CHAPTER 2

Spectroscopic Studies of Eu$^{3+}$ ions in Li-K-Zn Fluorotellurite Glasses

This Chapter deals with the spectroscopic studies of Eu$^{3+}$ ions incorporated Li-K-Zn fluorotellurite glasses, (70-x) TeO$_2$ + 10 Li$_2$O + 10 K$_2$O + 10 ZnF$_2$ + x Eu$_2$O$_3$, (0 ≤ x ≤ 2 mol%), prepared via melt quenching technique. Optical absorption from $^7$F$_0$ and $^7$F$_1$ levels of the Eu$^{3+}$-doped glass has been studied to examine the covalent bonding characteristics, energy band gap and Judd-Ofelt intensity parameters. The emission spectra ($^5$D$_0$ → $^7$F$_{0,1,2,3,4}$) of the glasses were used to estimate the luminescence enhancement, asymmetric environment in the vicinity of Eu$^{3+}$ ions, stimulated emission cross section and branching ratios. The phonon side band mechanism of $^5$D$_2$ level of the Eu$^{3+}$ ions in the prepared glass was examined by considering the excitation and Raman spectra. The radiative lifetime calculated using Judd-Ofelt parameters was compared with the experimental lifetime to estimate the quantum efficiency of $^5$D$_0$ level of Eu$^{3+}$ ions in Li-K-Zn fluorotellurite glass.
2.1 Introduction

Optical studies of different trivalent rare earth (RE$^{3+}$) ions incorporated in oxide glasses have been widely investigated owing to their attractive applications in various fields such as solid state lasers, optical data storage, planar waveguides, flat panel displays, fiber amplifiers etc. [1-4]. For these applications, longer lifetimes, sharp absorption and emission peaks and different excited levels appropriate for optical pumping are essential; which are peculiarities of RE$^{3+}$ ions. Fabrication of efficient optical devices embedded with RE$^{3+}$ ions necessitates good glass matrix host. Among various potential host materials, tellurium oxide based glasses have been recognized as apt matrices for the incorporation of different rare earth ions and transition metals to create interesting luminescence properties [5, 6]. These glasses doped with RE$^{3+}$ ions usually have very low phonon energy (~750 cm$^{-1}$), which is less than phosphate, borate, germanate and silicate glasses [7, 8]. Owing to their attractive physical properties such as low melting point, high refractive index, high dielectric constant and chemical durability, tellurite based glasses have drawn considerable scientific and technological attention for applications in optical fiber and nonlinear devices.

Among the RE$^{3+}$ ions, trivalent europium (Eu$^{3+}$) ion has the highest degree of utility due to its applications in photonic devices as red emitting phosphors with narrow and monochromatic nature of $^5D_0 \rightarrow ^7F_2$ transition. Because of the possibility of spectral hole burning in this transition at room temperature (RT) and its applicability in high density optical storage devices, Eu$^{3+}$ ions are attracting an excessive deal of attention. For Eu$^{3+}$ ions, phonon energy of the host material is not sensitive to the efficiency of red emission even if the larger phonon energy can accelerate the relaxation
processes [9-11]. Since photoluminescence (PL) emission is highly sensitive to the environment, Eu\(^{3+}\) ion incorporation and its spectral analysis can be used as a probe to investigate the local structure of the host glasses [12].

Fluoride contents in the glass can move the IR cut-off edge towards longer wavelengths, creating them extremely suitable for fiber amplifiers [13]. Also it can react with OH group to produce hydrogen fluoride, which diminishes the OH absorption in the glass matrix [14]. Owing to the collective benefits of both tellurite and fluoride glasses, fluorotellurite glasses are very valuable among various other glass hosts. Some network modifiers like K\(_2\)O and Li\(_2\)O create drastic variations in the properties of the glass network such as melting point, stability etc. Anions like oxygen become non-bridging when the divalent cations like zinc are incorporated in the glass network [15]. Hence network modifying cations, such as higher valence state ions, alkali and alkaline-earth metals etc. are put up randomly in the glass network in close proximity to non-bridging oxygen (NBO).

In the present work, optical studies of Eu\(^{3+}\) ions in Li-K-Zn fluorotellurite glasses have been carried out through absorption, PL and decay measurements for the substantial and potential advantages as specified above. The Judd-Ofelt (JO) parameters, \(\Omega_\lambda\) (where \(\lambda = 2, 4 \text{ and } 6\)) were scrutinized in view of absorption spectra of Eu\(^{3+}\) ions in the present glass system [16, 17]. The JO parameters were used to evaluate the radiative properties such as spontaneous emission probabilities, radiative lifetime etc. The phonon side band (PSB) analysis has been worked out by considering the excitation spectrum. Experimentally obtained lifetime of the \(^5D_0\) level of Eu\(^{3+}\) ions was used to estimate the quantum efficiency of the glass system investigated.
2.2 Experimental

2.2.1 Glass Preparation

$\text{Eu}^{3+}$-doped (70-x) $\text{TeO}_2 + 10 \text{Li}_2\text{O} + 10 \text{K}_2\text{O} + 10 \text{ZnF}_2 + x \text{Eu}_2\text{O}_3$

with $x = 0.0, 0.1, 0.5, 1.0, 1.5, 2.0$ (Glass codes and compositions are given in Table 2.1) were prepared by conventional melt quenching technique. Respective batches (about 15 g) of chemicals were thoroughly mixed in an agate mortar and heated at 800-900°C in a platinum crucible using an electric furnace for 2 hours. The so obtained homogeneously mixed melt were poured onto a preheated brass plate and annealed at a temperature of 150°C for 10 hours to remove thermal strains. The samples were then cooled to room temperature and polished before taking further studies.

