Synthesis, physical, optical and structural studies of $\text{B}_2\text{O}_3$-$\text{CdO}$-$\text{Al}_2\text{O}_3$-$\text{PbF}_2$ glasses modified with $\text{MoO}_3$ ions

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Abstract
This manuscript deals with the preparation and detailed physical and structural study of $\text{B}_2\text{O}_3$-$\text{CdO}$-$\text{Al}_2\text{O}_3$-$\text{PbF}_2$ glasses reinforced with $\text{MoO}_3$ ions. With the addition of $\text{MoO}_3$, the density and band gap values decreased while the refractive index increased, confirming the transformation of $\text{Mo}^{6+}$ ions to $\text{Mo}^{5+}$ ions and resulting in the generation of NBO’s in these glasses. The FTIR spectra revealed the presence of different borate and aluminate units. The FTIR spectra also indicated the conversion of $\text{Mo}^{6+}$ ions to $\text{Mo}^{5+}$ ions. The effect of $\text{MoO}_3$ ions on Raman spectra was clearly visible and indicated the conversion of $\text{BO}_4$ to $\text{BO}_3$ units, increasing NBO’s which helped to explain the density variation.

Keywords Cadmium borate glasses · Optical absorption · Refractive index · FTIR · Raman spectra

1 Introduction
The extreme importance of glasses has been increasing in day to day regular needs and in most of the areas, which in turn impelled researchers to magnify their view in various chemical compositions with borate, silicate, phosphate, etc. for its large area of applications (Wang et al. 2019; Venkateswara and Shashikala 2014). Because of its low melting point, transparency, thermal stability, and solubility, borate is being considered mostly as a glass forming material (Chandra et al. 2018; Mahesh et al. 2017). Physical, chemical, and optical characteristics all change significantly when $\text{Al}_2\text{O}_3$ is incorporated to the borate matrix. Depending on the proportion of $\text{Al}_2\text{O}_3$, it can be detected in the glass network as $\text{AlO}_4$ or $\text{AlO}_6$ units. An increase in $\text{Al}_2\text{O}_3$ concentration can greatly improve mechanical strength, chemical durability, and moisture resistance capacity. Alumino borate glasses

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can also mix with other metal oxides and transition metal ions (TMI) (Ahmed et al. 2022; Ashok et al. 2021; Lalitha Phani et al. 2018).

CdO is amongst the most prominent metal oxides being used glass compositions to increase density, and it is widely known that CdO is employed as control rods in nuclear reactors. Fluorides are added to borate glasses to give them a larger transmission window, solubility, and fluorescence lifespan, including other properties (Lalitha Phani et al. 2018; Mahmoud et al. 2020; Chandra Sekhar 2022). PbF$_2$, when added with borate glasses improves specific optical characteristics and IR transparency, which are employed in communication and laser engineering systems (Chandra et al. 2021a).

On the other hand, it was discovered that molybdenum ions exhibit exceptional activity and selectivity in a range of oxidation activities in various oxide glasses, making them suitable candidates for studying catalytic characteristics. Molybdenum ions may exist in a variety of valence states (+3, +4, +5, and +6), which may help the glasses to improve their optical, electrical, and electrochromic characteristics. Owing to electron hopping around molybdenum ions, the occurrence of molybdenum ions in multivalence states increases the electronic contribution to conduction (Ibrahim and Alkhammash 2021; Banagar et al. 2020; Saddeek 2007). Moreover, the glasses with heavy metal oxides such as MoO$_3$, CdO, PbO etc. find applications in Radiation shielding applications (Abouhaswa et al. 2021; Saddeek et al. 2022; Mostafa et al. 2020; Zakaly et al. 2021, 2022).

Ali et al. (2010) studied the influence of MoO$_3$ on PbO–Sb$_2$O$_3$–As$_2$O$_3$–MoO$_3$ glasses and concluded that the former and modifier role of MoO$_3$ in these glasses based on its mol%. Alrowaili et al. (2022) prepared the P$_2$O$_5$–B$_2$O$_3$–Li$_2$O–MoO$_3$ glasses and observed that the density, refractive index, metallization criteria and shielding ability were enhanced while the Urbach energy lowered with the MoO$_3$ concentration. Various other researchers, Shaaban et al. (2020), Rada et al. (2010), Manisha et al. (2001), etc. prepared glasses with various compositions containing the MoO$_3$ and confirmed that the glasses when incorporated with MoO$_3$ found better applications related to optical and shielding features. As a result, the union of borate with MoO$_3$ can result in the formation of glasses. Furthermore, recent research has shown that even a minute amount of TMI injected to glasses causes major alterations in the glass network. Moreover, when borate doped cadmium alumina matrix with variable mole percentages of metal fluoride and transition metal ion unveils the finest properties apart from the best optical possessions, electronic, optoelectronic and electro chromic applications.

