

Research Article

Collective Optical, FTIR, and Photoluminescence Spectra of CeO₂ and/or Sm₂O₃-Doped Na₂O–ZnO–P₂O₅ Glasses

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Glasses with the Na₂O–ZnO–P₂O₅ composition and doped with single CeO₂, Sm₂O₃, or mixed dopants were melted and studied. Collective optical, photoluminescence, and FT-infrared spectral studies were carried out. CeO₂-doped glasses show two extra UV absorption bands due to Ce⁴⁺ and Ce³⁺ ions while Sm₂O₃-doped samples reveal pronounced peaks collected into two segments from 367 to 472 nm and from 950 to 1623 nm which are characteristic of absorption from Sm³⁺ ions. The mixed dopants glasses show combined UV-visible–near-IR absorption peaks due to cerium (Ce⁴⁺, Ce³⁺) ions and samarium (Sm³⁺) ions. The photoluminescence spectra (PL) of the single CeO₂-doped and Sm₂O₃-doped glasses and even the mixed dopant sample reveal luminescence spectra after excitation which are characteristic of the rare-earth ions. The intensities for both excited or emitted peaks are found to increase with the increase of the rare-earth percent. FTIR spectra of the glasses show pronounced vibrational peaks related to phosphate groups (Q² and Q³ units) in accordance with the P₂O₅ percent (70 mol %).

1. Introduction

Phosphate glasses possess unique and interesting optical, thermal, and electrical properties which make them candidates for a wide range of applications [1, 2]. The low chemical durability of phosphate glasses has been changed by the addition of multivalent oxides (such as Al₂O₃, PbO, ZnO, Fe₂O₃), the resulting glasses have extended applications including sealing glass, optical glass, and biocompatible and bioactive glasses, and even iron phosphate has been studied extensively for encapsulation of some radioactive wastes [3, 4].

Phosphate glasses doped with a transition metal or rare-earth ions are considered as valuable materials for both optical and electrical applications [4–7]. They can incorporate high percent of TMs or REs with brilliant colors and distinctive optical and electrical properties [4, 6].

Extended studies of 3d transition metal ions doped within different phosphate glasses [8–12] indicated that most of the TMs ions exhibit their lower valences. This was assumed to be

due to the oxidoreduction equilibrium being shifted towards the reduced lower valence states [8]. On the other hand, most rare-earth ions are stable in trivalent valence state and their characteristic optical spectra remain unaffected by the host glasses when melted under normal atmospheric condition because their electronic shell is protected from the effects of the ligand fields by the outer 5s and 5p electrons [13–15]. An exception is sometimes found in the lighter rare-earth cerium ions which are frequently identified in both the three- and four-valence states [15].

Glasses with dopants of rare-earth ions have continuously drawn the attention through their potential applications in solid-state lasers, optical amplifiers, and three-dimensional displays [16, 17]. Samarium ion (Sm³⁺-4f⁵) is one of the highly distinguished lanthanide ions for being able to characterize the fluorescence properties such as its emitting ⁴G_{5/2} level. This mentioned level possesses relatively high quantum efficiency besides different quenching emission channels [18].

Cerium ions have the ability to exist in two possible valence states, i.e., Ce³⁺ and Ce⁴⁺, whose percents depend

TABLE 1: Chemical composition of the prepared glasses.

Sample	Mol %					
	P ₂ O ₅	ZnO	Na ₂ O	Al ₂ O ₃	CeO ₂	Sm ₂ O ₃
G1	70	20	10	1	0	0
G1	70	20	10	1	0.5	0
G2	70	20	10	1	2	0
G3	70	20	10	1	5	0
G4	70	20	10	1	0	0.5
G5	70	20	10	1	0	2
G6	70	20	10	1	0	5
G7	70	20	10	1	0.25	0.25
G8	70	20	10	1	1	1
G9	70	20	10	1	2.5	2.5

on the host material as well as on the preparation condition [19, 20].

In a previous publication [21], combined optical, FTIR, and photoluminescence spectral analysis have been carried out for Sm₂O₃ (0.2 → 3%) doped in host NaF–AlF₃-phosphate glasses before and after successive gamma irradiation. Spectral data indicate the stability of the Sm³⁺ ions with their characteristic absorption bands distributed into two regions at 350–900 and 1100–1600 nm even after gamma irradiation. The same behavior holds for the luminescence spectra. FTIR spectra of the mentioned fluorophosphates glasses show phosphate groups (mainly of Q² and Q³) with the assumption of the formation of (PO₃F), AlF₄, or AlF₆ groups, and the spectral data also show obvious stability towards gamma irradiation.

In the course of the present study, the main objective is to study combined optical, FTIR, and photoluminescence spectra of prepared single doped rare-earth oxide of either CeO₂ or Sm₂O₃ or with both the two RE oxides as mixed dopants in a host Na₂O–ZnO–P₂O₅ glass with added 1% Al₂O₃ for stability. The two selected rare-earth oxides are known to exhibit different characteristics. CeO₂ is able to exist in two different valences (Ce³⁺, Ce⁴⁺) and their specific spectra are within the UV–near visible region. On the other hand, Sm₂O₃ is accepted to be stable as trivalent Sm³⁺ ions under normal conditions and exhibits extended visible near-IR optical absorption.

It is expected that the collective spectral studies will throw more insight to find out the interferences or the mixing effects of both the two rare-earth oxides, specifically the ability of CeO₂ to act as oxidoreduction agent in the studied host glasses.

