5.1. Introduction

Rare earth (RE) ions incorporated into various oxides based glass have been a key to the improvement of many optical devices such as infrared lasers, compact microchip lasers, IR–visible up-converters, memory devices, flat-panel displays, fiber amplifiers and waveguide amplifiers for optical transmission network [1]. Glasses doped with rare–earth ions (RE) are proving to be luminescence materials as they have high emission efficiencies. Especially, glass hosts activated with trivalent rare earth ions posses broad emission bands that afford enhanced prospect of tuning, Q-switching of lasers and production of fiber amplifiers. RE ions doped glasses are excellent laser materials as they emit intense radiations in the visible, IR and NIR regions under suitable excitation condition [2]. The intensities of the transitions for rare-earth has been successfully estimated with the Judd-Ofelt theory. The three intensity parameter $\Omega_t$ ($t = 2, 4$ and $6$) that are sensitive to the environment of the rare-earth ions from this parameters the experimental optical properties are estimated.

Boric oxide ($\text{B}_2\text{O}_3$) is one of the considerable glass former and flux material among all the characteristic network formers [3]. An anomalous dependence of their structure on the molar fraction of oxide modifiers borate glasses posses high conductivity, the short range order around the network forming borons. The borate glasses offer excellent heat stability and lower melting temperature compared with other glasses [4]. In general borate glasses have lower thermal expansion coefficients and higher densities than other oxide glasses. Tellurium oxide ($\text{TeO}_2$) is a conditional glass former and forms glass only with modifiers such as alkali alkaline earth and transition metal oxides or other glass formers [5]. Because of its linear and nonlinear applications such as optical fiber amplifiers as well as its outstanding features, tellurite glass is a well known and interesting material such as low melting points, slow crystallization rates, good thermal and chemical stability, low cut off phonon energy, and high refractive index [6]. In fact, Tellurium oxide ($\text{TeO}_2$)-based glasses are characterized by maximum phonon frequencies such as silicate, borate, phosphate and germanates [7].
Rare earth ion doped tellurite glasses with various visible emissions are useful in developing new light sources, display devices, UV sensors and tunable visible lasers. Among the possible oxides, Nb₂O₅ and TeO₂ glasses are particularly interesting because they contribute to increase the nonlinear optical response of the glasses [8]. Addition of ZnO and Nb₂O₅ improves thermal stability, optical nonlinearity, vitrification of the glasses [9]. Due to their excellent transparency in a wide spectral region (0.3 - 6.0 μm), low phonon energy and good RE ions solubility the absorption and emission studies on boro tellurite glasses have been attracted many researchers. The low phonon energy glasses doped with Dy³⁺ ions have been studied for optical amplifiers and yellow–green up conversion applications. Host materials having low phonon energies are highly useful for obtaining high efficiency lasers and fiber amplifiers [10].

Keeping in view of the advantage of borotellurite glasses as well as the technological importance of Dy³⁺ ions, a systematic spectroscopic analysis has been carried out by the authors. The experimental data determined from the photoluminescence spectra and decay curves were examined in the relation to practical applications as potential candidates for the laser materials in the visible region.

5.2. Experimental method

Trivalent dysprosium (Dy³⁺) ions doped TCZNB glasses with molar compositions of (10TeO₂ + 15CaO + 5ZnO + 10Nb₂O₅ + (60−χ) B₂O₃ + χDy₂O₃ (where χ = 0.5, 1.0, 1.5 and 2.0 mol %) were prepared by melt quenching method. High purity chemicals were mixed thoroughly to get homogeneous powder and it was melted in a platinum crucible at 1450°C for one and half hour in an electric-furnace at ambient atmosphere. The melt was poured on to a pre-heated brass mould and then annealed at 350°C for 12h to remove thermal strains. The samples were polished to get a uniform thickness of 3 mm before going to physical and optical measurements.