2.2.2 Measurements

The refractive indices ($n$) measurements of the glasses were carried out at 632.8 nm using an (J.A. Woollam Co., Inc EC-400) ellipsometer. Absorption spectra of the TLKZnFeu10 glass were measured on Perkin Elmer Lambda-950 UV-Vis-NIR spectrophotometer with a spectral resolution of 0.5 nm in the wavelength region of 200-2500 nm. Horiba Scientific fluromax-4 Spectrofluorimeter was employed to observe the emission spectra of all the glasses at 393, 463 and 533 nm excitation wavelengths using Xe flash lamp. Excitation spectrum of the TLKZnFeu10 glass was measured using the same spectrofluorimeter by monitoring emission at 610 nm. Slit width and spectral resolution were kept at 3 nm and 0.2 nm, respectively for the measurement of these PL spectra. Raman spectrum of the same glass was measured using MultiRAM Raman 116 (Bruker) equipped with InGaAs laser at a power of 150 mW with a spectral resolution of 0.1 cm$^{-1}$. Lifetime measurements were recorded on Jobin Yvon Fluorolog-3 spectrofluorimeter using xenon arc lamp for 463 nm
excitation (with time resolution of 0.05 ms and repetition rate of 0.2 MHz).
All these measurements were made at room temperature (RT).

### Table 2.1 Physical properties for TLKZnFEu glasses

<table>
<thead>
<tr>
<th>Glass Code</th>
<th>TLKZnF</th>
<th>TLKZnFEu01</th>
<th>TLKZnFEu05</th>
<th>TLKZnFEu10</th>
<th>TLKZnFEu15</th>
<th>TLKZnFEu20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
<td>70TeO$_2$, 10Li$_2$O, 10K$_2$O, 10ZnF$_2$</td>
<td>69.9TeO$_2$, 10Li$_2$O, 10K$_2$O, 10ZnF$_2$, 0.1Eu$_2$O$_3$</td>
<td>69.5TeO$_2$, 10Li$_2$O, 10K$_2$O, 10ZnF$_2$, 0.5Eu$_2$O$_3$</td>
<td>69TeO$_2$, 10Li$_2$O, 10K$_2$O, 10ZnF$_2$, 1.0Eu$_2$O$_3$</td>
<td>68.5TeO$_2$, 10Li$_2$O, 10K$_2$O, 10ZnF$_2$, 1.5Eu$_2$O$_3$</td>
<td>69TeO$_2$, 10Li$_2$O, 10K$_2$O, 10ZnF$_2$, 2.0Eu$_2$O$_3$</td>
</tr>
</tbody>
</table>

- $d$: Density (g/cm$^3$), $t$: Optical path length (mm), $n$: Refractive Index,
- $N$: Concentration of Eu$^{3+}$ (×10$^{20}$ ions/cm$^3$), $r_p$: Polaron radius (nm),
- $\alpha_e$: Electronic polarizability (×10$^{-24}$), $V_m$: Molar volume (cm$^3$/mol), $R_m$: Molar refractivity (cm$^3$),
- $\varepsilon$: Dielectric constant, $\chi$: Electric susceptibility, $r_i$: Interionic distance (nm),
- $F$: Field strength (×10$^{15}$ cm$^2$), $R$: Reflection loss (%)
2.3 Results and Discussion

2.3.1 Physical properties

Density \((d)\), concentration \((N)\) and refractive index \((n)\) were determined and utilized to find various other physical parameters \([18, 19]\).

The polaron radius \((r_p)\) can be calculated from the ion concentration using the equation

\[
r_p = \frac{1}{2} \left( \frac{\pi}{3N} \right)^{1/3}
\]  

……(2.1)

Electronic polarizability \((\alpha_e)\) can be obtained from the Lorentz-Lorenz equation

\[
n = \left( \frac{1 + \frac{4\pi N A \alpha_e}{3 V_m}}{1 - \frac{4\pi N A \alpha_e}{3 V_m}} \right)^{1/2}
\]  

……(2.2)

where \(V_m\) is the molar volume.

Molar refractivity \((R_\mu)\) is evaluated as

\[
R_\mu = \left( \frac{n^2 - 1}{n^2 + 2} \right) \frac{M}{d}
\]  

……(2.3)

Dielectric constant \((\varepsilon)\) is given by

\[
\varepsilon = n^2
\]  

……(2.4)

The inter-ionic distance \((r_i)\) of the rare earth doped glass can be calculated by

\[
r_i = \left( \frac{1}{N} \right)^{1/3}
\]  

……(2.5)

Electric susceptibility \((\chi)\) is calculated by the formula

\[
\chi = \frac{n^2 - 1}{4\pi}
\]  

……(2.6)

and the Field strength \((F)\) is expressed as

\[
F = \frac{Z}{r_p^2}
\]  

……(2.7)

where \(Z\) is the charge of the ion and reflection loss \((R)\) is given by...
The above mentioned physical properties of various TLKZnFEu glasses were evaluated and collected in Table 2.1. Densities of the glasses were estimated using Archimedes’ principle with distilled water as the immersing liquid. It is evident that density of the glasses increases with increase in concentration of the dopant ions, which can be reasoned to the increase in molecular mass as the Eu₂O₃ replaces the TeO₂. Refractive index is an important parameter affecting the optical fibre amplifiers which influences the mode profiles [20]. Increase in density of the glasses is accompanied by increase in the index of refraction (n). The electronic polarizability (α_e) has a higher value than that of the previously reported Eu³⁺ doped phosphate glass [21], which is an indication of strong bonding between Eu³⁺ ions. Also the polaron radius (r_p) and the inter-ionic distance (r_I) decreases with refractive index whereas, the field strength increases, as expected.

2.3.2 Optical Absorption spectrum

The absorption spectra of 1.0 mol% of Eu³⁺ doped TLKZnF glass in the UV-Vis and NIR region are shown respectively in Figures 2.1 (a) and (b). The spectrum of Eu³⁺ usually contains transitions not only from the ground state (⁷F₀) but also from the thermally populated first excited state (⁷F₁), due to their narrow spacing. In the present study, nine absorption bands (two are in the NIR region) are observed in the spectra which can clearly be attributed to the f-f optical transitions of Eu³⁺ from the ⁷F₀,₁ to the various excited levels of 4f⁶ configuration. The observed peaks corresponding to different transitions are presented in Table 2.2, on the basis of energy level positions of Eu³⁺ ion reported in literature [5].
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Figure 2.1 (a) Absorption spectrum for TLKZnFeu10 glass in UV-Vis region

