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Effect of Gamma Irradiation on Dielectric and AC Conductivity Studies of Bismuth Borate Glasses Doped with V_2O_5

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Abstract

Objectives: To study gamma ray irradiation effect on dielectric and AC conductivity of V_2O_5 doped bismuth borate glasses designed with the compositions $50B_2O_3$-(50-X)Bi_2O_3-XV_2O_5 where, X = 0, 0.2, 0.4, 0.6, 0.8, 1.0 and establishing the conduction mechanism. **Methods:** Glasses were synthesized by traditional melt quenching technique at 1323K. The prepared samples were subjected to annealing at 623K, which helps to remove strain in the samples. Absence of crystalline phases in the samples was confirmed by X-ray diffraction studies. An independent measurement of dielectric constant, dielectric loss and AC conductivity was carried out for temperature range from 300Kto 493K by impedance analyzer. **Findings:** The physical properties of glass were achieved by studying the density and the molar volume. Dielectric constant (ε') and dielectric loss (ε'') were measured as a function of temperatures in the range from 300K to 493K, over the frequencies 10^2Hz – 10^6Hz before and after gamma ray irradiation. AC conductivity (σ_{AC}) of the glasses was measured as a function of frequency for different temperatures before and after gamma ray irradiation. **Novelty:** For the first time, it was attempted that the effect of gamma ray irradiation on dielectric and AC conductivity properties of bismuth-borate glasses doped with vanadium oxide has been investigated. Here we have observed the change in the variation of dielectric constant, dielectric loss and AC conductivity with frequency and temperature before and after gamma ray irradiation. The borate network becomes more compact after being exposed to gamma rays, and the energy band gap may even narrow. Furthermore, it has been found that the composition of the glass influences how radiation impacts conductivity.

Keywords: Oxide Glasses; XRD; Gamma Ray Irradiation; Dielectric Properties; AC Conductivity

1 Introduction

Amorphous materials are drawing a lot of interest because of their distinctive properties, which include excellent corrosion resistance, chemical resistance, hardness, and transparency [1]. These materials that have been exposed to high energy gamma radiation are always a popular topic of research. When these materials are exposed to high intensity radiation, such as gamma rays or x-rays, they change in terms of their optical, chemical, magnetic, and electrical properties [2,3].

As one of the main glass formers, B_2O_3 (boric acid) can be found in almost all glass materials with commercial significance. Due to their fascinating characteristics in numerous fields, including science, technology, and industry, these glasses are an extremely fascinating group of materials [4]. Among all oxide glasses borate-based glasses have attracted a lot of interest, due to their exceptional qualities such as low melting point, strong thermal stability, great transparency and high dielectric constant. B_2O_3 is well-known glass former and has $[BO_3]$ and $[BO_4]$ structural units linked through B-O-B linkage [5,6].

Heavy metal oxide (Bi_2O_3) is considered to be a non-conventional oxide with a glass-forming ability that can form a stable glass with B_2O_3. Bismuth oxide has the ability to give a share in the glass network both as former and modifier oxide. Bismuthate glasses are good for the fabrication of infrared transmission component, ceramic super conductors, and photonic devices [7].

Transition Metal Oxide (TMO) doped borate glasses (especially the vanadium) presents unique electronic features that nominates it to the usage in many applications such as optical switching devices, optical fibre, threshold and memory switching devices [8].

It is important to study gamma ray interaction with a glass system as it can lead to various changes in glass structural, optical, and electrical properties. The radiation interaction with the host glass may result in the displacement of lattice atoms or electronic defects involving changes in the lattice or impurity atoms 'valence state' [9].

Borobismuthate glasses doped with vanadium oxide glasses were investigated for physical, optical and structural properties in earlier studies and reported that they have good semiconducting behaviour [10]. The AC conductivity has not been studied.

Arunkumar V. Banagar, et al. (2020) [11], have reported the DC conductivity of strontium vanadium borate glasses by varying V_2O_5. The frequency variation with conductivity has not been investigated. In our work instead of strontium oxide we have used bismuth oxide for better conductivity observation.

