Journal of Ovonic Research Vol. 15, No. 6, November - December 2019, p. 393 - 400

EFFECT OF BI ADDITIVE ON OPTICAL AND ELECTRICAL PROPERTIES OF QUATERNARY CHALCOGENIDE $In_3Te_7Bi_xSe_{90-x}$ THIN FILMS

S. S. ASHRAF[a,*], M. ZULFEQUAR[b]
[a]*School of Engineering Sciences and Technology Jamia Hamdard , New Delhi - 62,India*
[b]*Department of Physics Jamia Millia Islamia, New Delhi -25,India*

Glassy alloy of $In_3Te_7Bi_xSe_{90-x}$ (x = 0,5,10,15) are prepared by melt-quenching technique.Thin filmsare deposited by the thermal evaporation technique on glass substrates under a pressure of 10^{-6}torr. The structural analyses of these films were carried out by X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Scattering (EDS).X-ray diffraction (XRD) of thin films was carried out to analyze the amorphous or polycrystalline behavior of the thin films. EDS analysis shows the presence of the compositional elements in the thin films.SEM shows the surface morphology of the thin films and development of grains. Optical studies were carried out by the Ultra violet visible (UV-Vis)Sperctoscopy in the range of 190-1100 nm.The analysis of optical absorption spectra shows indirect optical band gap. The optical band gap decreases with increasing Bismuth concentration from 1.38 eV to 1.02 eV. The DC conductivity was carried out in specially designed metallic sample holder with vacuum 10^{-4}Torr.The DC conductivity of thin films of $In_3Te_7Bi_xSe_{90-x}$ increases and the corresponding activation energy decreases with increasing of bismuth content which may be due to shift in Fermi level.

(Received August 8, 2019; Accepted November 27, 2019)

Keywords: Thin film, Band gap, DC Conductivity, Absorption coefficient, Activation energy

1. Introduction

Chalcogenide glasses are widely used due to its property of exhibit phase change under the influence of light, heat, pressure etc. Se based chalcogenide glasses are many applications in solid state electronic devices,memory devices etc.Since pure selenium is fragile and have short life time; therefore elements from group II-VI are added to make it more robust. These chalcogenide glasses are non-linear, low phonon energy and transparent in IR region which make it useful for optical switching [1-3]. Se-Te alloys have greater hardness, higher photosensitivityand smaller aging effects [4-7]. Optical band gap (E_g), extinction coefficient (k) and refractive index (n) are important parameters to study the amorphous semiconducting thin film. Thin films of $In_3Te_7Bi_xSe_{90-x}$ are found to exhibit the change in refractive index under the influence of UV-Vis light which makes that material to use in optical memory devices [8]. Ternary assets deliver an opportunity of altering and improving natural and physical liberty, for example band gap of InTeBi (1.68 eV) is lesser as compared to ZnSe (2.82 eV) which makes it appropriate for the tender in solar cells [9]. Due to this reason numerous researchers take interest to study of InTeBi alloy following electrical properties, structural, opticalproperties. Ensuing this way it may be conceivable to form novel materials with chemical and structure freedom, which has substantial care in the arena of device applications. The structure of the material and optical parameters in an amorphous semiconductor may be widely different consequence ofan impurity added into material [10]. Although in crystalline semiconductors a suitable impurity is continually to deliver a new donor or acceptor states, which is not vital in amorphous semiconductor [11]. An impurity may just change the mobility of the charge carries or might familiarize structural modification in its place of if a localized impurity level in the forbidden gap exists with or without alteration of the localized states in the prohibited gap in amorphous semiconductors [12].

