Middle East Journal of Applied Sciences
ISSN 2077-4613

Volume : 06 | Issue :04 | Oct.-Dec.| 2016
Pages: 911-921

Structural Characterization of $Se_{75}Te_{25-x}Ge_x$ [0 ≤ x ≤ 8] thin films

[1]S. M. Salem, [2]H. Zayied, [1,3]A. M. Salem, [4]G.B. Sakr and [1]N. Teleb

[1]Electron Microscope and Thin Films Department, National Research Centre, Dokki, Giza,Egypt.
[2]Physics Department, College of Girls for Arts, Science and Education, University of Ain Shams, Cairo, Egypt.
[3]University College-Umm Al-Qura University,Saudi Arabia Kingdom.
[4]Physics Department, Faculty of Education, University of Ain Shams, Cairo, Egypt.

Received: 20 Oct. 2016 / Accepted: 30 November 2016 / Publication date: 05 December 2016

ABSTRACT

Thin films of the $Se_{75}Te_{25-x}Ge_x$ [x=0, 2, 4, 6 and 8] ternaries systems have been prepared by Pulsed Laser Deposition [PLD] technique with appropriate film thickness onto clean glass substrates. The structure property of the deposited films was examined using X-ray diffractometer [XRD], and scanning electron microscope [SEM]. X-ray analysis showed that the amorphous nature of prepared powdery and obtained thin films. The elemental chemical composition of the powder as well as the deposited films has been investigated using [EDX]. Differential scanning calorimetric [DSC] analysis was used to evaluate the thermal stability of the ternary $Se_{75}Te_{25-x}Ge_x$ amorphous system. The overall mean bond energy <E>,and the average heat of atomization, $<H_s>$ as a function of the exact chemical composition of the ternaries $Se_{75}Te_{25-x}Ge_x$ systems have been also present for the bulk and thin films forms.

Key words: film thickness, glass, X-ray, electron microscope

Introduction

As a result of the specific electrical and optical properties of $Se_{75-x}Te_{25-x}Ge_x$ thin films, chalcogenide glasses have conquered an important place for the applications of the non-crystalline materials. Chalcogenide glasses are promising optical materials due to their transparency in IR region, relatively good thermal, mechanical and chemical properties and the low optical losses having their application in the field of fiber optics, xerography and novel memory devices (Chavhan and Sharma, 2006; Dongol *et al.,* 2006; Estrada-Raygoza *et al.,* 2006; Claudio *et al.,* 2006; Ray *et al.,* 2005 and Bureau *et al.,* 2004). It should be notice however, that such materials endorse an amorphous crystalline phase transition with electrical switching property which constitutes an advantageous feature suitable for various industrial applications (Morales-Sanchez *et al.,* 2010). In the present paper, an attempt has been made to study the effect of alloying "Ge" with chalcogenide Se-Te atoms in $Se_{75}Te_{25-x}Ge_x$films (with x= 2, 4, 6 and 8) structure properties. Also the coordination number "Z", mean bond energy<E>, and heat of atomization $<H_s>$will be calculated with different values of "Ge".

Experimental

Series of $Se_{75}Te_{25-x}Ge_x$ingot materials with different composition "x" were prepared by melt quenching techniqus (Abousehly *et al.,*2014b). Stoichiometric proportions of pure [99.999 %) elements (Selenium ,Tellurim and Germanium) were contained in the precleaned silica tube, sealed under vacuume at 10^{-3} Pa. The tubes were heated in an electrical furnace with a temperature rate of 3–4K/min up to 1050 K for 18 h. During the heating process, the tubes were frequently shaken to ensure the homogeneity of the samples. The molten sample was then rapidly quenched in the ice-cooled water to obtain the desired alloys in their glassy state.

$Se_{75}Te_{25-x}Ge_x$thin films were deposited on glass substrates using Pulsed Laser Deposition Technique [PLD] with a neodymium -doped yttrium aluminum garnet [Nd:YAG] laser (Coherent US)under a laser excitation wavelength of 1064 nm. The system operating in the so-called Q-switching mode with an output powers of 250 megawatts for pulse durations of 10 to 25 nanoseconds (Miller and Richard, 1998). The thickness of the deposited $Se_{75}Te_{25-x}Ge_x$thin films was determined using a model Dektak 3 profilometer device, and was confirmed analytically by the interference methods.

Corresponding Author: N. Teleb, Electron Microscope and Thin Films Department, National Research Centre, Dokki, Giza, Egypt.
E-mail: n_sleam@yahoo.com

To identify the crystal structure of the powder and film samples, the X-ray diffractometry (Philips X'pert] was employed, this x-ray device was operating at 40 kV and 30 mA, with CuKα radiation of wavelength "λ" of 0.15406 nm. The chemical composition of the investigated samples was examined by a model INCA x-sight energy dispersive X-ray spectrometry unit (Oxford, UK] interfaced with a model JOEL JEM-850 scanning electron microscope operating with an accelerating voltage of 30 kV.

