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# Spectroscopic properties of $Er^{3+}$ doped HMO glasses

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**ABSTRACT**

*The spectroscopic properties of $Er^{3+}$ : PbO - ZnO - CaO- $Al_2O_3$- $B_2O_3$ glasses have been studied. Racah coefficients ($E^1$, $E^2$ and $E^3$), Slater Condon parameters ($F_2$, $F_4$ and $F_6$), Spin orbit coupling parameters ($\xi_{4f}$), Configuration interaction parameters ($\alpha$ and $\beta$) have been calculated by using the absorption spectra. The ratios of $E_1/E_3$ and $E_2/E_3$ do not deviate much from the hydrogenic ratios. In the present work we have studied nephalauxetic effect, covalency and bonding parameters for $Er^{3+}$ glass systems. The phenomenological Judd-Ofelt intensity parameters $\Omega_2$, $\Omega_4$ and $\Omega_6$ were determined from the spectral intensities. The radiative transitions probabilities A, radiative life times ($\tau_R$), branching ratios ($\beta_R$) and absorption cross sections ($\sigma_a$) were evaluated for the lasing levels of certain exited states.*

**Key words**: Erbium, HMO glasses, Optical absorption, XRD, FT-IR.

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## INTRODUCTION

Over the past several years, rare earth (RE)-doped materials have been considered as key and technologically important components due to their applications in various fields such as color display, solid- state laser, Optical amplifiers Photo electronic devices [1-4]. Lanthanide ions are the suitable candidates for the luminescence processes owing to their abundant energy levels [4]. Especially $Er^{3+}$ ion possesses rich radiative transitions from violet to mid-infrared (3.45µm) region and its key role as the active dopant for the optical amplification and NIR light source at 1.53 µm wavelength, the standard fiber telecommunication wavelength [5-7].

Further it is well known that optical fibers are more easily fabricated to utilize the glass compared to crystals. It is observed from the Silica, Tellurite and fluoride glasses employed as a potential host for 1.53 µm optical fiber amplifiers [3, 8, 9]. Unfortunately, some disadvantages based on silica-based $Er^{3+}$ doped fiber amplifier (EDFA) restrict their further wide applications in optical communication such as low-doped concentration, narrow amplification bandwidth (~35nm), non-uniform gain spectrum, etc. [10,11]. Moreover, by considering the poor chemical durability of fluoride glasses and the poor stability against devitrification of tellurite glasses, it is considered to be more important to search for novel glass systems to be used as host materials in order to overcome these disadvantages and realize high efficiency and broadband operation in EDFA.

Recent decades have witnessed an increasing interest in heavy metal oxide glasses based on PbO - ZnO - CaO- $Al_2O_3$- $B_2O_3$ system both in fundamental research and in optical device fabrication because of their good transparency in the mid-infrared (up to ~8 µm) region the lowest phonon energy (~550 $cm^{-1}$), high refractive index

(~2.3) [6,12-14]. These special properties make them become more attractive class of materials for photonics and optical communication network. The main objective of this work is to carry out a study on the spectroscopic properties of $Er^{3+}$ doped PbO - ZnO - CaO- $Al_2O_3$- $B_2O_3$ glasses. Effects of variation in host environment on the optical properties of $Er^{3+}$ doped BZCAP glasses have been investigated and discussed.

## MATERIALS AND METHODS

The multi component BZCAP 1- 5 glass systems with the molar compositions of (50-x) PbO – x CaO - $4Al_2O_3$–$45ZnO.B_2O_3$–$1Er_2O_3$ (where x=10, 20, 30 and 40mol%) were prepared using Melt quenching technique [15].

The ingredients of the glasses were weighed to get 10g for each sample and mixed and uniformly grinded thoroughly in an agate mortar till the uniformly mixed fine powder is obtained. The raw mixed materials were placed in a porcelain crucible container and transferred to a high temperature furnace for melting. The temperature of the furnace is kept at $40^0$ C for about half an hour initially and slowly raised to reach 1050 $^0$C for melting for about one hour. The melt was quenched quickly by pouring on a smooth pre heated brass plate. The optically transparent glasses thus obtained were subjected to annealing at about 400 $^0$C to remove internal stresses, which were verified by examination through a polarizing microscope (Rudolph Instruments). The X-ray diffraction studies of these glass systems also indicated its amorphous nature [16].

