Spectroscopic studies of preparation conditions role on the shielding properties of MoO₃-doped Na₂O–ZnO–P₂O₅

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Abstract
Glassy samples from the undoped ternary system Na₂O–ZnO–P₂O₅ in combination with other samples from the same system doped with variable amounts of MoO₃ (0.25, 0.5, or 1 gm/batch) were successfully melted under ordinary, oxidizing, or reducing conditions followed by annealing. Fourier transform infrared spectrophotometric measurements in combination with optical absorption spectra were recorded before and after doping with variable concentrations of MoO₃ in multiple melting media both as prepared or after being subjected to (8 Mrad) gamma irradiation dose. The studied spectral properties of the glasses were correlated with variations with the existing valence state of the Mo ions and the effects of gamma irradiation on the optical spectra and IR vibrational bands together with the role of the condition of melting the batches. The optical spectra of the glasses reveal pronounced UV and visible bands due to trace iron (Fe³⁺) ions as impurities or the sharing of the low valence states of the added molybdenum ions. The FTIR peaks show condensed spectra of phosphate groups (Q², Q³), and the effects of dopant are limited because of low percent. Gamma irradiation causes distinct variations in the undoped spectra, but the MoO₃-doped glasses show some shielding behavior.

Keywords Phosphate glass · MoO₃ · Melting condition · Fourier transform infrared (FTIR) · Optical (UV/Vis) · Gamma irradiation

Introduction
Phosphate glasses can be classified as one of the three extensively studied vitreous glassy systems alongside traditional silicate and borate glasses. Phosphate glasses possess extended chemical compositions, and all have the basic building structural PO₄ group. They can incorporate high contents of a transition metal or rare earth oxides with the result of obtaining candidates with distinct brilliant colors beside variable optical and electrical properties [1–3]. The low chemical durability of phosphate glasses can be overcome by the introduction of multi-valent oxides such as Al₂O₃, PbO, and Fe₂O₃ which extended the applications of phosphate glasses including metal-sealing, optical components, to encapsulation of some types of radioactive wastes, and as biomaterials [4–6]. The incorporation of the specific transition metal oxides, MoO₃ or WO₃ displays special scientific interest besides the potential applications in various fields of optics [7–9].

Molybdenum ions like tungsten ions can be introduced in glasses in four different possible oxidation states, namely Mo³⁺ (d³), Mo⁴⁺ (d²), Mo⁵⁺ (d¹), or Mo⁶⁺ (d⁰) or a mixture of some of these states [10–13]. Parke et al. [10–14] reported the presence of Mo³⁺ ions in phosphate glassy matrix showing absorption bands at nearly 360 and 460 nm in their optical spectra in addition to other absorption bands within the spectral ranges 360–380 and 710–780 nm assigned to the presence of Mo⁵⁺ ions, while Mo⁴⁺ ions showed an absorption band at about 550 nm. It has been recognized that the presence of a high level of MoO₃ or WO₃ produces a photochromic effect [15–17]. Structural studies of these specific
glasses indicated the formation of $\text{WO}_6$ clusters and these highly polarizable clusters are responsible for the nonlinear and photochromic properties. However, glasses containing such transition metal ions often exhibit an intense and broad absorption band in the visible and near-IR regions which is attributed to the reduction of these transition metals to lower valencies during melting at high temperatures [7]. It is evident that redox effects during melting without controlled procedure produce absorption bands that limit the application of such glasses containing $\text{MoO}_3$ or $\text{WO}_3$ as optical candidates [9].

In this study, glasses were prepared based on the system $\text{Na}_2\text{O–ZnO–P}_2\text{O}_5$ with increasing added $\text{MoO}_3$ as dopant oxide (0.25, 0.5, 1%) with variable conditions of melting including normal melting under the atmospheric condition without any addition. Two other varieties of glasses were prepared through the addition of either oxidizing agent ($\text{NaNO}_3$) or of reducing agent (sugar). The study includes the investigation of optical and FT-infrared absorption spectra of the collectively prepared glasses within the three conditions of melting. The same spectral measurements were repeated after subjecting the glasses to a gamma dose of 8 Mrad ($8 \times 10^4$ Gy). This specific dose of gamma irradiation has been selected because earlier studies by the sharing of one of the authors showed that the intensities of generated defects in glasses increased with progressive increase in the dose of radiation until reaching about 6 Mrad, [18–20]. After that, a saturation of the induced defects was assumed to be reached. A further study in this work was carried out of measuring the thermal expansion properties of some selected glasses. These collective studies are expected to give more insight into the states of molybdenum ions on the three conditions of melting. Also, the work is intended to justify the effects of gamma irradiation on the two spectral properties of the studied glasses.