Figure 2.1 (b) Absorption spectrum for TLKZnFeu10 glass in NIR region
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The transition $^7F_0 \rightarrow ^5D_0$ is not often seen, for it is a forbidden electric dipole transition ($J_0 \rightarrow 0$). But $J$-mixing caused by the crystal field distribution [22] in the host matrix renders this transition partially allowed, which led a way for this transition to appear with a small intensity in the present glass. Further, the transitions $^7F_0 \rightarrow ^5D_1$ and $^7F_0 \rightarrow ^5D_3$ were also not expected to appear; since transitions from a lower level with $J = 0$ to upper levels with odd $J$ values are forbidden. However, since the energy level $^7F_1$ is close to $^7F_0$ level, the transitions $^7F_1 \rightarrow ^5D_{1,3}$ appear. The intensity of $^7F_0 \rightarrow ^5D_1$ magnetic-dipole allowed transition is relatively weaker than that of $^7F_0 \rightarrow ^5D_2$ (hypersensitive transition) induced electric-dipole allowed transition. The $^7F_0 \rightarrow ^5L_6$ is viewed to be the most intense transition though it is forbidden by $S$ and $L$ selection rules but allowed by $J$ selection rule. The absorption transitions originating from the lower levels $^7F_0$ and $^7F_1$ are evidently resolved.

2.3.2.1 Energy Band gap

The fundamental absorption edges of the absorption spectra were used to determine the optical band gap of the glass through direct allowed transition. The fundamental absorption method refers to the band to band transitions by using Mott and Davis relation [23]. The optical absorption coefficient, $\alpha(\nu)$ for TLKZnFEu10 glass was calculated using the following equation

$$\alpha(\nu) = \frac{A}{t} \quad \ldots (2.9)$$

where $A$ is the absorbance and $t$ is the optical path length. The quantity, $\alpha(\nu)$ in terms of photon energy can be expressed by the relation

$$\alpha(\nu) = \frac{B(h\nu-E_g)}{h\nu} \quad \ldots (2.10)$$
where $E_g$ is the optical band gap energy and $B$ is a constant [24]. Based on the inter-band electronic transitions, the index $n$ can have values from 0.5 to 3. The measured absorption fits well to Eq. (2.10) for direct allowed transitions with $n = 0.5$ of TLKZnFEu10 glass. Figure 2.2 depicts the variation of $\alpha^2$ with photon energy for 1.0 mol% Eu$^{3+}$-doped Li-K-Zn fluorotellurite glass. The optical energy band gap ($E_g$) for TLKZnFEu10 glass is estimated to be 3.36 eV and is similar to those reported for other Eu$^{3+}$-doped tellurite glasses [25].

Figure 2.2 Energy band gap diagram for TLKZnFEu10 glass

2.3.2.2 Nephelauxetic ratio and bonding parameter

Nature of Eu$^{3+}$-ligand bond and local structure around RE$^{3+}$ ion site in the host matrix could be determined from nephelauxetic ratio and bonding parameter. The positive or negative value of the bonding parameter represents the covalent or ionic nature of the RE$^{3+}$-ligand bond, respectively. The nephelauxetic ratio ($\beta$) can be found from the equation [26]
\[ \beta = \frac{\nu_c}{\nu_a} \] ......(2.11)

where \( \nu_c \) is the energy (in cm\(^{-1}\)) for a particular RE\(^{3+} \) ion transition in the crystal field and \( \nu_a \) is the energy (in cm\(^{-1}\)) for the same aquo-ion transition [27]. If \( \bar{\beta} \) is the average nephelauxetic ratio, the bonding parameter (\( \delta \)) is given by

\[ \delta = \frac{1-\bar{\beta}}{\bar{\beta}} \times 100 \] ......(2.12)

The calculated values of \( \bar{\beta} \) and \( \delta \) are presented in Table 2.2 and is in good agreement with previous reports of glasses having similar bonding nature [21, 28]. The positive value of \( \delta \) indicates the covalent bonding between Eu\(^{3+} \) ions and ligands in Li-K-Zn fluorotellurite glass.

**Table 2.2** Energies for TLKZnFEu10 glass (\( \nu_c \)) and aquo-ion (\( \nu_a \)) along with nephelauxetic ratio (\( \beta \)) and bonding parameter (\( \delta \))

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>( SLJ \rightarrow S'L'J' )</th>
<th>( \nu_c ) (cm(^{-1}))</th>
<th>( \nu_a ) (cm(^{-1}))</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>( ^7F_0 \rightarrow ^5L_6 )</td>
<td>25381</td>
<td>25400</td>
<td>0.9993</td>
</tr>
<tr>
<td>2.</td>
<td>( ^7F_1 \rightarrow ^5D_3 )</td>
<td>24038</td>
<td>24038</td>
<td>1.0000</td>
</tr>
<tr>
<td>3.</td>
<td>( ^7F_0 \rightarrow ^5D_2 )</td>
<td>21505</td>
<td>21519</td>
<td>0.9993</td>
</tr>
<tr>
<td>4.</td>
<td>( ^7F_0 \rightarrow ^5D_1 )</td>
<td>19011</td>
<td>19028</td>
<td>0.9991</td>
</tr>
<tr>
<td>5.</td>
<td>( ^7F_1 \rightarrow ^5D_1 )</td>
<td>18691</td>
<td>18691</td>
<td>1.0000</td>
</tr>
<tr>
<td>6.</td>
<td>( ^7F_0 \rightarrow ^5D_0 )</td>
<td>17271</td>
<td>17277</td>
<td>0.9997</td>
</tr>
<tr>
<td>7.</td>
<td>( ^7F_1 \rightarrow ^5D_0 )</td>
<td>16978</td>
<td>16920</td>
<td>1.0034</td>
</tr>
<tr>
<td>8.</td>
<td>( ^7F_0 \rightarrow ^7F_6 )</td>
<td>4815</td>
<td>4980</td>
<td>0.9669</td>
</tr>
<tr>
<td>9.</td>
<td>( ^7F_1 \rightarrow ^7F_6 )</td>
<td>4535</td>
<td>4630</td>
<td>0.9795</td>
</tr>
</tbody>
</table>

\( \bar{\beta} = 0.9941, \quad \delta = 0.5905 \) (covalent bonding)
### Table 2.3 Experimental and calculated values of oscillator strengths for TLKZnFEu10 glass

