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Effect of Gamma-ray on Producing Induced Colour Centres and on Positron Annihilation Lifetime of Bismuth-doped zinc Sodium Borate Glasses

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ABSTRACT

A melt quenching method have been used for preparing a glass composition of the form (70-x)%B_2O_3-15%ZnO-15%Na_2O-x%Bi_2O_3 (where x = 0, 5, 10, 15, 20, 25 mol %). The prepared glass was studied by FTIR and Positron annihilation lifetime measurements. FTIR analysis after 80 kGy γ-irradiation of bismuth-doped glass samples, show the dependence of the number of structural units BO_3 and BO_4 on the γ-irradiation dose. FTIR absorption spectra revealed that gamma irradiation produces a degree of a disorder or defects of the glass network which producing colour centres. The objective FTIR spectra were used to estimate the N_4 ratio and its dependence on the composition. Positron annihilation lifetime measurements were carried out for all samples before and after 80 kGy γ-irradiation. Irradiated samples show a colour change, which is most likely due to the formation of colour centres. Such colour changes due to γ-irradiation allow estimating that the prepared glass samples can be used as a shielding material or as a radiation indicator sensor.

1-INTRODUCTION

Glasses are important materials used in a radiation shielding. Shielding properties of the glass materials for gamma radiation and neutron sources can be improved by the addition of suitable modifier oxides. These modifiers are heavy metal oxides and have been used as an external agent in the glass compositions such as Bi_2O_3, PbO, CuO,..etc. [1, 2].

Gamma irradiation may produce a glass defect due to the change in the valence state of lattice and impurity atoms. Thus, glass becomes coloured due to the formation of colour centres [3, 4]. The formation of centres is of many types according to the glass composition [5, 6]. They are associated with optical absorption bands and EPR signals. Several spectroscopic techniques are used to describe the defect centres or colour centres induced by ionizing radiation as optical absorption, infrared and Raman spectroscopy [7] and positron annihilation lifetime spectroscopy [8, 9].

Positron annihilation lifetime (PAL) spectroscopy is one of the most remarkable techniques to investigate open volume in amorphous materials [10-12]. The positron annihilation life is measured using a sodium isotope (^{22}Na) as a positron source to be placed between two identical samples to be measured. Positrons will slow down after implantation into the investigated samples. There are three different pathways to positron annihilation. The first is the direct annihilation process with an electron, the second and third processes are called Positronium (Ps) which occurs after the formation of a positron-bound state with an electron. They depend on the relative spin of the two particles. These are Para-positronium (p-Ps) and Ortho-positronium (o-Ps). Para-positronium (p-Ps) occurs when the two relative spins are anti-parallel, while ortho-positronium (o-Ps) occurs when the two relative spins are parallel. Para-Ps (*p*-Ps anti-parallel spin) and Ortho-Ps (*o*-Ps parallel spin) can be found in a vacuum with intrinsic lifetimes 0.125 and 140 ns respectively [13]. The o-Ps is localized in a free-volume hole or pore. Its lifetimes shorten to 1-10 ns and could be related to the free volume hole size depending on the free volume properties of the prepared sample[14]. Each lifetimes component (τ_i) of positron annihilation has a corresponding intensity (I_i) related to

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the relative number of annihilations occurring at a particular lifetime. The o-Ps intensity ($I_{o\text{-}Ps}$) is proportional to the number of free volume holes. Therefore, the Positron annihilation lifetime (PAL) technique gives valuable information on both the average size and the relative number of free volume holes probed by o-Ps.

The main objective of the present work is to study the effect of 80 kGy γ-irradiation on the formation of defect centres or colour centres. The study includes Fourier transform infrared spectroscopy (FTIR) and Positron annihilation lifetime (PAL) spectroscopy in addition to density, molar volume, x-ray diffraction and energy band gap discussed in previous articles [15, 16] needed for this investigation. The investigated glassy system with purity up to 99.5% has the composition (70-x)% B_2O_3-15%ZnO-15%Na_2O-x%Bi_2O_3 (x = 5, 10, 15, 20, 25 mol%).

2-Experimental Procedures

Infrared absorption spectra of the prepared glass samples (70-x)% B_2O_3-15%ZnO-15%Na_2O-x%Bi_2O_3 (x = 5, 10, 15, 20, 25 mol%)[15, 16] after 80 kGy γ-irradiation has been measured at room temperature in the range 400-4000 cm^{-1}. Fourier Transform infrared spectrometer of the type (Thermo Nicolet 200 spectrometer) was used. The prepared glass samples were ground as a fine powder and mixed with potassium bromide (KBr) at a ratio 1: 100 mg. The mixtures were subjected to a pressure of 12 ton/cm^2 to produce small homogeneous pellets. The infrared absorption measurements are measured immediately after preparing the pellets.