* Corresponding author: shahabash@gmail.com

Research of the optical properties is responsible to the result of impurities between the conduction band and valance band of the materials is a subject of excessive attention, because the results of such studies provide ways to control effectively the optical properties of amorphous semiconductors. In amorphous semiconducting thin films the greatest noteworthy constraints are the optical band gap, refractive index and extinction coefficient. To determine its optical constants, optical conduct is used of a material. On behalf of reflectance and transmittance pleasant measurements films are perfect samples. Thus, a precise observation of the optical constants is enormously significant. In the present case we studied the $In_3Te_7Bi_xSe_{90-x}$(x = 0, 5, 10, 15) thin films. These prepared materials have been found to exhibit the change in refractive index under the influence of light. Optical band gap (E_g), extinction coefficient (k) and refractive index (n) are important parameters to study the amorphous semiconducting thin film. Chalcogenide thin films are found to exhibit the changes in refractive index under the influence of UV-Vis light which makethose materials to use in memory devices. The optical band gaps decrease with the increase of Bi content, this may be due to increase in grain size and increase in the density of defect states [13].The conduction at higher temperature (300-400^{0}K)takes place due to thermally assisted tunneling of electrons at the localized states near conduction band ege [14].

In this present work authors aim to study the optical constants and electrical properties of the $In_3Te_7Bi_xSe_{90-x}$(x = 0, 5, 10, 15) thin films. The properties mostly depend on the preparation and deposition technique. In the present paper, the authors aim to study the structural and optical properties of InTeBiSethin films prepared by melt-quenching technique which makes it likely to usage these type of materials to best not lone the magnitude nevertheless to the stage of illumination and significant in holographic optical data storage.

2. Experimental

Chalcogenide glass alloys $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) were prepared from high purity constituent elements (99.999%) in stoichiometric ratio by using melt quench technique. The constituent elements were sealed in quartz ampoules under a vacuum of 10^{-5}torr. The ampoule was kept inside a furnace at 900^{0}C for 12 hrs so that all elements were melted. The temperature was raised at the rate of 2^{0}C/min. During the heating process, the ampoule was shaken continuously so as to make it homogeneous. Quenching was done in ice water and the ingots were taken out by breaking the ampoule. Thermal evaporation technique used to deposit the films on clean glass substrate at a pressure of 10^{-6} torr.The films prepared are kept at deposition chamber for almost 24 hours so that metastable thermodynamic equilibrium is maintained.

The X-ray diffraction (XRD) patterns of the thin films of $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) give the important information about the nature and structure of the samples.Thin films ‘surface topography and composition have been studied by SEM image and EDS respectively. The optical measurement was carried out by using UV/Vis spectrophotometer (Model: Camspec M550 double beam) in spectral wavelength range 190–1100 nm. For electrical measurements the deposited film on glass substrate has length ~1.5 cm, electrode gaps ~0.4-1.2 mm and thickness ~400 nm. A DC voltage of 1.5 V was applied across the sample and the resulting current measured by a Keithley electrometer (6514). The DC conductivity was carried out in specially designed metallic sample holder with vacuum 10^{-5}Torr. The temperature of the film was controlled by mounting a heater inside the sample holder and measured by calibrated copper-constantan thermocouple near film.

3. Results and discussion

XRD analysis of thin film was carried out by A RegakuUltima IV X-ray Diffractometre. The radiation source Cu Kα_1 with λ = 1.54 A^0, diffraction angle in the range of 5^0 to 90^0 with scan speed of 2^0/min and a chart speed of 1 cm/min were maintained [15]. The XRD pattern of graph is shown in Fig 1. The XRD diffractograms show that the Bi-rich samples (x > 10%) have someextent crystallization peaks due to the presence of other phase of the material in Bi-rich samples. Amorphous nature of the $In_3Te_7Bi_xSe_{90-x}$ glass alloys decreases with increase of Bi concentration. Surface morphology of the thin film was analysed by Scanning Electron Micrograph (SEM) apparatus JEOL (Model JSM 6380). SEM image of thin film is shown in Fig 2. SEM image shows the growth of nuclei. The grains size decreases with the increase in Bi content. This may be due to reduction in disorderness and hence decrease in density of defect states [13].The dissociation energy for Se-In, Se-Se, Se-Te, Bi-Bi,Bi-Se ,Bi-Te and Bi-In are 257.5 KJ/mol, 239.3 KJ/mol, 259.8 KJ/mol, 200.4 KJ/mol ,280.3 KJ/mol,232.3 KJ /mol and 2018.0 KJ/molrespectively [16-17].Bismuth has greater affinity for selenium than tellurium. This shows that Bi-Se bonds require more energy to be dissociated which makes it robust.