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>$SLJ \rightarrow S'L'J'$</th>
<th>$E_{exp}$ (cm$^{-1}$)</th>
<th>$E_{cat}$ (cm$^{-1}$)</th>
<th>$\Delta E$ (cm$^{-1}$)</th>
<th>$f_{exp}$ ($\times 10^6$)</th>
<th>$f_{cat}$ ($\times 10^6$)</th>
<th>$\Delta f$ ($\times 10^6$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$^7F_0 \rightarrow ^5L_6$</td>
<td>25381</td>
<td>25375</td>
<td>6</td>
<td>1.650</td>
<td>0.376</td>
<td>1.274</td>
</tr>
<tr>
<td>2.</td>
<td>$^7F_1 \rightarrow ^5D_3$</td>
<td>24038</td>
<td>24040</td>
<td>2</td>
<td>0.118</td>
<td>0.181</td>
<td>-0.063</td>
</tr>
<tr>
<td>3.</td>
<td>$^7F_0 \rightarrow ^5D_2$</td>
<td>21505</td>
<td>21499</td>
<td>6</td>
<td>0.502</td>
<td>0.139</td>
<td>0.363</td>
</tr>
<tr>
<td>4.</td>
<td>$^7F_0 \rightarrow ^3D_1$</td>
<td>19011</td>
<td>19026</td>
<td>15</td>
<td>0.031</td>
<td>0.000</td>
<td>0.031</td>
</tr>
<tr>
<td>5.</td>
<td>$^7F_1 \rightarrow ^3D_1$</td>
<td>18691</td>
<td>18676</td>
<td>15</td>
<td>0.149</td>
<td>0.394</td>
<td>-0.245</td>
</tr>
<tr>
<td>6.</td>
<td>$^7F_0 \rightarrow ^5D_0$</td>
<td>17271</td>
<td>17286</td>
<td>15</td>
<td>0.007</td>
<td>0.000</td>
<td>0.007</td>
</tr>
<tr>
<td>7.</td>
<td>$^7F_1 \rightarrow ^5D_0$</td>
<td>16978</td>
<td>16936</td>
<td>42</td>
<td>0.020</td>
<td>0.000</td>
<td>0.020</td>
</tr>
<tr>
<td>8.</td>
<td>$^7F_0 \rightarrow ^7F_6$</td>
<td>4815</td>
<td>5029</td>
<td>214</td>
<td>2.192</td>
<td>0.667</td>
<td>1.525</td>
</tr>
<tr>
<td>9.</td>
<td>$^7F_1 \rightarrow ^7F_6$</td>
<td>4535</td>
<td>4679</td>
<td>144</td>
<td>0.429</td>
<td>1.636</td>
<td>-1.207</td>
</tr>
</tbody>
</table>

2.3.2.3 Judd-Ofelt intensity analysis

The experimental oscillator strengths of absorption transitions are evaluated using equation

$$f_{exp} = 4.32 \times 10^{-9} \int \varepsilon(\nu) d\nu$$

where $\varepsilon(\nu)$ is the molar absorptivity of a band at a wavenumber $\nu$ (cm$^{-1}$) [29] and the calculated oscillator strength is obtained from

$$f_{cat} = \frac{8\pi^2mc^2}{3\hbar(2J+1)} \sum_{\lambda=2,4,6} \Omega_\lambda \left| \langle \Psi J \| U^{(\lambda)} \| \Psi' J' \rangle \right|^2 \quad \ldots \ldots (2.14)$$

where $\Omega_\lambda$ is the JO intensity parameter determined from the electric dipole contribution of the experimental oscillator strength, $\| U^{(\lambda)} \|^2$ is the doubly reduced matrix elements (Appendix A) of unit tensor operator evaluated in the intermediate coupling approximation for the absorption transition and $m$ denotes the mass of the electron [16, 17]. The obtained values for experimental and calculated oscillator strengths for the observed absorption transitions are listed in Table 2.3. A least-square fitting method
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for Eq. (2.14) is used to determine $\Omega_\lambda$ parameters, which proposes the best fit between experimental and calculated oscillator strengths. The quality of the fit has been expressed by the root mean square (r.m.s.) deviation of oscillator strengths ($\sigma$).

$$\sigma = \left[ \frac{\sum (f_{exp} - f_{cal})^2}{N_i} \right]^{1/2}$$  .....(2.15)

where $N_i$ denotes the total number of excited energy levels used for least-square fit. The r.m.s deviation of TLKZnFEu10 glass is found to be 0.789×10^{-6}, which indicates that the experimental and calculated oscillator strengths are in good agreement. Spectroscopic quality factor of the glass can be expressed as

$$Q = \frac{\Omega_4}{\Omega_6}$$  ......(2.16)

where $\Omega_4$ and $\Omega_6$ are long range parameters associated with the bulk properties of the glass like viscosity and basicity. The value of $\Omega_2$, $\Omega_4$ and $\Omega_6$ for the TLKZnFEu10 glass along with other reported Eu$^{3+}$ doped glass systems are listed in Table 2.4 for a comparison [5, 30-32]. It is clear that $\Omega_\lambda$ values of TLKZnFEu10 glass follow the trend $\Omega_2 > \Omega_4 > \Omega_6$ which is same as that of some earlier reports (Table 2.4). The high value of $\Omega_2$ parameter confirms the covalence of Eu$^{3+}$-O bond and low symmetry around Eu$^{3+}$ ions, which is agreeable with the nephelauxetic effect (Table 2.2).

**Table 2.4** Comparison of $\Omega_\lambda$ (×10^{-20} cm$^2$) parameters of TLKZnFEu10 glass with previously reported glasses

<table>
<thead>
<tr>
<th>Glass code</th>
<th>$\Omega_2$</th>
<th>$\Omega_4$</th>
<th>$\Omega_6$</th>
<th>$Q$</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLKZnFEu10</td>
<td>3.77</td>
<td>1.66</td>
<td>0.44</td>
<td>3.77</td>
<td>Present work</td>
</tr>
<tr>
<td>79TeO$_2$–20Li$_2$CO$_3$–1Eu$_2$O$_3$</td>
<td>11.06</td>
<td>4.58</td>
<td>0.96</td>
<td>4.77</td>
<td>[5]</td>
</tr>
<tr>
<td>NaKBE</td>
<td>4.92</td>
<td>1.64</td>
<td>0.00</td>
<td>-</td>
<td>[30]</td>
</tr>
<tr>
<td>G1</td>
<td>3.45</td>
<td>2.93</td>
<td>0.99</td>
<td>2.96</td>
<td>[31]</td>
</tr>
<tr>
<td>BCAEu</td>
<td>3.37</td>
<td>2.10</td>
<td>0.33</td>
<td>6.36</td>
<td>[32]</td>
</tr>
</tbody>
</table>
2.3.3 Radiative properties and Luminescence spectra