The fast-fast coincidence spectrometer [17] with a resolution of ~350 ps using a ^{60}Co source at room temperature was used for the positron lifetime measurements. About 15 μCi of ^{22}Na activity was deposited and dried on a thin Kapton foil (7.6 μm thick). It is covered with an identical foil and afterward glued with epoxy glue. This assembly was used as the positron source sandwiched between two indistinguishable samples. Each sample was measured at least 2-3 times differed by a total number of elementary annihilation events in the range of 1- 2 million counts. The obtained spectra were analyzed using the L.T. computer program of Kansy [18], with a suitable correction for the positrons annihilated in the Kapton.

Three-lifetime components (τ_1, τ_2, and τ_3) were produced from the analysis of the measured spectra. The first- lifetime component τ_1 is due to the Par-Positronium (p-Ps) atom, which is fixed to the value 0.125 ns. While the intermediate lifetime component τ_2 is attributed to the direct annihilation of positrons with an electrons. However, the longest lifetime component τ_3 is related to the annihilation of Ortho-Positronium by "pick off" mechanism in the free volume sites present in the amorphous regions [19]. All these components were determined by the fit's variance ranged from 1.005 to 1.18. The determination of the o-Ps lifetime components, τ_3, provides valuable information about the mean size of free volume cavities probed by o-Ps. The third-lifetime component of the o-Ps according to the free-volume model [14], is given by the expression [20, 21]:

$$\tau_3 = 0.5[1 - (\frac{R}{\delta R+R}) + (1/2\pi)\,\mathrm{Sin}(\frac{2\pi R}{\delta R+R})\,]^{-1} \qquad \textbf{(1)}$$

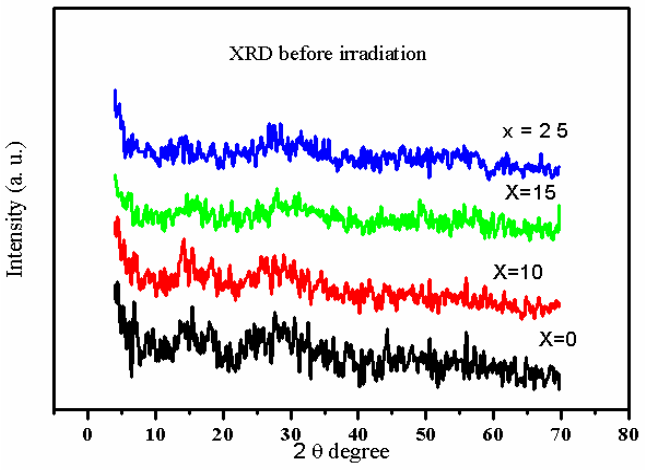
Where R is the free volume radius, R_0 is the spherical potential well radius and $\delta R = R_0 - R = 1.656$Å is the fitted empirical electron layer thickness. With this value of δR, the free volume radius R was calculated from Eqn.1 and the average size of the free volume holes V_f was determined from $V_f = (4/3)\pi R^3$ (in $Å^3$). Furthermore, the free volume hole fraction, F_v, can be found from the empirical equation [22]:

$$F_v = C\, V_f\, I_3 \qquad \textbf{(2)}$$

where V_f is in angstrom cube and *C* is an arbitrarily chosen scaling factor for a spherical cavity.

3-RESULTS AND DISCUSSIONS

X-ray diffraction patterns of the prepared glass samples listed in table 1 before and after 80 kGy gamma irradiation that studied in the previous articles [15, 16, 23] are shown in fig. 1. The figure exhibits no sharp peaks confirming the non-crystalline nature. Moreover, it reveals that the irradiated samples show a hump which might be due to form small crystallites in the nano range.



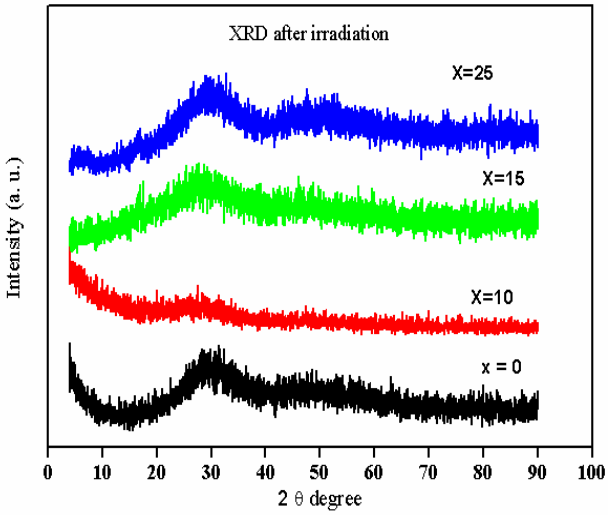
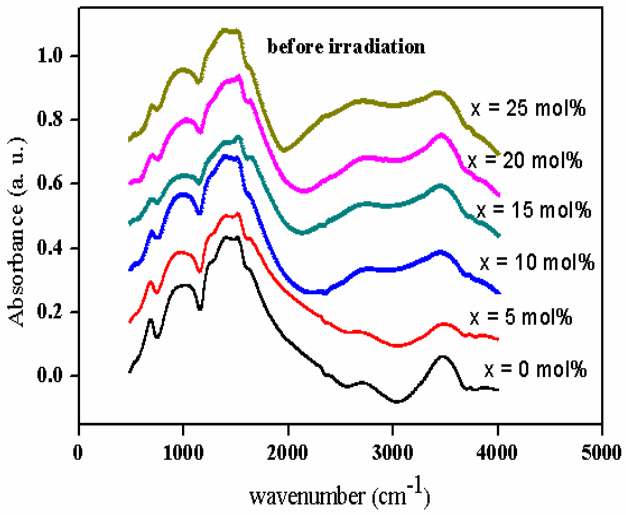


Fig. (1): XRD pattern of the glass samples before and after 80 kGy γ-irradiation

Table (1): Compositions of glasses (in mol %) prepared in the present work.