Room temperature optical absorption spectrum in the wavelength region 300-1800 nm was recorded using Perkin Elmer Lambda 950 spectrophotometer to obtain the absorption data from which the oscillator strength of the absorption bands.
could be measured experimentally. Refractive index for this glass was measured by an Abbe’s refractometer at sodium wavelength. By exciting the sample at 453 nm, photoluminescence spectra of TCZNB glasses in the region 300-700 nm were recorded. The lifetime of the \( \text{4F}_{9/2} \) level has been measured for all the four glasses using the Jobin Yvon Flurolog-3 spectrofluorimeter with xenon flash lamp as light source at \( \lambda_{\text{em}} = 577 \text{ nm} \) and \( \lambda_{\text{ex}} = 453 \text{ nm} \).

5.3. Results and discussion
5.3.1. Optical absorption spectra

The optical absorption spectrum of trivalent dysprosium (Dy\(^{3+}\)) ion doped TCZNB glasses in the spectral range from 300 to 1800 nm is shown in Figs. 5.1 and 5.2 respectively, and it contains eleven absorption bands corresponding to 379, 386, 425, 453, 472, 751, 800, 897, 1087, 1267, and 1678 nm due to the transition of Dy\(^{3+}\) ions from \( \text{6H}_{15/2} \) ground state to the \( \text{4I}_{11/2}, \text{4I}_{13/2}, \text{4G}_{11/2}, \text{4I}_{15/2}, \text{4F}_{9/2} \) \( \text{6F}_{j=3/2,5/2,7/2,9/2} \) and \( \text{6H}_{11/2} \) excited states. The bands observed in the absorption spectrum could be easily assigned on the basis of earlier reported works [11, 12]. The assignments of transitions have been done according to Carnall et.al [13] and are presented in Table 5.1. The band positions and spectral intensities of certain transitions of rare earth ions are found to be very sensitive to the ligand coordination and are hyper sensitive transitions that obeys the selection rules \( \Delta S = 0, \Delta L \leq 2 \) and \( \Delta J \leq 2 \). The \( \text{6H}_{15/2} \rightarrow \text{6F}_{11/2} \) transition centered at 7892 cm\(^{-1}\) shows higher intensity compared to the other transitions for the same ions and is noted as hyper sensitive transition in Dy\(^{3+}\) ion [14].
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Fig. 5.1 Vis absorption spectrum of 1.0 mol% Dy$^{3+}$-doped TCZNB glass.

Fig. 5.2 NIR absorption spectrum of 1.0 mol% Dy$^{3+}$-doped TCZNB glass.
5.3.2. Determination of optical band gap and Urbach energy

The optical band gap ($E_g$) is an important parameter for describing solid state luminescent materials. The optical band gap of glasses has been computed based on their absorption spectra, for understanding their optically induced transitions. The principle following to this technique is that a photon with energy greater than the band gap energy will be absorbed. The rapid rise in the absorption coefficient is referred to as the fundamental absorption edge. Normally, the optical absorption edge for amorphous materials is interpreted in terms of indirect transitions across an optical band gap. Absorption coefficient near the edge of the curve was determined at wavelength difference of 5 nm using the relation $\alpha (\omega) = \frac{2.303A}{t}$, where $t$ is the thickness of the sample and $A$ corresponds to absorbance. The relation between $\alpha (\nu)$ and the photon energy of incident radiation $h\nu$ is given by the relation $\alpha (\nu) = B (\frac{h\nu-E_g}{h\nu})^2$, where $E_g$ is the optical energy gap, $h\nu$ is the photon energy and $B$ is a constant called band tailing parameter. The relation can be written as $(\alpha h\nu)^{1/2} = B (h\nu- E_g)$. Using this relation optical energy gap value is determined by extrapolation of linear region of the plots of $(\alpha h\nu)^{1/2}$ against $h\nu$. The value of the optical band gap ($E_g$) is found to be 3.29 eV for 1.0 mol% Dy$^{3+}$-doped TCZNB glass, which was determined by plotting the graph between $(\alpha h\nu)^{1/2}$ and $h\nu$ from the absorption spectrum as shown in Fig. 5.3. The optical band gap energy of TCZNB glass is higher compared 1mol% of Lead Germanate Tellurite (LGT10) (3.12 eV) [15], Lead Calcium Zinc Sodium Fluoroborate (LCZSFB) (2.64 eV) [16], CaF$_2$ bismuth borate (2.55 eV) [17] glasses.