The electric and magnetic-dipole line strength, radiative transition probability, fluorescence branching ratio, radiative lifetime and stimulated emission cross section were determined for TLKZnF6Eu10 glass using JO parameters and refractive index. The radiative transition probability for a transition from the excited state $\Psi J$ to a lower state $\Psi'J'$ is the sum of electric and magnetic-dipole transition probabilities

$$A(\Psi J, \Psi'J') = A_{ed} + A_{md} = \frac{64\pi^4}{3h^3(2J+1)} \times \left( \frac{n(n^2+2)^2}{9} S_{ed} + n^3 S_{md} \right)$$

……(2.17)

where $S_{ed}$ and $S_{md}$ are the electric and magnetic-dipole line strengths, respectively [33], and are given by

$$S_{ed} = e^2 \sum_{\lambda=2,A,B} \Omega_{\lambda} | < \Psi J \parallel U^{(2)} \parallel \Psi'J' > |^2$$

……(2.18)

and

$$S_{md} = \frac{e^2h^2}{16n^2m^2c^2} | < \Psi J \parallel L + 2S \parallel \Psi'J' > |^2$$

……(2.19)

Local field corrections for electric and magnetic-dipole transitions adopted in Eq. (2.17) are $n(n^2+2)^2/9$ and $n^3$, respectively. The total radiative transition probability [34], $A_T(\Psi J)$ is expressed as

$$A_T(\Psi J) = \sum_{\Psi'J'} A(\Psi J, \Psi'J')$$

……(2.20)

The predicted radiative lifetime ($\tau_R$) can be calculated by

$$\tau_R = [A_T(\Psi J)]^{-1}$$

……(2.21)

and the fluorescence branching ratio, $\beta_R(\Psi J, \Psi'J')$ for a transition from the excited state $\Psi J$ to a lower state $\Psi'J'$ is given by

$$\beta_R(\Psi J, \Psi'J') = \frac{A(\Psi J, \Psi'J')}{A_T(\Psi J)}$$

……(2.22)

The detailed results of the predicted radiative properties of TLKZnF6Eu10 glass are presented in Table 2.5 for the $^5D_0$ excited state of Eu$^{3+}$ ion. It is well established that an emission transition having $\beta_R$ greater than 50% is

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considered to be more potential for laser emission [35]. It is obvious that transition $^5D_0 \rightarrow ^7F_2$ (red emission) has relatively high transition probability and branching ratio, attracting laser action. The total radiative transition probability and radiative lifetime of the $^5D_0$ level of Eu$^{3+}$ ions in the glass are evaluated as 483.01 s$^{-1}$ and 2.070 ms, respectively. Similar predicted lifetime is reported for other Eu$^{3+}$-doped glasses [27, 28].

**Table 2.5** Calculated radiative parameters of TLKZnFEu10 glass

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>$S'L'J'$</th>
<th>Energy (cm$^{-1}$)</th>
<th>$S_{ed}$ ($\times 10^{-22}$)</th>
<th>$S_{md}$ ($\times 10^{-22}$)</th>
<th>$A_{ed}$ (s$^{-1}$)</th>
<th>$A_{md}$ (s$^{-1}$)</th>
<th>$A$ (s$^{-1}$)</th>
<th>$\beta_R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$^7F_6$</td>
<td>12343.1</td>
<td>0.01</td>
<td>0.00</td>
<td>1.20</td>
<td>0.00</td>
<td>1.20</td>
<td>0.0025</td>
</tr>
<tr>
<td>2.</td>
<td>$^7F_5$</td>
<td>13422.4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>3.</td>
<td>$^7F_4$</td>
<td>14463.7</td>
<td>0.39</td>
<td>0.00</td>
<td>66.71</td>
<td>0.00</td>
<td>66.71</td>
<td>0.1381</td>
</tr>
<tr>
<td>4.</td>
<td>$^7F_3$</td>
<td>15433.4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
<tr>
<td>5.</td>
<td>$^7F_2$</td>
<td>16283.2</td>
<td>1.23</td>
<td>0.00</td>
<td>302.9</td>
<td>0.00</td>
<td>302.9</td>
<td>0.6271</td>
</tr>
<tr>
<td>6.</td>
<td>$^7F_1$</td>
<td>16943.5</td>
<td>0.00</td>
<td>0.40</td>
<td>0.00</td>
<td>112.2</td>
<td>112.2</td>
<td>0.2323</td>
</tr>
<tr>
<td>7.</td>
<td>$^7F_0$</td>
<td>17320.4</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Total radiative transition probability, $A_T = 483.01$ s$^{-1}$

Radiative lifetime, $\tau_R = 2.070$ ms

Figure 2.3 (a) depicts the luminescence spectra of Eu$^{3+}$ doped TLKZnF glasses for different concentrations at the excitation wavelength of 463 nm. Variation of luminescence intensity of $^5D_0 \rightarrow ^7F_2$ transition under varying dopant concentration is shown in Figure 2.3 (b) and it reveals that no luminescence quenching is occurred in the investigated range of ion concentrations. The spectra consist of inhomogeneously broadened bands corresponding to the transitions $^5D_0 \rightarrow ^7F_1$ ($J = 0, 1, 2, 3, 4$) of Eu$^{3+}$ ions. Of these, $^5D_0 \rightarrow ^7F_2$ is the most intense for all the concentrations.
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Figure 2.3 (a) Emission spectra of TLKZnF:Eu$^{3+}$ glasses