X	Glass system
0	70 B_2O_3 0Bi_2O_3 15ZnO 15Na_2O
5	65 B_2O_3 5Bi_2O_3 15ZnO 15Na_2O
10	60 B_2O_3 10Bi_2O_3 15ZnO 15Na_2O
15	55 B_2O_3 15Bi_2O_3 15ZnO 15Na_2O
20	50 B_2O_3 20Bi_2O_3 15ZnO 15Na_2O
25	45 B_2O_3 25Bi_2O_3 15ZnO 15Na_2O

FTIR absorption spectra of the prepared glass samples after 80 kGy γ-irradiation as well as that before irradiation that was discussed in the previous article [23] are shown in Fig.2.



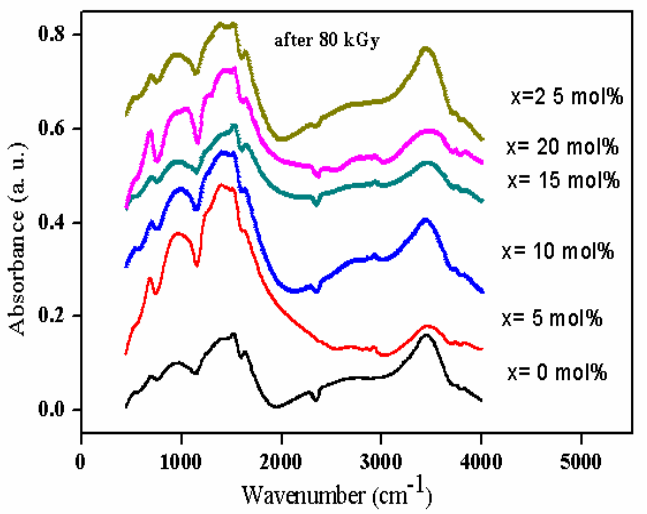


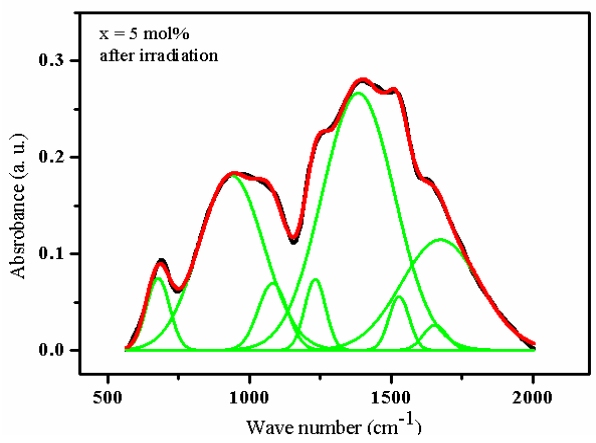
Fig. (2): Infrared spectra of the investigated glass (70-x) B_2O_3 - xBi_2O_3-15ZnO-15Na_2O mol% before and after 80 kGy γ-irradiation.

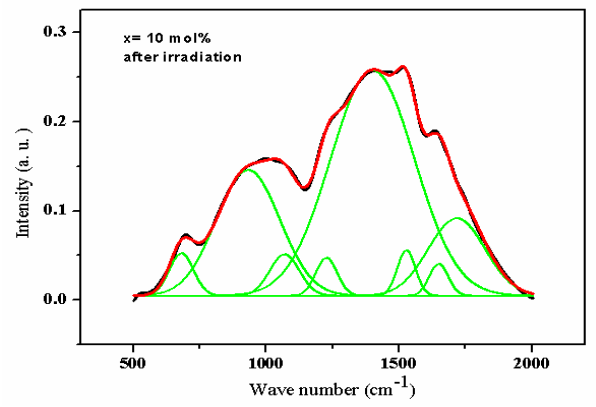
The figure reveals that γ-irradiation does not affect on the band positions. The only observed changes are in the intensity of the bands. FTIR intensity of the bands for each Bi_2O_3 concentrations of the glass samples after 80 kGy γ-irradiation in the region 500-1600 cm^{-1} are decreased than the corresponding one before irradiation except at 5 mol%. The decrease in the intensity of these bands with the higher Bi_2O_3 concentrations is attributed to the gamma-ray distorted the octahedral BiO_6 units into two groups of BiO_3 of short and long Bi-O bonds and forming BO_3 structural units [24, 25]. This result agrees very well with the increase in the values of N_4 ratio after 80 kGy γ-irradiation than the corresponding one before irradiation when Bi_2O_3 concentration changes up to 25 mol% as listed in Table 2, where the ratio N_4 is defined as the ratio of [concentration BO_4 units / concentration of (BO_4 + BO_3) units]. The increase in N_4 ratio means a decrease in BO_4 tetrahedral units which responsible for the increase in the non-bridging oxygen and vacancies. Therefore, γ-irradiation, due to liberating oxygen bonds, producing a degree of disorder or defect centres of the present glass samples referred to colour centres [3, 5]. These colour centres are responsible for changing the glass colours from yellow to dark brown [15]. Also, the increase in the intensity after 80 kGy γ-irradiation than that before irradiation for each Bi_2O_3 concentration in the region 2500-3500 cm^{-1} is due to gamma-ray breaks down more water molecules and liberating oxygen bonds that create stable defects in the prepared glass samples[26].