The refractive indices ‘n’ of the samples were determined using conventional methods [17]. The absorption spectra were recorded at room temperature in UV–Vis and NIR region on JASCOUV–vis–NIRV–670 spectrophotometer. The X-ray diffraction (XRD) measurements were performed using Bruker D8 Advance diffracto meter (Kα¼1.54A1) at 40 kV and 100 mA, at room temperature. Fourier Transform Infrared (FTIR) analyses were carried out using PerkinElmer Paragon 500 FTIR spectrophotometer in the wave number range 400–4000 $cm^{-1}$ using KBr pellet technique.

## RESULTS AND DISCUSSION:

### 1. Structure analysis

The XRD profile of the glasses namely BZCAP 1-5 glasses were given in Fig1.

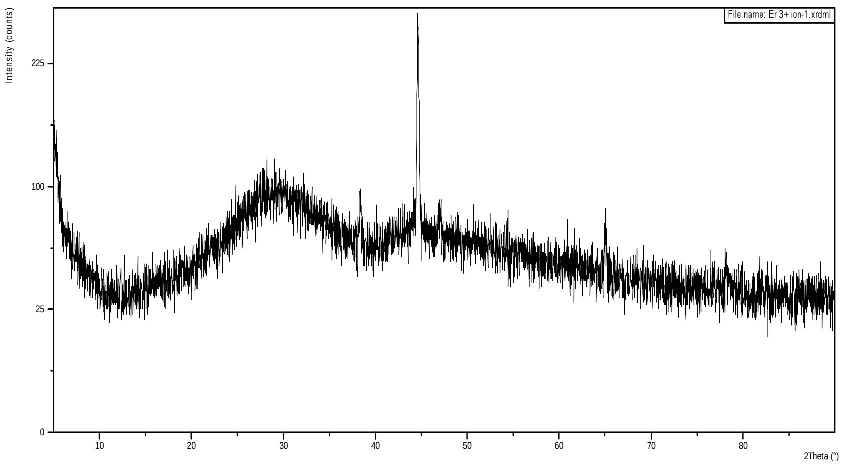


**Fig-1: XRD pattern of $Er^{3+}$ : BZCAP 1 glass**

The observed broad hump is the signature of the characteristic feature of amorphous nature of the material under study. The FTIR Transmission spectra in the range of 1800 to 400 cm-1 in fig 2 along with their assignments are given in table 1.

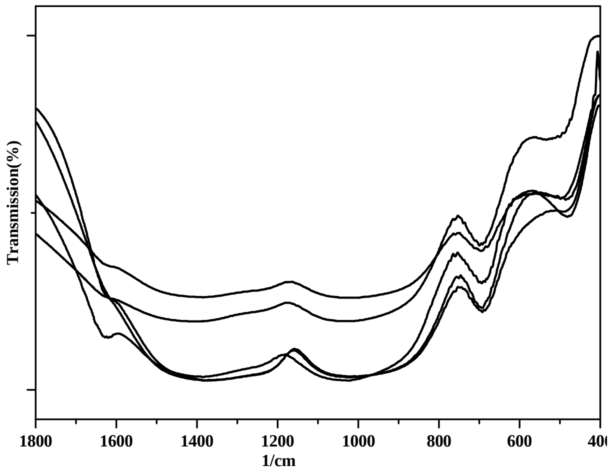


**Fig-2: FTIR Spectra of $Er^{3+}$ : BZCAP 1-5 glasses**

**Table -1: Assignments of FT IR in $Er^{3+}$: BZCAP1-5 glasses**

| Wave number ($cm^{-1}$) | FT- IR assignment |
|---|---|
| 476, 491 | stretching vibration in $PbO_4$ [2], B-O-B and Pb-O-B bending vibration as well as borate ring deformation |
| 693 | Bending of B-O-B linkage |
| 1014 | stretching of B-O bond stretching of tetrahedral $BO_4$ units |
| 1405 | B-O stretching vibrations of $BO_3$ units in chain and ring type Meta borate groups [2] |
| 1632 | Bending modes of OH groups [2] |

The various physical properties of $Er^{3+}$ BZCAP 1-5 glasses are calculated from the conventional formulae using experimental data and are given in table-2.