2. Experimental Details

The glasses were prepared from laboratory chemicals including ammonium dihydrogen phosphate (NH₄H₂PO₄) for P₂O₅, Na₂O was added in the form of anhydrous sodium carbonate (Na₂CO₃), and ZnO and Al₂O₃ were added as such. The dopant rare-earth oxides were introduced as CeO₂ and Sm₂O₃. The detailed chemical compositions of the glasses are given in Table 1.

The weighed batches were melted in covered alumina crucibles at 1100°C for 90 minutes in an electric SiC heated furnace (Vecstar, UK) under ordinary atmospheric condition. The melts were rotated at intervals of 20 minutes to reach mixing and homogeneity. Then the melts were poured into the stainless steel mold with the required dimensions. The prepared glasses were transferred immediately to an annealing muffle regulated at 300°C to obtain samples free from stress or strains. The annealing muffle was switched off after 1 hour with the samples inside and left to cool to room temperature at a rate of 30°C/h.

Characterizations of the produced glasses were carried out according procedures of the previous work [22] as follows:

Optical (UV-visible–NIR) absorption spectral measurements were carried out on polished glasses of equal thickness (2 mm ± 0.1 mm) using a recording spectrophotometer (type: JASCO V-570, JAPAN) covering the range 200 to 2500 nm.

Photoluminescence measurements were measured at room temperature under different excitation wavelengths using a fluorescence spectrophotometer (type: JASCO, FP-6500, JAPAN) equipped with a xenon flash lamp as the excitation light source. The scan speed is 0.15 step-1 with a step length of 0.25 nm and slit width of 0.2 nm.

The thermal expansion characteristics of the studied glasses were measured through specified samples using a recording dilatometer (type: NETZCH, 1-402 PC, Geratebau, GmbH, Selb, Germany) with a heating rate of 10°C/min up to both transformation region and dilatometric softening temperature. The thermal data were collected and analyzed.

FTIR measurements of the prepared glasses and their corresponding glass-ceramic derivatives were carried out at room temperature in the wavenumber range 4000–400 cm⁻¹ by a Fourier transform computerized spectrometer (type: FTIR-4600, JASCO Crop., JAPAN). Through the KBr disc technique glasses or glass-ceramics in the form of pulverized powder were examined by mixing 2 mg of the powdered samples and 200 mg KBr, and the mixtures were subjected to a load of 5 tons/cm² in an evocable die to produce clear homogeneous discs. The prepared discs were measured directly to avoid moisture attack. Infrared spectra were correlated for the dark current noises and background using the two-point baseline correction.

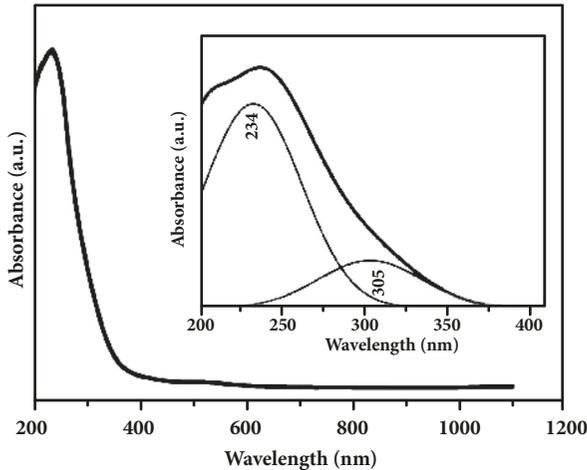


FIGURE 1: Optical absorption spectrum of base undoped $\text{Na}_2\text{O-ZnO-P}_2\text{O}_5$ glass with the deconvoluted spectrum of the UV region 200–400 nm.

3. Results and Discussion

3.1. Optical Absorption Spectra of the Prepared Glasses. Figure 1 shows the spectrum of the base undoped $\text{Na}_2\text{O-ZnO-P}_2\text{O}_5$ glass. The spectrum reveals distinct and broad UV absorption with the deconvoluted spectrum showing two peaks at 234 and 305 nm and without any further absorption to the end of measurements.

The undoped $\text{Na}_2\text{O-ZnO-P}_2\text{O}_5$ glass shows strong UV absorption (Figure 1) which is attributed to unavoidable trace iron impurities present within the chemicals used for the preparation of such glass. This assumption is based on extended postulations introduced by various scientists in the past [23, 24] and in recent studies on undoped phosphate glasses [7, 11–15, 24]. The strong support of this assumption comes from the review article by Duffy [25] who classified charge transfer UV spectra identified in undoped glasses. He claimed that the presence of traces from some transition metals (e.g., Fe^{3+} , Cr^{6+}) produces UV absorption bands developed through electron transfer mechanism, finding that even the traces of impurities are in the ppm level.

We are accepting the previous assumptions about the relation between the observed UV absorption in the studied undoped phosphate glass and traces iron (Fe^{3+}) ions present in the chemicals used.

Figure 2 illustrates the UV-visible absorption spectra of the three glasses containing varying CeO_2 contents (0.5, 2, 5% CeO_2). The three glasses reveal the same strong UV absorption extended from 200 nm to about 330 nm and the attached deconvoluted spectra show three peaks at 210, 264, and 300 nm. The spectral curves are very close to each other without any change with the increase of CeO_2 content.