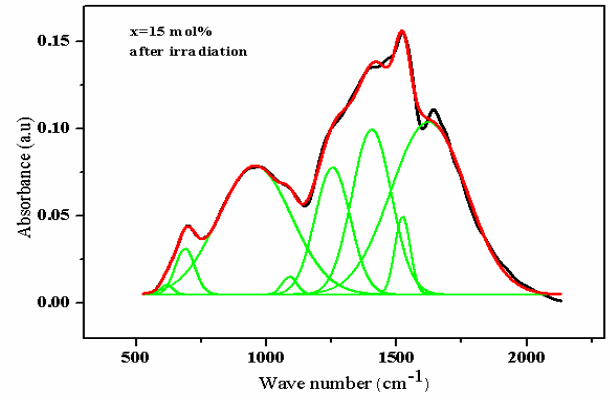
Table (2): N_4 ratio before and after 80 kGy γ-irradiation with Bi_2O_3 concentration

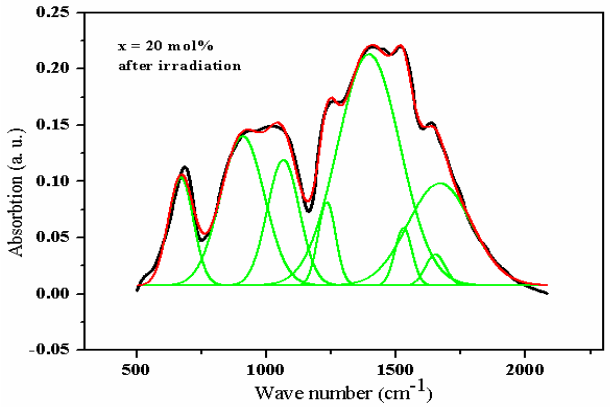
Bi_2O_4 concentration mol%	N_4 before 80 kGy γ-irradiation [23]	N_4 after 80 kGy γ-irradiation
5	0.34	0.396
10	0.296	0.541
15	0.227	0.437
20	0.327	0.416
25	0.262	0.291

Extensive investigation of the effect of 80 kGy γ-irradiation on bismuth-doped ZnO-Na_2O-B_2O_3 glasses reveals that the intensity of the infrared spectral bands in the region 500-1700 cm^{-1} changes as the bismuth concentrations change. It increases when bismuth concentration reaches to 5 mol%, decreases when Bi_2O_3 concentration changes from x= 5 to 15 mol%, increases when Bi_2O_3 concentration changes from x=15 to 20 mol%, and finally returns to decrease when Bi_2O_3 concentration changes from 20 to 25 mol%. The interpretation of these spectra can be carried out according to the concept introduced by Tarte and Condrate [27, 28] and applied by Dimitriev et al., Dimitrov et al. and Gattef et al.[29-31]. In such case, the deconvoluted spectra and the assignments of the observed bands after 80 kGy γ-irradiation for the investigated glass samples are given in fig.3 and tables 3.









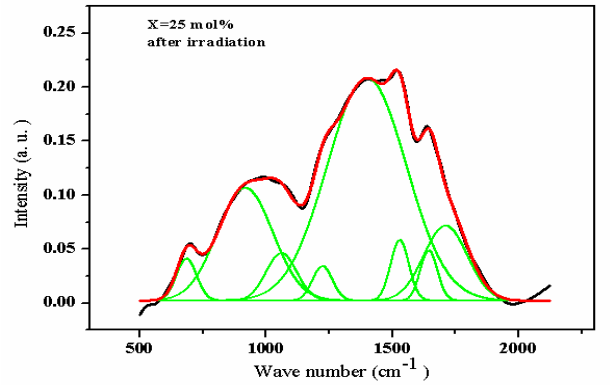


Fig. (3): Deconvolution of the infrared spectrum of the glass (70-x) B_2O_3-xBi_2O_3-15ZnO-15 Na_2O mol% after 80 kGy γ-irradiation.

Table (3): Assignments of absorption bands of the infrared spectra of the glass samples (70-x) B_2O_3 -xBi_2O_3-15ZnO-15Na_2O mol % after 80 kGy.