Results and Discussion

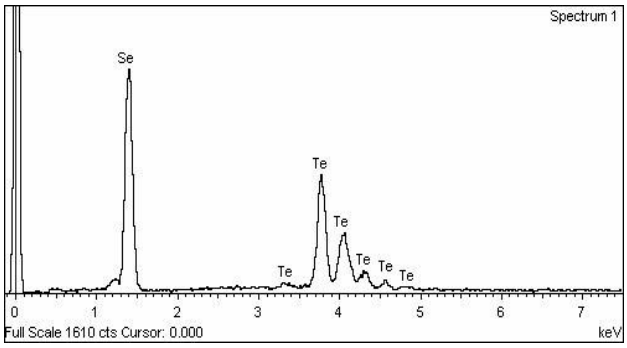
Structure characterization

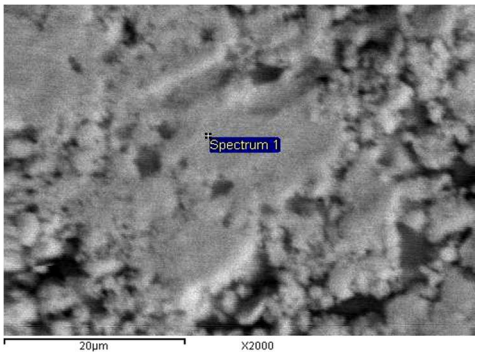
Energy dispersive X-ray spectroscopy

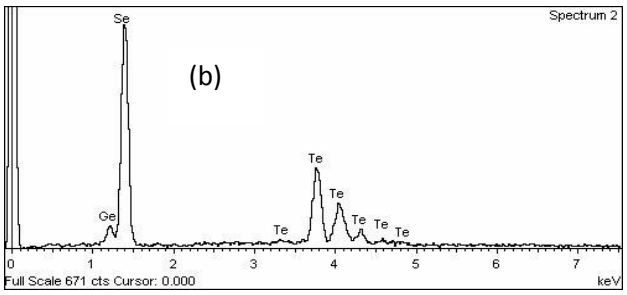
The prepared $Se_{75}Te_{25-x}Ge_x$ bulk materials have been investigated by means of energy dispersive X-ray spectrometry [EDX] to identify the chemical composition. Figure 1(a-e) shows the "EDX" spectra as well as the surface morphology of the investigated $Se_{75}Te_{25-x}Ge_x$ powder samples with x =0, 2, 4, 6 and 8.The obtained values for each constituent element were given in atomic percentage [at. %] were listed in table 1. The analysis of the "EDX" results confirms the purity of the prepared samples, as only the "Se" and "Te" elements are presence for pure $Se_{75}Te_{25}$ binary compound, whereas the "Ge" elements appears for the ternary samples beside the "Se" and "Te" elements. The surface morphology obtained for such compositions has a feature less with a uniform morphology, which supports their amorphous nature.

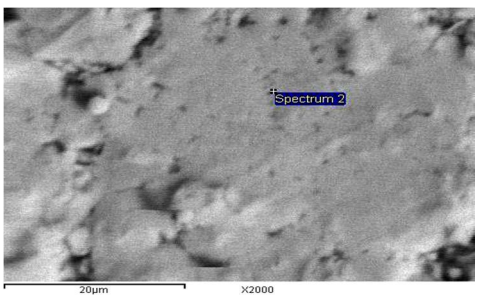
Table 1: Atomic ratios of the constituent elements and the corresponding chemical formula of the prepared $Se_zTe_yGe_x$ powder system along with the corresponding notations (a-e).

Calculated formula	Powder samples Exact elements at%			Exact powder formula
	Se	Te	Ge	
$Se_{75}Te_{25}$	73.86	26.14	-----	$Se_{73.86}Te_{26.14}$ (a)
$Se_{75}Te_{23}Ge_2$	75.21	23.66	1.13	$Se_{75.21}Te_{23.66}Ge_{1.13}$ (b)
$Se_{75}Te_{21}Ge_4$	75.85	20.47	3.68	$Se_{75.85}Te_{20.47}Ge_{3.68}$ (c)
$Se_{75}Te_{19}Ge_6$	74.60	20.19	5.21	$Se_{74.60}Te_{20.19}Ge_{5.21}$ (d)
$Se_{75}Te_{17}Ge_8$	74.57	19.29	6.14	$Se_{74.57}Te_{19.29}Ge_{6.14}$ (e)









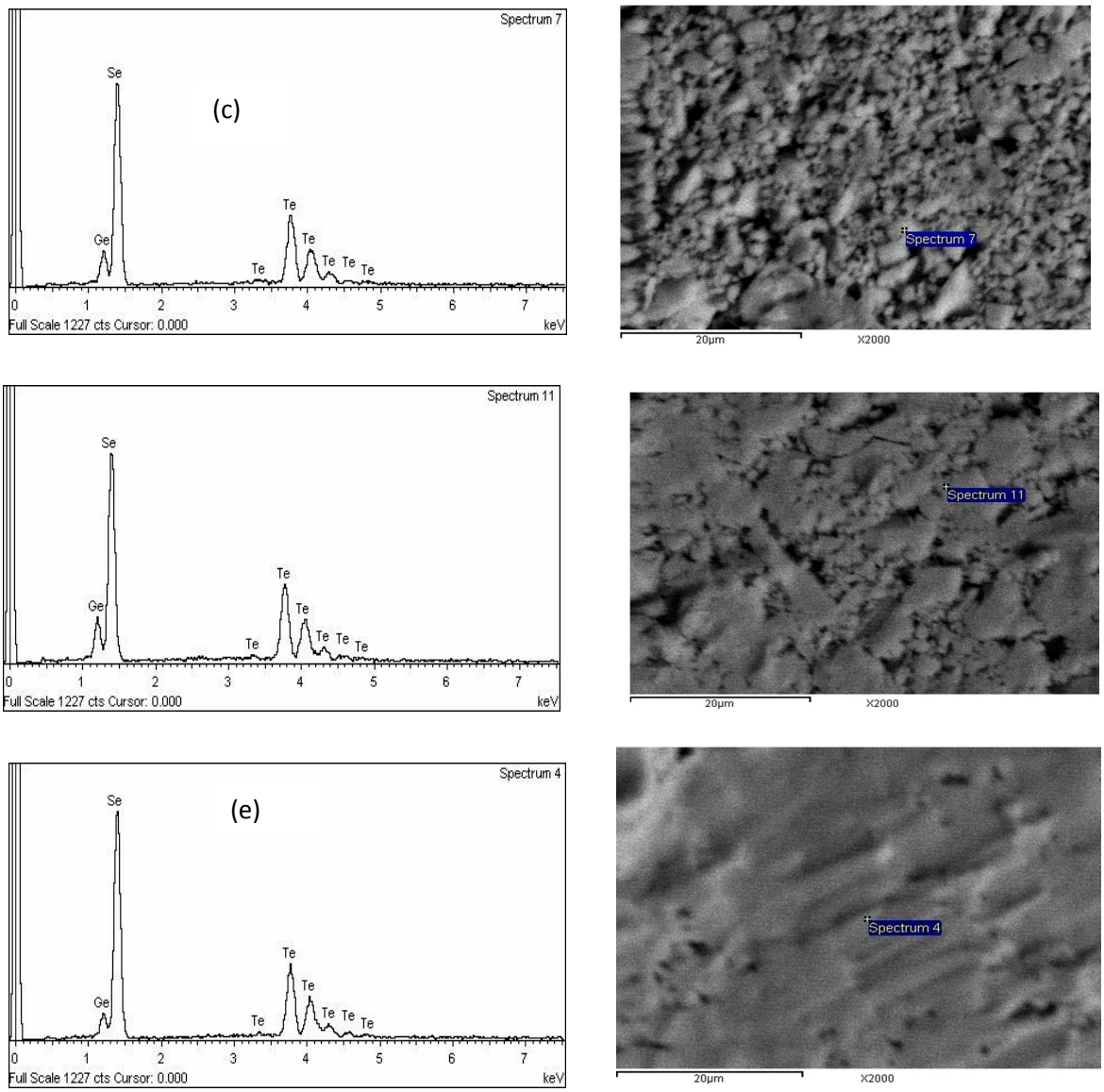
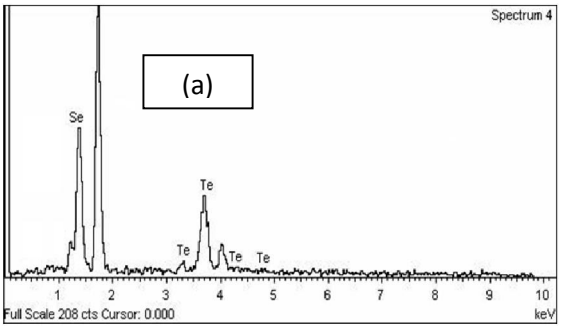


