

OPTICAL, LUMINESCENCE CHARACTERIZATION AND JUDD-OFELT ANALYSIS OF Sm_2O_3 -Doped TeO_2 - P_2O_5 - Sb_2O_3 - ZnO GLASS FOR LASER APPLICATIONS

Wiraphat Thanyaphirak^{1,2}, Patarawagee Yasaka^{1,2}, Kitipun Boonin^{1,2,*},
Nutthapong Discharoen³, and C.K. Jayasankar⁴

Received: July 18, 2024; Revised: October 11, 2024; Accepted: November 02, 2024

Abstract

This study conducts an extensive examination of the TeO_2 - P_2O_5 - Sb_2O_3 - ZnO - Sm_2O_3 glass composition, with a central focus on physical, structural, optical, and luminescence properties. The optical properties of Sm^{3+} ions were investigated by the absorption spectrum from the ground state $^6\text{H}_{5/2}$ to various excited states. The absorption spectra clearly revealed seven bands, with peaks at 972 nm, 1073 nm, 1222 nm, 1365 nm, 1468 nm, 1520 nm, and 1586 nm. These bands correspond to changes that correspond to energy levels $^6\text{F}_{11/2}$, $^6\text{F}_{9/2}$, $^6\text{F}_{7/2}$, $^6\text{F}_{5/2}$, $^6\text{F}_{3/2}$, $^6\text{H}_{15/2}$, and $^6\text{F}_{1/2}$, respectively. Examining the luminescence properties of the glass appears a luminescence spectra characterized by four prominent peaks. These peaks are distinctly attributed to the $^4\text{G}_{5/2} \rightarrow ^6\text{H}_s$ transitions, where s assumes values of 5/2, 7/2, 9/2, and 11/2, manifesting at wavelengths of 566 nm, 602 nm, 649 nm, and 708 nm, respectively. An interesting finding was the incorporation of Sm_2O_3 doped into the glass matrix at a concentration of 1 mol%, which produced an interesting quenching effect in the luminescence spectra. This quenching effect assumes paramount significance and catalyzes a comprehensive exploration of the Judd-Ofelt values. The values obtained through this analysis are pivotal in evaluating the potential of this glass composition for laser applications.

Keywords: Judd-Ofelt; Luminescence; Quenching effect; Sm_2O_3 ; TeO_2

¹ Physics Program, Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakhon Pathom, 73000, Thailand. E-mail: weraphat81@gmail.com; pyasaka@webmail.npru.ac.th; kboonin@webmail.npru.ac.th*

² Center of Excellence in Glass Technology and Materials Science (CEGM), Nakhon Pathom Rajabhat University, Nakhon Pathom 73000, Thailand.

³ Physics Program, Faculty of Science and Technology, Kamphaeng Phet Rajabhat University, Kamphaeng Phet, 62000, Thailand. E-mail: nutthapong_d@kpru.ac.th

⁴ Department of Physics, Sri Venkateswara University, Tirupati 517 502, India. E-mail: ckjaya@yahoo.com

* Corresponding author

DOI: <https://doi.org/10.55766/sujst9968>

Suranaree J. Sci. Technol. 32(3):030297(1-8)

Introduction

In recent years, the exploration of novel materials for diverse technological applications has considerable attention in the scientific community. Glass compositions, owing to their unique combination of physical, structural, and optical properties, have emerged as promising candidates for various technological advancements. Among these, the TeO₂-P₂O₅-Sb₂O₃-ZnO-Sm₂O₃ glass system stands out as a subject of intensive investigation, it offers many properties that make it attractive for applications in areas such as photonics and laser technology. This study examines TeO₂-P₂O₅-Sb₂O₃-ZnO-Sm₂O₃ glasses, where each element is crucial in crafting a material with synergistic advantages. TeO₂ and P₂O₅ provide the foundation, forming a robust glass matrix with excellent chemical stability and low phonon energy (Lesniak *et al.*, 2019). Sb₂O₃, acting as a network modifier, reduces moisture in glass (Zhang *et al.*, 2008). ZnO improves the glass-forming ability and reduces the crystallization rates of the glass network (Rammah *et al.*, 2020). Then began to investigate the optical behavior of Sm³⁺ ions within this glass matrix, employing the absorption spectrum as our investigative tool. By checking the absorption bands, we aim to shed light on the energy level transitions within the Sm³⁺ ions, which will emerge to provide a deeper understanding of its excited state configurations. Additionally, further studies are being conducted on the fluorescence of these glasses. Each point describes a change in the energy level of the samarium and is considered a unique change within ⁴G_{5/2} → ⁶H_s. This detailed analysis provides insight into the complex luminescence produced by Sm³⁺ ions within the glass matrix. All these results will hopefully increase the potential of glass for various laser applications.

This research aims to examine glass: TeO₂-P₂O₅-Sb₂O₃-ZnO-Sm₂O₃ to help understand the basics of material behavior and lead to possible uses in laser technology as well. This will be elucidated by optical and fluorescence characteristics. Along with investigating the quenching results and Judd-Ofelt values, the composition of this glass is known, and trends are considered for advances in laser technology and other photonic applications.