Wavenumber	IR band assignments (cm^{-1})
500-600	Bi–O–Bi + Bi–O in BiO_3 group.
600-800	Bi–O vibration.
900-1200	Stretching vibration of B-O bonds of BO_4 units in various structural from tri, tetra and penta borate groups.
1300-1700	B–O stretching vibrations of trigonal BO_3 units only.
2000-3500	Hydrogen bonding of molecular water.

The deconvoluted spectra indicate that there is no beak at 830 cm^{-1}, so the vibrations of octahedral BiO_6 units will be considered only than trigonal pyramidal BiO_3 units [32]. The decrease in the FTIR intensity of the bands in the region 800-1200 cm^{-1} which observed at the peaks 889, 1045 cm^{-1} when Bi_2O_3 concentration changes from 5 to 15 mol% signify the increase of the local disordering of the structural units due to the conversion of BO_4 units into BO_3 units and therefore, increasing the non-bridging oxygen and vacancies [33-35]. This is due to γ-irradiation breaks Bi-O bonds of BiO_6 and contributes to the BO_4 units with Bi^{+3} ions to form trigonal bipyramidal BO_4Bi units and producing the non-bridging oxygen [30, 31, 36]. While the increase in the FTIR intensity in the same region with the addition of Bi_2O_3 concentration from 15 to 20 mol% is due to Bi_2O_3 gives its oxygen atom to the boron atom to create a four coordinated state (BO_4) and bridging oxygen [37]. The conversion to BO_4 structural units is consistent with the extensive decreasing in the N_4 ratio after 80 kGy γ-irradiation when Bi_2O_3 content increases up to 25 mol% as shown in Fig. 4 and listed in Table 2. The decline in N_4 ratio indicates the increase in BO_4 tetrahedral units at the expense of BO_3 trigonal units. This means that the increase in the Bi_2O_3 concentration to 25 mol% during the exposure of the glass samples to 80 kGy γ-irradiation producing un-defined structural configuration i.e. a stable defect occurs which referred to a colour centres [3, 5]. Therefore, the glass with increasing Bi_2O_3 content is considered as a good shielding material for radiation[38]. On the other hand, the decrease in the FTIR intensity of the bands in the region 1200-1700 cm-1 which is observed at the peaks 1227, 1383, 1513, 1630 cm-1 when Bi2O3 changes from 5 to 15 mol% marks the change taking place in the glass structure which results in the transformation of BO3 structure units to BO4 units and therefore the non-bridging oxygen, as well as vacancies, decreases [39, 40]. Moreover, the change in the intensity of the FTIR spectra in the region 600-800 cm-1 which observed at 670 cm-1 are attributed to the combination of the Bi-O vibrational bonds [41, 42] and some superstructure borate units [43]. This is due to the addition of Bi2O3 responsible for the existence of both BiO3 and BiO6 units alone or together [42, 36].

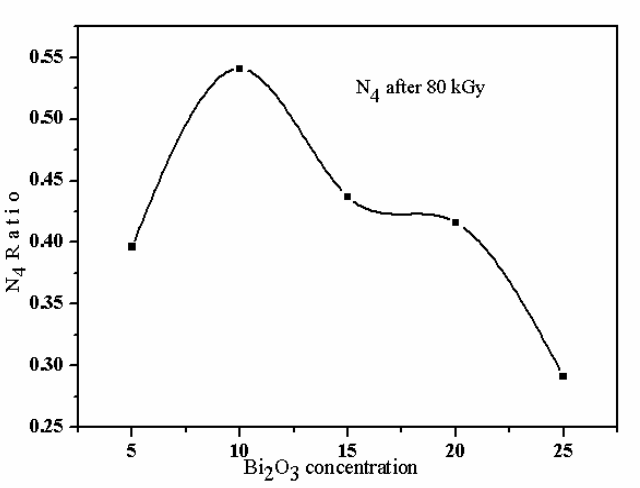


Fig. (4): N_4 ratio after 80 kGy γ-irradiation versus Bi_2O_3 concentration.

The above arguments agree very well with the anomalous behaviour of the energy gap and density ρ after 80 kGy γ-irradiation with the change in Bi_2O_3 concentrations [15]. Thus gamma irradiation yields a change in the structural configuration of the characteristic groups in the glass network. Therefore, the obtained FTIR data allows concluding that γ-irradiation causes cyclic effects i.e. firstly break some chemical bonds of BO_3 or BO_4 and then reforming other bonds of BO_4 or BO_3 respectively [44, 45]. Therefore, gamma irradiation produces a degree of glass network disorder or defects. This results in a change in the optical and physical properties especially to visible colouration which often referred to as colour centres [3, 4]. This is confirmed with the change in the colour of the glass samples from yellow to dark brown as gamma irradiation increases from 40 kGy to 80 kGy [15]. Therefore, bismuth borate glass can be used as a shielding material or radiation-sensitive to successive gamma irradiation [3, 38, 46, 47].