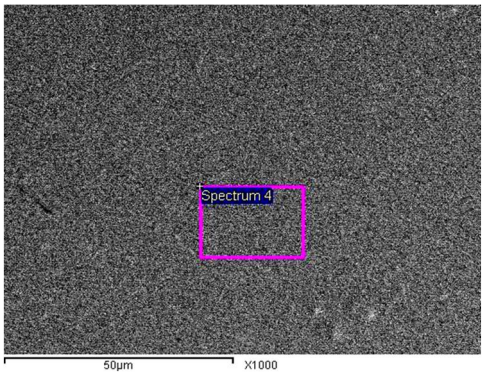
Fig. 1: (a-e) shows EDX spectrum and surface morphology of the prepared powder samples with different Ge content.

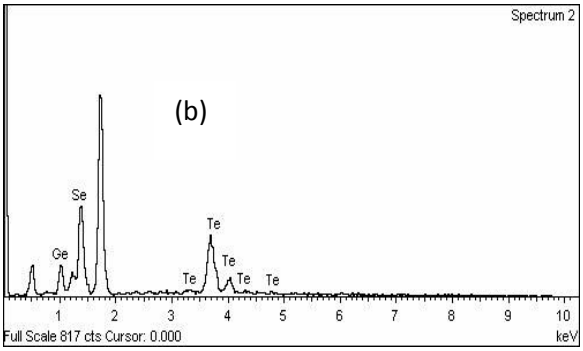
Composition of the investigated films was checked by energy dispersive X-ray spectrum analysis using a scanning electron microscope. The EDX spectra as well as the corresponding surface morphology of the as-deposited $Se_{75}Te_{25-x}Ge_x$ films with different "Ge" content was shown in Figure 2 [a-e]. The obtained data showed that the average atomic percentage ratios of the constituent elements were listed in table 2. It is indicating that the deposited films are nearly stoichiometry.

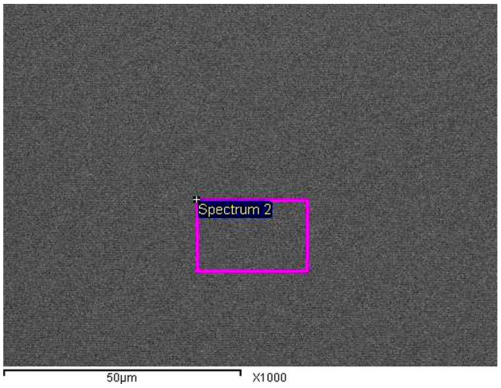
Table 2: Atomic ratios of the constituent elements and the corresponding chemical formula of the as-deposited $Se_zTe_yGe_x$ films along with the corresponding film notations (a-e).

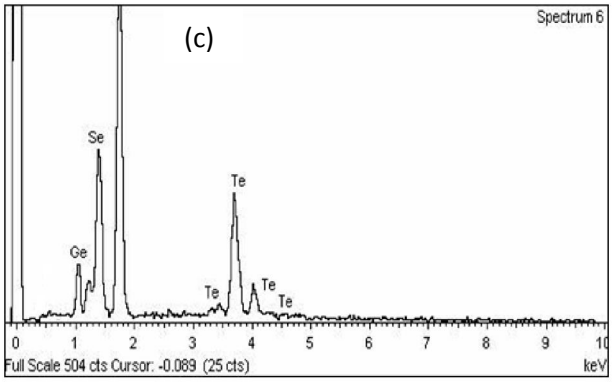
Calculated formula	Film samples Exact elements at%			Exact thin films formula	
	Se	Te	Ge		
$Se_{75}Te_{25}$	76.62	23.38	-----	$Se_{76.62}Te_{23.38}$	(a)
$Se_{75}Te_{23}Ge_2$	77.85	20.74	1.41	$Se_{77.85}Te_{20.74}Ge_{1.41}$	(b)
$Se_{75}Te_{21}Ge_4$	73.52	23.08	3.40	$Se_{73.52}Te_{23.08}Ge_{3.40}$	(c)
$Se_{75}Te_{19}Ge_6$	72.21	22.07	5.72	$Se_{72.21}Te_{22.07}Ge_{5.72}$	(d)
$Se_{75}Te_{17}Ge_8$	71.92	20.21	7.87	$Se_{71.92}Te_{20.21}Ge_{7.87}$	(e)

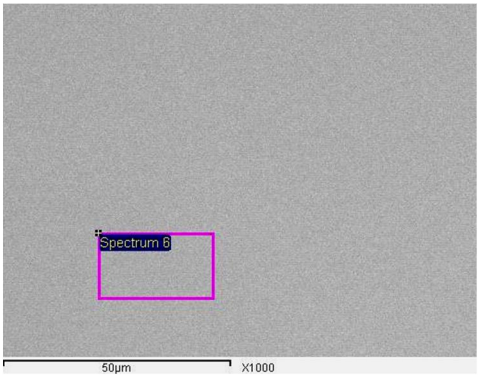

Spectrum 4
(a)
Se
Te
Te
Te
Te
1 2 3 4 5 6 7 8 9 10
Full Scale 208 cts Cursor: 0.000
keV