**Experimental details**

**Preparation of the glasses**

Glasses from the system $\text{P}_2\text{O}_5–\text{Na}_2\text{O–ZnO}$ with varying additions of $\text{MoO}_3$ were prepared from chemically laboratory pure materials. They include sodium dihydrogen orthophosphate ($\text{NaH}_2\text{PO}_4$) and $\text{ZnO}$. The chemicals used are of a local company for the sodium dihydrogen phosphate (ADWIC, Egypt, with 0.1% Fe as an impurity, while zinc oxide supplied by Sigma-Aldrich Co with Fe 0.001%, molybdenum oxide ($\text{MoO}_3$) from Alpha Chemika (India) with Fe 0.002% impurities. The dopant oxide $\text{MoO}_3$ was added over the weight of batch as such with the percents (0.25, 0.5, 1%). The weighed batches were melted in covered porcelain crucibles in a SiC electric furnace (Vecstar, UK) at a temperature of $1100 \pm 20$ °C for 90 min with rotating the melts at intervals of 30 min to promote complete mixing and acceptable homogeneity. The melts were poured into warmed stainless steel molds with the required dimensions. The prepared samples were transferred immediately to an annealing muffle furnace regulated at 280°C. After 1 h, the muffle was switched off and left to cool with the samples inside to room temperature at a rate of 30 °C /hour.

**Techniques or methods of measurements of properties**

**Optical absorption measurements**

The optical (UV–visible) absorption spectra before and after gamma irradiation were measured at room temperature in the range from 200 to 2500 nm using a recording spectrophotometer (type Shimadzu UV-3600, UV–VIS-NIR Spectrophotometer, Japan). Polished samples of equal thickness ($2 \text{ mm} \pm 0.1 \text{ mm}$) were measured, before and after gamma irradiation. The samples were measured twice to confirm the accuracy of the absorption peaks.

**Infrared absorption measurements**

The infrared absorption spectra of the glasses were measured at room temperature in the range 4000–400 cm$^{-1}$ by (Nicolet 6700 FT-IR, USA) infrared spectrophotometer, using the KBr technique disc. Two milligrams of powdered samples was mixed with 200 mg of KBr, and the mixture was subjected to a load of 5 tons/cm$^2$ to produce clear homogenous discs. The infrared absorption spectra were measured immediately at room temperature after preparing the desired discs to avoid moisture attack, with a resolution of 2 cm$^{-1}$. At least two IR spectra for each sample were recorded. Infrared spectra were corrected for the dark current noises and background using the two-point baseline corrections. After correction, the IR spectra were analyzed using the deconvolution method to identify the various hidden or overlapped peaks.

**Irradiation facility**

An Indian $^{60}$Co gamma cell (2000 Ci) was used as a gamma-ray source with a dose rate of 1.5 Gy/s (150 rad/s) at a temperature of 30°C. Each glass sample was subjected to a total dose of (8 Mrad $= 8 \times 10^4$ Gy).
Results

X-ray diffraction

Figure (1) illustrates the X-ray diffraction experimental data of the studied glasses. XRD pattern reveals the absence of any sharp peaks indicating and confirming the amorphous nature of the prepared glasses.

Optical absorption

Optical (UV–Visible) absorption spectra of the glasses melted under normal atmospheric conditions before and after gamma irradiation

Figure (2) illustrates the optical spectrum of the undoped ternary phosphate \((\text{Na}_2\text{O}–\text{ZnO}–\text{P}_2\text{O}_5)\) glass before irradiation which reveals strong UV absorption extending from 200 to 345 nm and reveals four small peaks at about 320, 335, and 345 nm and without any distinct absorption up to 2500 nm.

The optical spectra of the three MoO\(_3\)-doped samples show similar behavior, revealing strong UV absorption with some shift extension to a higher wavelength than that for the undoped glass, with three peaks at 345 nm and succeeded by a broad visible band centered at 780–800 nm and with two small curvature at 1890 and 2340 nm. The gamma-irradiated undoped glass reveals a slight change of the absorbance combined with the generation of an induced broad visible band centered at 580 nm. The irradiated MoO\(_3\)-doped glasses reveal a slight decrease in the UV spectrum but remain unchanged and parallel in the remaining spectrum.