Pavan Kumar Potuganti, et al. (2020) [12] have investigated optical and AC conductivity characterization of alkaline earth borobismuthate glasses doped with nickel oxide. Gamma ray irradiation effects on AC conductivity have not been studied.

The previous researchers Sahar A.El-Ghany et al**.** (2020) [13], investigated the effect of gamma ray irradiation on structural, physical and optical properties of bismuth borate

glasses containing different transition metals. But gamma ray irradiation effect on AC conductivity has not been reported.

Roopa et al. (2020) [14], have been studied the gamma irradiation on structural and optical properties of zirconium incorporated sodium borate glasses. In their work irradiation on conductivity properties have not been investigated.

As seen in the above reported literatures bismuth borate glasses doped with vanadium oxide (V_2O_5) have not been studied for gamma ray irradiation effects on conduction mechanisms. Therefore to overcome these "limits" and it was planned to prepare bismuth borate glasses doped with vanadium oxide at different concentrations. Further we have made an attempt to study the effect of gamma ray irradiation on dielectric constant, dielectric loss and AC conductivity. The obtained results are presented in this paper.

2 Methodology

The glass samples were prepared with the composition of $50B_2O_3$-(50-X) Bi_2O_3-XV_2O_5 where, X= 0, 0.2, 0.4, 0.6, 0.8, 1.0, by traditional melt-quenching technique and labelled as BiBV1, BiBV2, BiBV3, BiBV4, BiBV5, BiBV6 respectively.

The Analytical Reagents (AR) with 99.9% purity (Loba Chemicals) H_3BO_3, Bi_2O_3 and V_2O_5 were used as starting materials. Appropriate amounts (in mol %) of these powders were weighed in electronic balance and mechanically grinded with the help of an agate mortar and pestle. The homogeneous composition was melted in a silica crucible by using a high temperature muffle furnace with PID controller at temperature around 1323K for three hours.

The transparent and free from air bubble melt was poured on a brass plate containing smooth polished inner surface at room temperature. The samples were subsequently annealed at 623K at cooling rate of 274K per minute. Finally the samples were cooled to room temperature and the samples were polished with appropriate dimensions.

The details of the preparation of glasses have been described in references [15,16].

Powder XRD studies were carried out for the confirmation of non-crystallinity nature of the prepared glasses. This experiment was carried out in a Rigaku make diffractometer with Cu-Kα radiation in the Bragg's angle range from 10^0 to 100^0.

Core attributes: 3 kW sealed X-ray tube, D/teX Ultra 250 silicon strip detector.

Core option: HyPix-400 (2D HPAD) detector.
Core dimension: 1270 (W) x 1880 (H) x 1220 (D) mm.
Power Requirements: 3Ø, 200 VAC 50/60 Hz 30 A.

The density (ρ) of the samples was measured by Archimedes principle using digital microbalance (WENSAR Co.Ltd) in a suitable measuring jar. The density was determined using the formula

$$\rho_g = \frac{W_a}{W_a - W_L}\rho_L \tag{1}$$

Where W_a, W_L and ρ_L are the weight of the glass in air, weight of the glass in immersion liquid and density of the immersion liquid (toluene, density=0.865gm/cm^3) respectively. The molar volume V_m was calculated by using the relation

$$V_m = \frac{M_w}{\rho_g} \tag{2}$$

Where M_w– molecular weight of glass sample and ρ_g – density of glass sample[17].