Urbach plots are the plots where natural logarithm of absorption coefficients ($In\alpha$) is plotted against photon energy ($h\nu$). Such an Urbach plot for present borotellurite glass system is shown in Fig 5.4. The values of Urbach energy were calculated by determining slope of the linear region of the curve at lower phonon energies and taking their reciprocal is the value of Urbach energy ($E$). Urbach energy of the present glass system is 0.536 eV. The Urbach energy of TCZNB glass is lower compared to 1mol% of Erbium Borate Tellurite (ErBT) (0.574 eV) [18], 1mol% of Europium Borate Tellurite (EBT) (0.552 eV) [19] glasses.
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Fig. 5.3 Plot of $(\alpha h\nu)^{1/2}$ versus $h\nu$ for 1.0 mol% Dy$^{3+}$-doped TCZNB glass.

Fig. 5.4 Plot of $ln\alpha$ versus $h\nu$ for 1.0 mol% Dy$^{3+}$-doped TCZNB glass.
5.3.3. Oscillator strengths and J-O intensity parameters

The experimental and calculated oscillator strengths for 1.0 mol% Dy\textsuperscript{3+} ions doped TCZNB glass are tabulated in Table 5.1. The small root mean square deviation ($\delta_{\text{rms}}$) value of $0.26 \times 10^{-6}$ obtained between the experimental and calculated oscillator strengths indicating good fit between two values and also the validity of J-O intensity parameters. The J-O intensity parameters are important for investigating the local structure and bonding in the vicinity of RE ions. The trend of these J-O parameters in the present work is found in increasing order $2 > 4 > 6$. The resulting $1 (\times 10^{-20} \text{ cm}^2)$ parameters for glasses are found to be $2 = 11.30$, $4 = 3.30$ and $6 = 2.60$ respectively. The hypersensitivity has described by the magnitude of $2$ parameter provide information on the nature of the bond between RE ions and surrounding ligand, as well as symmetry of RE environment [20]. The $4$ parameters is related to the bulk properties and $6$ is inversely related to the rigidity of the medium and also affected by the vibronic transitions of the RE ions. A comparison of J-O intensity parameters and their trends in various glasses containing Dy\textsuperscript{3+} ions is shown in Table 5.2 [12, 21, 22].

**Table 5.1**
Experimental and calculated oscillator strengths ($\times 10^{-6}$) for 1.0 mol% Dy\textsuperscript{3+} -doped TCZNB glass.

<table>
<thead>
<tr>
<th>Transition ($^6H_{15/2}$→)</th>
<th>Energy (cm$^-1$)</th>
<th>$f_{\text{exp}}$</th>
<th>$f_{\text{cal}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^6H_{11/2}$</td>
<td>5959</td>
<td>1.206</td>
<td>1.516</td>
</tr>
<tr>
<td>$^6F_{11/2}$ + $^6H_{9/2}$</td>
<td>7892</td>
<td>9.880</td>
<td>9.845</td>
</tr>
<tr>
<td>$^6F_{9/2}$ + $^6H_{7/2}$</td>
<td>9199</td>
<td>3.085</td>
<td>3.116</td>
</tr>
<tr>
<td>$^6F_{7/2}$</td>
<td>11148</td>
<td>2.315</td>
<td>2.311</td>
</tr>
<tr>
<td>$^6F_{5/2}$</td>
<td>12500</td>
<td>2.195</td>
<td>1.008</td>
</tr>
<tr>
<td>$^6F_{3/2}$</td>
<td>13315</td>
<td>0.046</td>
<td>0.189</td>
</tr>
<tr>
<td>$^4F_{9/2}$</td>
<td>21186</td>
<td>0.428</td>
<td>0.176</td>
</tr>
<tr>
<td>$^4I_{15/2}$</td>
<td>22075</td>
<td>0.634</td>
<td>0.503</td>
</tr>
<tr>
<td>$^4G_{11/2}$</td>
<td>23529</td>
<td>0.307</td>
<td>0.112</td>
</tr>
<tr>
<td>$^4I_{13/2}$</td>
<td>25906</td>
<td>1.336</td>
<td>0.268</td>
</tr>
<tr>
<td>$^4I_{11/2}$</td>
<td>26385</td>
<td>0.388</td>
<td>0.483</td>
</tr>
</tbody>
</table>

$\delta_{\text{rms}}=0.259\times10^{-6}$
Table 5.2
Comparison of J-O intensity parameters (×10^{-20} cm^2), their trends for Dy^{3+} ions in TCZNB glass with different glass hosts.