The high content MoO\(_3\) (1%) shows a small distinct increase in both the UV and visible absorption with parallel behavior.

Optical (UV–Visible) absorption spectra of the glasses melted under oxidizing conditions (NaNO\(_3\))

The optical spectra of the glasses melted under oxidizing conditions (added NaNO\(_3\)) shown in Fig. (3) reveal very similar spectral absorption to that identified in the optical spectra shown in Fig. (2) of the glasses melted under normal conditions.

Optical absorption spectra of undoped and MoO\(_3\)-doped glasses melted with reducing agent

Figure (4) illustrates the optical spectra of the studied glasses melted in reducing conditions. The undoped glass of the basic composition \(\text{Na}_2\text{O}–\text{ZnO}–\text{P}_2\text{O}_5\) reveals strong ultraviolet absorption extending from 300 to about 400 nm with a distinct peak at 345 nm and without any further absorption to the end of measurement at 2400 nm. The spectrum of the glass containing the lowest MoO\(_3\) content (0.25%) reveals a strong UV absorption with a peak at 345 nm and followed by a medium peak at 357 nm and succeeded by a broad visible–near-IR band centered at 812 nm.

The second MoO\(_3\)-doped glass (0.5%) shows a strong UV absorption with a peak at 300 nm followed by two peaks at 375 and 444 nm and succeeded by a broad visible–near-IR band centered at 815 nm. The third MoO\(_3\)-doped sample (1%) shows a spectrum consisting of a strong UV–near-visible absorption from 200 to 500 nm with multi-split peaks at and followed by a centered visible peak at about 440 nm and succeeded by a strong visible–near IR broadband extending from about 530 nm to 1200 nm and with multi-split broad peaks at 716, 780, and 855 nm.

FTIR spectra of the glasses melted under atmospheric and oxidizing conditions

Figure (5) illustrates the IR spectral curves of the studied undoped and MoO\(_3\)-doped glasses melted at normal conditions. The IR spectrum of the undoped base glass reveals condensed vibrational bands within the mid-wave number region 400–1500 cm\(^{-1}\) followed by some separate peaks in the rest of the near IR spectrum. The detailed vibrational peaks identified from the undoped glass are summarized as follows:
(a) The appearance of a strong far-IR band with a peak at 530 cm\(^{-1}\).
(b) A medium band is identified with two peaks at about 714 and 782 cm\(^{-1}\).
(c) A very broad band is identified extending from about 900 to 1500 cm\(^{-1}\) with their peaks at about 983, 1030, 1096, 1272, and 1460 cm\(^{-1}\).
(d) A separate band is observed with two peaks at about 1648 and 1710 cm\(^{-1}\).
(e) Four peaks are identified at about 2000, 2430, 2853, and 2921 cm\(^{-1}\).
(f) A broad near IR band extending from about 3000 to 3750 cm\(^{-1}\) centered at 3438 cm\(^{-1}\).

The IR spectra of the MoO\(_3\)-doped glasses reveal almost the same vibrational bands within the mid-region from 400 to 1500 cm\(^{-1}\) as that observed from the undoped sample. Only some limited variations are observed including the decrease in the intensities of the bands at about 1683, 2867, 2921, and 2438 cm\(^{-1}\).

Figure (6) shows the IR spectra of the glasses melted under oxidizing conditions (addition of NaNO\(_3\)). The IR spectra of all the glasses are almost similar to the spectrum identified from the undoped glasses melted under normal atmospheric conditions. The only variation is that the intensities of the mid-bands from 850 to

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**Fig(2)** UV/Vis. optical absorption of prepared glasses of undoped sample and glasses containing variable Mo ion concentrations (0.25, 0.5, and 1%) melted under ordinary atmospheric conditions.
FT infrared absorption spectra of the studied undoped and MoO$_3$-doped glasses melted under reducing condition

Figure (7) illustrates the FTIR absorption spectra of the prepared reduced glasses. The undoped glass shows the following spectral features:

(a) A far-IR sharp peak is identified with a peak at 530 cm$^{-1}$.

(b) A double split medium band with two peaks at 714 and 775 cm$^{-1}$ is observed.