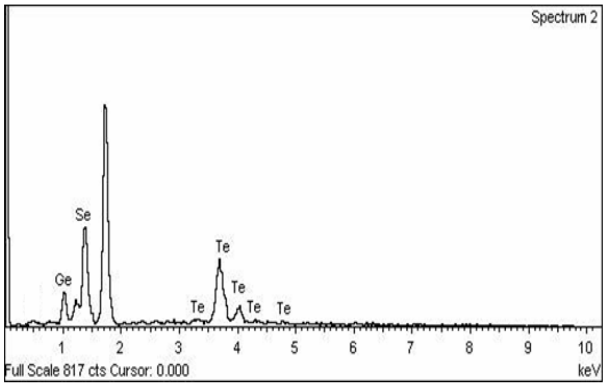

Spectrum 4
50µm
X1000

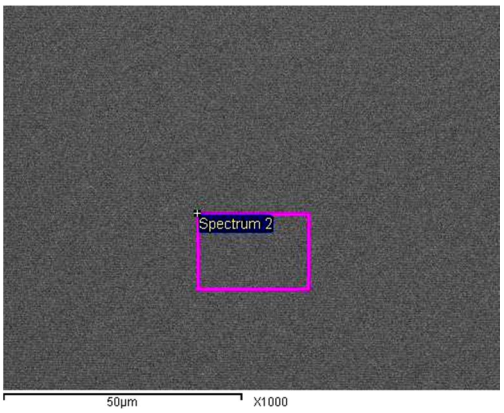

Spectrum 2
(b)
Ge
Se
Te
Te
Te
Te
Te
1 2 3 4 5 6 7 8 9 10
Full Scale 817 cts Cursor: 0.000
keV


Spectrum 2
50µm
X1000


Spectrum 6
(c)
Ge
Se
Te
Te
Te
Te
0 1 2 3 4 5 6 7 8 9 10
Full Scale 504 cts Cursor: -0.089 (25 cts)
keV


Spectrum 6
50µm
X1000


Spectrum 2
Ge
Se
Te
Te
Te
Te
Te
1 2 3 4 5 6 7 8 9 10
Full Scale 817 cts Cursor: 0.000
keV


Spectrum 2
50µm
X1000

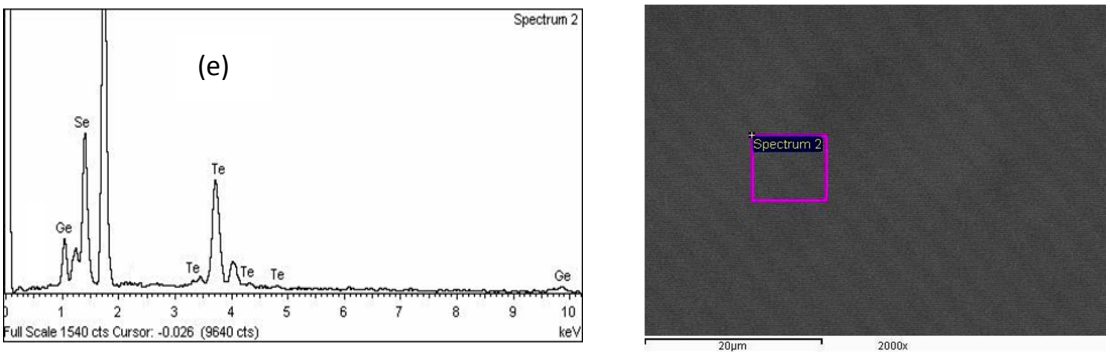


Fig. 2: Shows the EDX spectra and the corresponding surface morphology of the investigated as-deposited $Se_{75}Te_{25-x}Ge_x$films

X-ray diffraction

The x-ray was employed for identifying the crystal structure of prepared $Se_{75}Te_{25-x}Ge_x$[x=2, 4, 6 and 8] powdery and thin films samples. The obtained patterns are illustrated in figure 3 [a,b]. This figure indicates that there are no evidence peak, expected that this structure with the prepared powdery and thin films compositions are in amorphous state. It exhibited a broad hump around range 22-30^o within the investigated "2θ"range. Precisely the same behavior was obtained for all those films.

