Where the number of bond-stretching constraints per atom is \(N_{c} = Z / 2\), and of bond-bending constraints is \(N_{p} = 2Z - 3\). Both gaps and \(T_p\) depends on the strength of bonding, and it allows to determination of possible bonds and their type [heteronuclear and homonuclear bonds]. The values of “\(N_{con}\)" along with “Z” for Ge\(_{25-x}\)Ga\(_x\)Se\(_{75}\) are given in table 1. Figure 2, depicts the variation of “\(N_{con}\)" with “Ga” at %, Here “\(N_{con}\)" increase from 3.19 to 3.35 with increase in “Ga” at %, which shows in our composition that the number of constraints “\(N_{con}\)" acting on the network are balanced by the number of degrees of freedom “N” available from the atoms in the network. This means that network is rigid.
Fig. 1: Variation of Average Coordination Number with Gallium concentration.

Fig. 2: Variation of number of constraints Gallium concentration.

Deviation from the stoichiometry of composition:

The parameter “R” also plays an important role in the analysis of the results. The parameter “R” which determines the deviation of stoichiometry and is expressed by the ratio of the covalent bonding possibilities of chalcogen atoms to that of non-chalcogen atoms. Depending on “R” values, the chalcogenide systems can be organized into three different categories. For Ge$_{25}$,Ga$_x$Se$_{75}$ system, the parameter “R” is given by (Wakkad et al., 2000; Saxena and Bhatnager, 2003 and Saxena et al., 2013).

\[
R = \frac{cCN(Se)}{aCN(Ge) + bCN(Ga)}
\]  

(3)

where a, b, c are atomic frictions of Ge, Ga and Se respectively. The values of “R” are mentioned in table 1. The threshold at R=1 [the point of existence of only heteropolar bonds] marks the minimum selenium content at which a chemically ordered network is possible without metal–metal bond formation. For R>1, the system is chalcogen rich and for R<1, the system is chalcogen poor. From figure 3, it is clear that our system is chalcogen poor, “R” increase with the increase in content of gallium in the system but R<1.

Table 1: Value of the average coordination number and bonding constrains

<table>
<thead>
<tr>
<th>Ge</th>
<th>Ga</th>
<th>Se</th>
<th>Z</th>
<th>Neom</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>5</td>
<td>75</td>
<td>2.47</td>
<td>3.19</td>
<td>0.075</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>75</td>
<td>2.50</td>
<td>3.25</td>
<td>0.143</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>75</td>
<td>2.52</td>
<td>3.30</td>
<td>0.276</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>75</td>
<td>2.54</td>
<td>3.34</td>
<td>0.332</td>
</tr>
</tbody>
</table>
Mean Bond Energy, Glass Transition Temperature, and the density of the bulk Composition:

The overall mean bond energy for the Ge$_{25-x}$Ga$_x$Se$_{75}$ system is given by (Saxena et al., 2012 and Saxena et al., 2012).

$$<E> = E_c + E_{rm} \quad (4)$$

where “$E_c$” is overall contribution towards bond energy arising from strong heteropolar bonds and “$E_{rm}$” is contribution arising from weaker bonds that remains after the strong bonds have been maximized i.e. the average bond energy per atom of the remaining matrix. For Ge$_{25-x}$Ga$_x$Se$_{75}$ system, where [a + b + c]= 1, in selenium rich systems where there are heteropolar bonds and chalcogen-chalcogen bonds

$$E_c = 4aE_{(Ge-Ga)} + 3cE_{(Ga-Se)} \quad (5)$$

and

$$E_{rm} = \left(\frac{2c - 4a - 2b}{z}\right)E_{(Se-Se)} \quad (6)$$

denotes the average homopolar bonding energy, $E_{(Ge-Se)}$, $E_{(Ga-Ga)}$, $E_{(Ga-Se)}$ obtained from (Wakkad et al., 2000; Saxena et al., 2012 and Saxena et al., 2012). The values of mean bond energies $<E>$ for the compositions under investigation are given in table 2. It is clear from figure 4 that $<E>$ increases with increase in concentration of “Ga” from 5 to 20 at. %.