Positron annihilation lifetime (PALS) spectra were analyzed before and after 80 kGy γ-irradiation. The lifetime components (τ_1, τ_2, and τ_3) of positron annihilation have been estimated, along with their intensities (I_1, I_2 and I_3).

Fig. 5 shows the variation dependence of I_1 on Bi_2O_3 concentration before and after 80 kGy γ-irradiation where its lifetime component is fixed to 125 ps. It reveals that before irradiation I_1 intensity decreases from 32% to 18.7% when Bi_2O_3 concentration changes from 5% to 10 mol%. However, when Bi_2O_3 content changes from 10% to 20 mol%, I_1 is almost constant at about 18.7% and increases to 28.7% when Bi_2O_3 content

reaches to 25 mol%. After 80 kGy γ-irradiation, I_1 increased from 19.7% to 36% in the range (5-20 mol%) of Bi_2O_3 concentration, then decreased to reach 30.6% at the Bi_2O_3 content of 25 mol% for the measured samples. The increase of I_1 for the measured samples after 80 kGy γ-irradiation when Bi_2O_3 concentration changes up to 20 mol% can be attributed to the increase of the free electron concentration which interacts with the positron to form a para-positronium atom. This is may be due to the increase in Bi_2O_3 concentration during the exposure of 80 kGy γ-irradiation decreases the rate of producing the non-bridging oxygen caused by γ-irradiation. While at higher bismuth concentration of 25 mol% there is anomalous behaviour. Although the increase in Bi_2O_3 concentration increases BO_4 units and bridging oxygen [37] and consequently I_1 increases, I_1 decreased. This is confirming that γ-irradiation produces something change in the glass matrix, i.e. producing the defect centres. This result agrees with the FTIR analysis that gives a conclusion that the higher addition of Bi_2O_3 in ZnO-Na_2O-B_2O_3 glasses make them a good shielding material for gamma- radiation.

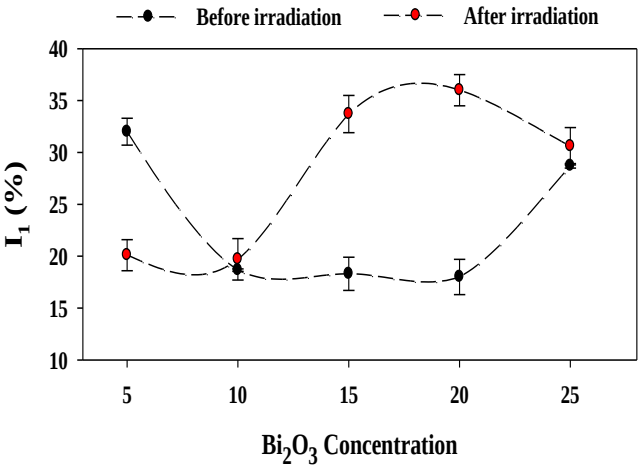


Fig. (5): Variation of I_1 (%) with Bi_2O_3concentration before and after 80 kGy γ-irradiation.

Fig.6 shows the dependence of intermediate lifetime components τ_2 and its intensity I_2 on Bi_2O_3 concentrations before and after 80 kGy γ-irradiation. The intermediate lifetime component and its intensity are directly related to the annihilation of trapped positrons with electrons in open volume defects (trapping centres)[48]. The figure shows the lifetime component τ_2 before 80 kGy γ-irradiation is almost the same around 0.35 ns for all Bi_2O_3 contents and its intensity I_2 ranged from 67% to 80.5 %. Whereas, after 80 kGy γ-irradiation τ_2 ranged from 0.340 % to 0.445 ns and its intensity I_2 ranged from 47.8% to 79.2 % for all Bi_2O_3 contents. On the other hand, the figure shows also that both τ_2 and I_2 before and after 80 kGy γ-irradiation behaves an opposite trend when Bi_2O_3 content changed from 5 to 25 mol%. The intermediate lifetime τ_2 after 80 kGy γ-irradiation is gradually increased to a maximum value of 445 ps when Bi_2O_3 concentration reaches to 20 mol% and then decreased to a minimum value of 342 ps at 25 mol% Bi_2O_3. The increase in τ_2 when Bi_2O_3 concentration reaches to 20 mol%, indicates that the effect of γ-irradiation that enhance the production of the non-bridging oxygen which is associated with the increase of electron density, decreases with the addition of Bi_2O_3. This is attributed to the addition of Bi_2O_3 increment the bridging oxygen due to it gives more of its oxygen atom to boron atom to form BO_4 units [37]. While the decrease in τ_2 when Bi_2O_3 concentration reaches to the value 25 mol%, indicates that there is an anomalous behaviour due to γ-irradiation. This may be attributed to γ-irradiation makes the rate of increase of BO_3 units somewhat greater than the rate of increase BO_4 units. This confirming with the decrease in N_4 ratio and with the γ-irradiation producing defect centres. Furthermore, the decrease in the intensity I_2 as Bi_2O_3 content reaches up to 20 mol% reveals that the annihilation process of the present glass occurs mainly either as free annihilation or self-annihilation of p-Ps [49]. The non-linear behaviour of τ2 and I2 agrees very well with the non-linear behaviour of the density and molar volume discussed before [23].