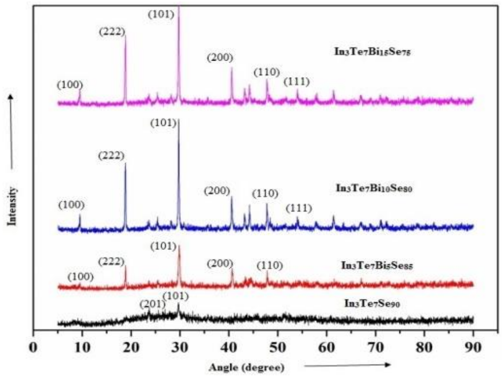

Fig.1. XRD pattern of $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) thin film.

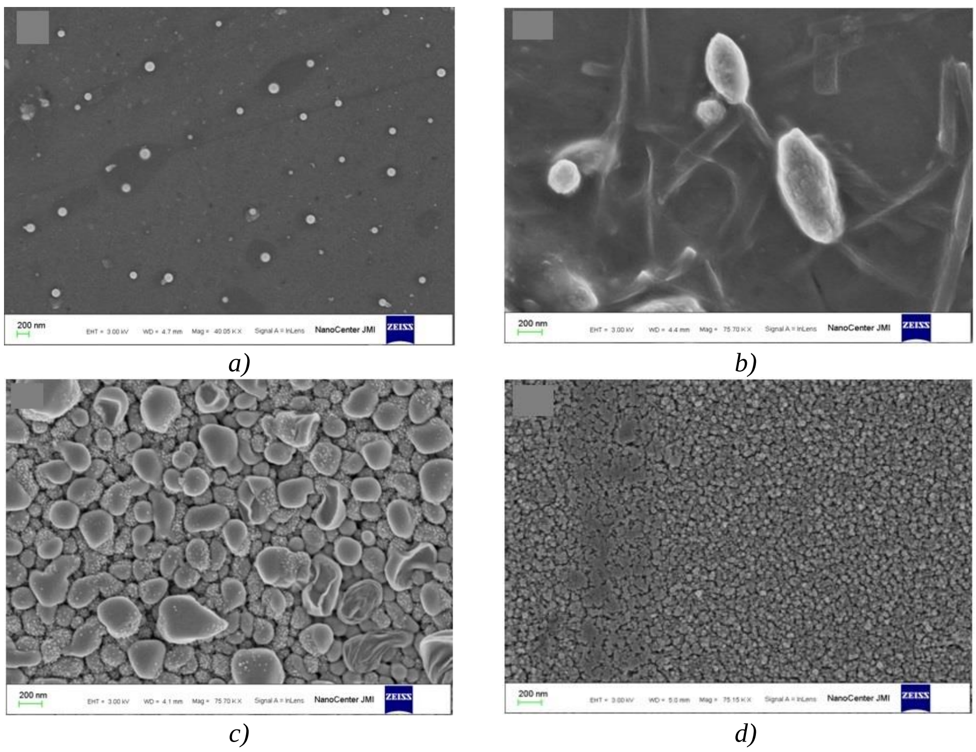

Fig. 2. SEM images of $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) thin films.

The elemental composition of as-prepared $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) thin films are checked by using the Energy Dispersive X-ray (EDX) spectroscopy. Fig.3. shows the typical EDX patterns of as-prepared thin films of $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15). This image confirms the presence of constituent's elements In, Te, Bi and Se. The calculated wt% values show Se (77.47%), Te (19.40%) and In (2.62%) for $In_3Te_7Se_{90}$, Se (62.49%), Te (24.49%),In (8.31%%) and

Bi (4.61%) for $In_3Te_7Bi_5Se_{85}$. Similarly the wt% values of other compositions agree well with experimentally taken wt% values. Intense peaks for Se found in the spectra of all samples are due to its high concentration as compared to other constituent such as In, Te and B.