An correlation of mean bond energy with glass transition temperature “$T_g$” was illustrated by (Mahmoud et al., 2002 and Saxena et al., 2012).

$$T_g = 311 \quad [\]$$

The values of “$T_g$” corresponding to $<E>$ is mentioned in table 2 and the variation of “$T_g$” with “Ga” content is shown in figure 5, which is clearly depicting the rise in glass transition temperature “$T_g$” with increasing the content of “Ga” due to rise in mean bond energy of the system.
The density $\rho$ of the bulk specimens of each composition was determined using the Archimedes method with distilled water as the immersion fluid (Sharma and Katyal, 2008 and He et al., 2013).

$$\rho = \frac{W_1}{W_1 + W_2} \times \rho_1$$ (8)

where $W_1$ is the weight of the sample in air, $W_2$ is the weight of the sample in water, $\rho_1$ is the density of water. It was found that density decrease with the increase in concentration of “Ga” from 5 to 20 at. %, the density decrease due to a smaller molecular weight of “Ga” than “Ge” are given in Table 2.

<table>
<thead>
<tr>
<th>Ge</th>
<th>Ga</th>
<th>Se</th>
<th>$\langle E \rangle$ (eV/mole)</th>
<th>Tg(°C)</th>
<th>$\rho$ (gm cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>5</td>
<td>75</td>
<td>2.555</td>
<td>241.705</td>
<td>2.740797</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>75</td>
<td>2.587</td>
<td>251.657</td>
<td>1.428827</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>75</td>
<td>2.616</td>
<td>260.676</td>
<td>1.405455</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>75</td>
<td>2.645</td>
<td>269.695</td>
<td>1.375394</td>
</tr>
</tbody>
</table>

The effect on the physical properties viz. average coordination number “Z”, number of constraints “N$_{con}$”, mean bond energy $\langle E \rangle$, glass transition temperature “T$_g$”, density “$\rho$”, with the variation in Gallium...
content has been studied theoretically in the present article for Ge$_{25-x}$Ga$_x$Se$_{75}$ [$x=5$ to 20 at. %] system. Mean bond energy is proportional to the transition temperature. It has been found that almost all the parameters, studied here, and the parameter “R” were increased with the increase in “Ga” content. The variations of the energy gap “E$_g$” with composition are discussed based on both the overall mean bond energy and the topological model based on the structural dimensionality considerations. This confirms the suitability of structural topological model to explain the compositional dependencies of the physical parameters, not only for bulk but also for thin films evaporated from them.

**Differential scanning calorimetry [DSC]:**

Differential scanning calorimetry [DSC] measures endothermic and exothermic processes in materials as a function of temperature associated with physical transitions. The result of [DSC] experiment is thermal curve that plot heat flow against temperature. Peaks in the curve are produced as a result of thermal transitions within the sample. Differential scanning calorimetry [DSC] was carried out on powdered and thin films Ge$_{25-x}$Ga$_x$Se$_{75}$. A weight of about 8.22 mg for samples with $x = 5, 10, 15$ and 20 as a typical representative samples, was sealed in a platinum cell, and scanned over a temperature range from room temperature to about 700°C at a uniform heating rate 5 deg/min and in a dynamical nitrogen atmosphere of 30 ml/min. Figure 6 shows three characteristic phenomena resolved in the temperature region studied. The first one corresponds to the glass transition temperature, $T_g = 238$°C, the second corresponding to the onset crystallization temperature, $T_c = 270$°C, and the third to the peak temperature of crystallization, $T_p = 430$°C. The DSC for powder compared thin films to know all the powder evaporated during the evaporation process.

**Fig. 6:** Shows the DSC curves for Ge$_{25-x}$Ga$_x$Se$_{75}$ (a) powder and (b) thin films

**Structural characterization:**

*Structural characteristics of the prepared bulk materials:*

Figure 7 illustrates the X-ray diffraction patterns [XRD] carried out for the prepared...
Ge\(_{25.4-x}\)Ga\(_x\)Se\(_{75}\) ingot materials in powder form 5 ≤ x ≤ 20. It is clearly seen from the figure that no structural planes observed through the entire "2θ" range [0–80°]. The patterns for the investigated powder had the same feature and exhibited a broad band around "2θ" range 20-40°. The Figure depicts that the prepared ingot is amorphous in nature.

Fig. 7: X-ray diffraction patterns of the prepared Ge\(_{25.4-x}\)Ga\(_x\)Se\(_{75}\) in a fine powder form, 5 ≤ x ≤ 20.

**Structural characteristics of Ge\(_{25.4-x}\)Ga\(_x\)Se\(_{75}\) thin films**

X-ray diffraction technique was employed for studying the structural details of these samples. The phenomenon of X-ray diffraction can be pictured as a reflection of the incident beam from the lattice planes. The X-ray diffraction patterns for a representative Ge\(_{25.4-x}\)Ga\(_x\)Se\(_{75}\) films \([x = 5, 10, 15\) and 20 \)] deposited at room temperature indicated that the as-deposited films are amorphous figure 8.