<table>
<thead>
<tr>
<th>Glass system</th>
<th>Ω_2</th>
<th>Ω_4</th>
<th>Ω_6</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCZNB [Present glass]</td>
<td>11.30</td>
<td>3.30</td>
<td>2.60</td>
<td>2 &gt; 4 &gt; 6</td>
</tr>
<tr>
<td>NaZnBS [22]</td>
<td>16.82</td>
<td>9.45</td>
<td>6.50</td>
<td>2 &gt; 4 &gt; 6</td>
</tr>
</tbody>
</table>

5.3.4. Luminescence analysis and radiative properties

An excitation spectrum for different concentrations of Dy^{3+} -doped TCZNB glasses is shown in Fig. 5.5. The luminescence spectra of the TCZNB glasses doped with different concentration of Dy^{3+} ions (0.5, 1.0, 1.5 and 2.0%) at room temperature in the spectral wavelength of 453 nm is shown in Fig. 5.6. The Dy^{3+} ions show a strong luminescence at 485 and 577 nm corresponding to the 4F_{9/2} → 6H_{13/2} (yellow) and 4F_{9/2} → 6H_{15/2} (blue) transitions [23]. The 4F_{9/2} → 6H_{13/2} and 4F_{9/2} → 6H_{15/2} transitions are more intense and due to magnetic dipole (MD) and electric dipole (ED) transitions, respectively [24]. The 4F_{9/2} → 6H_{13/2} transition is hypersensitive electric dipole transition (ΔJ = ±2) which has been strongly influenced by the coordination environment. On the other hand, the 4F_{9/2} → 6H_{15/2} transition is a magnetic dipole transition (ΔJ=0, ±1 but 0→0 forbidden) and less sensitive to the coordination environment [25]. The quenching of emission intensities with increase of Dy^{3+} ion concentration is due to the increase of non-radiative energy transfer [26]. As it apparent from the bandgap and absorption spectrum that when 453 nm is use, it primarily absorb in the band edge of tellurite glass and so can not propagate deep inside and emission may come either only from surface or from beneath surface.

The J-O theory has been applied to understanding the Dy^{3+} ion luminescence of glasses and to determine the radiative properties such as radiative transition probabilities (A_R), radiative lifetime (τ_R) and branching ratios (β_R) and stimulated emission cross-section (σ_e). The value of σ_e has been used to indentify the potential laser transitions of rare earth ions in host medium. The peak emission wavelength
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$(\lambda_p)$, effective linewidth ($\Delta\lambda_{\text{eff}}$), and branching ratios ($\beta_m$) are determined for $^4F_{9/2} \rightarrow ^6H_{13/2}$ and $^4F_{9/2} \rightarrow ^6H_{15/2}$ transitions. All the radiative parameters ($A_R$, $A_T$, $\tau_R$ and ($\beta_R$) and emission parameters ($\lambda_p$, $\Delta\lambda_p$, $\sigma_e$ and $\beta_m$) for the excited level of $^4F_{9/2} \rightarrow ^6H_{13/2}$ and $^4F_{9/2} \rightarrow ^6H_{15/2}$ are tabulated in Table 4. From the values of radiative transition probabilities in Table 5.3, it is noticed that $^4F_{9/2} \rightarrow ^6H_{13/2}$ transition has the highest radiative transition rate compared to other transitions; hence this transition is very useful for laser emission. The predicated branching ratios are found to be high for those transitions having maximum $A_R$ values [27]. The $\tau_R$ value of 999 $\mu$s in the present work is high compared to PTBDy (979 $\mu$s) [23], LBTAf (993 $\mu$s) [28], fluoroborate (964 $\mu$s) [29] matrices. The luminescence branching ratio characterizes the lasing power of a transition and it was well known that an emission transition with $\beta_R \geq 0.60$ is more potential for laser emission. In the present investigation $^4F_{9/2} \rightarrow ^6H_{13/2}$ transitions have higher $\beta_R$ value than the other transition and comparable to those reported in the literature [29]. The experimental $\beta_R$ values have been compared with the predicted values using J-O theory, it is found that their values are in close agreement with each other. In the present study, it could be observed that, the values of branching ratio ($\beta_R$) and stimulated emission cross-section ($\sigma_e$) for the $^4F_{9/2} \rightarrow ^6H_{13/2}$ transition are found to be maximum among all the transitions [30]. The value of $\sigma_e$ has been used to identify the potential laser transitions of rare earth ions in a host medium. A good laser transition can have a large stimulated emission cross-section. The peak emission cross-section ($\sigma_e$) of $32.25 \times 10^{-22}$ cm$^2$ for $^4F_{9/2} \rightarrow ^6H_{13/2}$ transition is quite high and found comparable with $^4F_{9/2} \rightarrow ^6H_{15/2}$ transition and other reported systems [28]. The gain bandwidth ($\sigma_e \times \Delta\lambda_p$) and optical gain ($\sigma_e \times \tau_R$) parameters are critical to predict the amplification of the medium in which the rare earth ions are situated. A good optical amplifier should have higher values of ($\sigma_e \times \Delta\lambda_p$) and ($\sigma_e \times \tau_R$). The relatively higher values of ($\sigma_e \times \Delta\lambda_p$) and ($\sigma_e \times \tau_R$) suggest that the 1.0 mol % Dy$^{3+}$ ion doped TCZNB glass is a suitable candidate for optical amplifiers.
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Fig. 5.5 Excitation spectra for different concentrations of Dy$^{3+}$-doped TCZNB glasses.

