

IMPACT OF ANNEALING TIME ON THE PROPERTIES OF Sm_2O_3 -DOPED BOROTELLURITE GLASSES FOR PHOTONIC APPLICATIONS

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Abstract

This study presents the effects of annealing time on the physical, structural, optical, and luminescence properties of Sm^{3+} -doped $\text{ZnO-BaO-B}_2\text{O}_3\text{-TeO}_2$ borotellurite glasses prepared using the melt-quenching technique. The glasses were annealed at 350°C for varying durations of 2, 4, 6, 8, and 10 hrs. The investigation revealed that density and refractive index decreased with increasing annealing time up to 8 hrs but increased after 10 hrs, inversely correlating with molar volume. Structural analysis using X-ray diffraction confirmed an amorphous phase, while FTIR spectroscopy identified characteristic vibrations of TeO_4 , BO_4 , and BO_3 units, which diminished with longer annealing times. Optical properties, assessed via UV-Vis-NIR absorption spectroscopy, displayed transitions from the ground state $^6\text{H}_{5/2}$ to various excited states. Luminescence studies indicated that the sample annealed for 8 hrs exhibited the highest luminescence, emitting orange light. Chromaticity coordinates were determined using the CIE 1931 color space. The shortest luminescence decay time was 0.863 ms for the 10 hrs annealed sample, while the longest was 0.873 ms for the 6 hrs sample. These findings elucidate the impact of annealing time on the material properties of Sm^{3+} -doped borotellurite glasses, underscoring their potential for photonic applications.

Keywords: Annealing times; Borotellurite; Luminescence; Sm^{3+} ion

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Introduction

Glasses are amorphous materials formed by rapidly cooling a molten liquid below its glass transition temperature, T_g . This process hinders the formation of a well-defined crystalline structure, resulting in a disordered atomic arrangement. (Kurudirek *et al.*, 2018). Doping glasses with lanthanide ions has been a topic of substantial interest in optics due to their unique luminescence properties. Compared to crystalline counterparts, glasses offer several advantages, including low-cost production, scalability, and ease of material processing (Nikl *et al.*, 1999; Vedda *et al.*, 2002). Borotellurite glasses, composed of B₂O₃ and TeO₂ as the primary network formers, have attracted significant attention due to their favorable properties, such as high density and relatively low melting temperatures, making them suitable for various photonic applications (Babu *et al.*, 2007; Sing *et al.*, 2014). Perovskite oxides, like ZnO and BaO, have been incorporated into glasses to modify their physical and chemical properties. With its wide bandgap, ZnO plays a crucial role in enhancing the luminescence efficiency of borate glasses (Elkhoshkhany *et al.*, 2018). Research suggests that ZnO bonds with oxygen within the glass network, potentially influencing the environment surrounding the dopant ions and their emission properties. Barium oxide (BaO), known for its high chemical stability and low melting point, is another attractive dopant material. Barium incorporation can influence the glass network's density and modify its refractive index, impacting light propagation characteristics (Hajer *et al.*, 2016).

Samarium oxide (Sm₂O₃) is a rare-earth element known for its unique luminescent properties. Sm³⁺ ions exhibit light emission characteristics desirable for various photonic applications when doped into glasses. Incorporating Sm₂O₃ into the glass network introduces energy levels within the bandgap that can be excited by external light sources, leading to photoluminescence phenomena. By tailoring the composition and processing parameters, Sm³⁺-doped glasses can be engineered to achieve specific emission wavelengths suitable for various technological applications (Kurita *et al.*, 1994; Rao *et al.*, 2017; Suaif *et al.*, 2019).

This study investigates the impact of annealing time on the structural, optical, and luminescence properties of Sm₂O₃-doped ZnO-BaO-B₂O₃-TeO₂ glasses fabricated using the melt-quenching technique. The prepared glass samples were subjected to different annealing times (2, 4, 6, 8, and 10 hrs) at a constant temperature (350°C) to explore the influence of annealing on various material

characteristics. The findings presented in this work aim to contribute to a deeper understanding of the structure-property relationships in Sm³⁺-doped borotellurite glasses and pave the way for developing novel photonic materials with tailored functionalities.