2 Experimental

The glass samples were prepared with unique composition 60B$_2$O$_3$-20CdO-5Al$_2$O$_3$-(15-x) PbF$_2$-xMoO$_3$ (where x=0, 0.5, 1, 1.5, and 2 mol%). The method employed in preparation of glass samples was melt quenching. All the required chemicals were annular grade, which are weighed with required mole percentages for five sets of glass compositions. The dissimilar mole percentages of chemicals being measured using an electronic monopan balance and then physically mixed in an agate mortar until the chemicals were uniformly blended. This mixer of chemicals was taken in porcelain crucible and kept in an electronic furnace, which is under normal atmospheric conditions, maintained at 1000 °C temperature for 1 h to melt congruently. Further melts are stirred to gain homogeneity. The obtained melt was quenched on steel plate, which is at 200 °C for couple of hours to release the internal stresses and finally the glass samples are ready for further characterization.
On a Philips Xpert Pro X-ray diffractometer, X-ray diffraction (XRD) spectra being measured in the range of 10°–80° for 2θ to know the nature of the specimens. The Archimedes principle is then used to evaluate density where Xylene is being used as the dipping liquid. For density measurements, three experimental pieces from each glass were collected, and the aggregate density of the three sample pieces was used to get the final density. The accuracy of the computation is 0.005 g/cc. Fourier transform infrared (FTIR) spectra were recorded using a Bruker FTIR spectrometer with a resolution of 0.5 cm⁻¹ and a precision of 0.01 cm⁻¹. On a J. Y. H. LABRAM-HR Raman spectrometer, Raman spectra of BCAPM glasses were scanned in the wavenumber range of 200–1800 cm⁻¹. On a Shimadzu UV-1800 Spectrometer in absorption mode, the UV–Visible spectra of BCAPM glasses were scanned across a wavelength range of 200 nm to 1000 nm. At room temperature, EPR spectra were scanned between 2500 and 4000G using a Bruker EPR spectrometer.

3 Results and discussions

3.1 X-ray diffraction (XRD)

Figure 1 shows the XRD patterns of the BCAPM glasses. The figure clearly displays wide humps between 20 ≈ 20° to 30°. Furthermore, there are no sharp peaks, implying that BCAPM samples are amorphous (Table 1).

3.2 Physical and optical properties

The density is indeed a significant physical characteristic which shares insights about solids; such evidence will be more beneficial if the structure is properly understood (Singh et al. 2014; Saddeek and Gaafar 2009). The volume of structural units contained in the glass may be determined using the density data of the samples. The density
values in the current BCAPM glass system were dropped nonlinearly from 4.072 g/cc (BCAPM0) to 4.009 g/cc (BCAPM4). The molar volume ($V_m$) was calculated using the measured density and molecular weight (M) data (Table 2). In Fig. 2, the fluctuation of $\rho$ and $V_m$ with MoO$_3$ is displayed.

The density of the BCAPM glasses drops non-linearly as the mole percentage of MoO$_3$ grows, as seen by the respective crystal densities of MoO$_3$ (4.70 gm/cc) and PbF$_2$ (8.44 gm/cc). Fractional substitution of PbF$_2$ (245.2 g/mol) by MoO$_3$ (143.94 g/mol) might potentially explain the reduction in density. The fall in density values might potentially be due to the conversion of [BO$_4$] units to [BO$_3$] units where [BO$_4$] is denser than [BO$_3$], according to the literature (Chandra et al. 2021b, 2021c).

Absorption spectra of BCAPM glasses are presented in Fig. 3. The analysis of the valence and conduction band transitions using the primitive absorption edge in the UV–Visible zone is a fascinating method. The prime aspect of the absorption edge in non-crystalline solids is the absorption coefficient $\alpha(\nu)$ with smaller values as a function of the photon energy $h\nu$ (Urbach and Phys. 1324).

\[
\alpha(\theta) = C \exp \left( \frac{h\theta}{\Delta E} \right)
\]

where $\Delta E$ is Urbach energy and $C$ is a constant. The $\alpha(\nu)$ can be obtained from the absorbance $A$ by using the equation below;

| Sample Code | Composition in mole% |
|-------------|-----------------------|
|              | B$_2$O$_3$  | CdO  | Al$_2$O$_3$ | PbF$_2$ | MoO$_3$ |
| BCAPM0      | 60     | 20   | 5          | 15      | 0       |
| BCAPM1      | 60     | 20   | 5          | 14.5    | 0.5     |
| BCAPM2      | 60     | 20   | 5          | 14      | 1       |
| BCAPM3      | 60     | 20   | 5          | 13.5    | 1.5     |
| BCAPM4      | 60     | 20   | 5          | 13      | 2       |

### Table 1 Sample code and the glass compositions

| Physical and optical parameters | Sample code |
|---------------------------------|-------------|
| Average molecular weight        | 141.754     |
| Density ($\rho$) gm/cc          | 4.072       |
| Molar Volume ($V_m$) cc/mol     | 34.80       |
| Optical band gap ($E_{opt}$) eV | 3.063       |
| Refractive index (n)            | 2.379       |
| Dielectric constant ($\varepsilon$) | 5.660   |
| Molar refractivity (Rm) cm$^{-3}$ | 21.17     |
| Electronic polarizability ($\alpha_m$) $10^{-21}$ cm$^{-3}$ | 8.38       |
| Urbach energy ($\Delta E$) eV   | 0.257       |