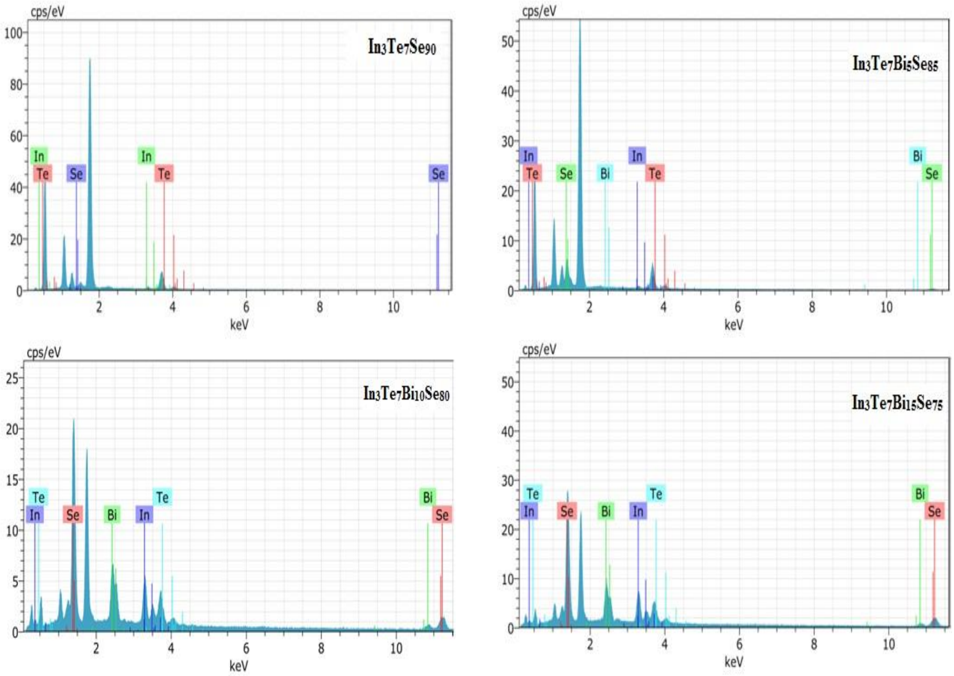

Fig. 3. Energy Dispersive X-ray Spectroscpy (EDS) of $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) thin films.

3.1 Optical Properties

The UV-Vis absorption spectra $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) thin film has been recorded in the wavelength range of 190-1100 nm by UV-Vis Spectrophotometre Model Comspec M550. The absorption coefficient (α) has been determined directly from the absorbance against wavelength curves using the relation [18-23]

$$\alpha = \text{optical density (OD) / thickness of the film} \quad (1)$$

It has been observed that absorption coefficient increases with increase of photon energy for all samples of $In_3Te_7Bi_xSe_{90-x}$ as shown in Fig 4.Energy of the band tail also called Urbach'senergy and optical band gap has been measured using Urbach's Rule [24] and Tauc relation [25] respectively. Urbach's energy (width of the band tail due to localized states in amorphous semiconductor) can be calculated as

$$\alpha = \alpha_0 \exp (h\upsilon/E_u) \quad (2)$$

where, α_0 is constant and E_u is called Urbach energy

The Tauc relation between absorption coefficient (α) and optical band gap (Eg) is given as

$$\alpha h\upsilon = A (h\upsilon - E_g)^n \quad (3)$$

where A is a constant called band tailing parameter and E_g is called optical band gap. The index 'n' is associated with the type of transition which has values ½, 2 for direct and indirect transitions respectively [16-18]. In present thin filmsof $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) obey indirect transition rule ie. n = 2 and it has been shown in Fig 5.The intercept of the graph gives the optical band gap.The optical parameters of $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) thin film at a wavelength of 700 nm are given in Table 1.