Materials and Methods

In the synthesis process of this glass sample, a mixture of 30TeO₂: 30BaO: 29B₂O₃: 10ZnO: 1Sm₂O₃ was prepared. The starting materials, comprising oxides of TeO₂, BaCO₃, H₃BO₃, ZnO, and Sm₂O₃ with a purity of $\geq 99.99\%$, were calculated according to their molar percentage ratios. The total weight of the compounds was set at 10 grams and prepared in a porcelain crucible. The mixture was heated for 1.5 hrs in an electric furnace at 1150°C. The molten glass was poured into a preheated graphite mold within the electric furnace and annealed for 2, 4, 6, 8, and 10 hrs at 350°C, as shown in Figure 1. After annealing, the samples were cut and polished to a uniform $1.0 \times 1.5 \times 0.3$ cm³ for optical measurements. X-ray diffraction (XRD) confirmed the glasses structure via the XRD instrument, XRD-6100 Shimadzu. FTIR spectroscopy (650–4000 cm⁻¹) using Cary-630 FTIR Spectrometer. Densities were determined by Archimedes' principle, and refractive indices were measured. UV-VIS-NIR (600–2000 nm) absorption spectroscopy investigated optical transitions. Photoluminescence (PL) and radioluminescence (RL) spectra were acquired using appropriate spectrometers. The CIE 1931 chromaticity diagram quantified the emitted light colors.

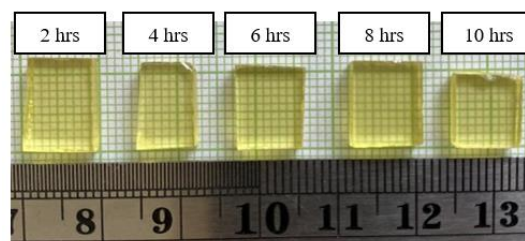


Figure 1. A photograph of the glass samples was subjected to different annealing times

Results and Discussion

Physical properties

The physical properties studied include density, molar volume, and refractive index, as

reported in Figure 2 from the obtained results. Figure 2 shows different behaviors in Sm^{3+} ions doped borotellurite glasses annealed for 8 and 10 hrs, especially at 10 hrs. As annealing time increases, the glass structure relaxes, releasing internal stresses and leading to a less dense and more expanded network. This causes a decrease in density and an increase in molar volume (V_m). At 8 hrs, the glass network reaches a stable state where the density decreases, and V_m increases in balance, indicating optimal structural relaxation. However, at 10 hrs, the network becomes over-relaxed, leading to further expansion, lower density, and a disproportionate increase in V_m , reflecting a less stable structure. The inverse relationship between density and V_m is due to the structural relaxation during annealing, where the atomic packing density decreases while the network expands (Kesavulu and Jayasankar, 2011)

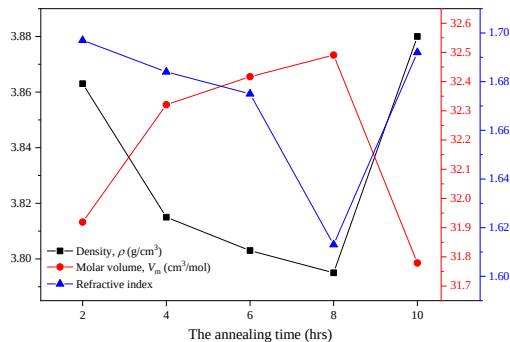


Figure 2. Physical properties were shown in the color line: density (■), molar volume (●), and refractive index (▲).

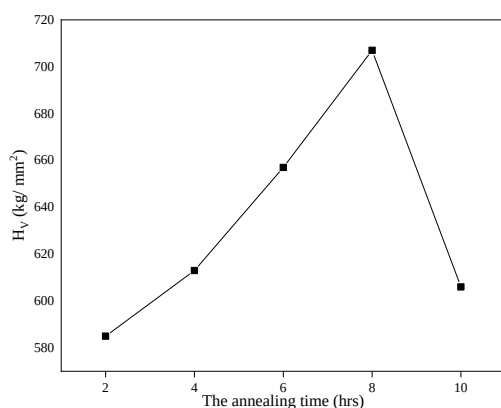


Figure 3. Microhardness (H_V) of Sm^{3+} -doped $\text{ZnO-BaO-B}_2\text{O}_3\text{-TeO}_2$ glass as a function of annealing time

Figure 3, illustrates the microhardness (H_V) values as a function of annealing time. The H_V values increase with longer annealing times,

indicating that the glass structure becomes more rigid, which strengthens the material. This is likely due to the influence of Sm^{3+} ions, which have a smaller radius and stronger ionic force, contributing to increased hardness. The enhancement in hardness and density can be attributed to changes in the internal glass structure, particularly the reduction in the presence of TeO_4 , BO_3 , and BO_4 groups, which improves the structural connectivity. The microhardness values peak at 8 hours of annealing, suggesting optimal structural formation. However, after 10 hours of annealing, the further reduction of TeO_4 , BO_3 , and BO_4 bonds in the glass network results in a decrease in microhardness, likely due to the onset of structural relaxation.