| Parameter                       | BCAPM0 | BCAPM1 | BCAPM2 | BCAPM3 | BCAPM4 |
|---------------------------------|--------|--------|--------|--------|--------|
| Average molecular weight        | 141.754| 141.248| 140.742| 140.235| 139.729|
| Density ($\rho$) gm/cc          | 4.072  | 4.057  | 4.041  | 4.025  | 4.009  |
| Molar Volume ($V_m$) cc/mol     | 34.80  | 34.81  | 34.82  | 34.83  | 34.84  |
| Optical band gap ($E_{opt}$) eV | 3.063  | 3.049  | 3.013  | 3.002  | 2.951  |
| Refractive index (n)            | 2.379  | 2.383  | 2.393  | 2.396  | 2.410  |
| Dielectric constant ($\varepsilon$) | 5.660  | 5.682  | 5.728  | 5.743  | 5.809  |
| Molar refractivity (Rm) cm$^{-3}$ | 21.17  | 21.21  | 21.30  | 21.34  | 21.45  |
| Electronic polarizability ($\alpha_m$) $10^{-21}$ cm$^{-3}$ | 8.38   | 8.40   | 8.44   | 8.45   | 8.50   |
| Urbach energy ($\Delta E$) eV   | 0.257  | 0.191  | 0.213  | 0.216  | 0.223  |
where ‘d’ is the thickness. Davis et al. (1970) and Tauc et al. (1972) suggested relation:

\[ \alpha(\theta) = \frac{2.303 A}{d} \]  

where  \( \alpha \) is the absorption coefficient,  \( A \) is the absorbance,  \( d \) is the thickness,  \( \theta \) is the angle of incidence,  \( h \) is Planck’s constant,  \( \nu \) is the frequency of light,  \( E_g \) is the bandgap, and  \( B \) is a constant.

\[ (ah\nu) = B^2(h\nu - E_g)^2 \]  

Figure 4 shows the Tauc plot of BCAPM glasses. The optical band gap (\( E_g \)) values (see Table 2) are acquired by extrapolating the linear region of the curve. With the enhancement of MoO\(_3\) from \( x=0 \) to 2 mol% in the current BCAPM glasses,  \( E_g \) declines from 3.063 eV (BCAPM0) to 2.951 eV (BCAPM4). With the insertion of MoO\(_3\), the bandgap drops, indicating that localised states for electrons near the conduction band are established. The bandgap can indeed be reduced by associating these localised states with the conduction band.
Conversion of Mo$^{6+}$ ions to Mo$^{5+}$ ions may have caused the reduction in band gap. Increases in Mo$^{5+}$ ions, which occupy octahedral positions and function as modifiers in the glass network, can lead to an increase in non-bridging oxygens and a drop in bandgap (Ibrahim and Alkhammash 2021; Lakshmana et al. 2018).

The inverse slope of the linear section of the Urbach plot, as illustrated in Fig. 5, is used to calculate Urbach energy. The magnitude of disorder present in the glass network can be accessed by the Urbach energy. These values were found to be much lower for the BCAPM glass system, indicating that the glass structure had less disorder (Thakur et al. 2015).

The other parameters such as refractive index ($n$), molar electronic polarizability ($\alpha_m$), and molar refraction ($R_m$) are evaluated using the following relations (Dimitrov and Sakka 1996; Dimitrov and Komatshu 2002; Duffy 1986).

\[
\frac{n^2 - 1}{n^2 + 2} = 1 - \sqrt{\frac{E_g}{20}}
\]  \hspace{1cm} (4)
With an excess of MoO₃ in BCAPM glasses, the n values were elevated from 2.379 (BCAPM0) to 2.410 (BCAPM4). As both R_m and α_m are related to molar volume, they show a raising trend with composition.

### 3.3 FTIR spectroscopy

FTIR spectroscopy is the measurement for acquiring infrared absorption or transmission spectra in order to detect the presence of various functional groups in materials. The influence of MoO₃ on the structural characteristics of BCAPM glasses containing lead fluoride may be studied using FTIR spectra. The infrared absorption spectra of BCAPM glasses are shown in Fig. 6 in the wave number range of 400 to 1600 cm⁻¹. The various IR bands observed from FTIR spectra are 423, 461, 517, 579, 673, 724, 901, 995, 1061, 1116, 1168, 1279, 1376, 1466, and 1549 cm⁻¹ and their assignments are listed in Table 3. In general, the IR examination reveals two distinct frequency zones. The stretching vibrations BO₃ and BO₄ borate units are attributed to the ranges from 1200 to 1600 cm⁻¹ and 800 to 1200 cm⁻¹, respectively (Saddeek 2004; Balachander et al. 2013; Chandra et al. 2021d). Significant differences in the infrared spectra during analysis revealed the emergence of three primary broad bands at around 670, 1050, and 1380 cm⁻¹. The widths of the bands become wider as the MoO₃ concentration increased, although the spectra indicated no change in the centre of the bands. Relying on their valence states, molybdenum ions can join the glass network as network modifiers or network formers, with Mo⁵⁺ ions claiming the modifying sites and Mo⁶⁺ ions claiming the former sites. By converting the hexavalent molybdenum ions to the pentavalent ions, the addition of MoO₃ at the expense of PbF₂ in BCAPM glasses increases Mo⁵⁺ ions (which function as modifiers).