Experimental Details

Glass samples for this investigation were fabricated through the melt quenching technique, comprehensive a range of compositions denoted by the formula (40-x)TeO₂-30P₂O₅-10Sb₂O₃-20ZnO-xSm₂O₃, where x range from 0.0 to 2.0 mol% which

gave the glass formula the name PTeSm. The materials TeO₂, P₂O₅, Sb₂O₃, ZnO, and Sm₂O₃ were weighed and blended in six distinct 10-gram batches and thoroughly stirred in crucibles to achieve homogeneity. Subsequently, the resulting powder was placed in crucibles, heated to 1000°C for 30 minutes using an electric furnace, and then poured into preheated graphite molds, where it was annealed for 3 hours at 300°C. Following this process, each sample was precisely cut into dimensions of 1.0 × 1.5 × 0.3 cm³, a comprehensive investigation of various properties. The density (ρ) of the samples was determined using a densitometer (model AND HR-200) by weighing the specimens. A Presidium Refractive Index Meter II measured the refractive index (n). The typical of samples were measured by X-ray diffraction (XRD) analysis employing a Rigaku SmartLab X-ray Diffractometer. The vibrational states of the currently available phosphor-tellurite glasses were investigated using the Fourier Transform Infrared Spectra (FTIR) technique with a Nicolet™ iS™5 FTIR spectrophotometer. UV-Vis-NIR absorption spectra were measured using a UV-3600 Shimadzu UV-VIS-NIR spectrophotometer. Additionally, excitation, emission, and lifetime spectra were measured by the Agilent Cary Eclipse fluorescence spectrometer.

Results and Discussion

Physical properties

The measured physical properties (density, molar volume, and refractive index) of PTeSm0.0, PTeSm0.1 PTeSm0.5, PTeSm1.0, PTeSm1.5, and PTeSm2.0 glasses are depicted in Figure 1. The observed trends are an increase in density and refractive index, values of density are 4.143, 4.155, 4.165, 4.171, 4.174, and 4.189 g/cm³, and values of refractive index are 1.735, 1.739, 1.744, 1.754, 1.757, and 1.763, respectively, with an elevated concentration of Sm₂O₃. This upward trend can be elucidated by the rise of non-bridging oxygen species (Muhammad Noorazlan *et al.*, 2013). The larger bond length and ionic radii of Sm₂O₃, when compared to TeO₂ and P₂O₅, increase the molar volume. Consequently, there is a general rise in molar volume values, values of density are 36.65, 36.59, 36.68, 36.86, 37.06, and 37.15 cm³/mol, as the concentration of Sm₂O₃ increases. This suggests the substitution of TeO₂ and P₂O₅ by Sm₂O₃ in the glasses, emphasizing the structural modifications induced by the varying concentrations of Sm₂O₃ in the glass matrix (Cetinkaya Colak, 2023).

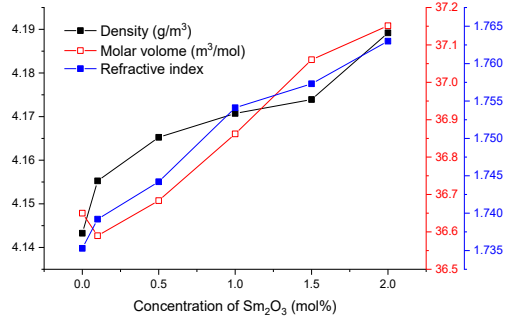


Figure 1. Physical properties of PTeSm glasses

Structural properties

X-ray diffraction (XRD) analysis was performed to determine the characteristics of the samples. Figure 2 displays the XRD measurements of PTeSm0.0, PTeSm0.1, PTeSm0.5, PTeSm1.0, PTeSm1.5, and PTeSm2.0 sample, corroborating the amorphous nature observed consistently across all samples. The X-ray pattern shows a broad peak, and low-angle scattering (approximately 28 degrees), indicating the widespread nature of the amorphous (Bhemarajam *et al.*, 2024). Notably, no discernible peaks associated with a crystalline phase are evident. The absence of well-defined crystal peaks and the presence of a broad diffuse scattering pattern collectively confirm the formation of a non-crystalline solid structure.

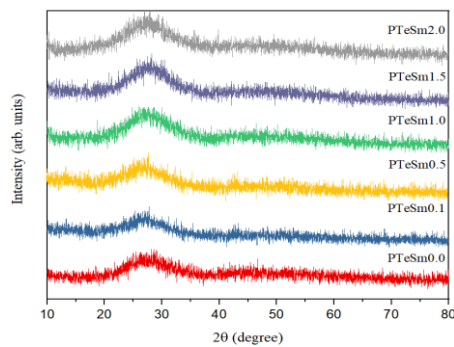


Figure 2. XRD pattern of PTeSm glass

The FTIR spectra of PTeSm0.0, PTeSm0.1, PTeSm0.5, PTeSm1.0, PTeSm1.5, and PTeSm2.0 glasses were measured between 400 and 3500 cm⁻¹, depicted in Figure 3, where distinct transmission peaks were observed at specific wavenumbers, including 501, 625, 1626, and 2500-3500 cm⁻¹. The corresponding assignments of these bands are outlined in Table 1. The vibration band centered at 501 cm⁻¹ is related to the vibrational bending of O=P-O linkages (Kuczek *et al.*, 2019). At 625 cm⁻¹, a Te-O symmetric stretching vibration mode from TeO₄ is identified, which corresponds to a P-O-P bending vibration mode (oxygen atom linkage,