The samples of the range from 4.11 to 4.94 mm thickness and cross sectional area in the range 88 to 133 (in $10^{-6}m^2$) , the well shaped glass samples were silver coated on both surfaces for good electric contact. By measuring capacitance (C) and dissipation factor ($tan\delta$) by using LCR (HP 4263B) meter with the accuracy of 10^{-3} and 10^{-4} over the frequencies range 100Hz to 1MHz and in the temperature range 300K to 493K. Dielectric constant (ε') and dielectric loss (ε'') are computed by equations (3) and (4) respectively. The AC conductivity (σ_{AC}) at various frequencies of the glasses was computed by using equation (5).

$$\varepsilon' = \frac{Cd}{\varepsilon_0 A} \tag{3}$$

$$\varepsilon'' = \varepsilon' tan\delta \tag{4}$$

$$\sigma_{AC} = \omega\varepsilon_0\varepsilon'' \tag{5}$$

Where, ε_0 is the permittivity of free space, $\omega = 2\pi f$ (f is the applied frequency), d is the thickness of the samples were measured by using micrometer screw gauge, δ is the dissipation factor and A is the cross sectional area of the glass[18].

Gamma ray irradiation of the samples has been carried out in a gamma chamber manufactured by BRIT, Mumbai. Specifications: Model-GC5000, Source Used: Co-60, Activity: 518 TBq, Dose rate: 15KGy/Hour[19].

3 Results and discussion

3.1 X-ray Diffraction (XRD Studies

The x-ray powder diffraction patterns of prepared glass samples are shown in Figure 1 . No sharp peaks are observed in the spectra of the patterns, which confirm the amorphous nature of all the glass samples[20].

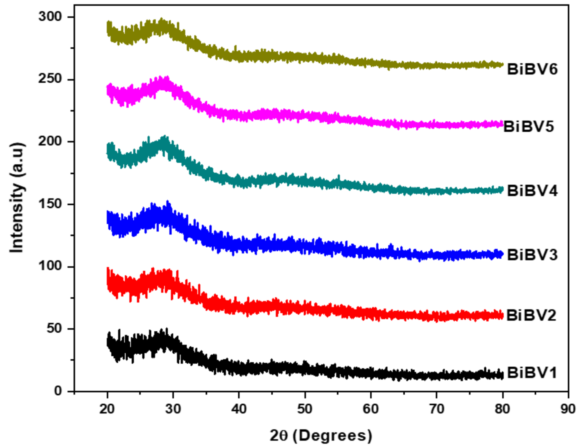


Fig 1. XRD patterns of prepared glass samples

3.2 Physical Properties

Table 1. Physical Properties of prepared glasses

Properties	Glass Samples					
	BiBV1	BiBV2	BiBV3	BiBV4	BiBV5	BiBV6
Density (g/cm3)	6.51	5.93	5.89	5.38	5.14	4.95
Molar Volume (cm3 / mol)	41.11	45.06	49.63	51.86	53.47	55.25

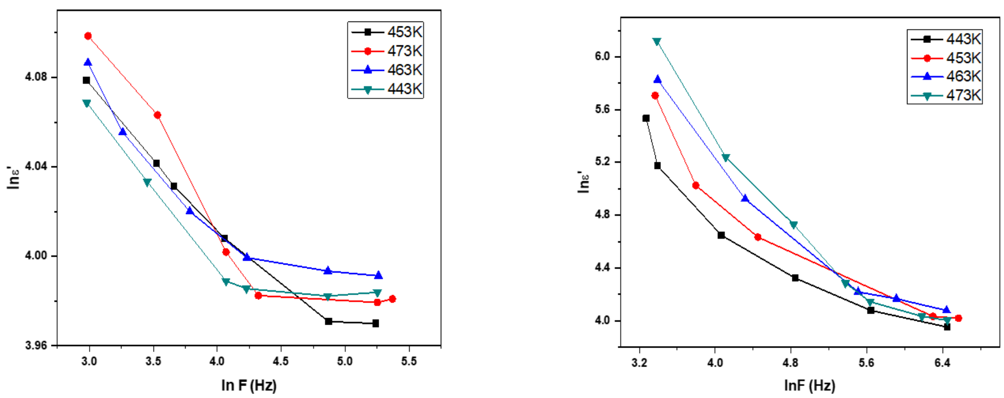
Density is an important physical property of a material which is capable to explain tightness in material structure. The measured densities along with molar volume were shown in Table 1. Densities of the samples were decreased from 6.5137 ± 0.0001 g/cm^3 to 4.9543± 0.0001 g/cm^3 as the concentration of vanadium oxide increases. In the same table , although the molecular weight of V_2O_5 is more than B_2O_3, density is found to not depend on V_2O_5 concentration and Bi_2O_3 has higher molar mass than V_2O_5 and B_2O_3.