The optical spectra of CeO_2 -doped glasses exhibit extended UV absorption with three distinct peaks at 210, 264, and 300 nm and without any variations with the increase of the CeO_2 content. The interpretation of the optical spectra of CeO_2 -doped glasses can be introduced as follows:

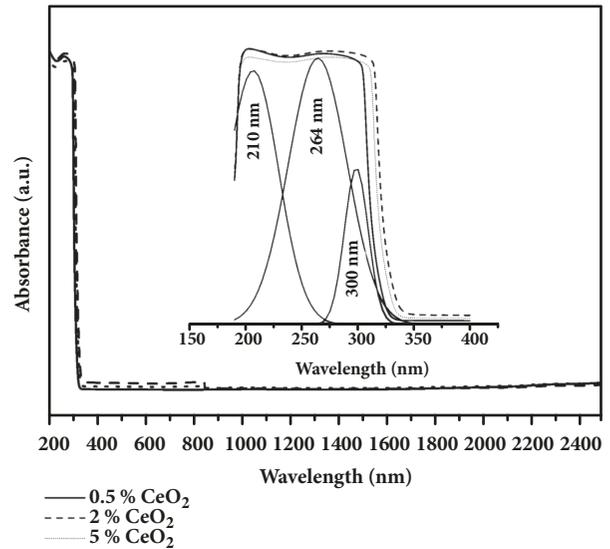


FIGURE 2: Optical absorption spectra of CeO_2 -doped glasses with the attached deconvoluted spectrum (200–400 nm).

- (1) The cerium ions belong to the lighter portion of the lanthanides and are recognized to be solely able to exist in two valences in glasses as Ce^{3+} and Ce^{4+} with the electronic configuration of f^4 and f^0 , respectively [15, 26, 27].
- (2) The optical spectrum of Ce^{3+} ion is an allowed transition ($f^4 \rightarrow d^1$) which is accepted to appear as an intense broad band in many solid materials and the absorption depends strongly on the host materials, but in glasses, the absorption of Ce^{4+} is charge transfer ($\text{O}^{2+} \rightarrow \text{Ce}^{4+}$) in nature and normally occurs at longer wavelength in comparison with that for Ce^{3+} [15, 26, 27].
- (3) Based on previous considerations, the optical absorption band at 264 nm can be related to Ce^{4+} ions, the band at 300 nm is correlated with Ce^{3+} ions, and the band at 210 nm is the same as the undoped sample related to trace iron impurities.

Figure 3 reveals absorption spectra of the three Sm_2O_3 -doped glasses. The optical spectrum of the first 0.5% Sm_2O_3 glass shows extended UV-visible to near IR absorption.

The optical spectrum consists of strong UV absorbed bands in the range 200–300 nm followed by the characteristic absorption of Sm^{3+} ions extending into two regions, the first part with 3 bands from about 367 to 472 nm and the second part extends within the region from about 950 to 1623 nm with 10 peaks. The samples containing higher Sm_2O_3 contents (2, 5%) show an increase in the intensities of the peaks and are specifically prominent in the second series.

The spectra of the Sm_2O_3 -doped glasses reveal distinct UV absorption besides distinct two absorption regions: the first comprises three peaks from about 367 to 472 nm, and the second consists of 10 peaks and extends from 950 to 1623 nm.

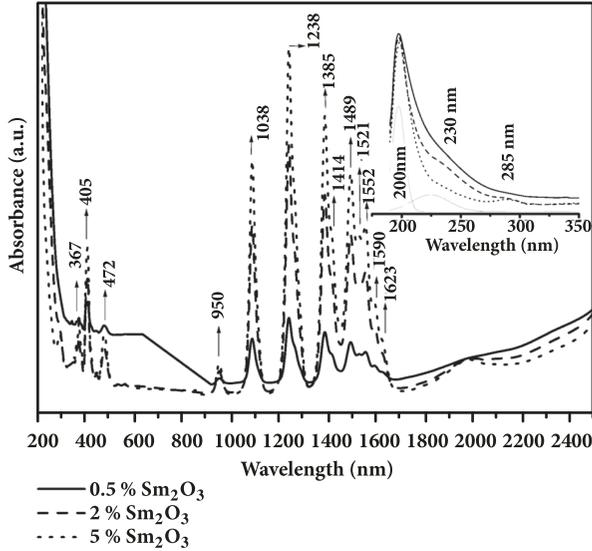


FIGURE 3: Optical absorption spectra of Sm_2O_3 -doped glasses with attached deconvoluted spectrum (UV 200–350 nm).

The overall extended optical spectrum covering the range from 200 to about 1700 nm is explained as follows:

- (i) The UV absorption band at 210 nm is correlated with trace iron (Fe^{3+}) present as impurities.
- (ii) It is recognized by many scientists [14–18, 21, 28–30] that the Sm^{3+} ion belongs to a d^5 electron configuration which is characterized by $198^{2s+1}L_j$ free ion levels. In glasses, the crystal field fine structure is not resolved due to an inhomogeneous line broadening, and the only absorption between $^{2s+1}L_j$ manifolds is observed experimentally. The identified peaks are observed to decrease with the presence of high atomic weights ions (Pb^{2+} , Bi^{3+}) [17, 21].
- (iii) The identified absorption peaks are considered to originate from transitions from ground state $^6\text{H}_{5/2}$ to the various excited states as cited in Table 2.

Figure 4 presents the absorption spectral bands of the three glasses containing mixed and equal dopants (0.25+0.25, 1.0+1.0, 2.5+2.5) of both Sm_2O_3 and CeO_2 . The spectra reveal the combination of the UV spectra due to cerium ions and the characteristic spectra of the two series of characteristic peaks due to Sm^{3+} ions.

3.2. Photoluminescence Spectra of the Studied Glasses. Figure 5 reveals the PL spectra of the three CeO_2 -doped glasses (0.5, 2, 5%). The PL spectra show two broad emission bands, a highly intense one at 335 nm and the second with medium intensity at 658 nm after the excitation with $\lambda_{\text{ex}} = 290$ nm, and they increase in intensity with the increase of CeO_2 content. On the other hand, with the emission at $\lambda_{\text{em}} = 658$ nm, a very broad band extending to 290 nm is identified with its deconvoluted peaks. The emission spectrum shows two broad bands: the first is at 332 nm and the second is

TABLE 2: Absorption peaks from Sm_2O_3 -doped $\text{Na}_2\text{O}-\text{ZnO}-\text{P}_2\text{O}_5$ glasses and their excitation levels, ground state $^6\text{H}_{5/2} \rightarrow$.