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Fig. 5.6 Fluorescence spectra for different concentrations of Dy$^{3+}$-doped TCZNB glasses.
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Table 5.3

<table>
<thead>
<tr>
<th>Transition</th>
<th>(\lambda_p) (nm)</th>
<th>(\Delta\lambda) (nm)</th>
<th>(\Delta v) (cm(^{-1}))</th>
<th>(\sigma(\lambda) \times 10^{-22}) cm(^2)</th>
<th>(A) (s(^{-1}))</th>
<th>(\tau) (µs)</th>
<th>(\beta)</th>
<th>(\beta_{\text{calculated}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^4F_{9/2} \rightarrow ^6H_{13/2})</td>
<td>577</td>
<td>0.378</td>
<td>0.830</td>
<td>830.7</td>
<td>17.06</td>
<td>32.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(^4F_{9/2} \rightarrow ^6H_{15/2})</td>
<td>485</td>
<td>0.621</td>
<td>0.169</td>
<td>169.9</td>
<td>17.83</td>
<td>03.15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(A = 1000.6\) \quad \tau = 999

5.3.5. Generation of white light and Dy-O bond covalency

An appropriate combination of yellow to blue (Y:B) intensity ratio in host matrix produce white light in addition to the generation and control of various colors in solid state lasers. In the present study, the evaluated Y:B ratios are 0.50, 0.65, 0.68 and 0.70 for 0.5, 1.0, 1.5 and 2.0 mol\% Dy\textsubscript{2}O\textsubscript{3} concentrations, respectively. The variation in Y:B ratio increases marginally up to 2.0 mol\% considerably with Dy\textsuperscript{3+} ion concentration. Table 5.4 represents Y:B ratio for various Dy\textsuperscript{3+} -doped glasses. It is interesting to note that, the Y:B intensity ratio higher for present glass compared those of reported glass in literature [21, 27, 31].

The luminescence color of the samples excited at 453 nm has been characterized by the CIE1931 chromaticity diagram. In the present investigation, the evaluated color coordinates are (0.28, 0.32), (0.31, 0.36), (0.30, 0.35) and (0.32, 0.36) for 0.5, 1.0, 1.5 and 2.0 mol \% Dy\textsubscript{2}O\textsubscript{3} concentrations. All these coordinates are located in the white light region of CIE chromaticity diagram as shown in Fig 5.7. For all concentrations, the deviation in the coordinates is very small as depicted in the Fig 5.7. The higher Y:B intensity ratios indicating the higher degree of covalence between dysprosium and oxygen ion [32]. The variation of Y:B intensity ratio of \(^4F_{9/2} \rightarrow ^6H_{13/2}\) and \(^4F_{9/2} \rightarrow ^6H_{15/2}\) transitions for various Dy\textsuperscript{3+} ions concentration increase in Dy-O covalence up to 2.0 mol\% in TCZNB glasses. From Fig.5.7 it is observed that among the borotellurite glasses, TCZNB glass exhibits a greater degree of covalence for Dy-O bond [30].
Fig. 5.7 CIE chromaticity diagram for Dy\(^{3+}\) ions in TCZNB glasses.