The molar volume of the glass samples were enhanced with V_2O_5 content. This increase of V_M with V_2O_5 content describes the increase in the number of non-bridging oxygen (NBOs). The molar volume depends on both molecular weight and density. However, the decreasing rate in density and increasing rate in molecular weight by increasing V_2O_5.

3.3 Dielectric properties

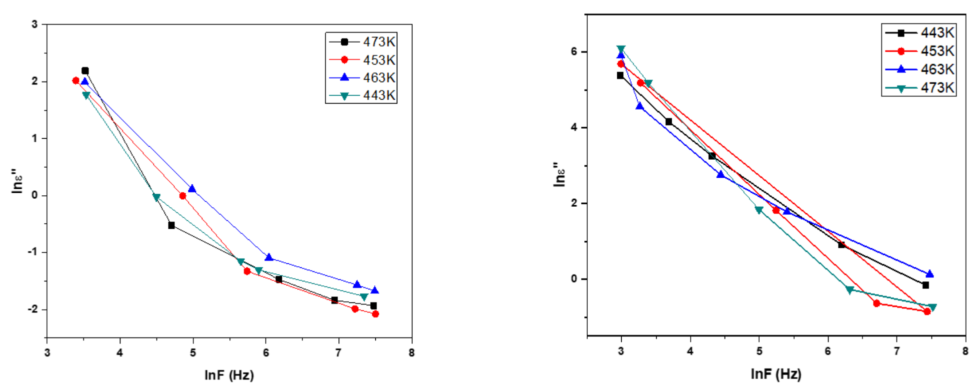
Dielectric measurements have been examined in the present set of glasses in the frequency range from 10^2 to 10^6 Hz. Figures Figure 2 (a) and Figure 3 (a) depicts the variations of dielectric constant (ε') and dielectric loss (ε'') with frequency at different temperatures before gamma ray irradiation. It has been observed from the figures that at low temperatures both these quantities show small variations with frequency. As the temperature increases, an increase in ε' as well as ε'' has been observed in the low frequency region. The nature of variations of both these parameters with temperature suggests that at low frequencies is mainly due to the space charge polarization effect. The values are compared with literatures and found these results are agrees with reports[21]. At higher frequencies of electric field, the hopping of charge carriers become less frequent which leads to a decrease in the polarization. This result leads in decrease the values of ε' and ε''. Further addition of vanadium ions may create more non-bridging oxygen ions. These non-bridging oxygen ions may create migration paths for the charge carriers which in turn increases space charge polarization and hence increases dielectric constant with temperature[22].

Figure 2 (b) and Figure 3 (b) depicts the variations of dielectric constant (ε') and dielectric loss (ε'') with frequency at different temperatures after gamma ray irradiation. It has been observed from the figures that at low temperatures, the behaviour of ε' and ε'' are similar to the values of before irradiation. But at higher frequency range, ε' and ε'' values nearly same due to glass network breaking because of high energy gamma irradiation.



(a) **(b)**

Fig 2. a) Variation of dielectric constant (ε') with frequency at different temperatures for BiBV5 glass before gamma irradiation. b) Variation of dielectric constant (ε') with frequency at different temperatures for BiBV5 glass, after gamma irradiation



(a) **(b)**

Fig 3. (a) Variation of dielectric loss (ε'') with frequency at different temperatures for BiBV5 glass, before gamma irradiation b) Variation of dielectric loss (ε'') with frequency at different temperatures for BiBV5 glass, after gamma irradiation

3.4 AC conductivity

AC conductivity versus frequency plots are depicted in figures Figure 4 (a) and (b), before and after gamma ray irradiation respectively. Small increase in σ_{AC} with frequency has been observed at lower temperatures. Temperature behaviour of ionic conductivity is an obvious behaviour of the glasses. An increase in temperature results in more hoppable ions available to contribute in conduction mechanism. Here the conductivity being contributed mainly by electron hopping between V^{4+} and V^{5+} ions. Due to small content of vanadium in our composition, we have observed only the variation of ac conductivity with frequency at different temperatures. The observed variations are agreed with reports, and we tried to calculate the conduction parameters like s value, beta value, etc. But we have not got the agreeable values of literature due to small content of vanadium in the composition[(23)].