Figure 2.3 (b) Variation of emission intensity with Eu$^{3+}$ ion concentration
Identical emission spectra have been reported in other Eu$^{3+}$ doped glasses [5, 28, 30]. Having made the comparison of experimental emission spectra with its radiative properties (Table 2.5), it is clear that $^5\!D_0 \rightarrow ^7\!F_{2,4}$ are purely electric-dipole transitions, in which $^5\!D_0 \rightarrow ^7\!F_2$ is the prominent one and $^5\!D_0 \rightarrow ^7\!F_1$ is a purely magnetic-dipole transition. The transition probability for this magnetic-dipole transition $^5\!D_0 \rightarrow ^7\!F_1$ is nearly independent of the host matrix. On the other hand, the intensity of the induced electric-dipole-allowed $^5\!D_0 \rightarrow ^7\!F_2$ transition is extremely sensitive to chemical bonds in the vicinity of Eu$^{3+}$ ion, which increases as the site symmetry of Eu$^{3+}$ centre decreases. Therefore, the luminescence intensity ratio of $^5\!D_0 \rightarrow ^7\!F_2$ to $^5\!D_0 \rightarrow ^7\!F_1$ transitions (red to orange ratio), widely known as the asymmetric ratio, provides a valuable information about the symmetry at the site of the Eu$^{3+}$ ions in any host matrix [36] and is calculated as 2.879 for TLKZnFEu10 glass. This value of asymmetric ratio is lower than that of other Eu$^{3+}$ doped tellurite glass [31], which can be attributed to the high regularity of the sites occupied by the Eu$^{3+}$ ions in comparison with those in other oxide glasses [37].

The computed color coordinates ($\bar{X}, \bar{Y}$) for the europium are superimposed in the CIE chromaticity diagram to check the validity of the obtained results. The degree of simulation necessary to match the color of specified power spectral density ($P(\lambda)$ ) be able to represented as

\begin{align}
X &= \int \bar{x}(\lambda)P(\lambda)d\lambda \quad \ldots(2.23) \\
Y &= \int \bar{y}(\lambda)P(\lambda)d\lambda \quad \ldots(2.24) \\
Z &= \int \bar{z}(\lambda)P(\lambda)d\lambda \quad \ldots(2.25)
\end{align}

Through an easy mathematic technique, it is essential only to quote the quantity of two of the reference stimuli to identify a color, as the three quantities ($x$, $y$ and $z$) are prepared all the time to sum to ‘1’. The $x$, $y$ and
z, i.e., the proportion of $X$, $Y$ and $Z$ of the light to the total of the three tristimulus values, are known as chromaticity coordinates, which are indicated as

$$x = \frac{X}{X+Y+Z} \quad \text{……(2.26)}$$

$$y = \frac{Y}{X+Y+Z} \quad \text{……(2.27)}$$

$$z = \frac{Z}{X+Y+Z} \quad \text{……(2.28)}$$

These are symbolized as chromaticity coordinates ($x$, $y$ and $z$) and are typically used to identify the saturation and hue of any color. CIE color stimuli values are presented in Appendix B. The $x$ and $y$ coordinates were calculated as 0.638 and 0.362, respectively.

Figure 2.4 CIE Chromaticity coordinate diagram for TLKZnFEu10 glass
From Figure 2.4, it is clear that the color coordinates of the TLKZnFEu10 glass are well fitted in the red region corresponding to the \( ^5\text{D}_0 \rightarrow ^7\text{F}_J \) transitions of \( \text{Eu}^{3+} \) ion. The color purity, which is the ratio of space separation between white point \((0.333,0.333)\) and a given coordinate to the distance from white point to shaped locus intersection [38] gives the gauge of saturation of a color and is found to be maximum (100%) for the present glass system.

The rate of energy extracted from a lasing material is determined by the stimulated emission cross-section and it provides insight of the potential lasing performance. The large stimulated emission cross-section is one attractive feature for the design and development of low-threshold and high gain laser applications. The stimulated emission cross-section of a transition is expressed as

\[
\sigma_e = \frac{\lambda_p A(\psi_J, \psi_J)}{8\pi c n^2 \Delta \lambda_{\text{eff}}} \quad \ldots \ldots \ldots (2.29)
\]

where \( \Delta \lambda_{\text{eff}} \) is the effective bandwidth of the transition, \( \lambda_p \) is the peak wavelength of emission band and \( c \) is the light velocity [39]. Gain bandwidth (\( \Delta G \)) is a critical parameter in determining the amplification of wave in a medium containing rare earth. It can be calculated as the product of effective line width (\( \Delta \lambda_{\text{eff}} \)) and stimulated emission cross-section (\( \sigma_e \)) at the wavelength of emission \( \lambda_p \)

\[
\Delta G = \Delta \lambda_{\text{eff}} \times \sigma_e(\lambda_p) \quad \ldots \ldots \ldots (2.30)
\]

Stimulated emission cross-section, experimental branching ratio and gain bandwidth for each transition in TLKZnFEu10 glass are presented in Table 2.6. The transition \( ^5\text{D}_0 \rightarrow ^7\text{F}_2 \) (red emission) shows high value of branching ratio and stimulated emission cross-section as compared to other transitions. The gain bandwidth (\( \Delta G \)) is evaluated as \( 14.089\times10^{-28} \text{ cm}^3 \) for this transition of \( \text{Eu}^{3+} \) ions in TLKZnFEu10 glass.
Table 2.6 Observed stimulated emission cross-sections and branching ratios of TLKZnFEu10 glass

<table>
<thead>
<tr>
<th>Sl no.</th>
<th>$S'L'J'$</th>
<th>$E_{exp}$ (cm$^{-1}$)</th>
<th>$\Delta \lambda_{eff}$ (nm)</th>
<th>$\sigma_\epsilon$ ($\times 10^{-21}$ cm$^2$)</th>
<th>$\Delta G$ ($\times 10^{-28}$ cm$^3$)</th>
<th>$\beta_{exp}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>$^7F_4$</td>
<td>14278</td>
<td>10.2861</td>
<td>0.523</td>
<td>5.3796</td>
<td>0.0084</td>
</tr>
<tr>
<td>2.</td>
<td>$^7F_3$</td>
<td>15380</td>
<td>6.5943</td>
<td>0.000</td>
<td>0.0000</td>
<td>0.0043</td>
</tr>
<tr>
<td>3.</td>
<td>$^7F_2$</td>
<td>16383</td>
<td>6.3753</td>
<td>2.210</td>
<td>14.0894</td>
<td>0.7238</td>
</tr>
<tr>
<td>4.</td>
<td>$^7F_1$</td>
<td>16961</td>
<td>10.8165</td>
<td>0.420</td>
<td>4.5429</td>
<td>0.2514</td>
</tr>
<tr>
<td>5.</td>
<td>$^7F_0$</td>
<td>17331</td>
<td>2.1993</td>
<td>0.000</td>
<td>0.0000</td>
<td>0.0122</td>
</tr>
</tbody>
</table>

Figure 2.5 shows the luminescence spectra of TLKZnFEu10 glass at three different excitation wavelengths 393, 463 and 533 nm. It is observed that the most intense luminescence is obtained for an excitation wavelength of 463 nm in TLKZnFEu10 glass.