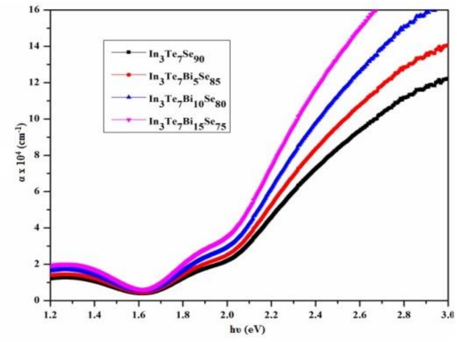

Fig. 4. Absorption coefficients versus photon energyin thin films of $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15).

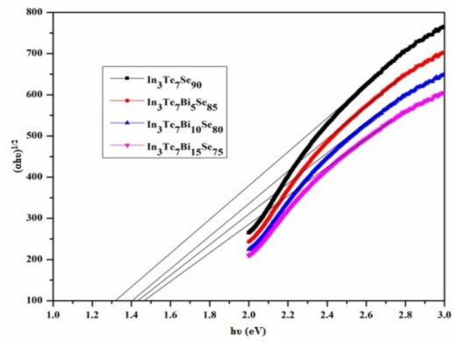

Fig.5. Plot of $(\alpha h\upsilon)^{1/2}$ against photon energy hυ (eV) in thin films of $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15).

Table 1.Optical parameters of $In_3Te_7Bi_xSe_{90-x}$(x = 0, 5, 10, 15) thin films at a wavelength of 700 nm.

Sample	E_g (eV)	α x 10^4 (cm^{-1})	k	n	Eu (eV)
$In_3Te_7Se_{90}$	1.38	3.46	0.283	4.13	0.58
$In_3Te_7Bi_5Se_{85}$	1.21	2.93	0.194	3.65	0.59
$In_3Te_7Bi_{10}Se_{80}$	1.12	2.12	0.163	3.28	0.61
$In_3Te_7Bi_{15}Se_{75}$	1.02	1.62	0.092	3.02	0.63

The value of optical band gap (E_g) has been calculated by taking the intercept on the X-axis. Calculated values for all samples of $In_3Te_7Bi_xSe_{90-x}$ are given in Table 1. It is evident from the table that the value of optical band gap (E_g) decreases with increasing bismuth content. This may be due to decrease in grain size, reduction in disordeness and decrease in density of defect states which results in increase of tailing bands [26-36].The decrease in the optical band gap can be discussed on the basis of density of state model proposed by Mott and Davis [37].Since chalcogenide thin films contain high concentration of unsaturated bonds or defects,therefore these defects are responsible for the presence of localized states in the amorphous semiconductor.

3.2.DC Conductivity

The DC conductivity of the $In_3Te_7Bi_xSe_{90-x}$ (x = 0, 5, 10, 15) thin films of thickness 400 nm was studied in the temperature range of 300 K-390 K using two probe method. The DC conductivity can be expressed by Arrhenius relation [37-41] as follows:

$$\sigma_{dc} = \sigma_0 exp\ (\Delta E/KT) \qquad (4)$$

where ΔE is called activation energy. K is Boltzmann constant and σ_0 is pre-exponential factor.

Fig.6shows the temperature dependent DC conductivity of thermally evaporated thin films.It is clear from the Fig. 13 that graph between 1000/T (K^{-1}) versus lnσ_{dc} gives straight line due to thermally activated process for dc conduction and its slope gives activation energy. The calculated values of conductivity (σ_{dc}), activation energy (ΔE) and σ_0 are given in Table 2.The conductivity increases with the increase in Bi content.It is suggested from the Table 2 that the conduction is due to thermally assisted tunneling of charge carriers in the localized states in band tails [42-46].

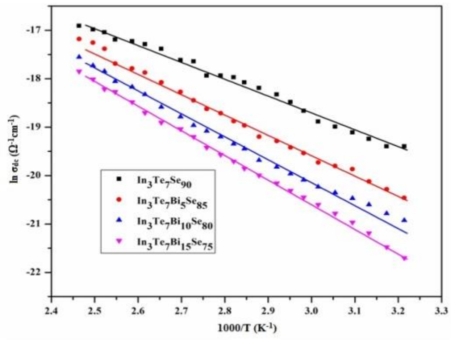

Fig. 6. Shows the plot between 1000/T (K^{-1}) versus ln σ_{dc}forIn$_3$Te$_7$Bi$_x$Se$_{90-x}$ (x = 0, 5, 10, 15) thin films.

