A significant role of MoO$_3$ on the optical, thermal, and radiation shielding characteristics of B$_2$O$_3$–P$_2$O$_5$–Li$_2$O glasses

Z. A. Alrowaili$^1$ · Atif Mossad Ali$^{2,3}$ · Ateyyah M. Al-Baradi$^4$ · M. S. Al-Buriah$^5$ · E. A. Abdel Wahab$^6$ · Kh. S. Shaaban$^7$

Received: 11 June 2021 / Accepted: 18 November 2021 / Published online: 4 January 2022
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2021

Abstract
The glass system 42.5P$_2$O$_5$–42.5B$_2$O$_3$–(15 − x) Li$_2$O–x MoO$_3$ x = (0, 2.5, 5.10 and 15), was fabricated using a melt-quenching technique. Optical features are examined depending on measuring the absorption and transmission of the prepared glasses. The energy gap ($E_{\text{opt}}$), increases from 2.23 to 2.49 e.V. Urbach ($E_u$), decreases from 0.513 to 0.5 e.V. Basicity, polarizability, electronegativity, and some physical constants are determined. The temperature of the glass transition $T_g$, increases from 493 to 532 °C, the temperature of onset glass crystallization $T_c$ increases from 493 to 532 °C and the temperature of the crystallization $T_p$ increases from 606 to 636 °C. Radiation shielding properties have been examined by Phy-X / PSD. The impact of adding MoO$_3$ to the glasses on their shielding ability was investigated. The lower value of the (MFP) sample has been detected at a higher MoO$_3$ concentration and it is good radiation attenuation glasses. For radiation protection applications, the investigational glasses had superior characteristics.

Keywords MoO$_3$ · XRD · Spectroscopic · DTA · Attenuation

*Kh. S. Shaaban
khamies1078@yahoo.com

1 Physics department, College of Science, Jouf University, P.O. Box: 2014, Sakaka, Saudi Arabia
2 Physics Department, Faculty of Science, King Khalid University, Abha 61413, Saudi Arabia
3 Department of Physics, Faculty of Science, Assiut University, Assiut 71516, Egypt
4 Department of Physics, College of Science, Taif University, P.O. Box 11099, Taif 21944, Saudi Arabia
5 Department of Physics, Sakarya University, Sakarya, Turkey
6 Physics Department, Faculty of Science, Al Azhar University, P.O. Box 71524, Assiut, Egypt
7 Chemistry Department, Faculty of Science, Al-Azhar University, P.O. Box 71524, Assiut, Egypt
1 Introduction

B₂O₃–P₂O₅ glasses with superior efficiency can be used in a variety of different settings. Borophosphate glasses are appropriate for solid-state batteries and nonlinear optics. Due to its evident advantages, lithium borophosphate is a classical glass that has become recognized in storage batteries. These glasses are used as storage batteries in optical and electronic instruments (Narwal et al. 2019; Khafagy et al. 2008; Albarzan et al. 2021; El-Maaref et al. 2021, 2019; Shaaban et al. 2020a, 2020b; Fayad et al. 2020). The characteristics of the combined glass (B₂O₃ + P₂O₅) networks vary from those of the single glass B₂O₃ and P₂O₅ networks.

Transition metal oxides (TMOs) are a fascinating group of semiconductor materials because of their technological advantages for use in microelectronics and display systems. MoO₃ among (TMOs), due to its excellent use in optical materials and electrochemical devices has received increasing attention in recent years. There is a goal that supports manufacturing these glasses regarding the MoO₃ used in these implementations. Different MoO₃ preparation glasses were developed and investigated in response to this broad range of applications (Raza et al. 2019; Santagneli et al. 2007; Sivakumar et al. 2006; Shaaban et al. 2019, 2017, 2020c; Rao et al. 2009; Shaaban and Saddeek 2017).

Due to the existence of MoO₄ and MoO₆ in the glass network, MoO₃ appears as the former non-conventional network. The existence of MoO₃ in glass systems does have a modifier impact on UV spectra (Raza et al. 2019; Santagneli et al. 2007; Sivakumar et al. 2006; Shaaban et al. 2019, 2017, 2020c; Rao et al. 2009; Shaaban and Saddeek 2017). There are increasingly diverse technologies for molybdenum borophosphate-based glasses, such as laser host fibers and superconducting switches.