However, a thin film annealed in vacuum at temperature 275 °C for 30 min [Figure 9 a] shows a polycrystalline structure indicates an amorphous-to-crystalline phase transition. The observed crystalline phase is characterized by the predominant appearance peaks which varies in intensity and slightly shifts its position as a function of Ga content. Analyses of this diffraction pattern confirm the hexagonal phase of the deposited film. A similar conclusion can be drawn for films annealed in vacuum at 300 °C for 30 min[Figure 9b]. whereas the X-ray diffraction pattern reflects an increasing in the relative intensity of the main observed planes, due to
increases the volume fraction of crystalline phase, besides appearing a new minor peaks corresponding to binary GeSe or GaSe, phase while Ge_{25-x}Ga_xSe_{75} still as a major phase. The appearances of these new peaks corresponding to the binary phases indicates that phase separation have began to occured. Although, the general form has the same feature, the intensity of the reflecting plane varies and the peak positions shifts slightly on passing from one composition to other. This finding is due to the partial replacement of Ge$^{2+}$ ions by Ga$^{2+}$ ions.

Figure 10[a,b] shows the variation of the experimental values of the interplaner spacing “d” versus the value of “x” for different diffraction planes. The Figure depicted that, the “d” values for a the selected planes slightly decrease with increasing the value of “x” for annealing at 275 and 300 ºC.

For hexagonal system the plane-spacing equation for the unit cell lattice parameters “a” and “c”, is given by (Rakhshani and Al-Azab, 2001).

$$\frac{1}{d^2} = \frac{4}{3} \left( \frac{h^2 + h k + k^2}{a^2} + \frac{l^2}{c^2} \right)$$

The volume of the unit cell, “V”, for hexagonal crystals is given by.

$$V = (3^{1/2}/2) a^2 c$$

The unit cell lattice parameters, “a” and “c”, as well as the volume of the unit cell, “V”, for different compositions are given in Table 3 and represent graphically in Figure11. The unit cell lattice parameters [Figure 11] vary almost linearly with composition ratio in a greement with that for ternary GeGaSe thin films,The inset of Figure 11 show the variation of ratio “c/a” with the composition, “x”, where in “c/a” ratio change from 3.824 to 3.833 as “x” increases from 5 to 20 in a good agreement with that for hexagonal phase [c/a =3.82] (Popov et al., 2003). The decrease in both lattice parameters values “a” and “c” with increasing “Ga” concentration was directly attributed to the fact that the radius of “Ge” ion [1.31Å] is less than that for “Ga” ion [1.41Å]. The unit cell volume are given in table 3 and shown in Figure12.
Fig. 9: X-ray diffraction patterns of Ge$_{25-x}$Ga$_x$Se$_{75}$ thin films annealed at 275 ºC (a) and 300 ºC (b) for 30 min.

Fig. 10: (a,b) shows the variation of the experimental d values for some main diffraction planes.
Fig. 11: Variation of the unit lattice parameters as a function of the composition, x.

Table 3 a: Values of lattice constants, a, c and the volume of the unit cell for different compositions for 275,300 °C

<table>
<thead>
<tr>
<th>Comp. (x)</th>
<th>a [nm]</th>
<th>c [nm]</th>
<th>V=(31/2/2) a2c [Å³]</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeGase</td>
<td>0.419</td>
<td>1.64</td>
<td>239.24</td>
<td>card</td>
</tr>
<tr>
<td>5</td>
<td>0.418</td>
<td>1.598</td>
<td>241.80</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.414</td>
<td>1.583</td>
<td>234.97</td>
<td>Present work</td>
</tr>
<tr>
<td>15</td>
<td>0.410</td>
<td>1.569</td>
<td>228.419</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.405</td>
<td>1.555</td>
<td>220.893</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 (b).

<table>
<thead>
<tr>
<th>Comp. (x)</th>
<th>a [nm]</th>
<th>c [nm]</th>
<th>V=(31/2/2) a2c [Å³]</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeGase</td>
<td>0.419</td>
<td>1.64</td>
<td>239.24</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>0.417</td>
<td>1.587</td>
<td>240.70</td>
<td>Present work</td>
</tr>
<tr>
<td>10</td>
<td>0.413</td>
<td>1.577</td>
<td>233.26</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>0.410</td>
<td>1.569</td>
<td>228.35</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>0.403</td>
<td>1.557</td>
<td>220.58</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 12: Spectral variation of the unit cell volume, V, of the thin film after annealing.

They decreased linearly with “Ga” content, in accordance with Vegards law, confirms the formation of substitutional solid solution of Ge$_{25.5}$Ga$_{75}$. The results obtained in the present work are in good agreement.
with that reported in (Nemec et al., 2000). Knowing the unit cell volume of the investigated samples, “V”, decrease with increasing the composition, “x”, and decrease with annealing at 275,300 °C [Table 3 a,b].