After gamma ray irradiation we have observed small changes in the variations of conductivity with frequency at low and high temperature due to glass network breaking.

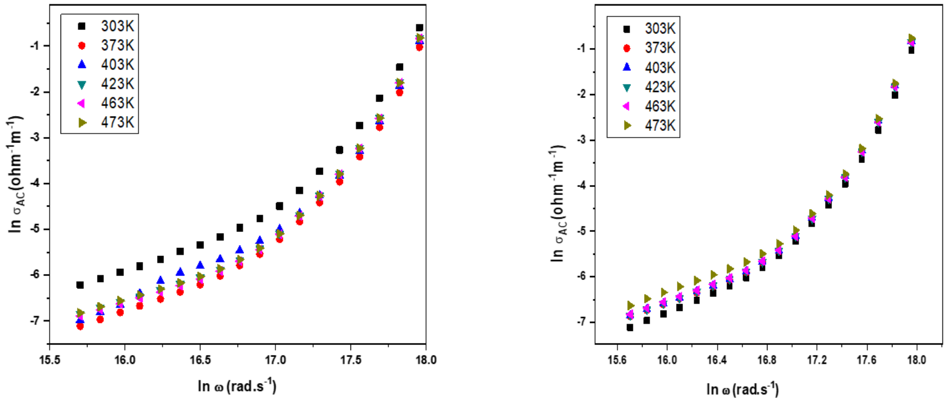


Fig 4. a) Variation in AC conductivity (σ_{AC}) with frequency at different temperatures for BiBV5 glass, before gamma irradiation. b) Variation in AC conductivity (σ_{AC}) with frequency at different temperatures for BiBV5 glass, after gamma irradiation

3.5. Gamma Ray Irradiation Effects

Gamma ray irradiation has a significant effect on the dielectric properties of bismuth borate glasses. Gamma irradiation can lead to the formation of colour centres, which can alter the refractive index and absorption coefficient of the glasses. This result leads to changes in the dielectric constant and tangent loss of the glasses. Additionally, gamma irradiation can also lead to the creation of defects in the glass structure, which can also affect the dielectric properties of the glasses. The extent of these changes will depend on the dose of gamma rays and the specific composition of the glasses[(24)].

The structural changes of the glasses due to gamma ray irradiation can affect the electrical properties of the glasses, such as the AC conductivity. Gamma irradiation can also leads to an increase in the number of free electrons and holes in the glass network, resulting in an increase in the AC conductivity. The extent of these changes will depend on the dose of gamma rays and the specific composition of the glasses[(25)].

4 Conclusion

Composition of glasses $50B_2O_3$-(50-X) Bi_2O_3-XV_2O_5 where, x = 0, 0.2, 0.4, 0.6, 0.8, 1.0, were prepared by conventional melt quenching technique. The XRD studies confirm amorphous nature of the prepared glasses. The density of the borate glass doped with vanadium content decreases with replacement of Bi_2O_3, due to the fact that Bi_2O_3 has higher molar mass than V_2O_5.

It was a new attempt of the present work, how dielectric constant, dielectric loss and AC conductivity of prepared glasses varies with respect to frequency and temperature at high energy gamma ray irradiation. The observed results before gamma irradiation are in agreed with the literature values. But after high energy gamma ray irradiation it was observed that remarkable changes in electrical properties and some parameters were not observed due to the glass network breakage and creation of defects in the network.