Structural properties

The structural properties were investigated through X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) analyses. The X-ray diffraction (XRD) pattern was investigated in the range of 10° to 80° . In Figure 4, the XRD patterns of the structure of all glass samples showed an amorphous structural phase. The X-axis of Figure 4 represents the diffraction angle (2θ) in degrees. The 2θ values correspond to the angles where constructive interference of X-rays occurs due to the crystal lattice planes. In this case, the broad hump from $2\theta = 10^\circ$ to 80° indicates the amorphous nature of the glass samples. The lack of sharp peaks suggests an absence of long-range crystalline order, typical for glassy materials. These broad features are related to the short-range order within the glass network, such as TeO_4 , BO_3 , and BO_4 units, as well as the distribution of Sm^{3+} ions in the matrix. In the region between 40° and 80° , the data shows only subtle features consistent with the amorphous nature of the samples. This region likely reflects diffuse scattering from the disordered atomic structure. Since glasses lack well-defined periodic atomic arrangements, XRD does not detect sharp peaks in this region, unlike crystalline materials. The absence of distinct peaks between 40° – 80° reinforces the conclusion that the material remains predominantly amorphous, even after annealing. The FTIR spectrum analysis with Transmittance mode measurements reported in the wavenumber range of $500 - 4000 \text{ cm}^{-1}$, as shown in Figure 5, indicated vibrations of the bonds in all samples. These vibrations were categorized into four regions: The first region, between $2080\text{--}3500 \text{ cm}^{-1}$, indicated the OH bending mode of vibration (Venkatramu *et al.*, 2007). The second region, between $1200\text{--}1600 \text{ cm}^{-1}$, indicated asymmetric stretching vibrations of B-O bonds in BO_3 triangular units. The third region, between $800\text{--}1200 \text{ cm}^{-1}$, showed stretching vibrations indicative of B-O

bonds in BO_4 units (Rafien *et al.*, 2020). The fourth region, between $660\text{--}780\text{ cm}^{-1}$, demonstrated vibrations of Te-O-Te bonds, where TeO_4 tetrahedral units were connected (Marimuthu *et al.*, 2009). The FTIR spectrum analysis revealed vibration positions within the structure at five positions: $2750, 2250\text{ cm}^{-1}$ (OH), 1326 cm^{-1} (BO_3), 858 cm^{-1} (BO_4), and 676 cm^{-1} (TeO_4). The potential influence of OH groups on the structural and optical properties of the glasses prompted an investigation into their presence within the glass network. H_3BO_3 , an O-H containing compound, was utilized as a precursor during the synthesis process, raising the possibility of O-H group incorporation. The presence of O-H groups affects the structural network, particularly in the formation of bonds and the stability of the glass matrix. Increased annealing times lead to changes in the vibrational modes of these bonds, which correlates with changes in density and molar volume (Pavani *et al.*, 2011). In this study, the positions of the bonds within each structure were reported in Table 1. The FTIR spectrum of all samples showed an increase in the %transmittance value for all three positions with increasing the annealing time. This result was due to decreased vibrations in each bond at their respective

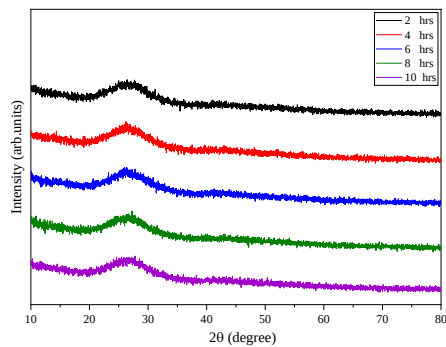


Figure 4. X-ray diffraction patterns of Sm^{3+} -doped $\text{ZnO-BaO-B}_2\text{O}_3\text{-TeO}_2$ glass sample

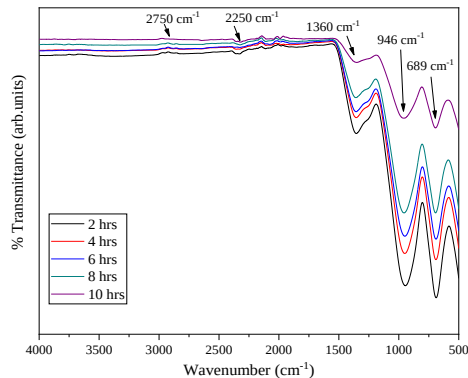


Figure 5. FTIR spectrum analysis of Sm^{3+} -doped $\text{ZnO-BaO-B}_2\text{O}_3\text{-TeO}_2$ glass sample

wavenumber positions, which are 1326 cm^{-1} (BO_3), 858 cm^{-1} (BO_4), and 676 cm^{-1} (TeO_4). The molar volume of samples that underwent a 2 to 8 hrs annealing process was increased as the distance between atoms inside the structure increased. However, when the annealing time was increased to 10 hrs, the vibrations of all three bonds were small due to decreased interatomic distance within the structure, which increased the molar volume in the sample (Rafien *et al.*, 2020).