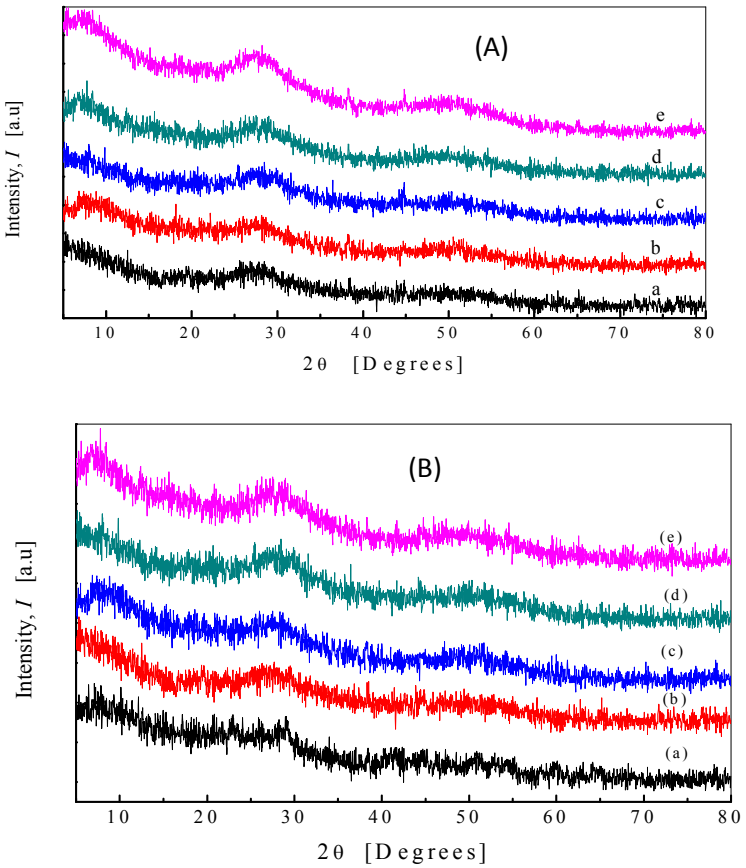
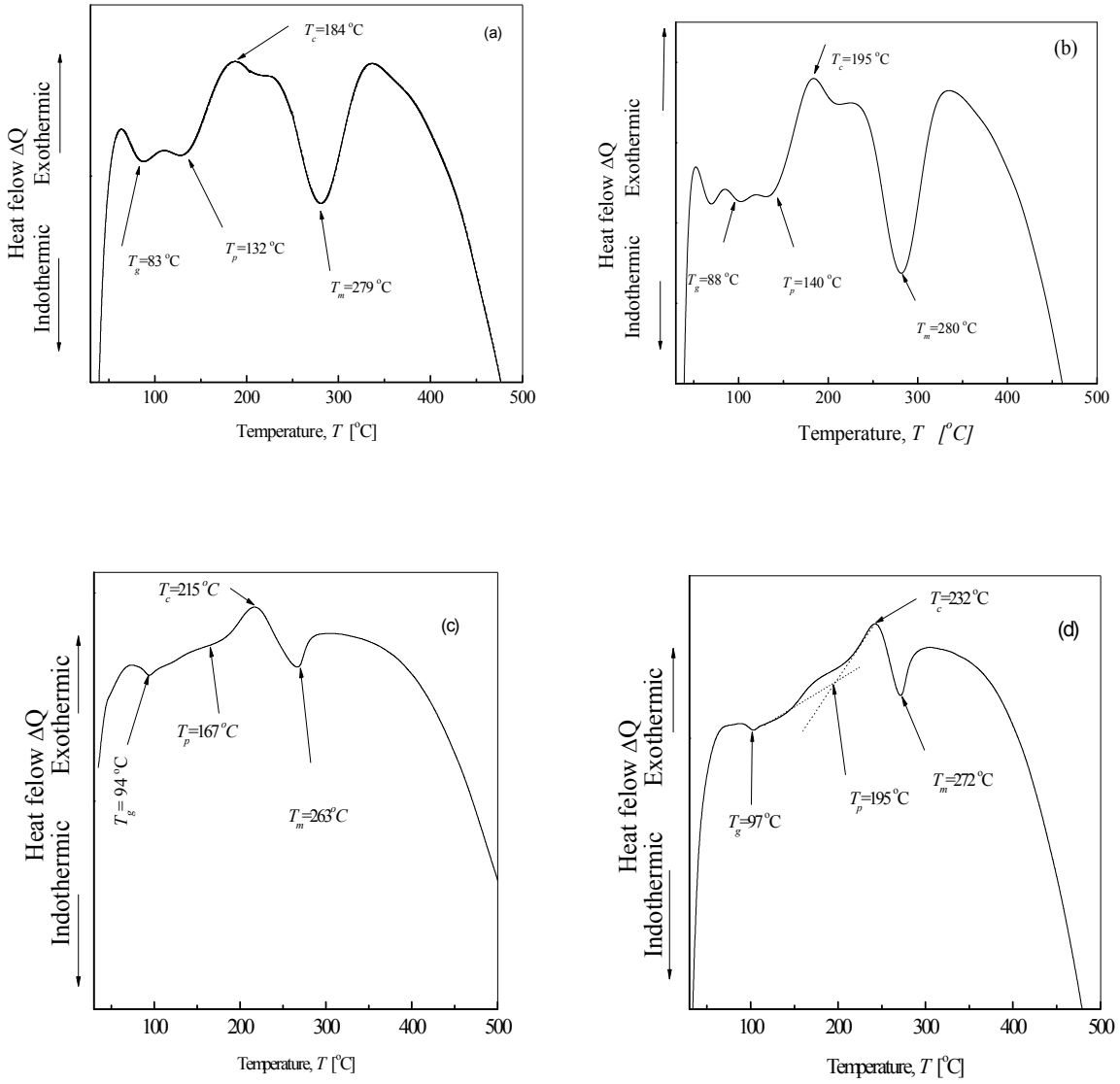


Fig. 3: (A) X-ray diffraction patterns of the prepared $Se_{75}Te_{25-x}Ge_x$ powders with x =0, 2, 4, 6 and 8 at%, with the corresponding notations a-e,(B) shows the x-ray diffraction patterns of the as-deposited films $Se_{75}Te_{25-x}Ge_x$.

Differential scanning calorimetric

Differential scanning calorimetric[DSC] thermogram were recorded for the ternary $Se_{75}Te_{25-x}Ge_x$ amorphous system to evaluate its thermal stability as well as the glass forming ability, the "DSC" thermogram for the sample notation [a-e] are shown in Figure 4. Four characteristic temperatures have been observed in such curve namely the glass transition temperature, "T_g" the onset of the crystallization temperatures, "T_c" [i.e., the temperature where the crystallization peak starts],crystallization temperatures, "T_p" and the melting temperature, "T_m". "T_g" shows the quality alternately of unbending nature of the glassy structure in chalcogenide glasses.The distinction for "T_c" furthermore "T_g" is pointer of both the thermal stability what is more "GFT". Those the higher the values of $[T_c-T_g]$, the more excellent will be the "GFT", as this higher worth of this difference, the additional delay in the nucleation transform (Singh *et al.,* 2010; Kumar and Singh, 2012) Values of T_g, T_p, T_c, T_m as well as the $[T_c-T_g]$ difference for the investigated samples are listed in Table 3. The variation of the glass transition temperature and the temperature difference, $[T_c-T_g]$ as a function of the exact "Ge" content at %,it can be observed that both values increase with the increasing "Ge" content in the investigated systems.



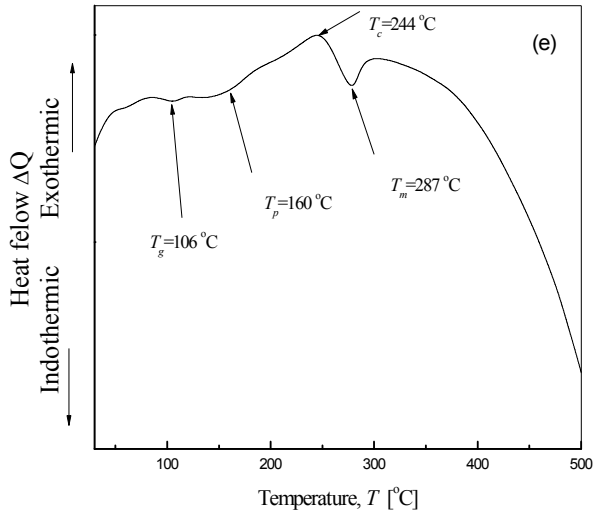


Fig. 4: shows the DSC thermo grams for the prepared powder samples with different Ge content

Table 3: values of T_g, T_p, T_c, T_m and the reduced glass transition temperature, H_{rg} for the prepared powder samples, along with the exact Ge at% as estimated from the EDX analysis.