BOs) (Elisa *et al.*, 2020). The band approximately around 905 cm⁻¹ is attributed to mode the of P-O-P that presents with asymmetry stretching vibration (Elisa *et al.*, 2020). Additionally, the bands around 1626 cm⁻¹ and 2500-3500 cm⁻¹ are related to various vibrations of O-H bonds (Selvi *et al.*, 2017), characteristic of phosphate glass with hygroscopic behavior, leading to O-H bond vibrations.

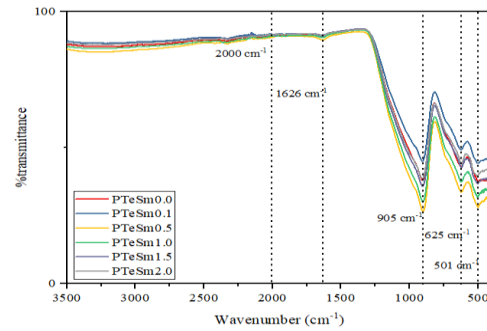


Figure 3. FTIR transmittance spectra of PTeSm

Table 1. Assignments of FTIR band

Band position (cm ⁻¹)	Assignments	Reference
501	bending vibration of O=P-O linkages	(Kuczek <i>et al.</i> , 2019)
625	The Te-O symmetrical stretching vibration mode originates from TeO ₄ , and it overlaps with the P-O-P bending vibration mode.	(Elisa <i>et al.</i> , 2020)
905	asymmetric stretching vibration mode of P-O-P	(Elisa <i>et al.</i> , 2020)
1626, 2500-3500	vibrations of O-H bonds	(Selvi <i>et al.</i> , 2017)

Figure 4 shows the Raman spectrum of PTeSm0.0, PTeSm0.1, PTeSm0.5, PTeSm1.0, PTeSm1.5, and PTeSm2.0 glasses, where the observed Raman bands indicate vibrational characteristics associated with the glass hosts, which are tellurite and phosphate. The specific Raman features for PTeSm glasses are defined and detailed in Table 2. Notably, the band around 601 cm⁻¹ is linked to anti-symmetrical stretching of the continuous network comprised of TeO₄ tetrahedral building blocks (Suzuki *et al.*, 2011). Furthermore, the Raman band at 747 cm⁻¹ is reported for the Te-O⁻ and Te=O band of stretching vibrations mode, involving non-bridging oxygen in both TeO₃ and TeO₃₊₁ polyhedral. An evident and violent band appears at 1067 cm⁻¹ relates to O-P-O the symmetry vibration mode.

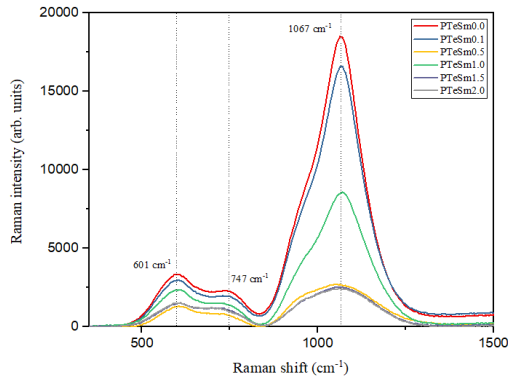


Figure 4. Raman spectra of PTeSm glasses

Table 2. Assignments of Raman band

Band position (cm ⁻¹)	Assignments	Reference
601	anti-symmetrical stretching of TeO ₄ tetrahedral building blocks	(Duan <i>et al.</i> , 2013)
747	for the Te-O ⁻ and Te=O band of stretching vibrations mode, involving non-bridging oxygen in both TeO ₃ and TeO ₃₊₁ polyhedral	(Duan <i>et al.</i> , 2013)
1067	O-P-O the symmetry vibration mode	(Murugan <i>et al.</i> , 2005)

Optical properties

The investigation of the absorption spectra between 350 and 1800 nm was conducted for PTeSm0.0, PTeSm0.1, PTeSm0.5, PTeSm1.0, PTeSm1.5, and PTeSm2.0 glasses doped Sm³⁺ ions. Figure 5 presents the UV-VIS-NIR absorption spectrum for varying Sm³⁺ ions concentrations. Each absorption spectrum revealed nine distinct bands at 402, 439, and 475 (visible range), and 946, 1086, 1239, 1381, 1483, and 1533 nm (NIR range). These bands correspond to transitions $^6H_{5/2} \rightarrow ^3P_{3/2}$, $^4I_{15/2}$, $^4I_{11/2}$ (visible range), and $^6F_{11/2}$, $^6F_{9/2}$, $^6F_{7/2}$, $^6F_{5/2}$, and $^6H_{15/2}$ (NIR range), respectively. The assignment of absorption peaks followed the principles outlined in Carnall *et al.*'s paper (Carnall *et al.*, 1968). Notably, with an increase in samarium concentration, each absorbance peak exhibited an elevation following the Beer-Lambert law. Due to the shielding effect on the 4f electrons that filled 5s and 5p shells, the NIR region displayed prominent peak intensities. Known for its hypersensitivity, the transition from $^6H_{5/2}$ to $^6F_{7/2}$ showed the maximum intensity and met the selection criteria ($\Delta S = 0$ and $\Delta J \geq 0$) (Ramteke *et al.*, 2017).