Peaks / nm	Excited state
367	$^4\text{D}_{1/2} + ^4\text{P}_{7/2}$
405	$^6\text{P}_{5/2}, ^4\text{K}_{11/2}$
472	$^4\text{I}_{1/2} + ^4\text{I}_{13/2} + ^4\text{M}_{15/2}$
950	$^6\text{F}_{11/2}$
1038	$^6\text{F}_{9/2}$
1238	$^6\text{F}_{7/2}$
1385	$^6\text{F}_{5/2}$
1489	$^6\text{F}_{3/2}$
1552	$^6\text{F}_{1/2}$
1623	$^6\text{H}_{15/2}$

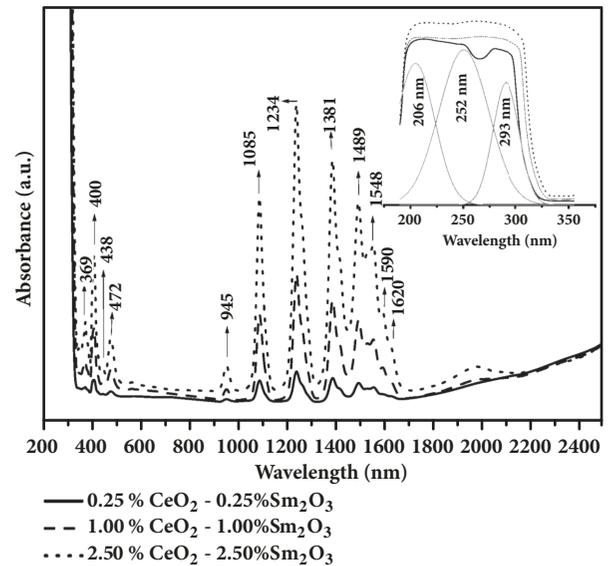


FIGURE 4: Optical absorption spectra of $\text{CeO}_2 + \text{Sm}_2\text{O}_3$ -doped glasses with attached deconvoluted spectrum (UV 200–350 nm).

a broad curvature centered at about 658 nm after excitation with 235 nm. The first band increases with the sharp peak with the increase of CeO_2 while the second band is retaining its broad feature.

Figure 6 illustrates the PL spectra of the three Sm_2O_3 -doped glasses (0.5, 2, 5%). Figure 6(c) reveals the excitation spectra after $\lambda_{\text{ex}} = 595$ nm showing 7 peaks extending from 320 and 450 nm with the highest peak at 402 nm, and their intensities increase with the Sm_2O_3 content. On the other hand, the emission spectrum after $\lambda_{\text{ex}} = 365$ nm reveals four broad bands which are identified at about 570, 600, 640, and 700 nm and their intensities increase with the increase of Sm_2O_3 content. With excitation at $\lambda_{\text{ex}} = 402$ nm, the emission spectra show the same peaks.

Figure 7 shows the PL spectra of the samples with mixed dopants of ($\text{CeO}_2 + \text{Sm}_2\text{O}_3$). The excitation spectra after excitation with $\lambda_{\text{em}} = 595$ (Figure 7(c)) show multiple extended peaks from 320 to 450 nm with the highest peak at about 402 nm and with two attached small peaks. The

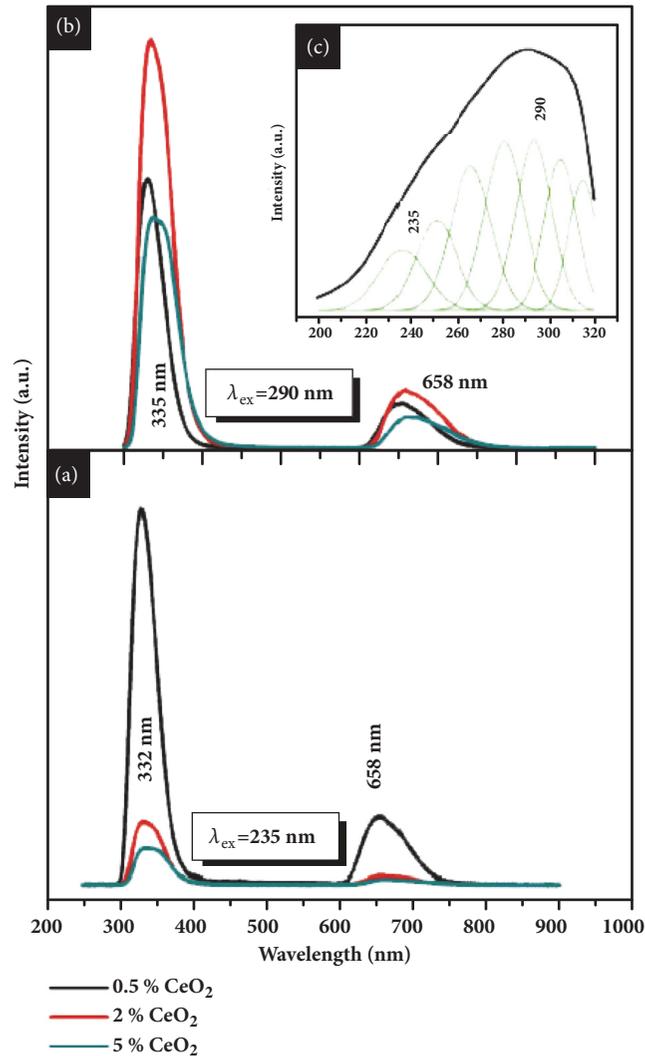


FIGURE 5: Photoluminescence spectra of CeO₂-doped glasses: (a) emission at 235 nm, (b) emission at $\lambda_{ex} = 290$ nm, and (c) excitations at $\lambda_{em} = 658$ nm.