The DC conductivity increases from 3.7 x 10^{-9} $\Omega^{-1}cm^{-1}$ for ternary glass to 2.6 x 10^{-4} $\Omega^{-1}cm^{-1}$ for quaternary glass at a temperature of 300K.The DC conductivity increases with increase of temperature for all samples of $In_3Te_7Bi_xSe_{90-x}$ (x = 0,5,10 and 15).This shows that these materials have characteristics of semiconductor. The activation energy decreases with increase of bismuth content which is likely due to increase in defects in the density of localized states [47-50]. The increase of the dc conductivity with decrease of activation energy with Bi concentration, we can show that the conduction is due to thermally assisted tunneling of charge carriers in the localized states present in the band tail. According to Davis and Mott [37], the activation energy alone does not indicate that this mechanism of conductivity is taking place in extended states above the mobility edge or by the hopping in localized states or due to the effect of impurity or defects.

For finding a distinction between these mechanisms, Davis and Mott suggested that the pre exponential factor for conduction in extended states should be two or three orders greater than the conduction in localized states. The magnitude of pre exponential factor (σ_0) lies in the range of 10^3 - 10^4 $\Omega^{-1}cm^{-1}$ which shows that the conduction is due to the excitation of charge carriers into the extended states. A still smaller value of σ_0 represents the conduction in localized states near the Fermi level. In this present samples, the value of σ_0 are much smaller 10^4 $\Omega^{-1}cm^{-1}$ (see Table 2) and hence the possibility of extended state conduction is completely ruled out and the localized state conduction in the band tails is most likely [51-52].

Table 2.Electrical parameters in $In_3Te_7Bi_xSe_{90-x}$ (x = 0,5,10 and 15) thin films at a temperature of 310 K.

Sample	σ_{dc} ($\Omega^{-1}cm^{-1}$)	σ_0 ($\Omega^{-1}cm^{-1}$)	ΔE (eV)
$In_3Te_7Se_{90}$	3.7 x 10^{-9}	3.1 x 10^{-3}	0.37
$In_3Te_7Bi_5Se_{85}$	2.1 x 10^{-7}	4.2 x 10^{-6}	0.21
$In_3Te_7Bi_{10}Se_{80}$	1.1 x 10^{-6}	2.8 x 10^{-7}	0.16
$In_3Te_7Bi_{15}Se_{75}$	2.6 x 10^{-4}	2.1 x 10^{-8}	0.12

4. Conclusion

Alloys of $In_3Te_7Bi_xSe_{90-x}$ (x = 0,5,10 and 15) have been deposited on ultraclean glass substrate by thermal evaporation technique at room temperature and under the pressure of 10^{-6}torr.XRD pattern confirms the amorphous nature of thin films.EDS analysis shows the presence of constituent elements in the thin films.SEM image tells surface morphology of the thin films. The optical band gap (E_g) decreases with increasing Bismuth concentration.This may be due to decrease in grain size, increasing disordeness and increase in density of defect states which results in increase of tailing bands.The optical absorption measurements shows indirect band transition which decreases with increase in bismuth concentration.The value of optical constants extinction coefficient (k) and refractive index (n) changes significantly with incident photon energy as well as with increasing bismuth concentration.The DC conductivity increases and the corresponding activation energy decreaseswhich may be due to increase in the density of localized states.