Table 1. The positions of FTIR of Sm^{3+} -doped $\text{ZnO-BaO-B}_2\text{O}_3\text{-TeO}_2$ glass

Wavenumber (cm^{-1})	IR band assignments	References
2750	OH bending mode of vibration	Pavani <i>et al.</i> , 2011
2250	OH bending mode of vibration	Pavani <i>et al.</i> , 2011
1360	B-O stretching (BO_3) units.	Marimuthu <i>et al.</i> , 2009
946	B-O bond stretching vibration in BO_4 tetrahedra from diborate groups.	Marimuthu <i>et al.</i> , 2009
689	Te-O-Te bridges between four co-ordinate tellurium atoms [TeO_4]	Ardelean <i>et al.</i> , 2000

Optical properties.

The absorption spectra of all glass samples subjected to annealing time changes are shown in Figure 6. The absorption spectra of Sm^{3+} ion exhibit 7 peaks, indicating energy level transitions from the ground state $^6\text{H}_{5/2}$ to various excited states in the wavelength range of $600\text{--}2000\text{ nm}$. The energy level transitions at the positions of each peak are as follows: at wavelengths 947 nm ($^6\text{F}_{11/2}$), 1085 nm ($^6\text{F}_{9/2}$), 1238 nm ($^6\text{F}_{7/2}$), 1385 nm ($^6\text{F}_{5/2}$), 1492 nm ($^6\text{F}_{3/2}$), 1550 nm ($^6\text{H}_{15/2}$), and 1589 nm ($^7\text{F}_{1/2}$) (Venkatramu *et al.*, 2007). The O-H groups introduce additional vibrational modes that can influence the absorption characteristics of the glasses. The presence of O-H groups can lead to absorption bands in the UV-Vis-NIR spectra, which may affect the transparency and refractive index of the glasses. As the annealing time increases, the impact of O-H groups on the vibrational modes decreases. The intensity of the highest absorption peak does not show a definite trend with increasing the annealing time of the glass samples. However, at wavelengths $1238, 1385, 1492$, and 1550 nm , the highest absorption intensity in the annealed samples for 2 hrs is observed to be highest. As shown in Figure 6, the absorption strength is not just a theoretical concept but a parameter with practical

implications. It is linked to the vibrations of OH, BO₃, BO₄, and TeO₄ groups observed in the FTIR spectrum in Figure 5. Understanding this link can help design and develop new materials with specific absorption characteristics. A higher vibration intensity corresponds to stronger bonding or more pronounced structural units within the glass network. This feature can be harnessed to create materials with enhanced strength and durability. A higher vibration of BO₄ or TeO₄ groups indicates a well-connected glass network, as these units contribute to the rigidity and structural integrity of the glass. Conversely, lower vibration intensity suggests weaker bonds or fewer structural units, indicating a more loosely connected network. This connection in the glass network directly affects the Sm³⁺ absorption transitions, a finding that can guide the development of materials with tailored absorption properties. A well-connected network with strong bonding can influence the local field around the Sm³⁺ ions, affecting their electronic environment and absorption characteristics of Sm³⁺ ions. Specifically, a stronger network can enhance the interaction of Sm³⁺ with the surrounding ligands, leading to sharper and more defined absorption transitions. On the other hand, a weaker network might cause broader, less intense transitions due to a less uniform local environment around Sm³⁺ at wavelengths 947, 1085, and 1589 nm, the highest absorption intensity at the samples annealed for 8 hrs, indicating relatively lower vibrations of BO₃, BO₄, and TeO₄ bonds at these positions, which is still sufficient for the energy absorption of Sm³⁺ ions at these wavelengths.