emission spectra reveal three peaks at about 560, 595, and 640 nm in both the excitations at $\lambda_{ex} = 365$ nm and at $\lambda_{ex} = 402$ nm, and the second peak is the highest one. On the other hand, upon excitation at $\lambda_{ex} = 290$ nm, three peaks are identified at about 570, 598, and 650 nm with the last one having the highest intensity. Also, the intensities increase with the increase of dopants.

The PL spectra of the studied single or mixed doped glasses are illustrated (Figures 5, 6, and 7). The PL data are explained as follows:

(a) For CeO₂ doped glasses:

- (i) The previous optical absorption data confirm the assumption of the presence of cerium ions in both the two valence states as both Ce³⁺ and Ce⁴⁺ ions.
- (ii) The excitation spectra of CeO₂-doped glasses are identified to be with different responses with the excitation peaks $\lambda_{ex} = 290$ nm or $\lambda_{ex} =$

332 nm. In the first case, two emission bands are observed at 335 and 658 nm with high intensity while in the second case the identified bands are low in intensity. These observed emissions and excitation data point out that the two valence states of cerium ions can be realized and identified in some excitations.

(iii) The excitation spectra of CeO₂-doped glasses reveal the main broad band at 290 nm.

(b) For Sm₂O₃-doped glasses: The PL spectra, shown in Figure 6, of the Sm₂O₃-doped glasses agree to a large extent with the PL spectra identified by Sm₂O₃-doped in fluorophosphate glasses previously published by the same authors [21]. These results are comparable with that reached by various authors [31, 32] for Sm₂O₃-doped in binary alkali phosphate, mixed alkali phosphate, and also lead phosphate glasses. The four emission bands at 570, 600, 640, and

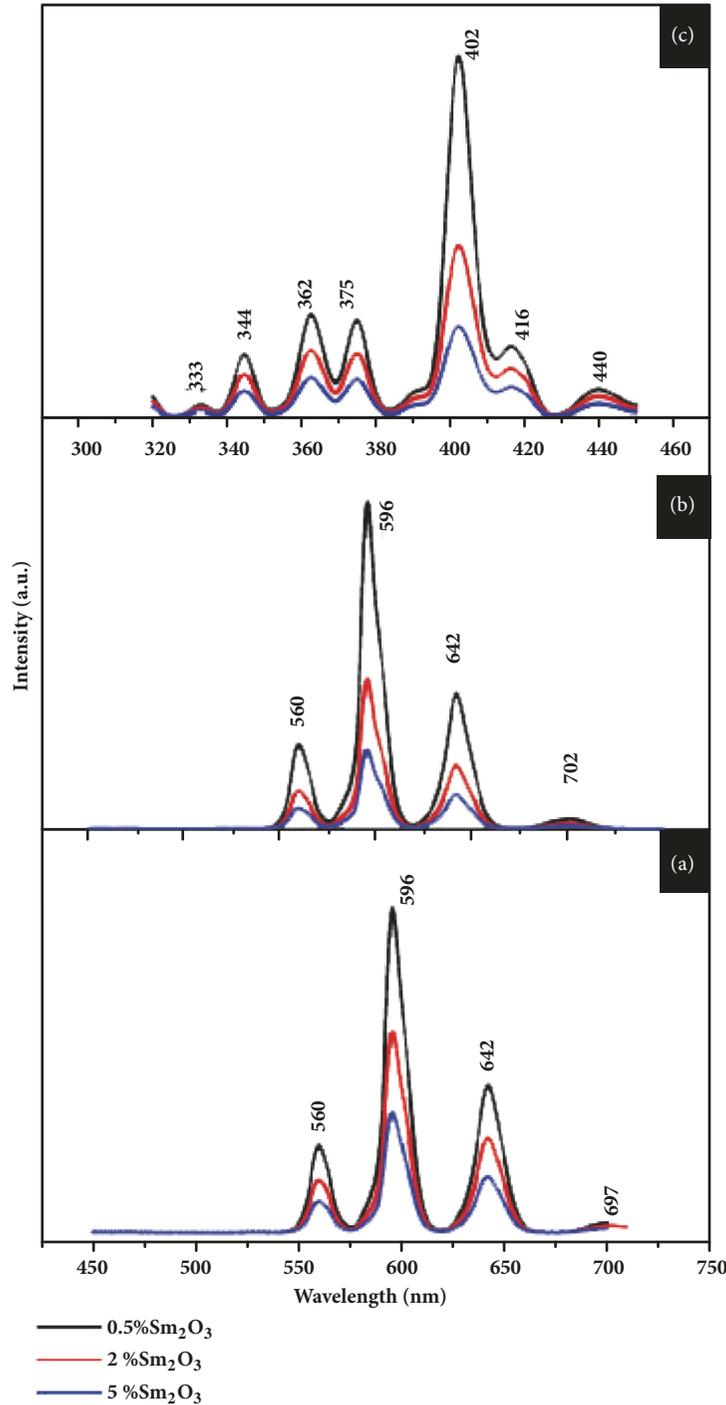


FIGURE 6: Photoluminescence spectra of Sm_2O_3 -doped glasses: (a) emission at 365 nm, (b) emission at $\lambda_{\text{ex}} = 402$ nm, and (c) excitations at $\lambda_{\text{em}} = 595$ nm.