Exact powder formula	Exact Ge at%	T_g [°C]	T_p [°C]	T_c [°C]	T_m [°C]	H_r
$Se_{73.86}Te_{26.14}$ (a)	0	83	132	184	279	1.05
$Se_{75.21}Te_{23.66}Ge_{1.13}$ (b)	1.13	88	140	195	280	1.27
$Se_{75.85}Te_{20.47}Ge_{3.68}$ (c)	3.68	94	167	215	263	2.52
$Se_{74.60}Te_{20.19}Ge_{5.21}$ (d)	5.21	97	195	232	272	2.50
$Se_{74.57}Te_{19.29}Ge_{6.14}$ (e)	6.14	(106)	160	244	287	3.81

Coordination number, mean bond energy, and heat of atomization for the ternary $Se_{75}Te_{25-x}Ge_x$ system

Chalcogenide systems, "Ge" is 4-fold coordinated furthermore "Se" Also "Te" is 2-fold coordinated complying with the '8-N' rule, "N" is the column in the periodic table with which the element belongs [Ferhat *et al.,* 1992; Mott and Philo, 1969). Therefore, utilizing those coordination numbers 4, 2 and 2, for "Ge", "Se" Also "Te", the coordination number, "Z" of the ternary $Se_{75}Te_{25-x}Ge_x$system can be calculated using the following formula (Aly *et al.,* 2009):

$$Z = \frac{(zCN_{(se)} + YCN_{(Te)} + XCN_{(Ge)}}{100} \quad (1)$$

Where z, y, and x are the exact atomic percentages of "Se", "Te" and "Ge", respectively, it is estimated from the "EDX" analysis and CN_{Se}, CN_{Te} and CN_{Ge} their respective coordination numbers. Those computed values of the "Z" are showing in Table 4.Figure 5 shows the variation of the calculated coordination numbers vs. the exact "Ge" content. It has been observed that the coordination numbers, "Z" increase with increasing the "Ge" content. This finding suggested that the cross linking of chains between the atoms increments for expanding of the "Ge". Since the worth of "Z" acquired in the investigated system lies in between 2.0 to 2.4 (Sharma *et al.,* 2012), one can conclude that the framework under examination is a greater glass former.

Chalcogenides can be classified into three groups which are:

(i) Floppy or under- coordinated glasses with $Z < 2.4$ and $N_T < 3$;
(ii) Optimally-coordinated or ideal glasses with $Z = 2.4$ and $N_T = 3$; and
(iii) Stressed-rigid and over-coordinated glasses with $Z > 2.4$ and $N_T > 3$.
Where

$$N_T = N_a + N_b \quad (2)$$

"N_T" the total number of constraints per atom, where "N_a"and "N_b"are bond stretching and bond bending constraints.

Figure (6a) depicts the variation of the total number of constraints as a function of the exact "Ge" content at%. For the ternary $Se_{75}Te_{25-x}Ge_x$ system. It is ascertained that total number from constraints rises by increasing 'Ge" at%.

In chalcogenide glass construction the lone pair electrons assume a great aspect. They have a flexible character (El-Sayed *et al.,* 2007)

$$L = V - Z \quad (3)$$

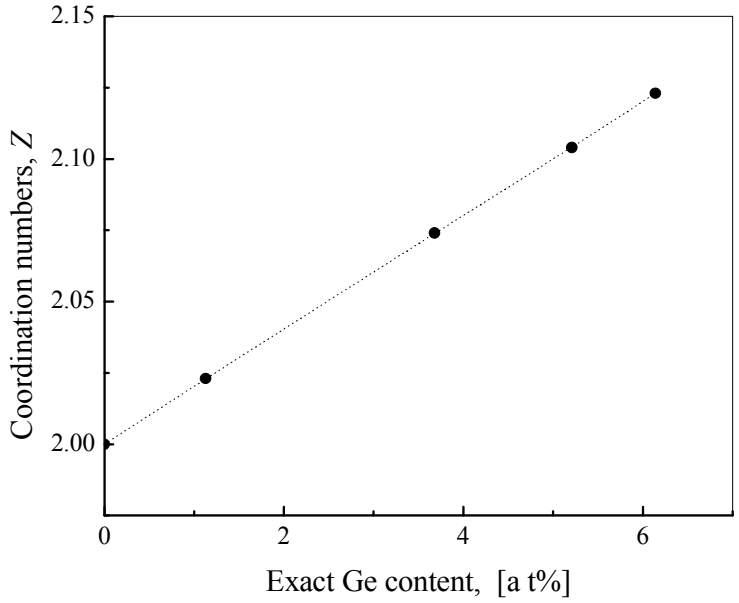


Fig. 5: Shows the variation of the coordination numbers vs. Ge content

Where "L" is lone pair electron and "V" is valence electrons. Figure (6b) shows the variation of the lone pair electrons vs. the exact "Ge" content at%. It observed that the "L" decrease by adding "Ge'. This finding was attributed to the raise in interaction of "Ge" atoms and "L" of the halogen atoms [Se and/or Te).This results indicates that in the glass there is strain energy. System under investigation declining by expanding in "L, so the larger number of "L" in the structure favor stable glass construction (El-Sayed *et al.,* 2007; Pamukchieva *et al.,* 2009). For a binary arrangement and also the ternary one (Zhenhua, 1991; Saxena *et al.,* 2012) recommended a simple criterion "L" necessary to be more than 2.6 in the binary system, but in the ternary one should be greater than 1. This is appearing in figure 6b where**,** the value of lone-pair electrons for the investigated system varies from 4 [for sample (a)] binary system to 3.75 [for sample (e)] ternary system. The ability of glass construction was deduced from those results.

The degree of cross-linking , the average" Z" and form of bond and bond energy of the system organization, all of those parameters used for calculating mean bond energy of the system. According to the correlation proposed by Tichy and Ticha (1994); Tichy and Ticha (1995), in selenium rich chalcogenide system the mean bond energy can be calculated as:

$$\langle E \rangle = \langle E_{cl} \rangle + \langle E_{rm} \rangle \quad (4)$$

Where$<E_{cl}>$ mean bond energy of the average cross-linking per atom (heteropolar bonds) and$<E_{rm}>$ the average bond energy per atom of the remaining matrix. The computed values of mean bond energy for investigated ternary system are listed in Table 4. Figure (7a) depicts the variation of the mean bond energy vs. exact "Ge" at %. It is clearing seen that in our system bond energy of the system increases with the increasing "Ge" content. The observed increase in the mean bond energy expanding by adding "Ge", is in context with the increase of the glass transition temperature, "T_g" for the investigated system. Where, according to Tichy and Ticha, (1994); Tichy and Ticha, (1995)a correlation between "T_g" and mean bond energy, <E> in the form:

$$T_g = 311[< E > -0.9] \quad (5)$$

Which indicates that an increase in the mean bond energy of the system reflect increase in the glass transition temperature.