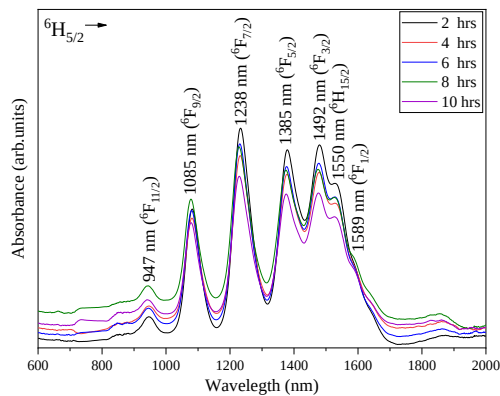
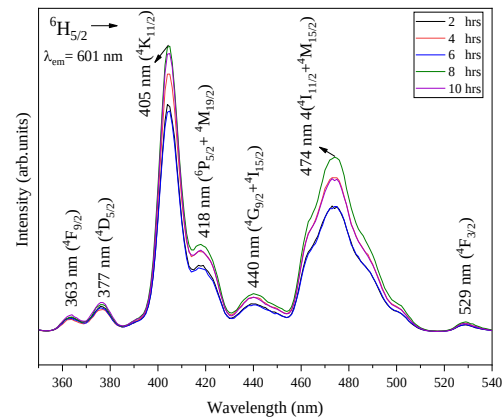


Figure 6. The absorption spectrum of Sm³⁺-doped ZnO-BaO-B₂O₃-TeO₂ glass sample

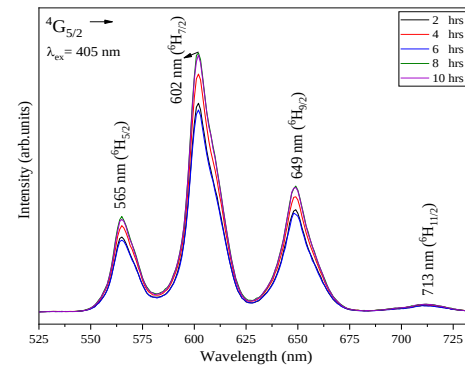
Luminescence properties.

Figure 7(a), the excitation spectra recorded in the 350 - 540 nm wavelength range for glass samples annealed from 2 to 10 hrs. The excitation spectra of the glass samples show that all seven peaks are observed when the emission wavelength

is 601 nm. These peaks indicate energy level transitions from the ground state ⁶H_{5/2} to various excited states at 363 nm (⁴F_{9/2}), 377 nm (⁴D_{5/2}), 405 nm (⁴K_{11/2}), 418 nm (⁶P_{5/2} + ⁴M_{19/2}), 440 nm (⁴G_{9/2} + ⁴I_{15/2}), 474 nm (⁴I_{11/2} + ⁴M_{15/2}), and 527 nm (⁴F_{3/2}) of Sm³⁺ (Venkatramu *et al.*, 2007). When the Sm³⁺ ion are excited to energy levels higher than the ⁴G_{5/2}



(a)



(b)

Figure 7. Luminescence properties, where a) the excitation spectra, and b) the emission spectrum

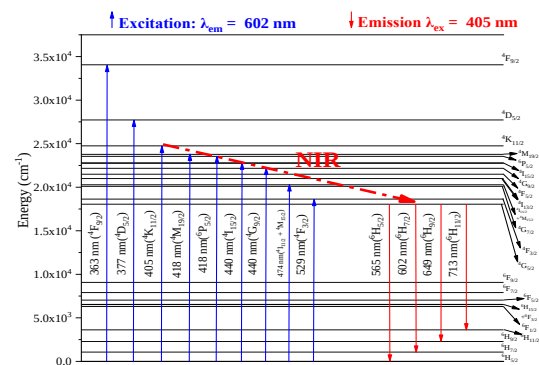


Figure 8. Energy level diagram of light excitation and luminescence of Sm³⁺ ion

level, they relax back to the $^4G_{5/2}$ level, releasing energy as luminescence within the glass matrix. This energy level diagram is depicted in Figure 8 (Carnall *et al.*, 1968; Yasaka *et al.*, 2019). Meanwhile, Figure 7(b) exhibits the emission spectra of the same set of glass samples tested, with results reported in the 525 - 750 nm wavelength range. When Sm³⁺ ion at the $^4G_{5/2}$ energy level transition to lower energy levels, such as $^6H_{5/2}$, $^6H_{7/2}$, $^6H_{9/2}$, and $^6H_{11/2}$, they emit energy in the form of light, which can be observed across various wavelengths as shown the highest intensity at the sample annealed of 8 hrs in the wave wavelengths positions of 565 nm, 602 nm, and 649 nm. In the emission spectra analysis using the CIE 1931 chromaticity diagram (Kiwsakunkran *et al.*, 2022), which represents all visible colors, the coordinates (x, y) calculated from the luminescence spectra were found to be (0.60, 0.40) for all Sm³⁺-doped glass samples studied, provides the orange color of luminescence. In Figure 9. The decay curves of