700 nm can be assigned to transitions ${}^4\text{G}_{5/2} \rightarrow {}^6\text{H}_{5/2}$, ${}^4\text{G}_{5/2} \rightarrow {}^6\text{H}_{7/2}$, ${}^4\text{G}_{5/2} \rightarrow {}^6\text{H}_{9/2}$, and ${}^4\text{G}_{5/2} \rightarrow {}^6\text{H}_{13/2}$, respectively, of Sm^{3+} ions as assigned by different authors [31, 32].

(c) For mixed dopants of $\text{CeO}_2 + \text{Sm}_2\text{O}_3$ -glasses: The PL spectra of the mixed dopants glasses reveal quite similar data to that obtained by Sm_2O_3 -doped glasses.

This refers to the dominance of the photoluminescence spectra of the Sm^{3+} ions than that for Ce^{3+} ions which are restricted to absorption of a lighter lanthanide.

3.3. *Thermal Expansion Measurements.* Figure 8 illustrates the thermal expansion behavior of selected four glasses

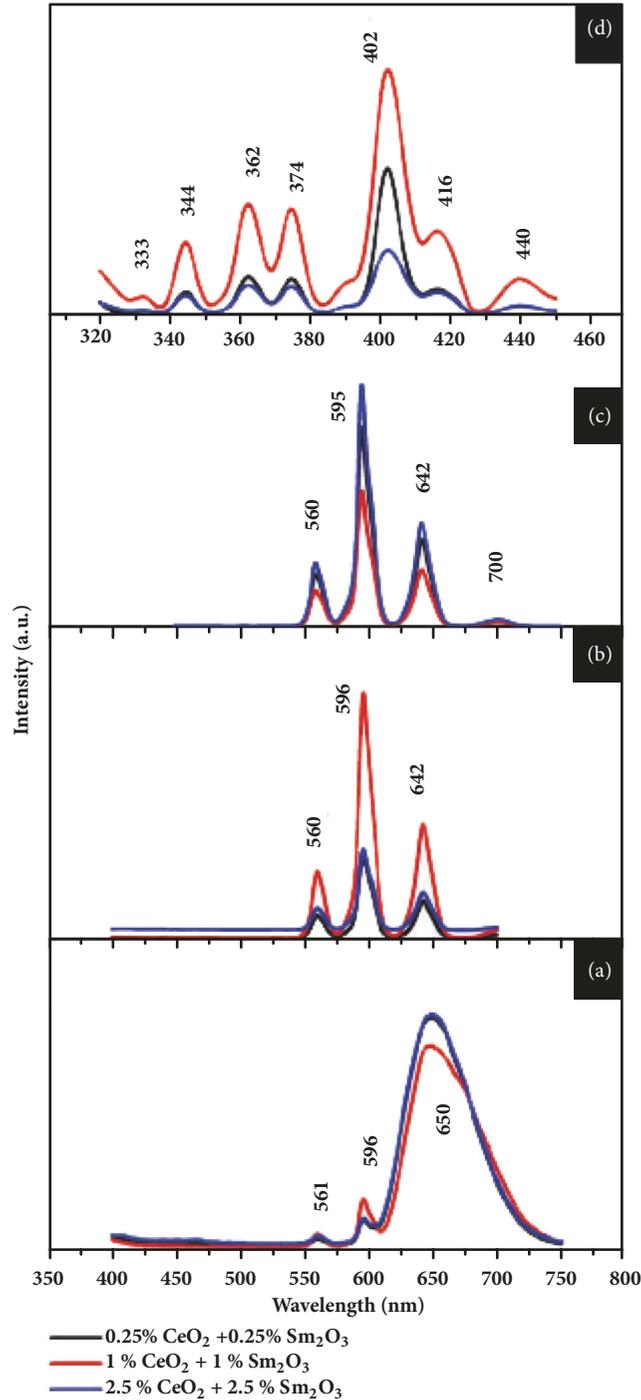


FIGURE 7: Photoluminescence spectra of mixed $\text{CeO}_2 + \text{Sm}_2\text{O}_3$ -doped glasses: (a) emission at $\lambda_{\text{ex}} = 290 \text{ nm}$, (b) emission at $\lambda_{\text{ex}} = 365 \text{ nm}$, (c) emission at $\lambda_{\text{ex}} = 402 \text{ nm}$, and (d) excitations at $\lambda_{\text{em}} = 595 \text{ nm}$.

including the undoped sample, 5% CeO_2 doped sample, 5% Sm_2O_3 -doped sample, and sample containing mixed dopants of 2.5 $\text{CeO}_2 + 2.5 \text{ Sm}_2\text{O}_3$. All the glasses show either negative or low thermal expansion coefficient within the temperature range 25–250°C, which then increases steadily with temperature until reaching the transformation range followed by a high increase in expansion until the dilatometric

softening temperature. After that, a rapid drop is observed. The dilatometric softening temperature is very close in the first three samples (412–418°C) and then highly increases with the mixed sample to reach 453°C.