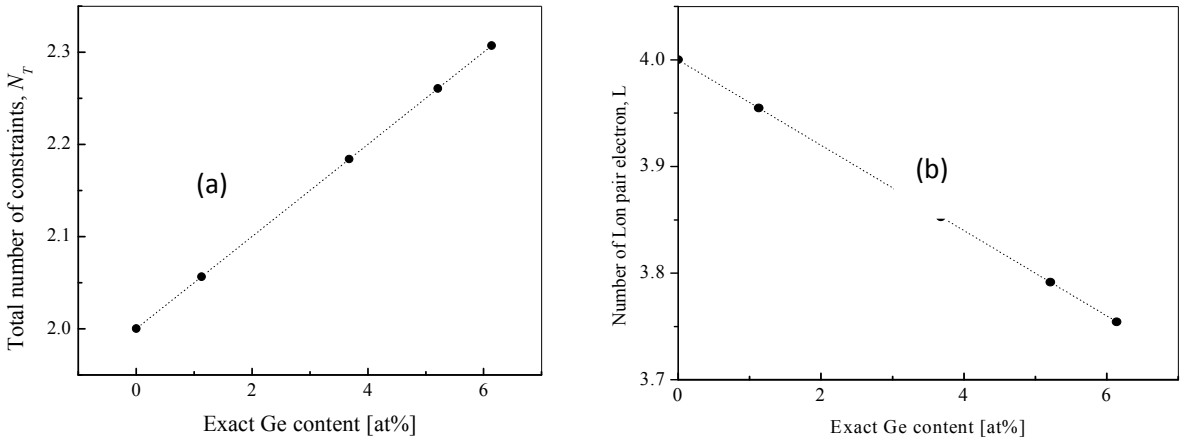


Fig. 6 (a,b): show variation of the total number of constraints $N_T$vs. exact Ge content at %.(b) *the variation of the* lone pair electron ,L as a *function of the Ge content.*

Table 4: values of the coordination number, Z, average number of valence electrons, V, mean bond energy, <E>, heat of atomization,H_s, average single bond energy, H_s/Z, and homopolar and heteropolar bond energies of the bulk $Se_{75}Te_{25-x}Ge_x$ ternary system.

Exact powder formula	Z	V	<*E*> [eV]	H_s [kcal.mol^{-1}]	H_s/Z [kcal.mol^{-1}]	Bond energy [kcal.mol^{-1}]	
$Se_{73.86}Te_{26.14}$ (a)	2	6	1.83	219.16	109.58	Ge-Se	49.10
$Se_{75.21}Te_{23.66}Ge_{1.13}$ (b)	2.023	5.98	1.96	221.60	109.54	Ge-Te	37.40
$Se_{75.85}Te_{20.47}Ge_{3.68}$ (c)	2.074	5.93	2.16	226.38	109.15	Se-Te	40.60
$Se_{74.60}Te_{20.19}Ge_{5.21}$ (d)	2.104	5.90	2.29	228.76	108.73	Ge-Ge*	37.60
$Se_{74.57}Te_{19.29}Ge_{6.14}$ (e)	2.123	5.88	2.38	230.42	108.54	Se-Se*	44.00
* Sedeek *et al*., Vacuume 51 (1998) 329.						Te-Te**	33.00
** Maged *et al*; Materials Chemistry and Physics, 56 (1998)184.							

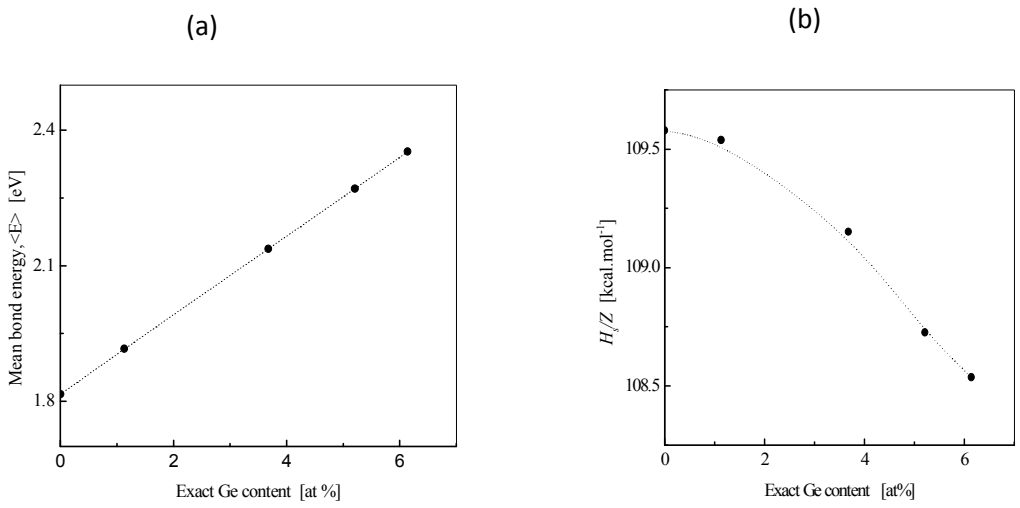


Fig. 7(a): variation of the mean bond energy vs. exact Ge content at %.(b) depicts the variation of the average single bond energy, H_s/Z as a function of the Ge content.

Sequently, "H_s" is the enthalpy of atomization, the enthalpy difference was needed for completely breaking of bonds between the atoms and reducing the compound bonds to the original atoms, and this was suggested through pauling (Pauling, 1960), $H_s[A-B]$for binary semiconductor of two atoms "A" , "B" at

normal pressure and temperature is equal to sum of heat of formation "ΔH" and average heat of atomization [H_S^A , H_S^B] of the two atoms and is given by the relation:

$$H_s(A-B) = \Delta H + \frac{1}{2}(H_s^A - H_s^B) \quad (6)$$

In the case of the ternary $Se_zTe_yGe_x$ system, the heat of atomization can be written as [Pamukchieva *et al.,* 2009):

$$H_s = \frac{zH_s^{Se} + yH_s^{Te} + xH_s^{Ge}}{z+y+x} \quad (7)$$

Where x, y, z are the atomic percentages of "Se", "Te" and "Ge", respectively, and $H_s^{Se} = 227, H_s^{Te} = 197$ and $H_s^{Ge} = 377$ are the corresponding heat of atomization. Therefore, using these values and the exact atomic percentages of the corresponding elements, the heat of atomization, "H_s" as well as the average single bond energy," H_s/Z"of the investigated system was calculated, and summarized in Table 4. Figure7b depicts the variation of the common single bond energy,"H_s/Z"as a function of the exact "Ge" ratio at %. It has been observed that the average single bond energy decreases by adding "Ge". This finding associate with the lesser value of heat of atomization of "Se" and "Te" with respect to "Ge", beside the lower values of bond energies of Se-Se and Te-Te bonds as compared to the Se-Ge bond.