The structural studies have been confirmed throughout the transmission electron micrograph and the corresponding electron diffraction patterns for films of thickness 105 nm suitable for transmission electron microscope investigation as shown in Figure 13.

It is a typical representative as-deposited and annealed Ge_{25-x}Ga_xSe_{75} films at temperature 300°C for 30 min. The amorphous state of the as-deposited films was confirmed from the observed diffuse rings pattern shown in Figure 13-a and the corresponding TEM micrograph, which contains randomly distributed tiny crystals cover most of the film surface. Improvement in the crystallinity of the deposited film was observed after annealing the deposited film in vacuum at 300°C for 30 min Figure 13.b. The corresponding diffraction pattern gave sharp rings pattern indicating polycrystalline structure. The increase in the intensity of the diffraction rings depends on the shape and volume of the diffracting crystals. The X-ray and TEM observations indicated that an amorphous–to-crystalline phase transition of Ge_{25-x}Ga_xSe_{75} films annealed at temperature, $T_a \approx T_c$ [Tc is the crystallization temperature as determined from DSC].

![TEM micrograph and the corresponding electron diffraction patterns of as-deposited film (a), and that annealed at 300 °C for 30 min.](image)

**Fig.13:** TEM micrograph and the corresponding electron diffraction patterns of as-deposited film (a), and that annealed at 300 °C (b), x=5.

The chemical compositions of the constituents elements of Ge_{25-x}Ga_xSe_{75} films deposited on carbon stub have been investigated (Champness, 2001). Figure 14 shows a typical energy dispersive X-ray spectrum [EDX] and the corresponding surface morphology of an as-deposited film [x=5]. The obtained data for different “Ga” concentrations revealed an excess of “Ge” and/or “Ga” with deficient in selenium. The deficient in “Se” element may be due to its high vapour pressure. The slightly deviation in stoichiometry for the deposited films is comparable with the experimental errors and consequently the films composition could be considered nearly stoichiometric. Table 4 gives the obtained results of the elemental chemical compositional for different value of “x”.

![EDX spectra of Ge_{25-x}Ga_xSe_{75} thin films on carbon stub, x=5. Inset show the surface morphology](image)

**Fig.14:** EDX spectra of Ge_{25-x}Ga_xSe_{75} thin films on carbon stub, x=5. Inset show the surface morphology
Table 4: Elemental analysis of Ge_{25-x}Ga_xSe_{75} thin films deposited on carbon stub.

<table>
<thead>
<tr>
<th>x</th>
<th>Ge at.%</th>
<th>Ga at.%</th>
<th>Se at%</th>
<th>Chemical formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>22.51</td>
<td>5.41</td>
<td>72.07</td>
<td>Ge0.94Ga0.225Se3.834</td>
</tr>
<tr>
<td>10</td>
<td>16.92</td>
<td>9.62</td>
<td>73.46</td>
<td>Ge0.70Ga0.452Se3.841</td>
</tr>
<tr>
<td>15</td>
<td>12.24</td>
<td>18.40</td>
<td>69.36</td>
<td>Ge0.47Ga0.6796Se3.848</td>
</tr>
<tr>
<td>20</td>
<td>21.87</td>
<td>5.84</td>
<td>72.29</td>
<td>Ge0.236Ga0.9075Se3.855</td>
</tr>
</tbody>
</table>

Conclusions

The addition of Ga to Ge-Se glassy alloys leads to changes in the physical properties. As it is clear from various figures and tables given above that almost all the parameters mentioned above, i.e., the average coordination number “Z”, number of constraints “N_con”, and the parameter “R” were increased with the increase in “Ga” content. The positive values of “R” confirm the alloys as chalcogen poor up to x = 20 at. %. The results show that mean bond energy <E> is proportional to glass transition temperature and both increases with the increase in content of “Ga”.

Nearly Stoichiometric Ge_{25-x}Ga_xSe_{75} thin film (5 ≤ x ≤ 20) was thermally evaporated at room temperature onto glass substrates from the corresponding pre-synthesised ternary mixture. X-ray diffraction studies of the prepared thin films have indicated that the material corresponds to a hexagonal structure. The linear behaviour for each of the lattice parameters, “a” and “c” with “Ga” content in accordance with Vegard’s law, indicates the formation of complete solid solutions of Ge_{25-x}Ga_xSe_{75}. X-ray and electron diffraction studies on the as-deposited and annealed films revealed an amorphous-to-crystalline phase transition at T_g ≈ 275°C.

References