\[
R_m = \frac{n^2 - 1}{n^2 + 2} \times V_m \tag{5}
\]

\[
\alpha_m = \left( \frac{3}{4 \pi N_A} \right) \times R_m \tag{6}
\]
The bands between 423 and 517 cm\(^{-1}\) in BCAPM glass system are attributed to \(\text{Pb}^{2+}\) and \(\text{Cd}^{2+}\) vibrations and vibrations of \(\text{AlO}_6\) octahedral (Ahmed et al. 2022; Ashok et al. 2021; Vedavyas and Chandra 2021). The peak near 579 cm\(^{-1}\) might be attributed to the Mo–O bond vibrations in distorted \(\text{MoO}_4\) (Iordanova 1994, Saddeek 2007; Abouhaswa et al. 2021). IR band positions observed 673 cm\(^{-1}\) in BCAPM glasses indicates the elongations of \(\text{B–O–B}\) bonds in \(\text{BO}_3\) units groups (Yadav et al. 2013). The peak at around 724 cm\(^{-1}\) is assigned to the bending vibrations of \(\text{B–O}\) linkages. The structure’s Mo–O–Mo bridging bonds are responsible for the band at 900 cm\(^{-1}\) (Saddeek 2007). \(\text{B–O}\) stretching vibrations of tetrahedral \(\text{BO}_4\) units, cause the bands between 995 and 1060 cm\(^{-1}\) (Rajyasree and Krishna Rao 2012; Ardelean et al. 2008). Stretching vibrations of tetragonal \(\text{BO}_3\) units from different borate groups cause the bands between 1116 and 1279 cm\(^{-1}\). The stretching elongations of the \(\text{B–O}\) of trigonal \(\text{(BO}_3\text{)}^3^-\) units are assigned to the band at approximately 1376 cm\(^{-1}\). Anti-symmetrical elongations \(\text{B–O–B}\) groups are responsible for the IR band at 1476–1549 cm\(^{-1}\) (Chandrakiram et al. 2012; Nagaraju et al. 2021; Chandra Sekhar 2019).

### Table 3 FTIR peak positions and their assignments

| IR band position (cm\(^{-1}\)) | Assignments |
|---------------------------------|-------------|
| 420–520                         | \(\text{Pb}^{2+}, \text{Cd}^{2+}\) and \(\text{AlO}_6\) octahedral |
| ~579                            | Mo–O bond vibrations |
| ~673                            | Stretching vibration of \(\text{B–O–B}\) bonds in \(\text{BO}_3\) units |
| ~724                            | Bending vibrations of \(\text{B–O}\) linkages |
| ~900                            | Mo–O–Mo bridging bonds |
| 990–1070                        | \(\text{B–O}\) stretching vibrations |
| 1110–1280                       | Stretching vibrations of tetragonal \(\text{BO}_3\) units |
| ~1376                           | Stretching elongations of the \(\text{B–O}\) of trigonal \(\text{(BO}_3\text{)}^3^-\) units |
| 1476–1549                       | Anti-symmetrical stretching vibrations of \(\text{B–O–B}\) groups |

The bands between 423 and 517 cm\(^{-1}\) in BCAPM glass system are attributed to \(\text{Pb}^{2+}\) and \(\text{Cd}^{2+}\) vibrations and vibrations of \(\text{AlO}_6\) octahedral (Ahmed et al. 2022; Ashok et al. 2021; Vedavyas and Chandra 2021). The peak near 579 cm\(^{-1}\) might be attributed to the Mo–O bond vibrations in distorted \(\text{MoO}_4\) (Iordanova 1994, Saddeek 2007; Abouhaswa et al. 2021). IR band positions observed 673 cm\(^{-1}\) in BCAPM glasses indicates the elongations of \(\text{B–O–B}\) bonds in \(\text{BO}_3\) units groups (Yadav et al. 2013). The peak at around 724 cm\(^{-1}\) is assigned to the bending vibrations of \(\text{B–O}\) linkages. The structure’s Mo–O–Mo bridging bonds are responsible for the band at 900 cm\(^{-1}\) (Saddeek 2007). \(\text{B–O}\) stretching vibrations of tetrahedral \(\text{BO}_4\) units, cause the bands between 995 and 1060 cm\(^{-1}\) (Rajyasree and Krishna Rao 2012; Ardelean et al. 2008). Stretching vibrations of tetragonal \(\text{BO}_3\) units from different borate groups cause the bands between 1116 and 1279 cm\(^{-1}\). The stretching elongations of the \(\text{B–O}\) of trigonal \(\text{(BO}_3\text{)}^3^-\) units are assigned to the band at approximately 1376 cm\(^{-1}\). Anti-symmetrical elongations \(\text{B–O–B}\) groups are responsible for the IR band at 1476–1549 cm\(^{-1}\) (Chandrakiram et al. 2012; Nagaraju et al. 2021; Chandra Sekhar 2019).