Both scientifically and technologically, the significant advances of alkaline borophosphate glasses are considerable. The existence of PO₄ and BO₄ structural units, this consequence approaches from the structural issues connected with covalent links. B₂O₃–P₂O₅–Li₂O–MoO₃ glasses system possess spread applications because of their radiation shielding and good FT-IR transmission (Elbers et al. 2005; Tricot et al. 2020; Koudelka and Mošner 2001; Magistris and Chiodelli 1983; Shaaban et al. 2021a; Sayed et al. 2021; Wahab et al. 2021; Moller and Mousseau 2013; Mettler et al. 2008; Tekin et al. 2019a; Nowak et al. 2019; König et al. 2019; Kosaka et al. 2019; Etzel et al. 2018; Chida et al. 2013; Kavaz et al. 2019a; Kalnins et al. 2016). In optoelectronics and radiation shielding, molybdenum lithium borophosphate glasses are very useful. Oxide-based phosphate glasses are important for lasers, solid-state batteries, and radiation shielding, because of their unique chemical, and thermal features. As a result, these glasses examined as a promising material for optoelectronic and shielding requests. The main goal of this article is to assist in the preparation of B₂O₃–P₂O₅–Li₂O–MoO₃ glasses and investigate their optical and neutron shielding using Phy-X/PSD (Şakar et al. 2020) properties.

2 Materials and methodology

The glass system 42.5P₂O₅–42.5B₂O₃–(15 – x) Li₂O–x MoO₃ x = (0, 2.5, 5.10 and 15), was fabricated using a melt-quenching technique which is followed by an annealing process. All the glasses were manufactured with chemically pure materials containing a purity of 99%. The starting basic material for P₂O₅ was pure (NH₄)₂HPO₄, (Merck). The starting basic material for Li₂O was pure Li₂CO₃ (Aldrich). The starting basic material for B₂O₃ was pure H₃BO₄.
A significant role of MoO₃ on the optical, thermal, and... 

As such, MoO₃ (Merck) was presented. To remove NH₃, H₂O, and CO₂, the batches were accurately weighed and placed into platinum crucibles and calcined for 1/2 h at 450 °C. The melting was then continued for 2 h in an electric furnace at 1050 °C. The molten were rotated twice to achieve homogenization. Finally, the molten glass was poured into a stainless-steel mold that had been preheated to the required dimensions. For annealing, glass samples were set at 350 °C. Table 1 shows the glass composition.

The nature of these glasses was assessed using a Philips X-ray diffractometer (model PW / 1710). The spectrophotometer was used to measure optical spectra of investigated glass system (type JASCO V- 670). The thermal investigation was carried out with a DTA-50 (Shimadzu-Japan). Phy-X / PSD can calculate a variety of shielding considerations (Şakar et al. 2020). Electron density (Nₐ) was predictable as: \( Nₐ = N \sum_i Z_i \). Effective cross-section of removal (Σᵣ) projected as: \( \Sigmaᵣ = \sum_i w_i \left( \frac{\Sigmaᵣ_i}{\rho} \right) \) and \( R = \sum_i \rho_i \left( \frac{\Sigmaᵣ_i}{\rho} \right) \). G–P fitting parameters have been predictable as \( P = \frac{P_1(\log Z_2−\log Z_{eq})+Z_2(\log Z_{eq}−\log Z_1)}{\log Z_2−\log Z_1} \). EABF and EBF were predicted using G–P fitting: \( B(E, X) = 1 + \frac{b−1}{K−1}(K^x−1) \) for \( K \neq 1 \), \( B(E, X) = 1 + (b−1)x \) K = 1 where \( K(E, X) = cx^d + d \tanh \left( \frac{x^d}{x \tanh(−2)} \right) −\tanh(−2) \).

3 Results and discussion

3.1 XRD

XRD of a glass system is shown in Fig. 1. It is seen that no discrete lines or sharp peaks indicate a high degree of glassy status, according to XRD. In all the synthesized glasses, there is no intense peak in the XRD pattern, except for a broad hump between angles 25° and 35°, as shown in Fig. 1. The sharp intensity at (30) 20 values concerning MoO₃ content attributed to a reduction in bond length and a higher coordination number.

3.2 Optical spectra

The optical properties of a material determine how it interacts with light. Engineers will be able to choose the right material for their application based on optical features like refractive index, absorption coefficients, polarizability, and metallization, among others. With increasing MoO₃ content, the UV–visible absorption of MoO₃–P₂O₅–B₂O₃–Li₂O glasses were discussed. Figures 2 and 3 depict the absorbance (\( A \)), transmitting (\( T \)), and

| Code | B₂O₃ | P₂O₅ | Li₂O | MoO₃ |
|------|------|------|------|------|
| G1   | 42.5 | 42.5 | 15   | 0    |
| G2   | 42.5 | 42.5 | 12.5 | 2.5  |
| G3   | 42.5 | 42.5 | 10   | 5    |
| G4   | 42.5 | 42.5 | 5    | 10   |
| G5   | 42.5 | 42.5 | 0    | 15   |

(88)
reflectance \((R)\) of glass samples (Shaaban et al. 2020d, 2020e, 2020f; Abdelghany et al. 2012; Abd-Allah et al. 2019; Saudi et al. 2020; Abdel Wahab et al. 2019; Somaily et al. 2020; Shaaban and El, 2020; Wahab and Shaaban 2018). Figure 4 depicts the glasses’ absorption coefficient.