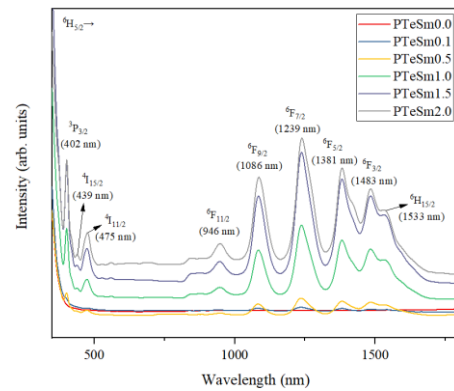


Figure 5. The absorbance spectra of PTeSm glass

Luminescence properties

The PTeSm0.1, PTeSm0.5, PTeSm1.0, PTeSm1.5, and PTeSm2.0 glasses' excitation spectra, which were captured at 350-500 nm while the emission wavelength was being observed at 598 nm, are shown in Figure 6. The wavelength at 362, 374, 402, 415, 439, 464, and 472 nm, seven different excitation bands are visible. These correspond to the transitions $^6H_{5/2} \rightarrow ^4D_{3/2}$, $^6P_{7/2}$, $^4F_{7/2}$, $(^6P, ^4P)_{5/2}$, $^4I_{15/2}$, $^4I_{13/2}$, and $^4I_{11/2}$, respectively (Mahamuda *et al.*, 2014). The highest powerful transition is $^6H_{5/2} \rightarrow ^4F_{7/2}$ at 402 nm, which will be used excitation source to measure the emission peak in all glasses. The emission peak of PTeSm glasses measured at 402 nm is shown in Figure 7. These spectra show three distinct color bands at 563, 598, and (645, 707) nm, which involve the energy of the transitions $^4G_{5/2} \rightarrow ^6H_{5/2}$ (greenish-yellow), $^6H_{7/2}$ (reddish-orange), and $(^6H_{9/2}, ^6H_{11/2})$ (intense reddish), respectively (Mahamuda *et al.*, 2014). A concentration quenching effect is represented by the following drop in intensity of all emission bands after reaching a concentration of 1.00 mol% of Sm³⁺ ions. Cross-relaxation energy transfer is thought to be caused by the decrease in inter-ionic distances that occurs when the concentration of Sm³⁺ ions rises, both between Sm³⁺ ions and host defects. Donor and acceptor ions receive a transfer of energy, which causes them to enter a metastable state. Among the four bands, the emission at 598 nm, which corresponds to the transition $^4G_{5/2} \rightarrow ^6H_{7/2}$, is the most noticeable. While $^4G_{5/2} \rightarrow ^6H_{9/2}$ and $^6H_{11/2}$ are exclusively electric dipoles ($\Delta J \leq 6$), the transitions $^4G_{5/2} \rightarrow ^6H_{5/2}$ and $^4G_{5/2} \rightarrow ^6H_{7/2}$ are magnetic dipoles ($\Delta J = 0, \pm 1$) (Rani *et al.*, 2019). Then, both processes are described with an energy diagram level in Figure 8.

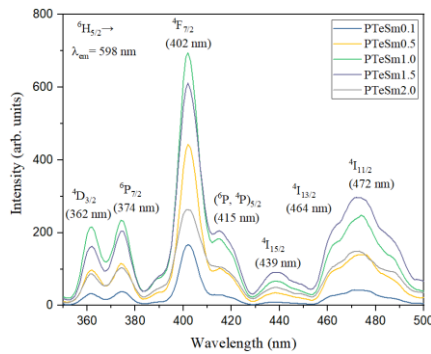


Figure 6. Excitation spectra of PTeSm glasses

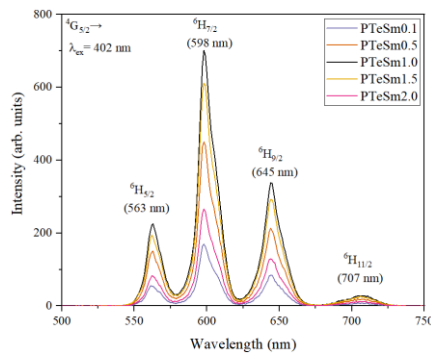


Figure 7. Emission spectra of PTeSm glasses

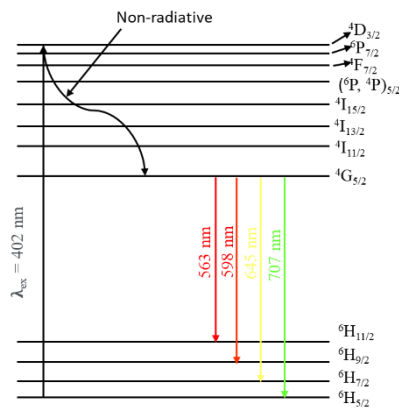


Figure 8. Energy diagram level of PTeSm glasses

Experimental lifetime values for excited states are widely recognized as important because they are crucial in calculating radiative and non-radiative decay rates in luminescence materials. Variations in local crystal symmetry exert a complex influence on the radiative decay rates at rare earth (RE) ion locations (Sharma *et al.*, 2018). Relaxation of multiphonon and Energy transfer that occur during the de-excitation process are factors that contribute to non-radiative decay. Such a non-radiative decay process emits the energy difference between energy levels not in the form of light but in the form of heat. For this purpose, photoluminescence (PL) decay