![Emission spectra at different excitation wavelengths (\(\lambda_{ex} = 393, 463\) and 533 nm) for TLKZnFEu10 glass](image)
The energy level diagram for Eu$^{3+}$ doped TLKZnF glass is illustrated in Figure 2.6. At excitation wavelengths of 393, 463 and 533 nm, Eu$^{3+}$ ions are excited to the upper $^5$L$_6$, $^5$D$_2$ and $^5$D$_1$ levels, respectively. Due to non-radiative relaxation from excited states of energy higher than $^5$D$_0$ state, the intense emission bands in the range of 570–700 nm are caused by the $^5$D$_0 \rightarrow {^7}F_J$ ($J = 0, 1, 2, 3, 4$) transitions. In glassy materials, due to the absence of a centre of symmetry, mixing of the 4f orbitals with opposite parity orbitals takes place and consequently it causes the existence of electric-dipole transitions ($^5$D$_0 \rightarrow {^7}F_{2,4}$). The absence of emissions starting from the excited levels of $^5$D$_J$ ($J = 1, 2, 3$) is due to the phonon energy found in the glasses, i.e. when the Eu$^{3+}$ ions are excited to any level above the $^5$D$_0$ level, there is a fast non-radiative multiphonon relaxation to this level. Since the relaxations from $^5$D$_{3,2,1} \rightarrow ^5$D$_0$ are non-radiative and emissions from these three excited states are suppressed, the $\Sigma ^5$D$_0 \rightarrow {^7}F_J$ emission intensity represents the total intensity of the Eu$^{3+}$ doped glasses.

**Figure 2.6** Partial energy level diagram of Eu$^{3+}$ ion in TLKZnFEu10 glass along with the possible excitation and emission transitions
2.3.4 Excitation spectrum and Phonon Side Band analysis

The excitation spectrum of the TLKZnFEu10 glass has been taken by monitoring the emission at 610 nm (Figure 2.7). The assigned transitions are indicated in the figure. The transitions obtained are \(^7\)F\(_0\)\(\rightarrow\)\(^5\)L\(_6\), \(^7\)F\(_1\)\(\rightarrow\)\(^5\)D\(_3\), \(^7\)F\(_0\)\(\rightarrow\)\(^5\)D\(_2\), \(^7\)F\(_0\)\(\rightarrow\)\(^5\)D\(_1\) and \(^7\)F\(_1\)\(\rightarrow\)\(^5\)D\(_1\) centered at 393, 414, 463, 525 and 533 nm, respectively. Among these, the excitation transition \(^7\)F\(_0\)\(\rightarrow\)\(^5\)D\(_2\) (463 nm) is more intense and for this transition high luminescence intensity is observed (Figure 2.5). The phonon side band (PSB) associated with the transition \(^7\)F\(_0\)\(\rightarrow\)\(^5\)D\(_2\) is observed on the high energy side of the peak.

![Excitation spectrum of TLKZnFEu10 glass](image)

**Figure 2.7** Excitation spectrum of TLKZnFEu10 glass

The phonon energy associated with the vibronic transition can be obtained from the shift of the PSB from the pure electronic transition. Figure 2.8 shows the possible phonon side band mechanism in TLKZnFEu10 glass. Phonon side band spectroscopy is an important tool for obtaining information about the local site symmetry and structural units.
present in the vicinity of the rare earth ion. The phonon side band spectra provide useful experimental data to analyze and study the variations of the non-radiative multiphonon decay processes of rare earth ions doped in the glassy matrices.

Figure 2.8 Energy level diagram for phonon side band mechanism

The non-radiative decay rate of an excited state is given by

\[ W_{nr} = W_{mp} + W_{ET} + W_{CR} + W_{OH} \] .... (2.31)

where \( W_{mp}, W_{ET}, W_{CR} \) and \( W_{OH} \) are the rates of multiphonon decay, energy transfer, cross-relaxation and decay due to water content in the sample. For low concentrations and negligible OH content in the glass, the probability for non-radiative process is mainly due to multiphonon relaxation.

The non-radiative decay rate due to the multiphonon relaxation is given by Miyakawa and Dexter [40]

\[ W_{mp} = W_0 e^{-\alpha \Delta E} \] .... (2.32)
where $W_0$ is the experimental parameter corresponding to the decay rate at zero energy gap and zero phonon emission. The host dependent parameter ($\alpha$) is given by

$$
\alpha = (\hbar \omega)^{-1} \left[ \ln \left( \frac{p}{g_{n+1}} \right) - 1 \right]
$$

……(2.33)

where $g$ is the electron phonon coupling strength and $p$ is the phonon number.

$$
p = \frac{\Delta E}{\hbar \omega}
$$

……(2.34)

where $\Delta E$ is the energy gap and $\hbar \omega$ is the phonon energy. The parameter $n$ is the Planck distribution function and is given by

$$
n = \left( e^{\frac{\hbar \omega}{k_B T}} - 1 \right)^{-1}
$$

……(2.35)

The electron-phonon coupling strength ($g$) is found to be 0.0176 for TLKZnFEu10 glass. The phonon number ($p$), the host dependent parameter ($\alpha$) and the relative decay rate ($W_{mp}/W_0$) for the different $^5\text{D}_J$ levels of Eu$^{3+}$ ions in TLKZnFEu10 glass are given in the Table 2.7. The emission efficiencies from the different $^5\text{D}_J$ levels depend on the non-radiative decay probability ($W_{nf}$), which in this case is associated with the multiphonon relaxation process.