(c) A very broad and distinct band is identified extending from about 800 to 1500 cm$^{-1}$ with multi-component four distinct peaks at 883, 960, 1096, 1272 cm$^{-1}$ and followed by a small peak at about 1460 cm$^{-1}$.

(d) A medium band is observed at 1648 cm$^{-1}$.

(e) Two connected split peaks are observed at 2857 and 2921 cm$^{-1}$.

(f) A very broad near IR band with a peak at 3438 cm$^{-1}$.

The MoO$_3$-doped glasses show nearly the same fundamental vibrational bands in nearly their wave number positions but reveal the high decrease in the intensities of the
bands at 1648 cm$^{-1}$ and the rest of near IR peaks at 2857, 2921, 3438 cm$^{-1}$.

**Deconvoluted IR Spectra of the base host glass**

Figure (8) illustrates the deconvoluted IR spectrum of the base phosphate glass; the identified deconvoluted peaks are at: 490, 535, 706, 768, 867, 911, 1012, 1156, 1287, 1360, 1455, 1645, and 1714 cm$^{-1}$.

**FTIR Spectra after gamma irradiation**

Figure (9) illustrates the FTIR of two selected glasses consisting of the base host glass and the highest MoO$_3$-doped sample after gamma irradiation; the composition of the derived IR data with that obtained before irradiation indicates that gamma irradiation slightly reduces the intensities of the IR vibrational bands in the undoped base glass. On the other hand, the MoO$_3$-doped glass shows maintenance of the IR bands due to the shielding effect of molybdenum ions, and the IR spectrum did not show any distinct variation after gamma irradiation.
Discussion

Interpretation of the identified strong UV absorption in the optical spectrum of the undoped Na₂O–ZnO–P₂O₅ glass.

Experimental optical results indicate the identification of distinct UV absorption with three peaks extending to 345 nm. This specific strong UV absorption can be related to being due to absorption of trace iron (mainly Fe³⁺ ions) present as impurities within the chemicals used for the preparation of the host glass. This postulation is based primarily on the published review article on charge transfer spectra in glasses introduced by prof Duffy [18]. He classified different UV absorption generally identified in various undoped glasses and referred that some transition metal ions (e.g., Fe³⁺, Cr⁶⁺) produce high intense UV absorption even if present in the ppm-level. This type of absorption involves the transfer of an electron from the glass network to the metal ion, and normally, it is highly intense and nominated as a charge transfer type. The same assignment has been adopted by Ehrt et al. in their publications [19, 20] and her recent review article [21]. ElBatal et al. [12, 22–25] have reconfirmed that the UV absorption bands identified in various phosphate glasses are correlated with trace ferric ions impurities within the chemicals used for their preparation. We accept the previous postulation regarding the origin of the UV absorption identified in the host undoped ternary phosphate glass to trace iron impurities (Fe³⁺ ions).

Interpretation of the optical spectra of MoO₃-doped glasses under varying melting conditions.

Careful inspection of Figs. 2, 3 and 4 indicates that the optical spectra of MoO₃-doped glasses melted under ordinary conditions (Fig. 2) are very similar to those melted...
under oxidizing conditions (Fig. 3) and quite different than the optical spectra of glasses melted under reducing condition (Fig. 4).

The first two Figs. 2 and 3 have common and similar UV–visible spectra consisting of extended UV spectra than that identified for the undoped glass beside the appearance of three broad curvatures centered at 840, 1840, and 2320 nm. The mentioned spectral features identified in Figs. 2 and 3 refer to the presence of both hexavalent and pentavalent molybdenum ions. The extension of the UV absorption than that for the undoped glass indicates that the hexavalent molybdenum ions with the (d⁰) configuration exhibit an extra UV band. On the other hand, the appearance of the curvatures at 840 nm refers to the presence of some pentavalent molybdenum ions.

It is concluded that Figs. 2 and 3 indicate the presence of both hexavalent molybdenum ions as major percent and secondary percent to the pentavalent molybdenum ions.

The optical spectra are shown in Fig. (4) in comparison with those shown in Figs. 2 and 3 indicate the appearance of a high intense broad visible band centered at about 785 nm beside the subsidiary UV band at about 370 nm. These different spectral features refer to the dominance of the pentavalent molybdenum ions when glasses were melted under reducing conditions.