References

[1] Jacques Lucas,Current Opinion in Solid State and Materials Science **4**(2), 181 (1999).
[2] D. Lezal, J. Pedlikova, J. Zavadil, J. Optoelectron. Adv. M. **6**(1), 133 (2004).
[3] Benjamin J.Eggleton, Barry Luther-Davies, Kathleen Richardson,Nature photonics **5**(3), 141 (2011).
[4] Jean-Pierre Guin, Tanguy Rouxel, Jean-Christophe Sanglebœuf, Isabelle Melscoët, Jacques Lucas, Journal of the American Ceramic Society **85**(6), 1545 (2002).
[5] Manohar Lal, Navdeep Goyal, Indian journal of pure & applied physics **29**(4), 303 (1991).
[6] C. Quémard, F. Smektala, V. Couderc, A. Barthelemy, J. Lucas, Journal of Physics and Chemistry of Solids **62**(8), 1435 (2001).
[7] T. Cardinal, K. A. Richardson, H. Shim, A. Schulte, R. Beatty, K. Le Foulgoc, C. Meneghini, J. F. Viens, A. Villeneuve,Journal of Non-Crystalline Solids **256**, 353 (1999).
[8] M. A. Majeed Khan, M. Zulfequar, Sushil Kumar, M. Husain,Journal of Modern Optics **50(**2), 251 (2003).
[9] D. P. Gosain, T. Shimizu, M. Ohmura, M. Suzuki, T. Bando, S. Okano, Journal of materials science **26**(12),3271 (1991).
[10] Tran Tri Nang, Masahiro Okuda, Tatsuhiko Matsushita, Shigeaki Yokota, Akio Suzuki, Japanese Journal of Applied Physics **15**(5),849 (1976).
[11] N. F. Mott, E. A. Davis, Electronic processes in non-crystalline solids, Clarendon, Oxford, 465 (1979).
[12] V. Pandey, N. Mehta, S. K. Tripathi, A. Kumar, J. Optoelectron.Adv. M. **7**(5), 2641 (2005).
[13] Sharma, Pankaj, Neha Sharma, Sunanda Sharda, S. C. Katyal, Vineet Sharma,Progress in Solid State Chemistry **44**(4), 131 (2016).
[14] M. A. Khan, Majeed, M. Zulfequar, M. Husain, Journal of materials science **38**(3), 549 (2003).
[15] S. S. Ashraf, M. Zulfequar, M. Uddin, Chalcogenide Letters **15**(4),227 (2018).
[16] Sara A. Cortes,Miguel A. Muñoz Hernández, Hidetaka Nakai, Ingrid Castro-Rodriguez, Karsten Meyer, Alison R. Fout, Deanna L. Miller, John C. Huffman, Daniel J. Mindiola, Inorganic Chemistry Communications **8**(10),903 (2005).
[17] Syed S. Ashraf, M. Zulfequar, Moin Uddin, Recent Innovations in Chemical Engineering (Formerly Recent Patents on Chemical Engineering) **11**(3), 172 (2018).
[18] K. Oe, Y. Toyoshima, H. Nagai, Journal of Non-Crystalline Solids **20**(3), 405 (1976).
[19] H. Keller, J. Stuke, Physica status solidi B**8**(3), 831 (1965).
[20] T. Igo, U. Toyoshima,Journal of Non-Crystalline Solids **11**(4), 304 (1973).
[21] N. Shroff, A. K. Chakravarti, Electronics Information & Planning **18**(12), 673 (1991).
[22] Dirk J. Gravesteijn, Applied optics**27**(4), 736 (1988).
[23] E. Kh. Shokr, M. M. Wakkad,Journal of materials science **27**(5), 1197 (1992).
[24] Franz Urbach, Physical Review **92**(5),1324 (1953).