measurements for the $4G_{5/2}$ fluorescence of Sm^{3+} ions in PTeSm glasses at the excitation wavelength (402 nm) are presented in Figure 9. A rise in the concentration of Sm_2O_3 causes the interatomic length between Sm^{3+} ions to decrease, which results in an uneven dispersion of Sm^{3+} ions across the glass network. Clusters or aggregations form in the host glass's immediate surroundings as a result of this non-uniform scattering. Energy is thus transferred between Sm^{3+} ions centers via resonant energy transfer and cross-relaxations (Rani *et al.*, 2019).

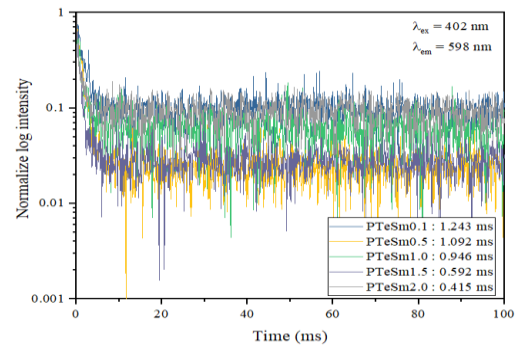


Figure 9. Luminescence decay curves of the PTeSm glass

The CIE 1931 approach was used to assess the color shined by samarium-doped PTeSm0.1 PTeSm0.5, PTeSm1.0, PTeSm1.5, and PTeSm2.0 glasses. Under excitation at 402 nm, the photoluminescence (PL) spectra of samarium-doped PTeSm0.1 PTeSm0.5, PTeSm1.0, PTeSm1.5, and PTeSm2.0 glasses show four different areas. Among the four, the orange area is the most prominent and has the maximum intensity. The diagram of CIE 1931 for samarium-doped PTeSm1.0 glasses is depicted in Figure 10. The values of (0.591, 0.408) are the CIE coordinates (x, y). This discovery indicates that the PTeSm1.0 glasses are quite appropriate for applications, notably in the orange area, under excitation (wavelength at 402 nm), which makes them extremely interesting for laser applications.

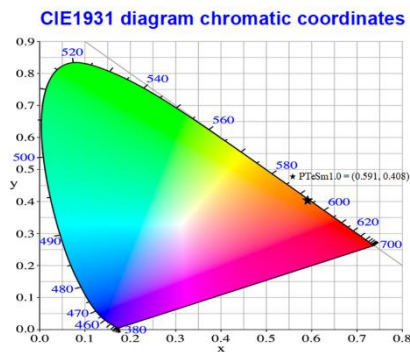


Figure 10. Diagram of CIE 1931

When evaluating the intensity of f-f transitions in rare-earth (RE) ions, oscillator strength values are typically characterized. The strength of the absorption transitions in each matrix was ascertained by determining the experiment oscillator strength (f_{exp}). Using a formula from the literature (Devi *et al.*, 2019), these values were computed from the area under the absorption spectra and the results are presented in Table 3. The experiment oscillator strength (f_{exp}) squared reduced matrix elements, and least squares analysis is used to estimate the JO intensity parameter, which yields the computed oscillator strength. Using a formula from the literature (Devi *et al.*, 2019), the corresponding computed oscillator strengths are listed in Table 3.

Table 3. The allocation of absorption bands, along with oscillator strengths experiment (f_{exp}) (10^{-6}) and calculated (f_{cal}) (10^{-6}), along with the root mean square (r.m.s) of PTeSm glasses.

Transition $^6\text{H}_{5/2}$	$f_{\text{exp}} (\times 10^{-6})$	$f_{\text{cal}} (\times 10^{-6})$
$^3\text{P}_{3/2}$	1.7319	1.4316
$^4\text{I}_{15/2}$	0.0632	0.0248
$^4\text{I}_{11/2}$	0.7854	0.0603
$^6\text{F}_{11/2}$	0.1561	0.1465
$^6\text{F}_{9/2}$	0.9479	0.8976
$^6\text{F}_{7/2}$	1.2661	1.3125
$^6\text{F}_{5/2}$	0.6769	0.7155
$^6\text{F}_{3/2}$	0.3967	0.3880
$^6\text{H}_{15/2}$	0.2882	0.0074
Rms =	0.279	