It is accepted that glass, like most solids, generally expands on heating. The possible dimensional changes which can occur with heating are very interesting and of particular

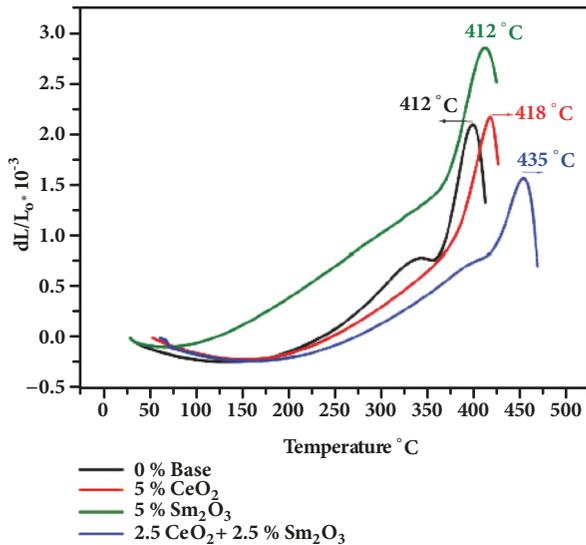


FIGURE 8: Dilatometric thermal expansion of some selected glasses.

importance for the application in sealing purposes and the capability of the glass to withstand thermal shock or cycling [4, 33].

Thermal expansion of close-packed structure (such as NaCl) is a direct result of an increase in bond length with increasing temperature. While the simple lattice vibration model works well for close-packed structures, an additional process can occur in less tightly packed network structures or nonperiodic arrangement state such as those found in glasses. Bond bending can alter the positions of atoms as can rotation about an axis. These processes can counterpart the expansion of the bond length due to the increased amplitude of vibrations, resulting in a very low expansion coefficient. Filling of interstices inhibits these mentioned vibration processes and tends to cause an increase in the thermal expansion coefficient.

The thermal data can thus be realized by the assumption that rare-earth ions are accepted to be situated within interstitial positions and thus lead to the identified increase of the dilatometric softening temperatures. The more filling of the interstices by mixed dopants is observed to give more increase in the dilatometric softening temperature.

3.4. FT-Infrared Absorption Spectra. Figure 9 shows the FTIR spectra of the three CeO₂-doped glasses. The IR spectra in general are almost similar and condensed extending from 400 to 1400 cm⁻¹ with distinct broad band at the far-IR region peaking at about 496 cm⁻¹ followed by a medium broad with two peaks at about 725 and 790 cm⁻¹ and succeeded by a very broad and distinct connected bands extending from about 850 to 1400 cm⁻¹ with four peaks at about 880, 980, 1086, and 1246 cm⁻¹. The deconvoluted spectrum shows the following 8 IR peaks: 410, 490, 725, 788, 878, 970, 1089, and 1246 cm⁻¹.

Figure 10 illustrates the FTIR spectra of Sm₂O₃-doped glasses. The IR spectra are observed to be the same as shown in Figure 9 and with similar spectral details. The

deconvoluted spectrum shows 9 IR peaks at 417, 463, 535, 684, 770, 880, 941, 1072, and 1273 cm⁻¹.

Figure 11 reveals the FTIR spectra of the glasses containing mixed dopants of the two RE oxides. The IR spectral curves are comparable to the spectra shown in Figures 9 and 10. The convoluted spectrum shows the following 8 IR peaks: 410, 515, 721, 784, 889, 945, 1083, and 1282 cm⁻¹.

The FTIR spectra are shown in Figures 9, 10, and 11 revealing the detailed IR vibrational bands due to CeO₂-doped glasses, Sm₂O₃-doped glasses, and selected mixed dopants glasses. The IR spectral curves show composite and extended peaks extending from 400 to 1400 cm⁻¹ and they are clearly analyzed through the deconvoluted process to indicate all the hidden or overlapped peaks of the glasses.

The interpretation of the IR results can be clearly understood on the following basic parameters [34–38]:

- (a) The IR vibrational bands are considered to be fingerprints of the structural building units within the studied glasses in comparison with that obtained from crystalline analogs.
- (b) The structural building units are virtually emanating or formed in relation to the chemical composition of all the constituents. The basic host glass is composed of main glass forming oxide (70% P₂O₅) which indicates that the expected glass forming phosphate groups are (Q²-Q³). The true modifier oxide constitutes of (10% Na₂O) while ZnO which is considered as conditional oxide has the ability to be a modifier or can share as (ZnO₄) groups in some cases where oxygens are available from alkali oxide to be able to form such tetrahedral groups. The 1% Al₂O₃ is added only to maintain chemical stability or preventing devitrification.
- (c) The detailed attributions of the vibrational peaks from the deconvoluted spectrum of the base undoped glass are summarized as follows [22, 34–39]:
 - (i) The far-IR peaks at 410–490 cm⁻¹ can be related to O–P–O bending or lattice mode vibrations of δ(PO₂).
 - (ii) The mid peaks at 725–790 cm⁻¹ are related to symmetric stretching vibrations of P–O–P bonding.
 - (iii) The peaks at 878–970, 1089 cm⁻¹ can be related to asymmetric stretching vibrations of PO₂ groups.
 - (iv) The peak at 1296 cm⁻¹ can be correlated with asymmetric stretching of doubly bonded oxygen vibrations (P = O) modes.
 - (v) The IR vibrational curves of the single doped (CeO₂, Sm₂O₃) or mixed dopants reveal no distinct variations but only some limited changes in some of the vibrational peaks and these can be related to some limited depolymerization of rare-earth oxides as dopants.