[25] J. Tauc, In Amorphous and Liquid Semiconductors, p. 159, Springer, Boston, MA, 1974.
[26] Shamshad A. Khan,M. Zulfequar, Zishan H. Khan, M. Ilyas, M. Husain, Optical Materials **20**(3), 189 (2002).
[27] M. Ilyas, M. Zulfequar, M. Husain,Journal of Modern Optics **47**(4),663 (2000).
[28] Noboru Tohge, Tsutomu Minami, Yoshitaka Yamamoto, Masami Tanaka,Journal of applied physics **51**(2), 1048 (1980).
[29] K. Sedeek, M. Fadel, Thin Solid Films **229**(2), 223 (1993).
[30] H. El-Zahed, A. El-Korashy,Thin Solid Films **376**(1-2), 236 (2000).
[31] Austine A.Mulama, Julius M. Mwabora, Andrew O. Oduor, Cosmas M. Muiva, Boniface Muthoka, Betty N. Amukayia, Drinold A. Mbete,New Journal of Glass and Ceramics **5**(02),16 (2015).
[32] M. V. Šiljegović, D. L. Sekulić, S. R.LukićPetrović, D. M. Petrović,Journal of Materials Science: Materials in Electronics **27**(2), 1655 (2016).
[33] AdyashaAparimita, MuktaBehera, C. Sripan, R. Ganesan, Shuvendu Jena, RamakantaNaik, Journal of Alloys and Compounds **739**,997 (2018).
[34] Pankaj Sharma, M. S. El-Bana, S. S. Fouad, Vineet Sharma, Journal of Alloys and Compounds **667**, 204 (2016).
[35] R. Golovchak, A. Kozdras, T. Hodge, J. Szlęzak, C. Boussard-Pledel, YaShpotyuk, B. Bureau,Journal of Alloys and Compounds **750**, 721 (2018).
[36] KumariAnshu, Ambika Sharma, Optik-International Journal for Light and Electron Optics **127**(1), 48 (2016).
[37] E. A. Davis, N. F. Mott,Philosophical Magazine **22**(179), 0903 (1970).
[38] V. Pandey, N. Mehta, S. K. Tripathi, A. Kumar, J. Optoelectron. Adv.M. **7**(5), 2641 (2005).
[39] S. A. Fayek, A. F. Maged, M. R. Balboul,Vacuum **53**(3-4), 447 (1999).
[40] A. S. Soltan, M. Abu El-Oyoun, A. A. Abu-Sehly, A. Y. Abdel-Latief,Materials chemistry and physics **82**(1), 101 (2003).
[41] K. Reddy, K. Venugopal, A. K. Bhatnagar, V. Srivastava,Journal of Physics: Condensed Matter **4**(23),5273 (1992).
[42] M. A. Khan, M. A Majeed, M. Zulfequar, M. Husain,Current Applied Physics **2**(5), 401 (2002).
[43] Brian Jeevan Fernandes, PumlianMunga, K. Ramesh, N. K. Udayashankar, Materials Today: Proceedings **5**(10), 21292 (2018).
[44]Yanina G.Fedorenko, Mark A. Hughes, Julien L. Colaux, C. Jeynes, Russell M. Gwilliam, Kevin Homewood, B. Gholipour et al., Thin Solid Films **589**, 369 (2015).
[45] DeepikaChoudhary, Hukum Singh, In International Conference on Fibre Optics and Photonics, p. Tu4A-50.Optical Society of America, 2016.
[46] Deepika, Hukum Singh, In AIP Conference Proceedings 1953(1), 090005 (2018).
[47] P. N. Musfir, S. Mathew, V. P. N. Nampoori, Thomas Sheenu, Chalcogenide Glass, Optik, (2019).
[48] A. Sharma, N. Mehta, Journal of Materials Science **50**(1), 210 (2015).
[49] Marco Nardone, M. Simon, I. V. Karpov, V. G. Karpov, Journal of Applied Physics **112(**7), 071101 (2012).
[50] Zishan H. Khan, M. Zulfequar, M. Ilyas, M. Husain, KhSelima Begum,Current Applied Physics **2**(2), 167 (2002).
[51] N. F. Mott, E. A. Davis, Electronic processes in non-crystalline semiconductors, Clarendon, Oxford, 220 (1979).
[52] M. A. Khan, M. A.Majeed, Sushil Kumar, M. Wasi Khan, M. Husain, M. Zulfequar, Materials Research Bulletin**45**(6), 727 (2010).
[53] A. Dahshan, Pankaj Sharma, K. A. Aly, Dalton Transactions **44**(33), 14799 (2015).