### 3.4 Raman spectroscopy

Vibrational spectroscopy is amongst the best means for understanding the structure of glasses. Glasses comprise structural units that are equivalent to crystalline examples and may be positioned freely in a 3D network while being amorphous. Among the most powerful vibrational spectroscopy approaches for exploring glass structure is Raman spectroscopy. Raman spectra of BCAPM glasses is shown in Fig. 7 and deconvolution spectra for BCAPM1 sample is depicted in Fig. 8 to locate exact Raman band positions. The various Raman bands observed from Raman spectra are 344 cm\(^{-1}\), 498 cm\(^{-1}\), 674 cm\(^{-1}\), 789 cm\(^{-1}\), (983 cm\(^{-1}\) shift 925 cm\(^{-1}\)), 1079 cm\(^{-1}\), 1229 cm\(^{-1}\), (1347 cm\(^{-1}\) shift 1337 cm\(^{-1}\)), 1437 cm\(^{-1}\), and 1738 cm\(^{-1}\) and their band assignments are given in Table 4. The Raman band rising sharply at 344 cm\(^{-1}\) is ascribed to corner-shared \(\text{MoO}_6\) octahedra (Kaur et al. 2016; Sekiya et al. 1995). Another band existing at 498 cm\(^{-1}\) is due to isolated diborate groups (Alemi et al. 2006). Anti-symmetric elongations of O–Mo–O linkages were observed in BCAPM glasses due to the presence of the Raman band at 674 cm\(^{-1}\) (Seguin et al. 1995). Another Raman band present at 789 cm\(^{-1}\) is attributed to stretching vibrations of Mo–O–Mo linkages and the formation of \(\text{AlO}_4\) tetrahedra (Ahmed et al. 2022; Kaur et al. 2016). An important band increasing sharply in BCAPM glasses is observed at ~950 cm\(^{-1}\) and is ascribed to the vibrations of Mo–O and Mo=O bonds in single and paired \(\text{MoO}_6\) units (Kaur et al. 2016; Sokolov et al. 2009). The two Raman peaks, one at...
Fig. 7 Raman spectra of BCAPM glasses

![Raman spectra of BCAPM glasses](image)

Fig. 8 Deconvoluted Raman spectra of BCAPM1 glass sample

![Deconvoluted Raman spectra of BCAPM1](image)

Table 4 Raman band positions and their assignments

| Raman band position | Band assignments                                        |
|---------------------|--------------------------------------------------------|
| ~344                | MoO$_6$ octahedra                                      |
| ~498                | Isolated diborates                                     |
| ~674                | Anti-symmetric elongations of O–Mo–O linkages          |
| ~789                | Stretching vibrations of Mo–O–Mo linkages and the formation of AlO4 tetrahedra |
| ~950                | Vibrations of Mo–O                                    |
| ~1079               | Existence of diborate groups                           |
| ~1340               | Pyroborate groups                                      |
| ~1437               | B–O$^-$ vibrations of the BO$_3$ units                 |
| ~1738               | Chain and ring type metaborate units                   |
344 cm$^{-1}$ and the other at 950 cm$^{-1}$, are clearly rising sharply with increasing MoO$_3$ in the current BCAPM glass system, as seen by Raman spectra. Furthermore, the Raman band at 950 cm$^{-1}$ is migrating from 983 to 925 cm$^{-1}$, and the intensity of this Raman band is growing with the concentrations of MoO$_3$. This might be due to the replacing of PbF$_2$ with MoO$_3$, which has a low molecular weight. The change of [BO$_4$] units to [BO$_3$] with MoO$_3$ concentration might be responsible for the shifting behavior towards lower frequencies and increased intensity in BCAPM glasses. This finding backs up the fact that increasing MoO$_3$ doping concentration reduces density variation in BCAPM glasses. The Raman band at 1079 cm$^{-1}$ is due to the existence of diborate groups. When the PbF$_2$ is replaced with MoO$_3$ in BCAPM glasses, the intensity of the Raman bands at 789 cm$^{-1}$ and 1229 cm$^{-1}$ were observed to be diminished from BCAPM0 to BCAPM4 glass samples and finally merged with the neighborhood Raman bands. An intense Raman band in BCAPM glasses at 1340 cm$^{-1}$ is assigned to pyroborate groups. When the PbF$_2$ is replaced with MoO$_3$ in BCAPM glasses, the bands near 1437 cm$^{-1}$ in this glass system are ascribed to B–O$^-$ vibrations of the BO$_3$ units and the band at 1738 cm$^{-1}$ is due to chain and ring type metaborate units (Meera et al. 1990; Dwivedi and Khanna 1995; Padmaja and Kistalah 2009).

4 Conclusions

The glasses with the formula 60B$_2$O$_3$-20CdO-5Al$_2$O$_3$-(15-x)PbF$_2$-xMoO$_3$ (where x = 0, 0.5, 1, 1.5, and 2 mol%) is been prepared using conventional melt quenching method. These samples were analyzed using physical, optical, FTIR and Raman spectroscopic techniques to investigate the impact of MoO$_3$ on the structural changes occur in the samples. Drop in the density of the samples with MoO$_3$ is attributed to the molecular weights of PbF$_2$/MoO$_3$ and the transformation of BO$_4$ to BO$_3$ units. Decline in the optical band gap values was observed, which were evaluated from UV–Visible spectra. This decline is due to transformation of Mo$^{6+}$ to Mo$^{5+}$ ions as MoO$_3$ content is increased at the expense of PbF$_2$. FTIR and Raman spectra confirmed the presence of different borate and aluminate groups. These spectra also supports the transformation of Mo$^{6+}$ to Mo$^{5+}$ ions and confirmed that the MoO$_3$ act as modifier in these glasses.