Conclusion

$Se_{75}Te_{25-x}Ge_x$ thin film was promising for many optical and electrical applications so the studying of structure is a good pointer for these applications. EDX confirms the purity of the prepared samples. Values of T_p, T_g, T_c, T_M were measured to be increase with increasing "Ge" content. The coordination number, "Z" investigated to be lies in between [2.0-2.123]. The total number of constraints increase with increasing of "Ge" in contrast with lone pair which was studied to be decrease [4 to 3.75] indicating the good exhibiting glass formation. As result of the small value of heat of atomization of "Se" and "Te" respect to "Ge", beside the lower values of bond energy of Se-Se and Te-Te bonds as compared to the Se-Ge bond. The common single bond energy reduced as the "Ge" increase. Lone pair electrons "L" and T_g, T_p, T_c, T_m values of $Se_{75}Te_{25-x}Ge_x$ ternaries systems has been investigated.

References

Abousehl, Y .M. A., N. Afify and K. A. Aly, *et al.,* 2014 Physical characterization of ternary In-Se-Te chalcogenide glasses ,New Hor Phys, 1: 43-49.

Aly, K.A., A. A. Othman and A.M. Abousehly, 2009. Effect of Te additions on the glass transition and crystallization kinetics of $(Sb_{15}As_{30}Se_{55})_{100-x}Te_x$ amorphous solids, J. Alloys Compd, 467: 417.

Bureau, B., X.H. Zhang and D.L. Coq, 2004. Recent advances in chalcogenide glasses, J Non-Crys Solids 345:276.

Chavhan, S. and R. Sharma, 2006. Growth, structural and optical properties of non-stoichiometric $CuIn(S_{1-x}Se_x)_2$ thin films deposited by solution growth technique for photovoltaic application, J Phys Chem Solids, 67: 767.

Claudio, D., O. Licea, B. Laine and G. Tarapaga, 2006. An analytical model to represent crystallization kinetics in materials with metastable phase formation, J Non-Crys Solids, 352: 51.

Dongol, M., M.M. El-Nahass, M. Abou-Zied, A. El-Denglawey, 2006. Effect of Tl addition on the electrical properties of amorphous $As_{20}Se_{80-x}Tl_x$ films, Physica B 371: 218.

El-Sayed, S.M., H.M. Saad, G.A. Amin, F.M. Hafez and M. Abd-EI-Rahman, 2007. Physical evolution in network glasses of the Ag–As–Te system, J. Phys. Chem. Solids, 68: 1040.

Estrada-Raygoza, I.C., M. Sotelo-Lerma, R. Ramirez Bon, 2006. Structural and morphological characterization of chemically deposited silver films, J Phys Chem Solids, 67: 782.

Ferhat, A., R. Ollitrault-Fichet, V. Mastelaro, S. Benazeth, R. Rivet, 1992. Etude des verres du système Ag-Ge-Te, J. Phys. IV France 02 : C2-201-C2-206.

Kumar S. and K. Singh, 2012. Glass transition, thermal stability and glass-forming tendency of $Se_{90-x}Te_5Sn_5In_x$ multi-component chalcogenide glasses, Thermochimica Acta, 528: 32.

Maged. A. F., K. L. Montasser and H. H.Amer.1998, Materials science communication optical absorption of amorphous semiconductors $Ge_{20}As_{30}Se_{50-x}Te_x$ and the effect of 7-irradiation.Materials chemistry and physics 56,184-188.

Miller, J. and F. H. Richard, 1998. Laser Ablation And Desorption, London: Academic, pp: 1-126.

Morales-Sanchez, E., B. Lain, E. Prokhorov, M.A. Hernandez-Landaverde, G. Trapaga and J. Gonzalez-Hernandez.2010. Crystallization process in $Ge_2Sb_2Te_5$ amorphous films, Vacuum, 84: 877-81.

Mott, N.F. and Philo, 1969. Conduction in non-crystalline materials, Mag 19: 835.

Pamukchieva, V., A. Szekeres, K. Todorova, M. Fabian, E. Svab, Z.S. Revay and L. Szentmiklosi, 2009. Evaluation of basic physical parameters of quaternary Ge–Sb-(S, Te) chalcogenide glasses, J. Non-Cryst Solids, 355: 2485.

Pauling, L.,1960. The Nature of the Chemical Bond, 3rd ed. Cornell University Press, New York, 1960.

Ray, C.S., S.T. Reis and R.K. Brow, 2005. A New DTA Method for Measuring Critical Cooling Rate for Glass Formation , J Non-Crys Solids, 351: 1350.

Saxena, M., M.K. Agarwal, A.K. Kukreti and N. Rastogi, 2012. An Influence of Ga Content on Physical Parameters of Quaternary $Ge_{10}Se_{80-x}Ga_xTe_{10}$ glasses, Advances in Applied Science Research, 3: 1440.

Sedeek, K., E. A. Mahmoud, A. Said and A. M. Nassar, 1998.The effect of Te isoelectronic substitution on the electrical and optical properties of the Ge—S—Se amorphous chalcogenide system studied in thin films. Vacuum 51, 329-333.

Sharma, N., S. Sharda, V. Sharma and P. Sharma, 2012. EVALUATION OF PHYSICAL PARAMETERS FOR NEW QUATERNARY $Ge_{19-y}Se_{63.8}Sb_{17.2}Te_y$ CHALCOGENIDE GLASSES, Chalcogenide Letters, 9: 355.

Singh, A.K., N. Mehta and K. Singh, Philos, 2010. Effect of indium additive on glass-forming ability and thermal stability of Se–Zn–Te chalcogenide glasses, Mag. Lett., 90: 2010.

Tichy, L. and H. Ticha, 1995. Covalent bond approach to the glass transition temperature of chalcogenide glasses, J. Non-Cryst. Solids, 198: 141.

Tichy, L. and H. Ticha, Mater,1994. on the chemical threshold in chalcogenide glasses, Lett., 21: 313.

Zhenhua, 1991. Chemical Bond Approach to the Chalcogenide Glass L, J Non-crystalline Solids, 127: 298.