Table 2.7 The electron-phonon coupling strength ($g$), the host dependent parameter ($\alpha$) and the relative decay rate for $^5\text{D}_J$ ($J = 1, 2$ and $3$) levels of Eu$^{3+}$ ion in TLKZnFEu10 glass

<table>
<thead>
<tr>
<th>Levels</th>
<th>$p$ (×10$^{-3}$ cm)</th>
<th>$\alpha$ (×10$^{-5}$)</th>
<th>$W_{mp}/W_0$ (×10$^5$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^5\text{D}_1$</td>
<td>2.35</td>
<td>5.23</td>
<td>11.142</td>
</tr>
<tr>
<td>$^5\text{D}_2$</td>
<td>3.37</td>
<td>5.72</td>
<td>0.064</td>
</tr>
<tr>
<td>$^5\text{D}_3$</td>
<td>3.86</td>
<td>5.90</td>
<td>0.005</td>
</tr>
</tbody>
</table>
Figure 2.9 Comparison of phonon side band with Raman spectrum for TLKZnFEu10 glass

Figure 2.9 shows the comparison of phonon side band with Raman spectrum of TLKZnFEu10 glass. It is observed from the figure that the phonon side band occurs at a mean energy shift of 739 cm\(^{-1}\) from the zero phonon line \(^7F_0 \rightarrow ^5D_2\), which is typical for tellurite glasses [41]. This vibrational level is verified with the Raman spectrum (see Figure 2.9) in which the prominent band is obtained around 746 cm\(^{-1}\), which is associated with the TeO\(_3\) trigonal pyramid units [42]. The band at 447 cm\(^{-1}\) can be attributed to the symmetric stretching vibration of Te-O-Te linkages, which are formed by the vertex-sharing of TeO\(_3\) trigonal bipyramid units, TeO\(_{3+1}\) polyhedra and TeO\(_3\) trigonal pyramid units [41, 43, 44]. The resonance at 108 and 275 cm\(^{-1}\) bands are attributed to the low frequency \(E_2\) vibrations of zinc oxide in the glass matrix and local vibrations of zinc atoms in the vicinity of extrinsic dopants, respectively [45, 46].
The relative probabilities for the non-radiative decay for the glass sample are quite smaller than the borate, phosphate and silicate glasses because of the low phonon energy of the tellurite glasses [47]. The value of $g$ is an indication of the strength of covalent bond between the rare earth ion and the local sites. Eu$^{3+}$ ion has a strong affinity towards the groups containing NBO, because they are easily available for charge compensation [48, 49]. The value obtained here indicates a strong covalent Eu$^{3+}$-O bonding which increases the non radiative decay process [50].

### 2.3.5 Decay analysis

Since the interaction among the optically active Eu$^{3+}$ ions is negligible, the fluorescence decay curves can be fit to the single exponential function

$$y = y_0 + A e^{-t/\tau} \quad \cdots \cdots (2.36)$$

where $t$ is the time after excitation. The non-radiative decay rate can be expressed as [40]

$$W_{NR} = \frac{1}{\tau_{exp}} - \frac{1}{\tau_R} \quad \cdots \cdots (2.37)$$

The quantum efficiency ($\eta$) of the fluorescent level is equal to the ratio of the measured lifetime to the predicted lifetime and is given by

$$\eta = \frac{\tau_{exp}}{\tau_R} \times 100 \% \quad \cdots \cdots (2.38)$$

The gain coefficient ($g$) is the product of experimental lifetime ($\tau_{exp}$) and stimulated emission cross-section ($\sigma_e$) at the wavelength of emission $\lambda_p$. It is given by

$$g = \tau_{exp} \times \sigma_e (\lambda_p) \quad \cdots \cdots (2.39)$$

The luminescence decay for the $^5D_0 \rightarrow ^7F_2$ transition of the Eu$^{3+}$ ion in TLKZnF glasses has been measured. Figure 2.10 shows the decay profile of the TLKZnFEu10 glass as a representative case. It is clear that the decay
profile is almost single exponential and the determination of lifetime is straightforward. Lifetimes of the $^5D_0$ level of Eu$^{3+}$ in the glass systems are procured by taking the first e-folding time of the decay intensity. Further, they do not significantly depend on the dopant concentration, as seen from the inset of Figure 2.10.

![Figure 2.10](image)

**Figure 2.10** Luminescence decay from the $^5D_0$ level of TLKZnFEu10 glass by monitoring $^5D_0 \rightarrow ^3F_2$ transition at 610 nm

These lifetimes for the $^5D_0$ level of the Eu$^{3+}$ ion in the studied glasses are lower than those of Eu$^{3+}$ doped borotellurite glass [51] but higher than those of Eu$^{3+}$ doped tellurite glass [52, 53]. Non-radiative decay rate ($W_{NR}$), quantum efficiency ($\eta$) and gain coefficient ($g$) were evaluated using Eqs. (2.37) - (2.39) as 0.453 ms$^{-1}$, 51.6% and 2.36×10$^{-24}$ cm$^2$s, respectively. Since the quantum efficiency of the material is high enough, it has potential applications in the electroluminescent device (for example red phosphor in colour TV).
2.4 Conclusions

Concisely, we have fabricated different concentrations of Eu$^{3+}$-doped Li-K-Zn fluorotellurite glasses with high stability and transparency. Nature of the Judd-Ofelt intensity parameters was found to be $\Omega_2 \geq \Omega_4 \geq \Omega_6$. The covalent nature of the Eu$^{3+}$-ligand bond in the glass network was confirmed by the positive value of bonding parameter and higher value of JO intensity parameter, $\Omega_2$. The glasses exhibit enhanced PL intensity with the Eu$^{3+}$ ion concentration and strong red emission occurs at 610 nm ($^5D_0 \rightarrow ^7F_2$) under blue light irradiation. The assessment of optical studies suggests that these glasses have the potential to be used as a noble laser material and can be used in electroluminescent devices due to the large stimulated emission cross-section and branching ratio for the $^5D_0 \rightarrow ^7F_2$ transition. The PSB analysis of the Eu$^{3+}$ ions in Li-K-Zn fluorotellurite glass shows that the multiphonon relaxation of Eu$^{3+}$ ions in the present glass matrix is due to the TeO$_3$ trigonal pyramid units having energy $\sim 746$ cm$^{-1}$. Decay rates of $^5D_0$ level of Eu$^{3+}$ ions in the present glass system were observed to be independent of Eu$^{3+}$ ion concentration and have a single exponential behavior.
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