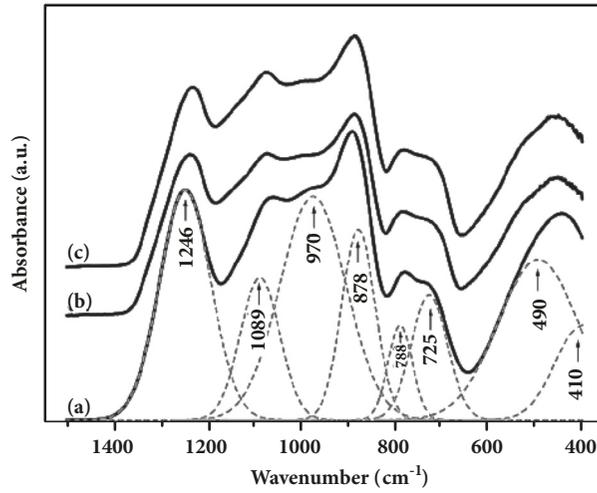


FIGURE 9: FT-infrared absorption spectra of (a) 0.5%, (b) 2%, and (c) 5% CeO₂-doped glasses.

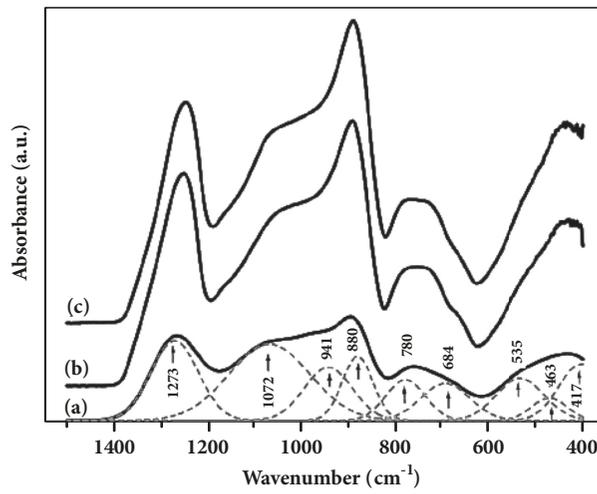


FIGURE 10: FT-infrared absorption spectra of (a) 0.5%, (b) 2%, and (c) 5% Sm₂O₃-doped glasses.

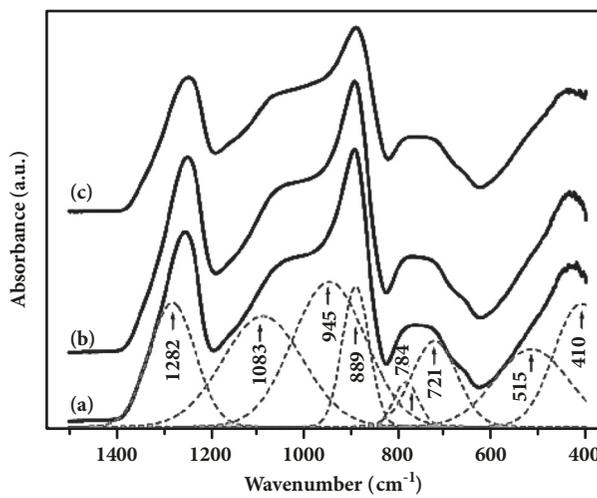


FIGURE 11: FT-infrared absorption spectra of (a) 0.25% CeO₂ + 0.25% Sm₂O₃, (b) 1% CeO₂ + 1% Sm₂O₃, and (c) 2.5% CeO₂ + 2.5% Sm₂O₃-doped glasses.

4. Conclusion

Combined optical, FTIR, and photoluminescence spectra have been carried out for CeO₂- or Sm₂O₃-doped host Na₂O–ZnO–P₂O₅ glasses or with combined mentioned dopants. Optical data show UV absorption for the undoped glass with an extension to two additional UV bands due to both Ce⁴⁺ and Ce³⁺ ions, while Sm³⁺-doped glasses show two further additional series in the visible and near IR regions. Photoluminescence spectra reveal characteristic excitation and emission bands for the CeO₂- and Sm₂O₃-glasses. FTIR spectra show extended vibrational bands within the region 400–1700 cm⁻¹ correlated with phosphate groups (mainly Q² and Q³ units). The IR spectra did not show additional bands due to the dopants indicating their housing in modifying positions. Thermal expansion measurements confirm the previous assumption and are reflected on the dilatometric softening temperature in the mixed dopant glasses. The various doped glasses reveal closely similar IR spectral curves with minor variations in the intensities of some bands due to depolymerization effects of the rare-earth ions. The thermal expansion measurements indicate the housing of rare-earth ions in modifying positions, and the mixed dopants are assumed to cause more filing of the network structure.

All the studied properties indicate that the optical spectra of the single dopant (CeO₂, Sm₂O₃) are different although they belong to the lanthanides. On the other hand, the IR spectra reveal similar spectral details for the two dopants (CeO₂, Sm₂O₃) because they are housed in interstitial positions and their low percent did not affect the vibrational bands due to phosphate groups. The same holds for the thermal properties. The mixed dopant glasses show the combined optical spectra for lanthanides. While FTIR spectra cause no distinct effect, the thermal data reveal combined effect of two dopants.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

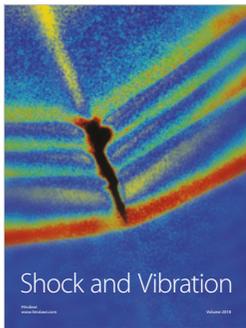
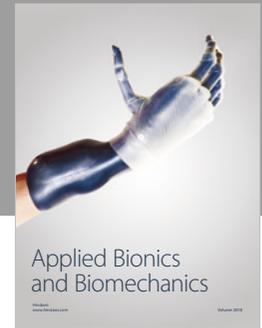
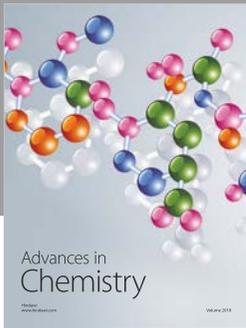
Conflicts of Interest

The authors declare that they have no conflicts of interest.

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