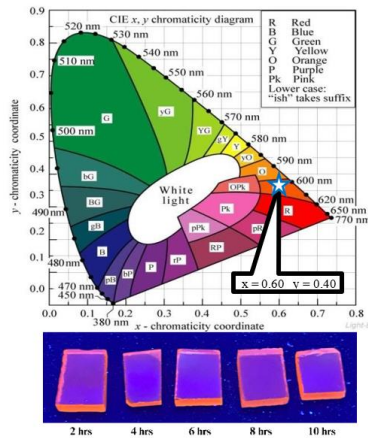


Figure 9. CIE 1931 Standard Colorimetric Diagram indicating the Color Coordinates of Light Emitted from Sm³⁺ ions Doped Glass

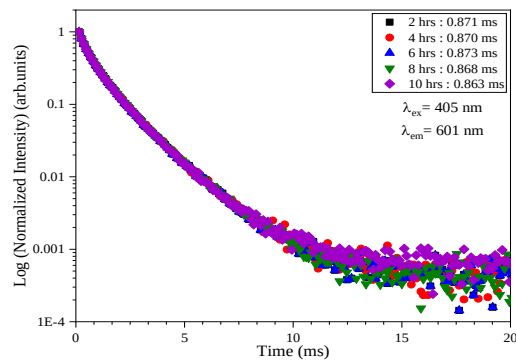


Figure 10. The decay time curves of Sm³⁺-doped ZnO-BaO-B₂O₃-TeO₂ glass sample

glass samples that have changed in annealing time were obtained at the emission wavelength of 602 nm using 405 nm excitation light, indicating energy level transitions from excited states $^4G_{5/2}$ to $^6H_{7/2}$. The samples annealed between 2 and 8 hrs show a general trend of increasing luminescence intensity. This suggests that the shorter annealing times are sufficient to create a favorable environment for the Sm³⁺ ion to emit light effectively (Venkatramu *et al.*, 2007). The highest intensity is observed in the sample annealed for 8 hrs, indicating optimal energy transfer and minimal non-radiative decay processes at this annealing time. The sample annealed for 10 hrs shows a decrease in luminescence intensity compared to the 8 hrs sample (Kiwsakunkran *et al.*, 2022). This could be due to the formation of microstructural changes or defects in the glass matrix that lead to increased non-radiative decay pathways, thereby reducing the overall luminescence efficiency. The decay times for the Sm³⁺-doped glass samples are relatively consistent (Figure 10), with slight variations for 2 hrs (0.871 ms), 4 hrs (0.870 ms), 6 hrs (0.873 ms), 8 hrs (0.868 ms), and 10 hrs (0.863 ms). The minor differences in decay times indicate that the structural changes induced by different annealing times do not significantly affect the lifetime of the luminescence. However, the slight decrease in decay time for the 10 hrs sample further supports the idea of increased non-radiative processes. The findings suggest that an 8 hrs annealing time is optimal for achieving the highest luminescence intensity. This is beneficial for lighting and display technologies applications where high efficiency and stable color output are required. In 1962, Judd and Ofelt independently developed the theoretical framework for calculating the induced electric dipole matrix element. Their fundamental concept is that the intensity of forbidden f-f electric dipole transitions can result from the admixture into the $4f^N$ configurations of opposite parity (e.g., $4f^{N-1} n'd1$ and $4f^{N-1} n'g1$) (Ardelean *et al.*, 2000). To determine the oscillator strengths " f_{exp} " experimentally for absorption bands and compare them with calculated ones (f_{cal}) from existing literature (Largot *et al.*, 2019), the JO parameters $\Omega_{2,4,6}$ can be derived by matching the experimental and calculated oscillator strengths through a least square fitting method. The oscillator strength is related to absorption intensity, and its values for different transitions in absorption bands are computed using JO theory. Table 2 presents both experimentally measured and theoretically calculated oscillator strengths, showing good agreement with an overall root mean square deviation (RMS) value of 0.05 for the 8-hour glass sample. The JO parameters $\Omega_{2,4,6}$, obtained via least

square fitting, reveal that the Ω_2 parameter depends on Ln–O covalency and asymmetry around the Ln^{3+} ion site, while Ω_4 and Ω_6 are long-range parameters related to bulk properties such as viscosity and rigidity of the matrix.