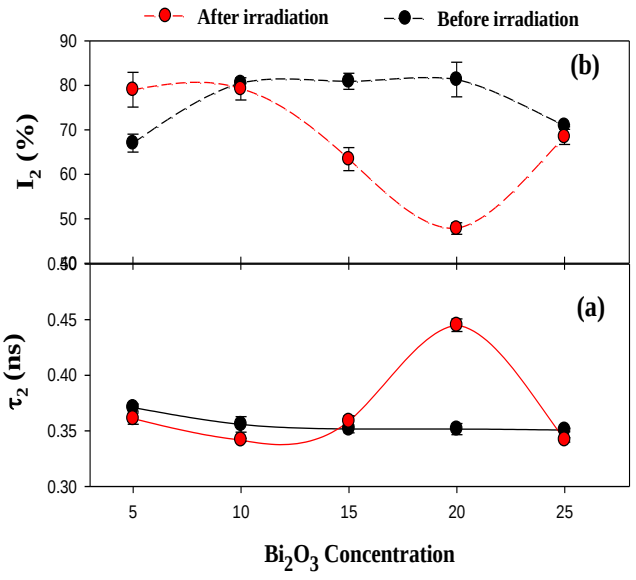


Fig. (6): Variation of (a): τ_2 (ns) and (b): I_2 (%) with Bi_2O_3 concentration before and after 80 kGy γ-irradiation.

The dependence of the lifetime τ_3 and its intensity I_3 (%), which describe the annihilation parameters of the o-Ps in amorphous regions, on Bi_2O_3 concentration for the measured samples before and after 80 kGy γ-irradiation

are shown in fig. 7. The figure shows that the behaviour of τ_3 with Bi_2O_3 concentration before and after 80 kGy γ-irradiation has the same trend. However, their values after γ-irradiation are lower than that before γ-irradiation except at 15 mol% Bi_2O_3 where τ_3 reaches to the higher value 2.015ns. The addition of Bi_2O_3 increases the bridging oxygen while γ-irradiation increases the non-bridging oxygen. Therefore, this agrees with the conclusion that γ-irradiation producing defect centres in the glass network [3]. On the other hand, fig. 7 shows after 80 kGy γ-irradiation an opposite trend of I_3 and τ_3 when Bi_2O_3 concentration ranged from 15 to 25 mol%. The decrement in τ_3 and the increment in I_3 when Bi_2O_3 concentration changes from 15 to 20 mol% indicate a decline in the size of free volume holes and consequently the average formation probability for o-Ps increased. This is due to the addition of Bi_2O_3 decreases the effect of γ-irradiation that increment the non-bridging oxygen and vacancies. Therefore, there is a disordered in the glass samples that produce colour centres. While the increase in τ_3 and the decrease in I_3 when Bi_2O_3 concentration changes from 20 to 25 mol% indicate an increment in the size of free volume holes. This means that the rate of increment of the non-bridging oxygen is somewhat greater than the increment of bridging oxygen. The same trend in τ_3 before and after γ-irradiation and the difference in their values insure that γ-irradiation produces stable defects with the increase in Bi_2O_3 [3]. This result leads to concluding that γ-irradiation causes cyclic effects, i.e. first break bonds and reforming other bonds. Thus γ-irradiation with the addition of Bi_2O_3 produces an anomalous behaviour of the glass samples.

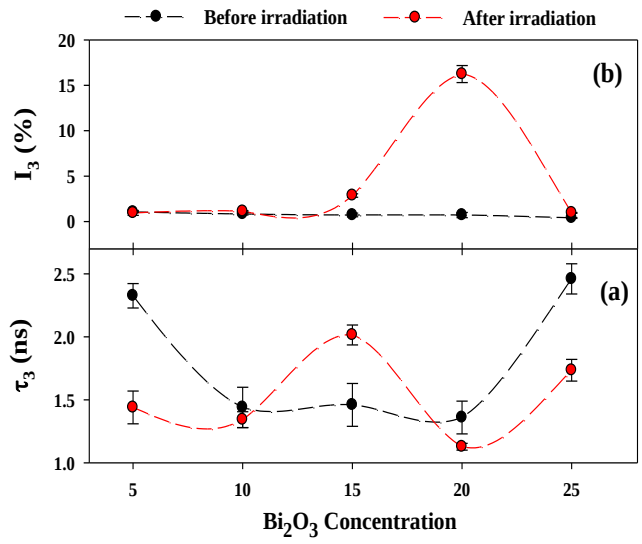


Fig. (7): Variation of (a): τ_3 (ns) and (b): I_3 (%) with Bi_2O_3 concentration before and after 80 kGy γ-irradiation.