It plays a crucial part in figuring out the structures, bonding, and transition probabilities of the RE ions in the host glass. The symmetry surrounding the RE ions is presented by changes in Ω_2 , and this symmetry is well known to be sensitive to structural alterations in the glass matrix. Conversely, Ω_4 and Ω_6 convey the general characteristics of the glass, including its hardness, basicity, viscosity, and vibronic transition near RE ions (Jamalaiah *et al.*, 2009; Lakshminarayana *et al.*, 2017). All glasses under examination show a

similar trend in the JO intensity parameters, with $\Omega_4 > \Omega_6 > \Omega_2$ greater stiffness, improved viscosity, and a greater ionic character indicated by higher values of Ω_4 and Ω_6 . On the other hand, smaller values of Ω_2 indicate the lowering of covalency between the Sm³⁺ ions and ligand ions. This thorough examination emphasizes how important JO intensity parameters are for understanding the structural, bonding, and transition probability properties of samarium in the matrix of host glass.

Table 4. A comparative analysis involves examining the Judd Ofelt intensity parameters Ω_2 , Ω_4 , and Ω_6 (expressed in 10^{-20} m^2) of PTeSm1.0 glasses alongside the corresponding values reported for samarium in other studies.

Equations found in the literature (Lakshminarayana *et al.*, 2017) were used to calculate the properties of the radiative for the observed emission transitions of samarium in PTeSm glasses. These properties included total radiative transition rates ($A\tau$) (A_R), radiative transition probability, radiative lifetime (τ_R), and branching ratio (β_R). Table 5 displays the computed values that were obtained. Examining Table 5's data in detail reveals that the transition $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{7/2}$ has greater A_R values than other emission transitions. Furthermore, by establishing correlations between absorption and emission spectral data, important spectroscopic properties were computed for the excited states ($^6\text{H}_{5/2}$, $7/2$, $9/2$, and $11/2$): these included effective bandwidths ($\Delta\lambda_{\text{eff}}$), branching ratio of experimental (β_{exp}), and emission cross-sections (σ). Table 6 presents the data comprehensively. The σ values serve as indicators of the rate at which energy is produced with the lasing material and provide important insights into the material's potential laser performance. Additionally, the branching ratio (β_R), a crucial laser construction parameter, was evaluated. The examination of the characteristics and the related values presented in Table 6 lead to the conclusion that the most notable transition is $^4\text{G}_{5/2} \rightarrow ^6\text{H}_{7/2}$ is the most prominent, followed by $^6\text{H}_{9/2}$, $^6\text{H}_{5/2}$, and $^6\text{H}_{11/2}$. Looking at the branching ratio, it was discovered that the experimental value

Table 4. A comparative analysis involves examining the Judd Ofelt intensity parameters Ω_2 , Ω_4 , and Ω_6 (expressed in 10^{-20} m^2) of PTeSm1.0 glasses alongside the corresponding values reported for samarium in other studies

Glass code	JO parameter			Trends
	$\Omega_2 (\times 10^{-20})$	$\Omega_4 (\times 10^{-20})$	$\Omega_6 (\times 10^{-20})$	
PTeSm1.0 (present)	0.27	1.15	0.90	$\Omega_4 > \Omega_6 > \Omega_2$
TeWLiSm (Sailaja <i>et al.</i> , 2015)	0.19	2.81	2.78	$\Omega_4 > \Omega_6 > \Omega_2$
NBZPSm05 (Prasad <i>et al.</i> , 2015)	0.11	4.44	4.10	$\Omega_4 > \Omega_6 > \Omega_2$
LBTAf (Jamalaiah <i>et al.</i> , 2009)	0.27	2.52	2.47	$\Omega_4 > \Omega_6 > \Omega_2$
ZLNBSm (Devi <i>et al.</i> , 2019)	0.13	3.18	2.67	$\Omega_4 > \Omega_6 > \Omega_2$

Table 5. Transition probabilities (A_R) (s^{-1}), branching ratio (β_R), and radiative lifetimes (τ_R) (ms) of PTeSm1.0 glasses

Transition $^4G_{5/2} \rightarrow$	λ_p (nm)	A_R from JO(s^{-1})	β_R		τ_R (ms)
			Exp	Cal from J-O	
$^6H_{5/2}$	563	23.58	0.1495	0.1542	0.153
$^6H_{7/2}$	598	67.38	0.5344	0.4406	
$^6H_{9/2}$	644	27.69	0.2827	0.1811	
$^6H_{11/2}$	707	13.31	0.0333	0.087	

Table 6. The characteristics of emission, including emission wavelength (λ_p) (in nm), effective bandwidths ($\Delta\lambda_p$) (in nm), stimulated emission cross-sections (σ) (multiplied by 10^{-23}) (in cm^2), gain bandwidth ($\sigma \times \Delta\lambda_p$) (multiplied by 10^{-28}) (in cm^3), and optical gain parameters ($\sigma \times \tau_R$) (multiplied by 10^{-25}) (in cm^2s), have been systematically investigated for the emission transitions within PTeSm1.0 glasses

Transition $^4G_{5/2} \rightarrow$	λ_p (nm)	$\Delta\lambda_p$ (nm)	$\sigma (\times 10^{-23})$ (cm^2)	$\sigma \times \Delta\lambda_p$ (10^{-28}) (cm^3)	$\sigma \times \tau_R$ (10^{-25}) (cm^2s)
$^6H_{5/2}$	563	141.33	0.72	1.02	11.05
$^6H_{7/2}$	598	162.15	2.28	3.69	34.81
$^6H_{9/2}$	644	177.98	1.15	2.05	17.65
$^6H_{11/2}$	707	251.12	0.56	1.42	8.64

is greater than that of JO and greater than 0.5, which is a good result for consideration as a laser medium material. This was discovered by comparing the experimental values with the values estimated from JO. However, because of the influence of peaks other than those displayed, the values derived from JO computations do not equal 1. This is the same reason why the JO calculation is not equal to the experimental.