Table 2. Oscillator strength (f_{exp} & f_{cal}), least square fitting (δ_{rms}) value of 8 hrs sample

Transition ${}^6\text{H}_{5/2} \rightarrow$	$f_{\text{exp}} (\times 10^{-6})$	$f_{\text{cal}} (\times 10^{-6})$
${}^6\text{F}_{11/2}$	0.2887	0.3507
${}^6\text{F}_{9/2}$	2.2026	2.1264
${}^6\text{F}_{7/2}$	2.9161	2.9634
${}^6\text{F}_{5/2}$	1.5069	1.4880
${}^6\text{F}_{3/2}$	1.3046	1.3081
δ_{rms}	0.05	

Compared to studies (Yasaka *et al.*, 2019), (Agarwal *et al.*, 2009), (Basavapoornima and Jayasankar, 2014), (Yashodha *et al.*, 2020), (Manjunath *et al.*, 2018), the higher value of Ω_2 indicates that the current glass samples exhibit greater Ln–O covalency and a more asymmetric structure around the lanthanide ions. Therefore, the JO parameter Ω_2 is covalency-dependent, while Ω_4 and Ω_6 are structure-dependent. Based on the results presented in Table 3, it is found that the values of Ω_4 and Ω_6 are similar, indicating that the structural environment around the Sm^{3+} ions in the sample with the highest emission spectrum has a similar configuration. This suggests the suitability of this material for applications requiring orange-emitting materials. The JO parameters $\Omega_{2,4,6}$, along with the refractive index (n), can be used to predict radiative properties. These parameters, compared with those

of other glasses, are shown in Table 3. The radiative transition probability (A), effective line width ($\Delta\lambda_{\text{eff}}$), and branching ratio (β_R) for a transition $\psi J \rightarrow \psi' J'$ were calculated based on existing literature (Yashodha *et al.*, 2020). This study evaluates several radiative properties, such as radiative transition probability, effective line width, branching ratio, and stimulated emission cross-section, using the calculated JO intensity parameters. These values are listed in Table 4 for the 8 hrs glass sample. For laser design, the branching ratio is particularly important because it indicates the likelihood of achieving stimulated emission from a specific transition. The values of the branching ratio and stimulated emission cross-section provide valuable insights into the lasing potential of the materials. In Table 5, the comparison of JO parameters for the ${}^4\text{G}_{5/2} \rightarrow {}^6\text{H}_{7/2}$ transition of the 8 hrs annealed Sm_2O_3 -doped borotellurite glass with other reported literature was provided. The emission band for the ${}^4\text{G}_{5/2} \rightarrow {}^6\text{H}_{7/2}$ transition is found to be at a wavelength consistent with other Sm^{3+} ions doped glass systems reported in the literature. For example, the emission band for Sm^{3+} ions in ZBS3 glasses (Agarwal *et al.*, 2009) has been found at similar wavelengths, indicating that the optical environment around the Sm^{3+} ions is comparable in the present glass. The effective bandwidth observed for the 8 hrs annealed sample is reported to be 13.28 nm, which is within the expected range for Sm^{3+} ions doped glasses. Similar effective bandwidths, typically between 10–15 nm, have been observed in other glass systems, supporting the conclusion that the present glass can compete with existing materials in photonic applications. The transition probability A for the

Table 3. Comparison of $\Omega_{2,4,6}$ ($\times 10^{-20} \text{ cm}^2$) with other reported literature

Code name	Ω_2	Ω_4	Ω_6	Trend	References
8 hrs	2.84	2.42	2.41	$\Omega_2 > \Omega_4 > \Omega_6$	Present work
ZBaBoT 0.5	0.83	0.47	0.28	$\Omega_2 > \Omega_4 > \Omega_6$	Yasaka <i>et al.</i> , 2019
ZBS3	2.49	1.64	1.61	$\Omega_2 > \Omega_4 > \Omega_6$	Agarwal <i>et al.</i> , 2009
PKAPbNSm10	2.61	5.87	3.22	$\Omega_4 > \Omega_6 > \Omega_2$	Basavapoornima and Jayasankar, 2014
$\text{La}_{1-x}\text{Sm}_x\text{OCl}$	0.41	0.48	0.62	$\Omega_6 > \Omega_4 > \Omega_2$	Yashodha <i>et al.</i> , 2020
$\text{Sr}_2\text{SiO}_4:\text{Sm}^{3+}$	0.52	0.28	0.39	$\Omega_2 > \Omega_6 > \Omega_4$	Manjunath <i>et al.</i> , 2018

Table 4. The emission band position (λ_p , nm), effective bandwidth ($\Delta\lambda_{\text{eff}}$, nm), transition probability (A , s^{-1}), emission cross-section (σ_e , $\times 10^{-22} \text{ cm}^2$), calculated and experimental branching ratios (β_R) for 8 hrs sample