The borate network becomes more compact after being exposed to gamma ray irradiation and there is possibility of the energy band gap may even narrow. Furthermore, it has been found that the composition of the glass influences with radiation effects. Gamma ray irradiation leads to the creation of defects in the glass structure, which also affect the dielectric properties and AC conductivity of the glasses.

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References

1) Bhogi A, Kistaiah P. Thermal and structural characterization of lithium borate glasses doped with Fe(III) ions: The role of alkaline earths. *Optical Materials*. 2020;109:110345. Available from: https://doi.org/10.1016/j.optmat.2020.110345.
2) Krishnan ML, Kumar VVRK. Structural and optical properties of γ-ray irradiated BaF2– Bi2O3–SiO2Glasses. *Journal of Luminescence*. 2020;217:116745. Available from: https://doi.org/10.1016/j.jlumin.2019.116745.
3) Abd-Elnaiem AM, Saudi HA, Zakaly HMH, Issa SAM, Rashad M. The effect of composition and γ-irradiation on the Vickers hardness, structural and optical properties of xLiNbO3-25CaO-35PbO-(40-x) waste systems. *Ceramics International*. 2021;47(13):18751–18760. Available from: https://doi.org/10.1016/j.ceramint.2020.03.210.
4) Bhogi A, Kistaiah P. Spectroscopic properties of alkali alkaline earth borate glasses doped with Fe3+ ions. *Journal of the Australian Ceramic Society*. 2020;56(1):127–138. Available from: https://doi.org/10.1007/s41779-019-00426-3.
5) Srinivas B, Bhogi A, Naresh P, Chary MN, Shareefuddin M, Alrowaili ZA, et al. Fabrication, optical and radiation shielding properties of BaO-TeO2-B2O3-Cr2O3 glass system. *Optik*. 2022;258:168877. Available from: https://doi.org/10.1016/j.ijleo.2022.168877.
6) Mohamed SN, Halimah MK, Subban RHY, Yahya AK. AC conductivity and dielectric properties in mixed ionic–electronic 20Na2O–20CaO–(60 – x)B2O3–xV2O5 glasses. *Physica B: Condensed Matter*. 2021;602:412480. Available from: https://doi.org/10.1016/j.physb.2020.412480.
7) Sallam OI, Ezz-Eldin FM, Elalaily NA. Influence of doping transition metals and irradiation on some physical properties of borate glass. *Optical and Quantum Electronics*. 2020;52(4):1–20. Available from: https://doi.org/10.1007/s11082-020-02319-3.
8) Ahmed EM, El-Ghamaz NA, Albhbah SM. Limited frequency domain of the ac conductivity of some As2O3.V2O5.CuO.Nd2O3 glasses. *Journal of Non-Crystalline Solids*. 2021;558:120659. Available from: https://doi.org/10.1016/j.jnoncrysol.2021.120659.
9) Fayad AM, Shaaban KS, Abd-Allah WM, Ouis M. Structural and Optical Study of CoO Doping in Borophosphate Host Glass and Effect of Gamma Irradiation. *Journal of Inorganic and Organometallic Polymers and Materials*. 2020;30(12):5042–5052. Available from: https://doi.org/10.1007/s10904-020-01641-3.
10) Pothuganti PK, Bhogi A, Kalimi MR, Reniguntla P. Physical and Optical Properties of Borobismuthate Glasses Containing Vanadium Oxide. *Glass Physics and Chemistry*. 2020;46(2):146–154. Available from: https://doi.org/10.1134/S1087659620020078.
11) Banagar AV, Kumar MP, Nagaraja N, Tipperudra A, Jakati S. DC electrical conduction in strontium vanadium borate glasses. *Materials Science-Poland*. 2020;38(2):359–366. Available from: https://doi.org/10.2478/msp-2020-0022.
12) Pothuganti PK, Bhogi A, Kalimi MR, Reniguntla PS. Optical and A.C conductivity characterization of alkaline earth borobismuthate glasses doped with nickel oxide. *Optik*. 2020;220:165152. Available from: https://doi.org/10.1016/j.ijleo.2020.165152.