Glass spectrum in the UV and VIS areas were used for the estimated the bandgap energy \(E_{\text{opt}}\) is estimated by \((\alpha \cdot \hbar \nu)^{1/2} = B(\hbar \nu - E_{\text{opt}})\). Figure 5 explores of \((\alpha \cdot \hbar \nu)^{1/2}\) against photon energy \((\hbar \nu)\) to evaluate the indirect \(E_{\text{opt}}\) from the intercept. \(E_{\text{opt}}\) increases with increasing MoO\(_3\), as revealed in Table 2. \(E_u\) has been calculated \(\propto 0 \exp \left( \frac{\hbar \nu}{E_u} \right)\).

Fig. 6 and Table 2 show that there is an inverse relationship between the values of \(E_{\text{opt}}\) and \(E_u\) as shown in Fig. 7.
A significant role of MoO$_3$ on the optical, thermal, and…

The refractive index was calculated using: 
\[ n = \frac{(1-R)^2 + k^2}{(1+R)^2 + k^2} \] 
\( n \) is presented in Fig. 8 for fabricated glasses. It has already been stated that density increases, then the refractive index for corresponding glass is rising. As a result, it can be directly compared to \( R, \rho \), and opposite to \( V_m \).

Glass polarizability and molar polarization were computed as best as possible: 
\[ R_m = \left[ \left( n^2 - 1 \right)/\left( n^2 + 2 \right) \right] V_m, \alpha_m = \left( \frac{3}{4\pi N} \right) R_m, \text{ and } \alpha^2_0 = \frac{\nu_m}{2\pi} \left( \frac{\alpha^2 - \alpha^2_0}{n^2+2} \right) \sum \alpha_{\text{cat}} \] 
\( \alpha^2_0 \) is connected to \( \alpha^2 - \alpha^2_0 \); \( \Lambda = 1.67 \left( 1 - \frac{1}{\alpha^2_0} \right) \). Figures 9, 10 and 11 exemplify the \( R_m, \alpha_m \) and \( \Lambda \) separately. The refractive index is trending in the same direction with MoO$_3$ content has been reported.

The molar refraction \( R_m \) is linked to the \( E_{\text{opt}} \) and \( V_m \) of the glasses by this formula.
Fig. 5  \((\alpha \ h\nu)^{1/2}\) against \((h\nu)\) to calculate \(E_{opt}\)

Table 2  values of physical properties

| code | G 1 | G 2 | G 3 | G 4 | G 5 |
|------|-----|-----|-----|-----|-----|
| \(N_a\) | 3.55 | 3.6 | 3.65 | 3.75 | 3.85 |
| \(M\) (mol) | 94.4 | 97.25 | 100.1 | 105.8 | 111.51 |
| \(R_m\) (cm\(^3\)/mol) | 23.92 | 21.6 | 21.02 | 20.62 | 19.2 |
| \(\alpha_m\) (\(\text{A}^3\)) | 9.49 | 8.56 | 8.34 | 8.18 | 7.6 |
| \(M\) | 0.33 | 0.34 | 0.345 | 0.347 | 0.353 |
| \(R_L\) | 0.666 | 0.659 | 0.655 | 0.653 | 0.647 |
| \(\chi\) | 0.6 | 0.624 | 0.64 | 0.65 | 0.67 |
| \(\alpha^m\) | 1.4 | 1.39 | 1.38 | 1.376 | 1.365 |
| \(\chi\) | 2.96 | 2.939 | 2.924 | 2.917 | 2.898 |
| \(E_{opt}\) (eV) | 2.23 | 2.32 | 2.38 | 2.41 | 2.49 |
| \(E_a\) (eV) | 0.513 | 0.511 | 0.508 | 0.0503 | 0.5 |

Fig. 6  \(\ln(\alpha)\) against \((h\nu)\) for prepared glasses
A significant role of MoO$_3$ on the optical, thermal, and…

**Fig. 7** $E_{opt}$ and $E_u$ versus concentration of MoO$_3$

**Fig. 8** Refractive index for prepared glasses

**Fig. 9** $R_m$ for prepared glasses
$$R_m = Vm \left( 1 - \sqrt{E_g / 20} \right)$$

It is used in isotropic materials to give molar refraction in the average form. The \( R_m \) can be obtained by known the molar polarizability, \( \alpha_m \) as,

$$\alpha_m = \left( \frac{3}{4\pi N} \right) R_m.$$ 

Reflection loss \( R_L = \left( \frac{R_m}{V_m} \right) \). Because \( V_m \) decreases with Mo+, \( (R_m) \) and \( (R_L) \) decline. The metallization criterion is expected to be as follows: \( M = 1 - \frac{R_m}{V_m} \). The electronegativity \( (\chi) \) is estimated to be as follows: \( \chi = 0.2688 E_{opt} \). \( \chi \) values increase as Mo+ increases. The polarizability of electrons and optical basicity \( \alpha^\circ \) are estimated to be as follows: \( \alpha^\circ = -0.9 \chi + 3.5 \) and \( \lambda = -0.5 \chi + 1.7 \). Because \( \alpha^\circ \) and \( \lambda \) have the inverse of \( \chi \), they decrease as Mo+ increases. These items are listed in Table 2.