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Declarations

Conflict of interest The authors whose names are listed immediately below the title of the manuscript certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers’ bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

References

Abouhaswa, A.S., Zakaly, H.M.H., Issa, S.A.M., Rashad, M., Pyshkina, M., Tekin, H.O., El-Mallawany, R., Mostafa, M.Y.A.: Synthesis, physical, optical, mechanical, and radiation attenuation properties of
TiO2–Na2O–Bi2O3–B2O3 glasses. Ceram. Int. 47, 185–204 (2021). https://doi.org/10.1016/j.ceramint.2020.08.122

Ahmed, M.R., Sekhar, K.C., Ahammed, S., Sathe, V., Alrowaili, Z.A., Amami, M., Olarinoye, I.O., Al-Buriah, M.S., Tongue, B.T., Shareefuddin, M.: Synthesis, physical, optical, structural and radiation shielding characterization of borate glasses: a focus on the role of SrO/Al2O3 substitution. Ceram. Inter. 48, 2124–2137 (2022). https://doi.org/10.1016/j.ceramint.2021.09.301

Alemi, A.A., Sedghi, H., Mirmohseni, A.R., Golsanamlu, V.: Synthesis and characterization of cadmium doped lead-borate glasses. Bull. Mater. Sci. 29, 55 (2006). https://doi.org/10.1007/ BF02709356

Alrowaili, Z.A., Ali, A.M., Al-Baradi, A.M., Al-Buriah, M.S., Wahab, E.A., Shaaban, K.S.: A significant role of MoO3 on the optical, thermal, and radiation shielding characteristics of B2O3–P2O5–Li2O glasses. Opt. Quant. Electr. 54, 88 (2020). https://doi.org/10.1007/s11082-021-03447-0

Aly, K.A., Dahshan, A., Saddeek, Y.B.: Effect of MoO3 additions on the thermal stability and crystallization kinetics of PbO–Sb2O3–As2O3 glasses. J Therm Anal Calorim 100, 543–549 (2010). https://doi.org/10.1007/ s10973-009-0018-3

Ardelean, I., Cora, S., Rusu, D.: EPR and FT-IR spectroscopic studies of Bi2O3–B2O3–CuO glasses. Phys. B 403, 3682–3685 (2008). https://doi.org/10.1016/j.physb.2008.06.016

Ashok, B., Sekhar, K.C., Chary, B.S., Ramadevudu, G.: Chary M N and Shareefuddin Md, Physical and structural study of Al2O3–NaBr–B2O3–CuO glasses. Indian J. Phys. 96, 1521–528 (2021). https://doi.org/10.1007/s12648-021-02048-7

Balachander, L., Ramadevudu, G., Shareefuddin, Md., Sayanna, R., Venudhar, Y.C.: IR analysis of borate glasses containing three alkali oxides. Sci. Asia 39, 278–283 (2013). https://doi.org/10.2306/scienceasia1513-1874.2013.39.278

Banagar, A.V., Prashant Kumar, M., Nagaraja, N.: Effect of mixed transition metal ions in B2O3–V2O5–MoO3 glass system. J. Elect. Mater 49, 7370–7378 (2020). https://doi.org/10.1007/s11664-020-08499-8

Sangeetha .G., Chandra Sekhar, K., Hameed, A., Narasimha, R.G., Chary, M., Shareefuddin, Md.: Influence of CaO on the structure of zinc sodium tetra borate glasses containing Cu2+ ions. J. Non-Cryst. Solids 563, 120784 (2021b). https://doi.org/10.1016/j.jnoncrysol.2021.120784

Chandra Sekhar, K., Hameed, A., Sathe, V.G., Chary, M.N., Shareefuddin, M.D.: Physical, optical and structural studies of copper-doped lead oxychloro borate glasses. Bull. Mater. Sci (2018). https://doi.org/10.1007/s12034-018-1604-4

Chandra Sekhar, K., Shareefuddin, M., El-Denglawey, A., Saddeek, Y.B.: Structural and optical properties of BaTiO3 modified cadmium alkali borate glasses. Phys. Scr. 97, 035704 (2022). https://doi.org/10.1088/1402-4896/ac53c7

Chandrakiram, G., Kumar Yadav, A., Kumar Singh, A.: A review on infrared spectroscopy of borate glasses with effects of different additives. ISRN Ceram. (2012). https://doi.org/10.5402/2012/428497

Ciceo-Lucacel, R., Ardelean, I.: FT-IR and Raman study of silver lead borate-based glasses. J. Non-Cryst. Solids 353, 2020–2024 (2007). https://doi.org/10.1016/j.jnoncrysol.2007.01.066

Davis, A., Mott, N.F.: Conduction in non-crystalline systems V. Conductivity, optical absorption and photoconductivity in amorphous semiconductors. Philos. Mag. 22, 903–922 (1970). https://doi.org/10.1080/14786437008221061

Dimitrov, V., Komatsu, T.: Classification of simple oxides: a polarizability approach. J. Solid State Chem. 163, 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, 736 (1990). https://doi.org/10.1063/1.360962

Duffy, J.A.: Chemical bonding in the oxides of the elements: a new appraisal. J. Solid State Chem. 62, 145–157 (1986). https://doi.org/10.1016/0022-3697(86)90225-2

Dwivedi, B.P., Khanna, B.N.: Cation dependence of raman scattering in alkali borate glasses. J. Phys. Chem. Solids 56, 39–49 (1995). https://doi.org/10.1016/0022-3697(94)00130-8