Table 5.4
Comparison of Y/B intensity ratios of TCZNB glass for different concentrations (in mol %) with different glass systems.

<table>
<thead>
<tr>
<th>Glass System</th>
<th>0.5</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCZNB [Present work]</td>
<td>0.50</td>
<td>0.65</td>
<td>0.68</td>
<td>0.70</td>
</tr>
<tr>
<td>LCZSFB [27]</td>
<td>0.68</td>
<td>0.70</td>
<td>-</td>
<td>0.71</td>
</tr>
<tr>
<td>Lead tellurofluoroborate [21]</td>
<td>-</td>
<td>0.88</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lead fluorophosphate [31]</td>
<td>-</td>
<td>0.63</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

5.3.6. Decay analysis

The lifetime of the \(^{4}F_{9/2}\) excited level in TCZNB glasses at various concentration of Dy\(^{3+}\) ions were recorded under excitation at 453 and emission at 577 nm, and the decay curves for all the concentrations 0.5, 1.0, 1.5 and 2.0 mol% are found to be single exponential behavior [25]. The measured lifetimes (\(\tau_m\)) obtained by taking e-folding times of the decay curves are 302, 162, 111, and 75 \(\mu\)s for 0.5, 1.0, 1.5 and 2.0 mol% glasses are shown in Fig.5.8. The measured lifetime (\(\tau_m\)) of excited states significantly decreases with increase of Dy\(^{3+}\) ion concentration due to the
energy transfer (ET) process. The measured lifetime ($\tau_m$) of $^{4}F_{9/2}$ level is found to be 162 μs which is higher in magnitude than those of 1.0 mol% Dy$^{3+}$ ions doped LTT (152 μs) [30], borate (140 μs) [22], flurozirconate (120 μs) [33] and phosphate (100 μs) [22]. The radiative lifetime ($\tau_R$) calculated from J-O analysis is 999 μs. The difference between experimental and calculated lifetimes may due to multi-phonon relaxation and cross relaxation [2]. The decay time is evident from the radiative and experimental decay times that the emission from the $^{4}F_{9/2}$ level contains both radiative and non-radiative contributions [23]. Fig.5.9 shows the energy level diagram along with emission transitions in TCZNB glasses.

**Fig. 5.8** The decay profiles of $^{4}F_{9/2}$ level for different concentrations of Dy$^{3+}$ ions in TCZNB glasses.
5.4. Conclusions

The room temperature absorption and fluorescence spectra of Dy\(^{3+}\)-doped TCZNB glasses were recorded and analyzed using the J-O theory. The J-O parameters are calculated and found to be compared with other reported values. For all the concentration of Dy\(^{3+}\) ions, the fluorescence decay curves show single exponential nature associated with quenching of lifetime with increase in Dy\(^{3+}\) ion concentration due to enhancement of energy transfer processes between Dy\(^{3+}\) ions. The large emission cross-section of \(0.32 \times 10^{-20}\) cm\(^2\) for \(4\text{F}_{9/2} \rightarrow 6\text{H}_{13/2}\) transition corresponding to 577 nm supports that the present glass host is a good candidate for active medium.

The variation of the lifetime of \(4\text{F}_{9/2}\) level and the fluorescence yield for the \(4\text{F}_{9/2} \rightarrow 6\text{H}_{13/2}\) (577 nm) transition with glass composition has been studied. The CIE chromaticity color coordinates calculated for emission spectra of Dy\(^{3+}\)-doped TCZNB glasses show that the suitability of the glasses to generate white light. The magnitude of chromaticity coordinates for the emission spectra of Dy\(^{3+}\): TCZNB glasses have been found to be in the white light region.
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