The dispersion \( E_o \) and \( E_d \) was calculated as (Wemple and Didomenico 1971; Abdel-Aziz et al. 2001, 2006; Chiad et al. 2016). The hypothesis designated by \( n^2 - 1 = \frac{E_oE_d}{E_o^2 - E_d^2} \) (Alothman et al. 2021; Tekin et al. 2019c; Kaur et al. 2016; Sayyed et al. 2020; Agar...
et al. 2019; Al-Baradi et al. 2021a; Shaaban et al. 2021b). The plotting of \((n^2 - 1)^{-1}\) with \((h\nu)^2\) for fabricated glasses and \(E_o\) and \(E_d\) are predictable from the intercept and slope of Figs. 12 and 13. It mentioned that with increasing MoO\(_3\), \(E_o\) and \(E_d\) were slightly enhanced. The optical energy \(E_{\text{opt}}\) that represent \(E_{\text{opt}} = \frac{E_d}{2}\). Refractive Static index at an infinite wavelength
(n₀) was estimated by
\[ n₀ = \sqrt{1 + \frac{E_d}{E_0}} \] and the static dielectric \( \varepsilon_\infty = n_0^2 \). The oscillator’s wavelength (λ₀) and strength (S₀) were calculated using the following formula
\[ n^2 - 1 = \frac{S_0\lambda_0^2}{1 - \left(\frac{\lambda_0}{2}\right)^2}. \] These items are recorded in Table 3.

### 3.3 DTA

The thermal analysis (DTA) of glass samples is demonstrated in Fig. 14. The temperature of the glass transition, Tg, is 493–532 °C. The temperature of the glass crystallization Tc starts at 537–580 °C. The temperature of the glass crystallization Tc ends at 606–645 °C. According to DTA observations, Tg increases from 493 to 532 °C, Tc increases from 537 to 580 °C and Tp increases from 606 to 645 °C with the increase of MoO₃ content. The transformation of Li–O to Mo–O linkages is significantly associated with this behavior. Thermal stability estimated by \( \Delta T = (Tc - Tg) \), weighted thermal stability \( Hg = \Delta T/Tg \) and \( S = (T_p - T_c)\Delta T/T_g \). It observed that all thermal stability of samples improved as MoO₃. The \( T_g, T_c, T_p \), and thermal stability values are obtainable in Table 4.

### 3.4 Photon shielding features

The level of protection was assessed in this article by increasing MoO₃ at the expense of Li₂O with the composition 42.5B₂O₃–42.5P₂O₅–(15 – x) Li₂O–x MoO₃, (0 ≤ x ≥ 15).
A significant role of MoO$_3$ on the optical, thermal, and...

mean free path (MFP) is depicted in Fig. 15. It was stated that as photon energy increases, the values of (MFP) increment. This insight revealed that as the photon’s energy increases, it becomes capable of transmitting samples on purpose. Because the lower value of the (MFP) sample has a higher MoO$_3$ content, good radiation attenuation glasses are available. (El-Sharkawy et al. 2020; El-Rehim et al. 2020; Singh et al. 2007, 2005; Mostafa et al. 2013; Waly et al. 2016; Tekin et al. 2019b, 2019c; Mahmoud et al. 2021; Kavaz et al. 2019b; Alomairy et al. 2021; Alothman et al. 2021; Kaur et al. 2016; Sayyed et al. 2020; Agar et al. 2019; Al-Baradi et al. 2021a, 2021b; Shaaban et al. 2021b).

Figure 16 demonstrates the ($N_{\text{eff}}$) of fabricated glasses. It is demonstrated that ($N_{\text{eff}}$) decreases and then rises as energy increments. This significant decrease is accredited to
the interaction of Compton scattering. The effect of forming pairs at higher energy levels as MoO₃ is linked to the increase in \( N_{\text{eff}} \).

The ASC of fabricated glasses is presented in Fig. 17. The ASC and ESC values are expected to decrease as energy rates increase. The Compton scattering interaction is responsible for this decline. The \( C_{\text{eff}} \) of fabricated glasses is depicted in Fig. 18. With the increase in photon energy, it is predicted that \( C_{\text{eff}} \) will decrease. The impact of pair-creation was reflected in the increase in \( C_{\text{eff}} \).

The EBF and EABF of fabricated samples have been characterized by Figs. 19 and 20. EBF and EABF values are determined by the lower energy and concentration of the glasses. At lower energy levels, EBF and EABF values are low, but they rise as energy levels rise. After that, gradually decrease as the energy level rises. So, we can divide the energy scale into three parts low, medium, and high. The first part (low energy): the typical phase is the photoelectric effect, and the relationship is reversed with light, and the glasses will absorb the energy photons. The photons are therefore not allowed
to build up. In the second part (medium energy): the common process is the Compton scattering, the values of EBF and EABF is improved in all samples independent from the MFP. Through this part, the photons stay in the samples for a long time, as these
Fig. 20  EABF for the prepared glasses
processes lead to high accumulation value due to multiple scattering processes. Third parts (high energy): the communal method is pair production. In this process, EBF and, EABF is decreased with energy. Therefore, these data helped in the determination of maximum radiation intensity occur. In this research, the highest radiation occurs on the surface of the glasses. In Fig. 21, fast cross-section neutron removal (FNRC) is shown. It was stated that MoO3 improved FNRC.