Conclusion

In this comprehensive study, the investigation of Sm_2O_3 -doped TeO_2 - P_2O_5 - Sb_2O_3 - ZnO glass has provided valuable insights into its physical, structural, optical, luminescence, and Judd Ofelt properties. The physical properties, exhibited consistent trends, showing a discernible increase with the rising concentration of samarium. This observation suggests a direct correlation between the incorporation of samarium and the alteration of the glass's physical characteristics. Structural analysis using X-ray diffraction (XRD) confirmed typical of glass that is an amorphous structure, while Fourier-transform infrared spectroscopy (FTIR) and Raman spectroscopy revealed a matrix composition comprising phosphate and tellurite components. This structural insight is crucial for understanding the fundamental nature of the glass, providing a foundation for its optical and luminescent behaviors. Examining the optical properties, the absorption spectra revealed a discernable range within the visible and near-infrared (NIR) regions, with peak intensities following to the Beer-Lambert

law. This indicates the potential utility of the glass for optical applications, particularly in the development of lasers. Luminescence studies further emphasized the favorable characteristics of the glass, with the maximum intensity observed at 1.00 mol% samarium concentration. The emission spectra were leveraged to calculate CIE 1931 color coordinates, revealing an orange light emission, and emphasizing the glass's suitability for specific applications. The Judd Ofelt analysis yielded insightful results, particularly noting that while the Ω_2 parameter was comparatively lower than other lanthanides, it was the highest in the case of samarium. This suggests a unique spectroscopic behavior, highlighting the distinctive role of samarium in influencing the glass's optical properties. In synthesis, the amalgamation of phospho-tellurite, antimony, zinc, and samarium in the glass matrix demonstrates promising characteristics, making it a compelling candidate for the development of laser applications. The culmination of physical, structural, optical, luminescence, and Judd Ofelt analyses underscores the potential of this glass composition, offering avenues for further exploration in the realm of advanced optical materials and laser technology.

Acknowledgments

K. Boonin would like to thank the support received from the Visiting Professor of Research Project from Nakhon Pathom Rajabhat University. The authors would like to thank the Center of Excellence in Glass Technology and Materials Science

(CEGM) and Kamphaeng Phet Rajabhat University, which provided expertise and equipment for this research.