The same introduced postulation and interpretations of the bands due to hexavalent Mo⁶⁺ ions in the UV region and the
visible broadband due to pentavalent Mo\(^{5+}\) ions have been previously given by several authors [6–8, 15, 16, 20, 21].

Interpretation of the FT infrared spectra of the studied glasses

The experimental FTIR spectra appear condensed within the mid-region (400–1500 cm\(^{-1}\)), and the understanding and explanation of the detailed IR results are based on the following basis [24–30]. The formed IR vibrational bands are virtually depending on the constitutional chemical composition and specifically on the glass-forming oxide percent which forms the fundamental building groups in the glass network, and hence, it can be recognized that:

a- The host glass is composed of main P\(_2\)O\(_5\) with 70% as a network forming oxide with phosphate groups (mainly Q\(^2\) and Q\(^3\) types) and with modifier oxide Na\(_2\)O with 24%, and the rest is ZnO with 6%. ZnO is known to be conditional oxide which can act as modifier oxide or former with ZnO\(_4\) with the necessary oxygen ions available from neighboring alkali oxide.

b- The identified IR vibrational bands are representing fingerprints of the network structural units in agreement to similar units in crystalline analogs.

c- Figs. 4, 5, and 6 reveal the vibrational bands for the same glasses after varying conditions of melting. Inspection and comparison of the details vibrational bands in the three figures indicate the resemblance of Figs. 4 and 5 and show limited differences especially in the intensities of the bands.

d- The assignments of the vibrational bands shown for the undoped glass in Figs. 5, 6 and the deconvoluted spectrum shown in Fig. (8) are summarized as follows [25–31].

i- The distinct broad far-IR band with a peak at 503 cm\(^{-1}\) can be related to bending vibrations of O–P–O bonding, (PO\(_2\)) modes of metaphosphate groups.

ii- The peaks at about 704 and 780 cm\(^{-1}\) are related to symmetric stretching vibrations of P–O–P linkages.

iii- The peaks at 875 is correlated to asymmetric stretch of P–O–P, while the IR bands at 1030 and 1097 cm\(^{-1}\) are due to symmetric and asymmetric stretching vibrations of PO\(_3\) units, respectively.

iv- The peak at about 1276 cm\(^{-1}\) is related to PO\(_2\) asymmetric stretching of the doubly bonded (P = O) modes.

v- The peak at about 1626 cm\(^{-1}\) is related to vibrations of OH, water.

vi- The band at about 2430 attributed for the residual carbon dioxide

vii- The peaks at about 2867 and 2921 cm\(^{-1}\) can be related to vibrations of water, OH.

viii- The near IR broad band centered at about 3450 cm\(^{-1}\) can be related to vibrations of water, OH, POH.

The observed limited changes between IR spectra melted under different conditions are explained as follows:

a- The distinct decrease in the intensities of the bands at about 1640, 2857, 2921 cm\(^{-1}\) and the near IR broadband centered at 3439 cm\(^{-1}\) upon increasing MoO\(_3\) (Fig. 4) can be related to the chemical stability in the glasses upon adding the TM ions (Mo\(^{6+}\)). This stability effect reduces the ability of the MoO\(_2\)-doped glasses to absorb water or moisture in the powder form and thus the cited bands are known to be assigned to vibrations of water, OH, or POH. The previous results are concerned with glasses melted under the ordinary atmospheric condition where the molybdenum ions are expected to be existing in both hexavalent and pentavalent states.

b- The glasses melted under oxidizing conditions (Fig. 5) reveal only the decrease in the mid-bands extending from about 900–1350 cm\(^{-1}\) where molybdenum ion concentration reaches (1% MoO\(_3\)). These results can be related to the suggested depolymerization effect caused by the Mo ions through changing of the metaphosphate groups. Similar behavior has been identified by some authors about the action of copper ions [28] or iron ions [29] on phosphate glasses. Also, the distinct appearance of the far-IR bands may be related to the addition of NaNO\(_3\) which seems to affect the ability of the powder grains to absorb water or moisture.

Figure (7) shows that the melting of the glasses under reducing conditions causes the distinct decrease in the main IR vibrational bands within the mid-region 600–1350 cm\(^{-1}\). It can be suggested that during the melting process with the reducing agent, the redox reaction between the molybdenum ions and the reducing agent affects to some extent the structural building units leading to the decrease in their intensities.