4 Conclusions

In the existing research, molybdenum lithium borophosphate glasses $42.5P_2O_5-42.5B_2O_3-(15-x) Li_2O-xMoO_3$ where $x = (0 \leq x \leq 15)$ were fabricated with conventional melt-quenching procedures. Optics, thermal, and shielding factors were observed. The findings showed the following objects:

1. Because of the increase in MoO$_3$, the metallization of these glasses was improved.
2. The 2.23 for G 1, 2.32 for G 2, 2.38 for G 3, 2.41 for G 4, and 2.49 for G 5 were identified as the indirect optical bands that were collected.
3. Urbach energies of these samples were reduced as the content of MoO$_3$ increased.
4. As the density of the investigated samples increments, the refractive index rises as well.
5. These glasses were investigated for molar polarization, polarizability, and optical basicity.
6. $T_g$, $T_e$, $T_p$, and thermal stability values are enhanced with MoO$_3$.
7. The fabricated samples’ gamma shielding features were predictable. The impact of adding MoO$_3$ to the glasses on their shielding ability was mentioned.
8. The lower value of the (MFP) sample has more MoO$_3$ are good radiation attenuation glasses are available.
9. As the concentration of MoO$_3$ increased, these glasses have a high cross-section neutron removal rate.

The findings discovered that as MoO$_3$ increases the glass system can result in significant improvements in attenuation and optical characteristics. Furthermore, it is possible
to use this glass in optoelectronics, optical devices, and a radiation shield for use in x-ray centers.

Acknowledgements  We would like to thank Taif University Research Supporting Project number (TURSP-2020/24), Taif University, Taif, Saudi Arabia. Moreover, the authors express their gratitude to the Deanship of Scientific Research at King Khalid University for funding this work through research groups program under grant number R.G.P. 2/137/42.

References

Abd-Allah, W.M., Saudi, H.A., Shaaban, K.S., et al.: Investigation of structural and radiation shielding properties of 40B₂O₃–30PbO–(30–x) BaO-x ZnO glass system. Appl. Phys. A 125, 275–285 (2019). https://doi.org/10.1007/s00339-019-2574-0

Abdel-Aziz, M.M., Elmetwally, E.G., Fadel, M., Labib, H.H., Afifi, M.A.: Optical properties of amorphous Ge-Se-Ti system films. Thin Solid Films 386, 99–104 (2001)

Abdel-Aziz, M.M., Yahia, I.S., Wahab, L.A., Fadel, M., Afifi, M.A.: Determination and analysis of dispersive optical constant of TiO₂ and Ti₂O₃ thin films. Appl. Surf. Sci. 252(23), 8163–8170 (2006)

 Abdelghany, A.M., ElBatal, F.H., Azooz, M.A., Ouis, M.A., ElBatal, H.A.: Optical and infrared absorption spectra of 3d transition metal ions-doped sodium borophosphate glasses and effect of gamma irradiation. Spectrochim. Acta Part A Mol. Biomol. Spectrosc. 98, 148–155 (2012). https://doi.org/10.1016/j.saa.2012.08.049

Agar, O., Sayyed, M.L., Tekin, H.O., Kaky, K.M., Baki, S.O., Kityk, I.: An investigation on shielding properties of BaO, MoO₃ and P₂O₅ based glasses using MCNPX code. Results Phys. 12, 629–634 (2019). https://doi.org/10.1016/j.rinp.2018.12.003

Al-Baradi, A.M., Wahab, E.A.A., Shaaban, K.S.: Preparation and characteristics of B₂O₃–SiO₂–Bi₂O₃–TiO₂–Y₂O₃ glasses and glass-ceramics. SILICON (2021a). https://doi.org/10.1007/s12633-021-01286-y

Al-Baradi, A.M., El-Rehim, A.F.A., Alrowaili, Z.A., et al.: FT-IR and gamma shielding characteristics of 22SiO₂–23Bi₂O₃–37B₂O₃–13TiO₂–(5–x) LiF–x BaO glasses. SILICON (2021b). https://doi.org/10.1007/s12633-021-01481-x

Albarzan, B., Almuqrin, A.H., Koubisy, M.S., Wahab, E.A.A., Mahmoud, K.A., Shaaban, K., Sayyed, M.I.: Effect of Fe₂O₃ doping on structural, FTIR and radiation shielding characteristics of aluminium-lead-doped glasses. Prog. Nucl. Energy 141, 103931 (2021). https://doi.org/10.1016/j.pnucene.2021.103931