The variation of free volume hole fraction (F_r%), as calculated using equation (2) of the glass samples before and after 80 kGy γ-irradiation as a function of Bi_2O_3 content is shown in figure 8. The results showed that before γ-irradiation F_r% decreases from 135% at 5 mol% Bi_2O_3 to about 40% at 10 mol% Bi_2O_3 and fixed to this value until 25 mol% Bi_2O_3 concentration. After 80 kGy γ-irradiation, F_r % increases gradually from about 55 at 5 mol% of Bi_2O_3 concentration to 438 at 20 mol% of Bi_2O_3 concentration. This may be attributed to the rate of the increment in the percentage of I_3 is greater than the rate of decrement in the average size of free volume holes. The result indicates that the increase in Bi_2O_3 decline the effect of γ-irradiation that increases the non-bridging oxygen of the studied glass which associated with defect centres. However, the decrease in Fr% value around 65 at 25 mol% Bi_2O_3 may be attributed to the rate of increment in the average size of free volume holes is less than the rate of decrement in the percentage of I_3 or due to the decreasing in I_3% to small value. This means that γ-irradiation with the addition of Bi_2O_3 produces an anomalous behaviour of the glass samples. The obtained data agree with FTIR analysis and allow to concluding that the addition of a higher quantity of Bi_2O_3 to the ZnO-Na_2O-B_2O_3 glasses improving the shielding properties of the glass.

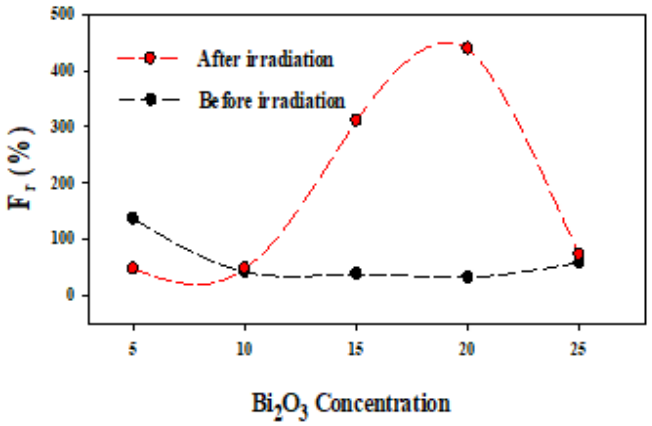


Fig. (8): Variation of F_r (%) with Bi_2O_3 concentration before and after 80 kGy γ-irradiation.

CONCLUSION

The effect of gamma radiation on a bismuth-doped borate glass system of composition (70-x)B_2O_3-xBi_2O_3-15ZnO-15Na_2O (where x = 0, 5, 10, 15, 20, 25 mol. %) was studied by using FTIR spectroscopy, and positron annihilation lifetime (PAL) spectroscopy. The obtained results led to the following conclusions:

Gamma radiation was found to have no little effect on the position of the FTIR bands. The only change is in

these bands' strength. This is attributable to the breakup of Bi-O bonds and the formation of BO_3 or BO_4 units related to the rise or decrease of non-bridging oxygen and vacancies. These can contribute to the development of colour centres and thus the colour of the glass changes from yellow to brown.

The positron annihilation lifetime measurements showed that the intermediate lifetime τ_2 of trapped positrons is almost the same for all the measured samples before γ-irradiation. While for the 80 kGy γ-irradiated samples, a reduction in τ_2 from 445ps to 342ps for the sample when Bi_2O_3 concentration reaches to 25 mol %. It can be concluded that γ-irradiation produces an anomalous behaviour in the structural configuration of the studied glass samples that increasing the rate of increment of BO_3 somewhat greater than the rate of increment of BO_4 units.

Ortho-positronium trapping in the amorphous region reveals the opposite behaviour of the lifetime τ_3 and its intensity I_3 when Bi_2O_3 content changes from 15 to 25 mol%. The decreasing of the lifetime τ_3 and the increasing of its intensity I_3 at lower Bi_2O_3 concentration (20 mol%) indicate that the addition of Bi_2O_3 decreases the effect of γ-irradiation that increment the non-bridging oxygen and vacancies. While the increase in τ_3 and the decrease in I_3 when Bi_2O_3 concentration changes from 20 to 25 mol% indicate that γ-irradiation increases the rate of increment of the non-bridging oxygen is somewhat greater than the increment of bridging oxygen. result lead to concluding that γ-irradiation causes cyclic effects.

The free volume hole fraction (F_r %) of the glass samples before γ-irradiation showed a little variation at higher concentration of Bi_2O_3. Whereas after γ-irradiation with 80 kGy, F_r % increases to the value of 438 at 20 mol % of Bi_2O_3 content which may be attributed to the rate of the increment in the percentage of I_3 is greater than the rate of decrement in the average size of free volume holes. Whereas, at 25 mol % Bi_2O_3 content F_r % reaches 65 % indicating that γ-irradiation with the addition of Bi_2O_3 produces an anomalous behaviour of the glass samples which produces the defect centres and therefore, the glass becomes coloured.

Finally, it can be concluded that, increasing the content of the bismuth oxide in the borate glass system leads to an enhancement of its characteristics to be used as a gamma radiation detector or as a radiation indicator sensor.

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