**Table - 2: Various Physical properties of $Er^{3+}$ : BZCAP1-5 glasses**

| Parameter | BZCAP1 | BZCAP2 | BZCAP3 | BZCAP4 | BZCAP5 |
|---|---|---|---|---|---|
| Refractive index, n | 1.740 | 1.741 | 1.743 | 1.744 | 1.746 |
| Density d (gm/$cm^3$) | 3.970 | 4.054 | 4.092 | 4.212 | 4.306 |
| Optical path length(cm) | 0.280 | 0.257 | 0.292 | 0.268 | 0.290 |
| $Er^{3+}$ ion concentration ($10^{20}$ ions /ml) | 0.205 | 0.972 | 1.954 | 2.991 | 3.757 |
| Optical dielectric constant, ε | 3.028 | 3.031 | 3.038 | 3.042 | 3.049 |
| Reflection loss R (%) | 7.294 | 7.308 | 7.337 | 7.352 | 7.380 |
| Molar refractivity Rμ ($cm^3$) | 20.683 | 18.451 | 20.508 | 20.148 | 19.949 |
| Inter-ionic distance η (Å) | 36.536 | 21.749 | 17.232 | 14.952 | 13.858 |
| Poloron radius $r_P$ (Å) | 14.724 | 8.765 | 6.944 | 6.026 | 5.585 |
| Field strength F ($10^{+15}$ $cm^{-2}$) | 0.598 | 1.687 | 2.688 | 3.569 | 4.155 |
| Electric susceptibility χ | 0.1613 | 0.1616 | 0.1621 | 0.1624 | 0.1630 |
| Numerical aperture (NA) | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |

## 2. Absorption Spectra

The absorption spectrum of BZCAP 1-5 glass samples are recorded in the wavelength range of 400-1600 nm are shown in fig 3(a) & 3(b).The absorption peaks corresponding to the transitions from the ground state $^4I_{15/2}$ to the various excited states are marked in the spectra. Due to the strong absorption by the host glasses in the UV range, the absorption bands below 420 nm could not be distinguished. The experimental oscillator strength ($f_{expt}$) for the following absorption bands $Er^{3+}$ : $^4I_{13/2}$, $^4I_{11/2}$, $^4I_{9/2}$, $^4F_{9/2}$, $^4S_{3/2}$, $^2H_{11/2}$, $^4F_{7/2}$, $^4F_{5/2}$ are determined with known values of $Er^{3+}$ ion concentration (in mol%), sample thickness(t), peak positions and peak areas by using the following equation.

$$f_{exp} = 4.32X10^{-9} \int \varepsilon(\nu)\, \Delta\nu \qquad \rightarrow \quad (1)$$

The Judd-Ofelt intensity parameter $\Omega\lambda$ ($\lambda$=2,4,6) [18,19] have been determined by using the experimentally measured oscillator strengths following least square fitting [20] procedure. The experimental ($f_{expt}$) and caculated ($f_{cal}$) oscillator strengths of the observed bands are given in table-3.

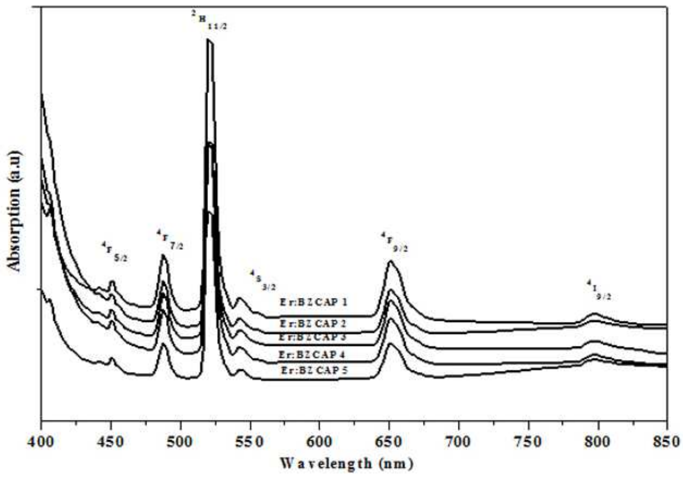


**Fig-3(a): Optical absorption spectra of $Er^{3+}$ : BZCAP 1-5 glasses**

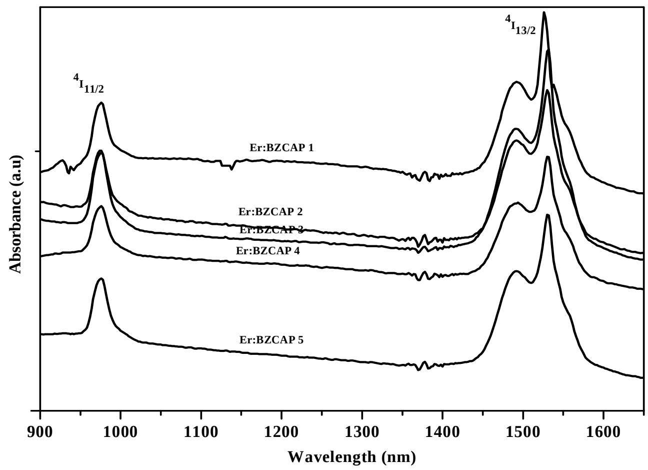


**Fig-3(b): Optical absorption spectra of $Er^{3+}$ : BZCAP 1-5 glasses**

**Table 3: Experimental and calculated band intensities (f x $10^{-6}$) and rms deviation of $Er^{3+}$ : BZCAP1-5 glasses**