Alomairy, S., Al-Buriahi, M.S., Abdel Wahab, E.A., Srwunkum, C., Shaaban, K.: Synthesis FTIR and neutron/charged particle transmission properties of Pb3O₄–SiO2–ZnO–WO3 glass system. Ceram. Int. 47, 17322–17330 (2021). https://doi.org/10.1016/j.ceramint.2021.03.045

Alothman, M.A., Alrowaili, Z.A., Alzahrani, J.S., Wahab, E.A.A., Olininoye, I.O., Srwunkum, C., Shaaban, K.S., Al-Buriahi, M.S.: Significant influence of MoO₃ content on synthesis, mechanical, and radiation shielding properties of B₂O₃-PbO-Al₂O₃ glasses. J. Alloy. Compd. 882, 160625–160633 (2021). https://doi.org/10.1016/j.jallcom.2021.160625

Chiad, S.S., Habubi, N.F., Abass, W.H., Allah, M.H.A.: Effect of thickness on the optical and dispersion properties of Cd₂.4Se₂.6 thin films. J. Opt. Elec. Adv. Mat. 18(9–10), 822 (2016)

Chida, K., Kaga, Y., Haga, Y., Kataoka, N., Kumasaka, E., Meguro, T., Zuguchi, M.: Occupational dose in interventional radiology procedures. Am. J. Roentgenol. 200(1), 138–141 (2013). https://doi.org/10.2214/AJR.11.8455

Dimitrov, V., Komatsu, T.: Classification of simple oxides: a polarizability approach. J. Solid-State Chem. 163(1), 100–112 (2002). https://doi.org/10.1006/jssc.2001.9378

Dimitrov, V., Sakka, S.: Electronic oxide polarizability and optical basicity of simple oxides I. J. Appl. Phys. 79(3), 1736–1740 (1996). https://doi.org/10.1063/1.36096

Duffy, J.A.: A common optical basicity scale for oxide and fluoride glasses. J. Non-Cryst. Solids 109(1), 35–39 (1989). https://doi.org/10.1016/0022-3093(89)90438-9

Duffy, J.A., Ingram, M.D.: Comments on the application of optical basicity to glass. J. Non-Cryst. Solids 144, 76–80 (1992). https://doi.org/10.1016/0022-3093(89)90385-0

Elbers, S., Strojek, W., Koudelka, L., Eckert, H.: Site connectivities in silver borophosphate glasses: new results from 11B{31P} and 31P{11B} rotational echo double resonance NMR spectroscopy. Solid-State Nucl. Magn. Reson. 27(1–2), 65–76 (2005). https://doi.org/10.1016/j.ssnmr.2004.08.007
A significant role of MoO$_3$ on the optical, thermal, and…

El-Maaref, A.A., Badr, S., Shaaban, K.S., Wahab, E.A.A., El Okr, M.M.: Optical properties and radiative rates of Nd$^{3+}$ doped zinc-sodium phosphate glasses. J. Rare Earths. 37, 253–259 (2019). https://doi.org/10.1016/j.jre.2018.06.006

El-Maaref, A.A., El-Agmy, R.M., Shaaban, K.S., et al.: Optical and spectroscopic study of Nd$_2$O$_3$-doped SBN glass in the near-infrared, visible and UV regions under pumping up-conversion emissions. Eur. Phys. J. plus 136, 804–826 (2021). https://doi.org/10.1140/epjp/s13360-021-01798-x

El-Rehim, A.A., Zahran, H., Yahia, I., et al.: Radiation, crystallization, and physical properties of cadmium borate glasses. SILICON (2020). https://doi.org/10.1007/s12633-020-00798-3

El-Sharkawy, R.M., Shaaban, K.S., Elsaman, R., Allam, E.A., El-Taher, A., Mahmoud, M.E.: Investigation of mechanical and radiation shielding characteristics of novel glass systems with the composition xNiO-20ZnO-60B$_2$O$_3$-(20–x) CdO based on nano metal oxides. J. Non-Cryst. Solids 528, 119754–119763 (2020). https://doi.org/10.1016/j.jnoncrysol.2020

Etzel, R., König, A.M., Keil, B., Fiebig, M., Mahnknecht, A.H.: Effectiveness of a new radiation protection system in the interventional radiology setting. Eur. J. Radiol. 106, 56–61 (2018). https://doi.org/10.1016/j.ejrad.2018.07.006

Fayad, A.M., Shaaban, K.S., Abd-Allah, W.M., et al.: Structural and optical study of CoO doping in borophosphate host glass and effect of gamma irradiation. J. Inorg. Organomet. Polym. (2020). https://doi.org/10.1007/s10904-020-01643-1

Kalnins, C.A.G., Ebendorff-Heidepriem, H., Spooner, N.A., Monro, T.M.: Enhanced radiation dosimetry of fluoride phosphate glass optical fibres by terbium (III) doping. Opt. Mater. Express 6(12), 3692–3703 (2016). https://doi.org/10.1364/OME.6.003692