References

- Bhemarajam, J., Varkolu, M., Syam Prasad, P., and Prasad, M. (2024). Effect of Yb^{3+} ions on spectroscopic and optical properties of Bi_2O_3 - B_2O_3 - Li_2O - PbO glass system. Results in Optics, 14:100582. <https://doi.org/10.1016/j.rio.2023.100582>
- Carnall, W.T., Fields, P.R., and Rajnak, K. (1968). Electronic energy levels of the trivalent lanthanide aquo ions. IV. Eu^{3+} . Journal of Chemical Physics, 49(10):4424-4442. <https://doi.org/10.1063/1.1669893>
- Cetinkaya Colak, S. (2023). Soda-lime-silica glass structure with MoO_3 doping: An optical approach. Optik, 293:171408. <https://doi.org/10.1016/j.ijleo.2023.171408>
- Devi, C.B.A., Rajesh, D., Reddy, M.L.P., and Ratnakaram, Y.C. (2019). Spectroscopic studies and lasing potentialities of Sm^{3+} ions doped single alkali and mixed alkali fluoro tungstentellurite glasses. Optics and Laser Technology, 111:176-183. <https://doi.org/10.1016/j.optlastec.2018.09.051>
- Duan, Z., Zhang, C., Zhai, Y., Fan, M., and Yang, Z. (2013). New phospho-tellurite glasses with optimization of transition temperature and refractive index for hybrid microstructured optical fibers. Optical Materials, 35(12):2473-2479. <https://doi.org/10.1016/j.optmat.2013.07.001>
- Elisa, M., Marangoni, M., Berneschi, S., Cosi, F., Soria, S., and Pelli, S. (2020). A new zinc phosphate-tellurite glass for magneto-optical applications. Nanomaterials, 10(9):1-19. <https://doi.org/10.3390/nano10091875>
- Jamalaiah, B.C., Kumar, J.S., Babu, A.M., Suhasini, T., and Moorthy, L.R. (2009). Photoluminescence properties of Sm^{3+} in LBTAf glasses. Journal of Luminescence, 129(4):363-369. <https://doi.org/10.1016/j.jlumin.2008.11.001>
- Kuczek, J., Jeleń, P., Sułowska, J., and Szumera, M. (2019). Correlation between glass transition effect and structural changes in multicomponent iron phosphate-silicate glasses. Journal of Thermal Analysis and Calorimetry, 138(6):4145-4153. <https://doi.org/10.1007/s10973-019-08465-5>
- Lakshminarayana, G., Qiu, J., and Naik, R. (2017). Structural, thermal and optical investigations of Dy^{3+} -doped B_2O_3 - WO_3 - ZnO - Li_2O - Na_2O glasses for warm white light emitting applications. Journal of Luminescence, 186:283-300. <https://doi.org/10.1016/j.jlumin.2017.02.049>
- Lesniak, M., Li, Y., Nowogrodzki, K., Lukowiak, A., Pisarska, J., and Pisarski, W.A. (2019). Spectroscopic properties of erbium-doped oxyfluoride phospho-tellurite glass and transparent glass-ceramic containing BaF_2 nanocrystals. Materials, 12(20):3429. <https://doi.org/10.3390/ma12203429>
- Mahamuda, S., Swapna, K., Venkateswarlu, M., Srinivasa Rao, A., Shakya, S., and Vijaya Prakash, G. (2014). Spectral characterization of Sm^{3+} ions doped oxy-fluoroborate glasses for visible orange luminescent applications. Journal of Luminescence, 154:410-424. <https://doi.org/10.1016/j.jlumin.2014.05.017>
- Muhammad Noorazlan, A., Mohamed Kamari, H., Zulkefly, S. S., and Mohamad, D.W. (2013). Effect of erbium nanoparticles on optical properties of zinc borotellurite glass system. Journal of Nanomaterials, 2013(1). <https://doi.org/10.1155/2013/940917>
- Murugan, G.S., Suzuki, T., and Ohishi, Y. (2005). Phospho-tellurite glasses containing heavy metal oxides for ultrabroad band fiber Raman amplifiers. Applied Physics Letters, 86(22):1-3. <https://doi.org/10.1063/1.1944225>
- Prasad, V.R., Babu, S., Rajesh, D., and Ratnakaram, Y.C. (2015). Optical investigations of Sm^{3+} doped lead free zinc phosphate glasses. Physics and Chemistry of Glasses: European Journal of Glass Science and Technology Part B, 56(4):159-168. <https://doi.org/10.13036/17533562.56.4.159>
- Rammah, Y.S., Özpölat, F., Alim, B., Şakar, E., El-Mallawany, R., and El-Agawany, F.I. (2020). Assessment of gamma-ray attenuation features for La^{3+} co-doped zinc borotellurite glasses. Radiation Physics and Chemistry, 176:109069. <https://doi.org/10.1016/j.radphyschem.2020.109069>
- Ramteke, D.D., Balakrishna, A., Kumar, V., and Swart, H.C. (2017). Luminescence dynamics and investigation of Judd-Ofelt intensity parameters of Sm^{3+} ions containing glasses. Optical Materials, 64:171-178. <https://doi.org/10.1016/j.optmat.2016.12.009>
- Rani, P.R., Veeraiah, V., Swapna, K., and Ratnakaram, Y.C. (2019). Structural, absorption and photoluminescence studies of Sm^{3+} ions doped barium lead alumino fluoro borate glasses for optoelectronic device applications. Materials Research Bulletin, 110:159-168. <https://doi.org/10.1016/j.materresbull.2018.10.033>
- Sailaja, B., Stella, R.J., Rao, G.T., Raja, B.J., Manjari, V.P., and Ravikumar, R.V.S.S.N. (2015). Physical, structural and spectroscopic investigations of Sm^{3+} doped ZnO mixed alkali borate glass. Journal of Molecular Structure, 1096:129-135. <https://doi.org/10.1016/j.molstruc.2015.05.002>
- Selvi, S., Marimuthu, K., and Muralidharan, G. (2017). Effect of PbO on the B_2O_3 - TeO_2 - P_2O_5 - BaO - CdO - Sm_2O_3 glasses - Structural and optical investigations. Journal of Non-Crystalline Solids, 461:35-46. <https://doi.org/10.1016/j.jnoncrysol.2017.01.028>
- Sharma, R., Kumar, A., Sharma, P., and Kaur, R. (2018). Spectroscopic study of Pr^{3+} ions doped zinc lead tungsten tellurite glasses for visible photonic device applications. Optical Materials, 78:457-464. <https://doi.org/10.1016/j.optmat.2018.02.054>
- Suzuki, T., Shiosaka, T. W., Miyoshi, S., and Ohishi, Y. (2011). Computational and Raman studies of phospho-tellurite glasses as ultrabroad Raman gain media. Journal of Non-Crystalline Solids, 357(14):2702-2707. <https://doi.org/10.1016/j.jnoncrysol.2011.02.040>
- Zhang, B., Chen, Q., Song, L., Li, H., Hou, F., and Zhang, J. (2008). Fabrication and properties of novel low-melting glasses in the ternary system ZnO - Sb_2O_3 - P_2O_5 . Journal of Non-Crystalline Solids, 354(18):1948-1954. <https://doi.org/10.1016/j.jnoncrysol.2007.11.007>