Ibrahim, A.M., Alkhammash, H.I.: Influence of extra-addition of sulfur on the optical, electrical, and photocconductivity of the borate glasses containing MoO3. J. Mater. Sci: Mater. Electron. 32, 7294–7306 (2021). https://doi.org/10.1007/s10854-021-05440-5

Jordanova, R., Dimitrov, V., Dimitriev, Y., Klissurski, D.: Glass formation and structure of glasses in the V2O5–MoO3–Sb2O3 system. J. Non-Cryst. Solids 180, 58–65 (1994). https://doi.org/10.1016/0022-3093(94)90397-2

Kaur, A., Khanna, A., González, F., Pesquera, C., Chenc, B.: Structural, optical, dielectric and thermal properties of molybdenum tellurite and borotellurite glasses. J. Non-Cryst. Solids 444, 1–10 (2016). https://doi.org/10.1016/j.jnoncrysol.2016.04.033
Mahesh, M.H., Sable, D.B., Solunke, M.B., Jadhav, K.M.: Network structure analysis of modifier CdO doped sodium borate glass using FTIR and Raman spectroscopy. J. Non-Cryst. Solids 474, 58–65 (2017). https://doi.org/10.1016/j.jnoncrysol.2017.08.028

Mahmoud, K.A., Tashlykov, O.L., SayyedM, I., Kavaz, E.: The role of cadmium oxides in the enhancement of radiation shielding capacities for alkali borate glasses. Ceram. Int. 46, 23337–23346 (2020). https://doi.org/10.1016/j.ceramint.2020.02.219

Manisha, P., Hirota, K., Tsujigami, Y., Sakata, H.: Structural and electrical properties of MoO3-TeO2 glasses. J. Phys. D. Appl. Phys. 34, 459 (2001)

Meera, B.N., Sood, A.K., Chandrabhas, N., Ramakrishna, J.: Raman study of lead borate glasses. J. Non-Cryst. Solids 126, 224–230 (1990). https://doi.org/10.1016/0022-3093(90)90823-5

Mostafa, A.M.A., Issa, S.A.M., Zakaly, H.M.H., Mek, A.O., Marek, L.: FTIR and Raman spectroscopy studies of ZnO-doped BaO-2B2O3 glass matrix. Vibrat Spect 105, 102921 (2019). https://doi.org/10.1016/j.vibspect.2019.05.003

Padmaja, G., Kistaia, P.: Infrared and Raman spectroscopic studies on alkali borate glasses: evidence of mixed alkali effect. J. Phys. Chem. A 113, 2397–2404 (2009). https://doi.org/10.1021/jp809318e

Phani, A.L., Sekhar, K.C., Chakradar, R.P., Chary, M.N., Shareefuddin, M.: EPR and FTIR spectroscopic studies of MoO3-Sc2O3-P2O5 glasses doped with molybdenum ions. Mater. Res. Express 5, 035204 (2018). https://doi.org/10.1088/2053-1591/aab64d

Rada, M., Rada, S., Pascuta, P., Culea, E.: Structural properties of molybdenum-lead-borate glasses. Spectrochim. Acta Part A 77, 832–837 (2010). https://doi.org/10.1016/j.saa.2010.08.014

Rajyasree, Ch., Krishna Rao, D.: Spectroscopic properties of RBiBO4 (R = Ca, Sr) glasses doped with TiO2. J. Mol. Struct. 1007, 168–174 (2012). https://doi.org/10.1016/j.molstruc.2011.10.039

Rao, B.L., Raju, K.J., Prasad, S.V.: Optical absorption spectra of PbO-Sc2O3-P2O5 glasses doped with molybdenum ions. Mat. Today 5, 26298 (2018). https://doi.org/10.1016/j.matpr.2018.08.080

Saddeek, Y.B.: Structural analysis of alkali borate glasses. Phys. B 344, 163–175 (2004). https://doi.org/10.1016/j.physb.2003.09.254

Saddeek, Y.B., Gaafar, M.S.: Physical and structural properties of some bismuth borate glasses. Mat. Chem. Phys. 115, 280–286 (2009). https://doi.org/10.1016/j.matchemphys.2008.12.004

Saddeek, Y.B., Abousehly, A.M., Hussien, S.I.: Synthesis and several features of the Na2O-B2O3-Bi2O3-MoO3 glasses. J. Phys. d: Appl. Phys. 40, 4674–4681 (2007). https://doi.org/10.1088/0022-3727/40/15/048

Saddeek, Y.B., Zakaly, H.M.H., Sekhar, K.C., Issa, S.A.M., Alharbi, T., Badawi, A., Shareefuddin, M.: Investigations of mechanical and radiation shielding properties of BaTiO3-modified cadmium alkali borate glass. Appl. Phys. A 128, 1–10 (2022). https://doi.org/10.1007/s00339-022-05413-3

Seguin, L., Figlarz, M., Cavagnat, R., Lassegues, J.C.: Infrared and Raman spectra of MoO3, molybdenum trioxides and MoO2-xH2O molybdenum trioxide hydrates. Spectrochim. Acta Part A 51, 1323–1344 (1995). https://doi.org/10.1016/0584-8539(94)00247-9

Sekhar, K.C., Ahmed, M.R., Narsimlu, N., Deshpande, U., Sathe, V.G., Shareefuddin, M.: The effect of the addition of CaF2 and PbF2 on boro-tellurite glasses doped with chromium ions. Mater. Res. Express 6, 125206 (2019). https://doi.org/10.1088/2053-1591/ab619f