Kaur, P., Singh, D., Singh, T.: Heavy metal oxide glasses as gamma rays shielding material. Nucl. Eng. Des. 307, 364–376 (2016). https://doi.org/10.1016/j.nucengdes.2016.07.029

Kavaz, E., Tekin, H.O., Agar, O., Altunsoy, E.E., Kilicoglu, O., Kamislioglu, M., Sayyed, M.I.: The Mass stopping power/projected range and nuclear shielding behaviors of barium bismuth borate glasses and influence of cerium oxide. Ceram. Int. 45, 15348–15357 (2019b). https://doi.org/10.1016/j.ceramint.2019.05.028

Kavaz, E., Tekin, H.O., Agar, O., Altunsoy, E.E., Kilicoglu, O., Kamislioglu, M., Abuzaid, M.M., Sayyed, M.I.: The Mass stopping power/projected range and nuclear shielding behaviors of bismuth barium borate glasses and influence of cerium oxide. Ceram. Int. 45(1215), 15348–15357 (2019a). https://doi.org/10.1016/j.ceramint.2019.05.028

Khafragy, A.H., El-Adawy, A.A., Higazy, A.A., El-Rabaie, S., Eid, A.S.: Studies of some mechanical and optical properties of (70–x) TeO$_2$-15B$_2$O$_3$-15P$_2$O$_5$-xLi$_2$O glasses. J. Non-Cryst. Solids 354(27), 3152–3158 (2008). https://doi.org/10.1016/j.jnoncrysol.2008.01.013

König, A., Etzel, R., Thomas, R., Mahnknecht, A.: Personal radiation protection and corresponding dosimetry in interventional radiology: an overview and future developments. Röfo–Fortschritte Auf Dem Gebiet Der Röntgenstrahlen Und Der Bildgebenden Verfahren 191(06), 512–521 (2019). https://doi.org/10.1055/a-0800-0113

Kosaka, H., Monzen, H., Matsumoto, K., Tamura, M., Nishimura, Y.: Reduction of operator hand exposure in interventionial radiology with a novel finger sack using tungsten-containing rubber. Health Phys. 116(5), 625–630 (2019). https://doi.org/10.1097/HP.0000000000000992

Koudelka, L., Mošner, P.: Study of the structure and properties of Pb–Zn borophosphate glasses. J. Non-Cryst. Solids 293–295(2001). https://doi.org/10.1016/s0022-3093(01)00765-7

Magistris, A., Chiodelli, G.: Silver borophosphate glasses: ion transport, thermal stability and electrochemical behaviour. Solid State Ion. 9–10(1), 611–615 (1983). https://doi.org/10.1016/0167-2738(83)90303-X

Mahmoud, M., Makhlouf, S.A., Alshahrani, B., et al.: Experimental and simulation investigations of mechanical properties and gamma radiation shielding of lithium cadmium gadolinium silicate glasses doped erbium ions. SILICON (2021). https://doi.org/10.1007/s12633-021-01062-y

Mettler, F.A., Huda, W., Yoshizumi, T.T., Mahesh, M.: Effective doses in radiology and diagnostic nuclear medicine: a catalog. Radiol. 248, 254–263 (2008). https://doi.org/10.1148/radiol.2481071451

Mollér, A.P., Mousseau, T.A.: The effects of natural variation in background radioactivity on humans, animals and other organisms. Biol. Rev. 88, 226–254 (2013). https://doi.org/10.1011/j.1469-185X.2012.00249.x

Mostafa, A.G., Hassaan, M.Y., Ramadan, A.B., Hussein, A.Z., Abdel-Haseib, A.Y.: Characterization of iron sodium phosphate glasses doped Ba$^{2+}$ cations for using as radioactive waste encapsulation. Nat. Sci. 11, 148–155 (2013)

Narwal, P., Dahiyta, M.S., Kundu, P., Yadav, A., Hooda, A., Khasa, S.: Compositional dependence of properties in calcium substituted sodium borophosphate glasses containing VO$^{2+}$ ions. Bull. Mater. Sci. 42(3), 105–113 (2019). https://doi.org/10.1007/s12034-019-1812-6
Nowak, M., Sans-Merce, M., Lemesre, C., Elmiger, R., Damet, J.: Eye lens monitoring programme for medical staff involved in fluoroscopy guided interventional procedures in Switzerland. Phys. Med. 57, 33–40 (2019). https://doi.org/10.1016/j.ejmp.2018.12.001

Rao, L.S., Reddy, M.S., Rao, D.K., Veeraiah, N.: Influence of redox behavior of copper ions on dielectric and spectroscopic properties of Li2O–MoO3–B2O3: CuO glass system. Solid-State Sci. 11(2), 578–587 (2009). https://doi.org/10.1016/j.solidstatesciences.2008.06.022