13) El-Ghany SA, Nabhan E, Saudi HA. Effect of gamma ray on some properties of bismuth borate glasses containing different transition metals. *SN Applied Sciences*. 2020;2(5):1–1. Available from: https://doi.org/10.1007/s42452-020-2115-7.
14) Roopa, Eraiah B. Effect of Gamma Irradiation on Structural and Optical Properties of Zirconium Incorporated Sodium Borate Glasses. *Transactions of the Indian Ceramic Society*. 2020;79(2):67–76. Available from: https://doi.org/10.1080/0371750X.2020.1715839.
15) Husenkhan DB, Sankarappa T, Malge A. DC Conductivity of Lithium-Zinc-Boro- Phosphate Glasses. *Indian Journal of Science and Technology*. 2021;14(46):3416–3424. Available from: https://doi.org/10.17485/IJST/v14i46.1890.
16) Prabhu NS, Hegde V, Sayyed MI, Agar O, Kamath SD. Investigations on structural and radiation shielding properties of Er3+ doped zinc bismuth borate glasses. *Materials Chemistry and Physics*. 2019;230:267–276. Available from: https://doi.org/10.1016/j.matchemphys.2019.03.074.
17) Ouis MA, Abd-Allah WM, Sallam OI. Gamma ray interaction with soda lime silicate glasses doped with V2O5, CuO or SrO. *Applied Physics* . 2022;128(5):1–2. Available from: https://doi.org/10.1007/s00339-022-05522-z.
18) Malge A, Sankarappa T, Sujatha T, Ashwajeet JS, Devidas GB. Dielectric properties and AC conductivity of rare earth ions doped borotellurite glasses. *AIP Conference Proceedings* . 2019;2161:20026. Available from: https://doi.org/10.1063/1.5127617.
19) Madhukumar R, Byrappa K, Wang Y, Sangappa Y. Effect of gamma irradiation on synthesis and characterization of bio-nanocomposite SF/Ag nanoparticles. *Radiation Effects and Defects in Solids*. 2017;172(11-12):915–921. Available from: https://doi.org/10.1080/10420150.2017.1418873.
20) Barde RV, Nemade KR, Waghuley SA. Impedance spectroscopy study of the AC conductivity of sodium superoxide nanoparticles doped vanadate based glasses. *Materials Science for Energy Technologies*. 2021;4:202–207. Available from: https://doi.org/10.1016/j.mset.2021.06.004.
21) Boora M, Malik S, Kumar V, Bala M, Arora S, Rohilla S, et al. Investigation of structural and impedance spectroscopic properties of borate glasses with high Li+ concentration. *Solid State Ionics*. 2021;368:115704. Available from: https://doi.org/10.1016/j.ssi.2021.115704.
22) Pothuganti PK, Bhogi A, Kalimi MR, Reniguntla PS. Influence of TiO2 ions on structural properties and AC conductivity of BaO-Bi2O3-B2O3 glass system. *Materials Today: Proceedings*. 2021;38:2200–2204. Available from: https://doi.org/10.1016/j.matpr.2020.05.770.
23) Japari SJ, Yahya AK, Hisam R. Effects of mixed-alkali oxides on AC conductivity and dielectric properties of xNa2O-(20-x)K2O-30V2O5-50TeO2 glasses. *Results in Physics*. 2020;16:102905. Available from: https://doi.org/10.1016/j.rinp.2019.102905.
24) Ramesh P, Hegde V, Keshavamurthy K, Pramod AG, Jagannath G, Aloraini DA, et al. Influence of gamma irradiation on photoluminescence and nonlinear optical properties of Eu3+ activated heavy metal borate glasses. *Optical Materials*. 2021;116:111102. Available from: https://doi.org/10.1016/j.optmat.2021.111102.
25) Madhu A, Eraiah B, Srinatha N. Gamma irradiation effects on the structural, thermal and optical properties of samarium doped lanthanum–lead- borotellurite glasses. *Journal of Luminescence*. 2020;221:117080. Available from: https://doi.org/10.1016/j.jlumin.2020.117080.