Interpretation of the effect of gamma irradiation on the combined spectral properties

Effect of gamma irradiation on glass

Perfect crystalline materials are realized to be unaffected upon being subjected to ionizing gamma irradiation. On the other hand, glasses are accepted to be non-periodic solids and exhibit intrinsic defects or pre-existing defects such as non-bridging oxygen, vacancies, and impurities,
and upon gamma irradiation, some physical and chemical properties are assumed to show changes. These formed-induced changes or defects can be followed by many tools such as measuring their optical or E.S.R spectra after gamma irradiation. During gamma irradiation, pairs of electrons and positive holes are generated and thus induced defects are expected to be formed including ionization, radiolysis, and photochemical reactions [14, 20, 32].

Interpretation of gamma irradiation on the optical spectra and FTIR spectra of the studied glasses.

Gamma irradiation on the undoped glass causes a slight increase in the UV absorption besides the generation of an induced visible band centered at 580 nm appeared in base sample. These specific responses can be interpreted as follows:

(a) The host undoped glass is a ternary phosphate glass (70 P₂O₅–15 Na₂O–ZnO15 mol%) and generally, phosphate glasses are favoring the lower valencies of the transition metal ions [4, 6, 9, 16]. Hence, the trace unavoidable iron impurities present in the glass contains a measurable percent of ferrous (Fe²⁺) ions besides some few ferric (Fe³⁺) ions. This assumption is confirmed by the appearance of curvature centered at 1070 nm which is accepted to be the characteristic position for the absorption due to ferrous ions [9]. Upon gamma irradiation, some of the ferrous ions react or capture liberated positive holes and the net result is the formation of additional ferric ions (Fe³⁺) or (Fe²⁺)⁺ and the result is the observed increase in the intensity of the UV absorption in the vicinity of the characteristic position of the absorption of the ferric ions (200–310 nm) [9].

(b) The generation of an induced visible band upon gamma irradiation of the undoped glass can be related to the formation of phosphorus oxygen hole center (POHC) through the assumption of the effect of generated hole center on the phosphate network itself. The same assumption has been accepted by various authors [13, 14, 20].

The MoO₃-doped glasses reveal quite different responses toward gamma irradiation. The UV absorption shows a slight decrease in intensity and the visible absorption remains unchanged with parallel behavior. The last-mentioned results can be explained by assuming that the liberated electrons and positive holes are faced with the MoO₃-doped glasses by two different transition metal ions (traces of iron ions and dopants of molybdenum ions) and it is obvious that a competition of reactions between the two TM ions and the generated pairs of electrons and positive holes. The identified optical results of the MoO₃-doped glasses reveal that molybdenum ions capture positive holes or shield their effects in increasing the UV absorption or the formation of an induced visible positive hole. It can be assumed that molybdenum ions shield or retard the effect of generated positive holes. Several authors have agreed that molybdenum ions (and tungsten ions) are possessing the capability of reducing the effect of gamma irradiation [10, 31, 32]. This specific behavior can be related to the relatively heavy mass of the Mo ions which retard or block the free passages of electrons or position holes during the irradiation process and also to photochemical reaction as discussed before.

Regarding the almost maintenance of the FTIR results after gamma irradiation, it is assumed that previous studies [40→43] indicate that the structural building units generally remain unaffected by irradiation except by the identification of some change in the band angles and/or band lengths leading to slight changes in the intensities of some of the vibrational bands.

Conclusion

Glasses from the system P₂O₅ 70%–Na₂O 24%–ZnO 6% consisting of undoped and doped with varying MoO₃ contents (0.25–0.50–1%) were prepared under three varying conditions (normal–atmospheric–oxidizing–reducing). Characterization of the prepared glasses includes collective optical and FT infrared absorption spectra before and after gamma radiation with a specified dose (8 Mrad). The spectral results indicate that the two melting conditions of the normal atmospheric and oxidizing conditions produce similar optical spectra while the reducing condition initiates the low valence state of pentavalent molybdenum. FTIR spectra reveal distinct vibrational bands due to (Q², Q³) structural phosphate groups. The molybdenum ions as dopants cause no distinct variations in the IR spectra due to their low percent to affect the structural phosphate glasses. Gamma irradiation affects the spectrum of the undoped glass through photochemical reactions with trace impurities, and the generation of an induced POHC. The MoO₃-doped glasses reveals shielding behavior toward gamma irradiation and the spectral curves show stability.

Conflict of interest

All authors declared that there is no conflict of interest.

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