Raza, S.H., Afzal, N., Rafique, M., Imran, M., Ahmad, R.: Structural and morphological properties of annealed MoO3 films on different substrates. Surf. Rev. Lett. (2019). https://doi.org/10.1142/s0218625x19501506

Şakar, E., Özpolat, Öü.Fı., Alım, Bü., Sayyed, M.I., Kurudirek, M., PhyX / PSD: Development of a user-friendly online software for calculation of parameters relevant to radiation shielding and dosimetry, Radiat. Phys. Chem. 166, 108496–108508 (2020). https://doi.org/10.1016/j.radphyschem.2019.108496

Santangeli, S.H., de Araujo, C.C., Strojek, W., Eckert, H., Poirier, G., Ribeiro, S.J.L., Messaddeq, Y.: Structural studies of NaPO3–MoO3 glasses by solid-state nuclear magnetic resonance and Raman spectroscopy, J. Phys. Chem. B 111(34), 10109–10117 (2007). https://doi.org/10.1021/jp072883n

Saud, H.A., Abd-Allah, W.M., Shaaban, K.S.: Investigation of gamma and neutron shielding parameters for borosilicate glasses doped europium oxide for the immobilization of radioactive waste. J Mater Sci: Mater Electron. 31, 6963–6976 (2020). https://doi.org/10.10852-02-03261-6

Sayeed, M.A., Ali, M.A., Abd El-Rehim, A.F., et al.: Dispersion parameters, polarizability, and basicity of lithium phosphate glasses. J. Electron. Mater. 50, 3116–3128 (2021). https://doi.org/10.1007/s12633-019-3182-8

Shaaban, K.S., El-Sayed, Y.: Optical properties of Bi2O3 doped borotellurite glasses and glass-ceramics. Optik–Int. J. Light Electron Opt. 203, 163976–163977 (2020). https://doi.org/10.1016/j.ijleo.2019.163976

Shaaban, K.S., Saadik, Y.B.: Effect of MoO3 content on structural, thermal, mechanical and optical properties of (B2O3-SiO2-Bi2O3-Na2O-Fe2O3) glass system. SILICON 9(5), 785–793 (2017). https://doi.org/10.1007/s12633-017-9558-5

Shaaban, K., Abdel Wahab, E.A., El-Maaref, A.A., et al.: Judd-Ofelt analysis and physical properties of erbium modified lithium gadolinium silicate glasses. J Mater Sci: Mater Electron. 31, 4986–4996 (2020). https://doi.org/10.1007/s10904-020-03065-8

Shaaban, K.S., Wahab, E.A.A., Shaaban, E.R., et al.: Electronic polarizability, optical basicity, thermal, and optical investigations of (65B2O3–30Li2O–5Al2O3) glasses doped with titanate. J. Electron. Materi. 49, 2040–2049 (2020d). https://doi.org/10.1007/s11664-019-07889-x

Shaaban, K.S., Abo-naf, S.M., Abd Elmaaeem, A.M., Hassouna, M.E.M.: Studying effect of Mo3 on elastic and crystallization behavior of lithium diborate glasses. Appl. Phys. A 123(6), 457 (2017). https://doi.org/10.1007/s00339-017-1052-9

Shaaban, K.S., Abo-Naf, S.M., Hassouna, M.E.M.: Physical and structural properties of lithium borate glasses containing MoO3. SILICON 11, 2421–2428 (2019). https://doi.org/10.1007/s12633-016-9519-4

Shaaban, K.S., Yousef, E.S., Mahmoud, S.A., et al.: Mechanical, structural, and crystallization properties in titanate doped phosphate glasses. J. Inorg. Organomet. Polym. (2020a). https://doi.org/10.1007/s10904-020-01574-x

Shaaban, K.S., Wahab, E.A.A., Shaaban, E.R., et al.: Electronic polarizability, optical basicity, and mechanical properties of aluminum lead phosphate glasses. Opt. Quant. Electron. 52, 125 (2020b). https://doi.org/10.1007/s11082-020-2191-3

Shaaban, K.S., Zahran, H.Y., Yahia, I.S., et al.: Mechanical and radiation-shielding properties of B2O3–P2O5–Li2O–MoO3 glasses. Appl. Phys. A 126, 804 (2020c). https://doi.org/10.1007/s00339-020-03982-9

Shaaban, K.S., Koubisy, M.S.I., Zahran, H.Y., et al.: Spectroscopic properties, electronic polarizability, and optical basicity of titanium-cadmium tellurite glasses doped with different amounts of lanthanum. J. Inorg. Organomet. Polym. (2020f). https://doi.org/10.1007/s10904-020-01640-4

Shaaban, K.S., Al-Baradi, A.M., Alrowaili, Z.A., et al.: Structural, thermal, and mechanical characteristics of yttrium lithium borate glasses and glass–ceramics. J. Mater. Sci.: Mater. Electron. (2021a). https://doi.org/10.1007/s10854-021-07158-w
A significant role of MoO$_3$ on the optical, thermal, and...