Transition ${}^4\text{G}_{5/2} \rightarrow$	λ_p	$\Delta\lambda_{\text{eff}}$	A	σ_e	β_R (exp)	β_R (cal)
${}^6\text{H}_{5/2}$	565	10.45	21.92	1.19	0.15	0.08
${}^6\text{H}_{7/2}$	602	13.28	103.14	5.20	0.54	0.38
${}^6\text{H}_{9/2}$	649	14.41	88.60	5.56	0.28	0.33
${}^6\text{H}_{11/2}$	713	15.46	22.58	1.92	0.02	0.08

Table 5. The Comparison of emission band position (λ_p , nm), effective bandwidth ($\Delta\lambda_{\text{eff}}$, nm), transition probability (A , s⁻¹), emission cross-section (σ_e , $\times 10^{-22}$ cm²), calculated and experimental branching ratios (β_R) for 8 hrs sample with other reported literature

Transition $^4G_{5/2} \rightarrow$	λ_p	$\Delta\lambda_{\text{eff}}$	A	σ_e	β_R (exp)	β_R (cal)	References
$^6H_{7/2}$	602	13.28	103.14	5.20	0.54	0.38	Present work
$^6H_{7/2}$	600	-	134.76	6.09	0.61	-	Yasaka <i>et al.</i> , 2019
$^6H_{7/2}$	562	-	94.00	10.50	-	0.32	Agarwal <i>et al.</i> , 2009
$^6H_{7/2}$	598	11.2	227.00	1.15	0.57	0.47	Basavapoornima and Jayasankar, 2014
$^6H_{7/2}$	608		52.53	3.983	0.59	0.41	Yashodha <i>et al.</i> , 2020
$^6H_{7/2}$	598	-	32.31	3.82	0.66	0.38	Manjunath <i>et al.</i> , 2018

$^4G_{5/2} \rightarrow ^6H_{7/2}$ transition is calculated and compared with other Sm³⁺ ions doped glasses. In this study, the probability is consistent with reported values in similar borate and tellurite-based systems, implying strong radiative transitions and good emission properties. The calculated branching ratio for the 8 hrs annealed sample shows a value of 0.54 for the $^4G_{5/2} \rightarrow ^6H_{7/2}$ transition. This value is comparable to those reported in the literature for Sm³⁺-doped glasses, where the β_R is typically found between 0.50 and 0.57. The experimental value aligns well with the theoretical prediction, indicating that the sample's radiative characteristics are on par with established materials used in photonics. In summary, the 8 hrs annealed Sm₂O₃-doped borotellurite glass exhibits competitive radiative properties when compared with other reported Sm³⁺ ions-doped glass systems, as shown in Table 5. The parameters like emission band position, bandwidth, transition probability, and branching ratio are within the expected ranges and highlight the potential of this material for photonic applications.

Conclusions

In this research, the ZnO-BaO-B₂O₃-TeO₂ glass system doped with Sm³⁺ ion prepared by melting method resulted in rapid cooling. The annealing time was varied at 2, 4, 6, 8, and 10 hrs. XRD structural analysis confirmed that all glasses in this study had amorphous structures. The annealing time affects the structural relaxation of the glass matrix, which in turn influences the density and molar volume. Specifically, the glass samples annealed for 8 hours showed optimal structural characteristics, enhancing connectivity within the glass network. Beyond 8 hours, the samples exhibited a decline in density due to over-relaxation, which was reflected in their molar volume and microhardness values. This is attributed to the BO₃, BO₄, and TeO₄ units

having the shortest bond distances, consistent with FTIR spectroscopy analysis. The absorption spectroscopy analysis revealed that all samples exhibited 7 absorption peaks, characteristic of Sm³⁺. This indicates that the energy level transitions from the ground state $^6H_{5/2}$ to various excited states. Luminescence properties excited by light at a wavelength of 405 nm indicate energy level transitions of Sm³⁺ ion from $^6H_{5/2}$ to $^4K_{11/2}$, with the highest emission peak at 602 nm, indicating transitions from $^4G_{5/2}$ to $^6H_{7/2}$ under the same excitation. The emission properties of Sm³⁺ ions, notably the $^4G_{5/2} \rightarrow ^6H_{7/2}$ transition, were highly dependent on the annealing conditions. The 8 hrs annealed sample demonstrated superior luminescent properties, including higher emission intensity and favorable radiative parameters such as transition probability and branching ratio. These properties highlight the glass's potential for efficient photonic applications. The findings of this study suggest that Sm³⁺ ions doped borotellurite glasses, particularly when annealed for 8 hrs, have excellent potential for use in photonic devices. Their ability to combine enhanced luminescence with structural stability makes them strong candidates for advanced photonic applications such as lasers. Future work can explore further composition and processing techniques enhancements to maximize the material's photonic performance.

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