Sekhar, K.C., Kavitha, B., Narsimlu, N., Sathe, V., Alothman, M.A., Olarinoaye, I.O., Al-Buriah, M.S., Shareefuddin, M.: Enhancement of shielding ability using PbF2 in Fe-reinforced bismuth borate glasses. Electronics 32, 23047–23065 (2021a). https://doi.org/10.3390/epip/32307778

Sekhar, K.C., Hameed, A., Narsimlu, N., Alzahrani, J.S., Alothman, M.A., Olarinoaye, I.O., Al-Buriah, M.S., Shareefuddin, M.: Synthesis, optical, structural, and radiation transmission properties of PbO/Bi2O3/B2O3/Fe2O3 glasses: an experimental and in silico study. Res. Phys. 117, 111173 (2021c). https://doi.org/10.1016/j.epjplus.2021.111173

Sekhar, K.C., Narsimlu, N., Al-Buriah, M.S., Yakout, H.A., Olarinoaye, I.O., Alomairy, S., Shareefuddin, M.D.: Synthesis, optical, and radiation attenuation properties of CaF2-TeO2-Na2B4O7-CuO glass system for advanced shielding applications. Eur. Phys. J. plus 136, 903 (2021d). https://doi.org/10.1140/epjp/s13360-021-01906-x

Sekiya, T., Mochida, N., Ogawa, S.: Structural study of MoO3-TeO2 glasses. J. Non-Cryst. Solids 185, 135–144 (1995). https://doi.org/10.1016/0022-3093(94)00667-9
Shaaban, K.S., Zahran, H.Y., Yahia, I.S., Elsaeedy, H.I., Shaaban, E.R., Wahab, E.A., Yousef, E.S.: Mechanical and radiation-shielding properties of B2O3–P2O5–Li2O–MoO3 glasses. Appl. Phys. A 126, 804 (2020). https://doi.org/10.1007/s00339-020-03982-9

Singh, L., Thakur, V., Punia, R., Kundu, R.S., Singh, A.: Structural and optical properties of barium titanate modified bismuth borate glasses. Solid State Sci 37, 64–71 (2014). https://doi.org/10.1016/j.solidstate.sciences.2014.08.010

Sokolov, V.O., Plotnichenko, V.G., Koltashev, V.V., Grishin, I.A.: On the structure of molybdate–tellurite glasses. J. Non-Cryst. Solids 355, 239–251 (2009). https://doi.org/10.1016/j.jnoncrysol.2008.11.017

Tauc, J., Menth, A.: States in the gap. J. Non-Cryst. Solids 8, 569–585 (1972). https://doi.org/10.1016/0022-3093(72)90194-9

Thakur, V., Singh, A., Punia, R., Kaur, M., Singh, L.: Effect of BaTiO3 on the structural and optical properties of lithium borate glasses. Ceram. Inter. 41, 10957–10965 (2015). https://doi.org/10.1016/j.ceram.int.2015.05.039

Urbach, F.: The long-wavelength edge of photographic sensitivity and of the electronic absorption of solids. Phys. Rev. 92, 1324 (1953). https://doi.org/10.1103/PhysRev.92.1324

Vedavyas, S., Chandra, S.K., et al.: Physical and structural studies of cadmium lead boro-tellurite glasses doped with Cu2+ ions. J Mater Sci: Mater Electron. 32, 3083–3091 (2021). https://doi.org/10.1007/s10854-020-05058-z

Venkateswara, R.G., Shashikala, H.D.: Structural, optical and mechanical properties of ternary CaO–CaF2–P2O5 glasses. J. Adv. Ceram. 3(2), 109–116 (2014). https://doi.org/10.1007/s40145-014-0099-8

Wang, W.C., Zhou, B., Xu, S.H., Yang, Z.M., Zhang, Q.Y.: Recent advances in soft optical glass fiber and fiber lasers. Pro. Mater. Sci. 101, 90–171 (2019). https://doi.org/10.1016/j.pmatsci.2018.11.003

Yadav, A.K., Gautam, C.R., Gautam, A., Mishra, V.K.: Structural and crystallization behavior of (Ba, Sr) TiO3 borosilicate glasses. Phase Trans. 86, 1000–1016 (2013). https://doi.org/10.1080/01411594.2012.747686

Zakaly, H.M.H., Saudi, H.A., Issa, S.A.M., Rashad, M., Elazaka, A.I., Tekin, H.O., Saddeek, Y.B.: Alteration of optical, structural, mechanical durability and nuclear radiation attenuation properties of barium borosilicate glasses through BaO reinforcement: experimental and numerical analyses. Ceram. Int. 47, 5587–5596 (2021). https://doi.org/10.1016/j.ceramint.2020.10.143

Zakaly, H.M.H., Issa, S.A.M., Tekin, H.O., Badawi, A., Saudi, H.A., Henaih, A.M.A., Rammah, Y.S.: An experimental evaluation of CdO/PbO-B2O3 glasses containing neodymium oxide: Structure, electrical conductivity, and gamma-ray resistance. Mater. Res. Bull. 151, 111828 (2022). https://doi.org/10.1016/j.materesbull.2022.111828

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