| | BZCAP1 | | BZCAP2 | | BZCAP3 | | BZCAP4 | | BZCAP5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Level | $f_{expt}$ | $f_{calc}$ | $f_{expt}$ | $f_{calc}$ | $f_{expt}$ | $f_{calc}$ | $f_{expt}$ | $f_{calc}$ | $f_{expt}$ | $f_{calc}$ |
| $^4I_{13/2}$ | 0.984 | 0.988 | 1.481 | 1.332 | 0.936 | 0.912 | 0.952 | 0.917 | 0.592 | 0.618 |
| $^4I_{11/2}$ | 0.547 | 0.488 | 0.524 | 0.635 | 0.481 | 0.422 | 0.405 | 0.426 | 0.444 | 0.304 |
| $^4I_{9/2}$ | 0.351 | 0.395 | 0.335 | 0.174 | 0.319 | 0.291 | 0.319 | 0.280 | 0.287 | 0.289 |
| $^4F_{9/2}$ | 2.074 | 2.044 | 1.531 | 1.528 | 1.659 | 1.643 | 1.627 | 1.613 | 1.451 | 1.426 |
| $^4S_{3/2}$ | 0.319 | 0.339 | 0.234 | 0.534 | 0.255 | 0.335 | 0.351 | 0.339 | 0.287 | 0.205 |
| $^2H_{11/2}$ | 8.709 | 8.713 | 5.754 | 5.758 | 5.327 | 5.334 | 5.321 | 5.323 | 5.892 | 5.900 |
| $^4F_{7/2}$ | 1.568 | 1.606 | 1.223 | 1.907 | 1.276 | 1.449 | 1.223 | 1.448 | 1.010 | 1.041 |
| $^4F_{5/2}$ | 0.319 | 0.414 | 0.255 | 0.651 | 0.234 | 0.409 | 0.351 | 0.414 | 0.191 | 0.249 |
| rms dev. | ±0.040 | | ±0.265 | | ±0.081 | | ±0.073 | | ±0.054 | |

The rms deviation ($\delta$) for the $f_{expt}$ and $f_{cal}$ is calculated by using the following equation

$$(\delta \text{ rms}) = [\sum(f_{cal} - f_{expt})^2/\sum f^2{}_{expt}]^{1/2} \qquad \rightarrow \quad (2)$$

Where summation is taken over the bands used to calculate $\Omega_\lambda$ parameters. The low values obtained for $\delta$rms indicate the good fitting procedure employes in the present study. Jorgensen and Reisfeld [21] have noted that $\Omega_2$ parameter is indicative of covalent bonding, while $\Omega_6$ parameter is related to the rigidity of the host [22]. In the present study $\Omega_2$ is related with the symmetry of the glass while $\Omega_6$ is inversely proportional to the covalency of Er -O bond. The covalency of the Er - O bond is assumed to be related with the local basicity around the RE sites, which can be adjusted by the composition or structure of the glass host [23].

The Judd-Ofelt parameters obtained for BZCAP 1-5 glasses are given in table 4. The BZCAP 1 glass exhibits higher magnitude of $\Omega_2$ which indicate more asymmetry of the ligand field near the rare earth ion. This characteristic can be attributed to the presence of Pb ion with higher concentration it appears from the table 3 $\Omega_2$ parameter $\Omega_6$ parameter exhibit higher and lower magnitudes in all the glasses except BZCAP 2 glass. The rigidity of the host dependent $\Omega_6$ parameter exhibits more value in BZCAP 2 glass reflects higher magnitudes of rigidity over the other glasses. The J-O parameters, which contain implicity the effect of the odd-symmetry crystal field terms, exhibit the influence of the host on the radiative transition probabilities. It has been observed that the $\Omega_2$ parameter is related to the asymmetry of the ligand field near the RE ions, i.e higher the asymmetry, the larger is $\Omega_2$ [24]. The variation of PbO concentration with intensity parameters as shown in fig 4. The (SQF) quality factor $\Omega_4/\Omega_6$ obtained 0.554 for BZCAP 2 glasses recommend a good candidature for laser action [25].

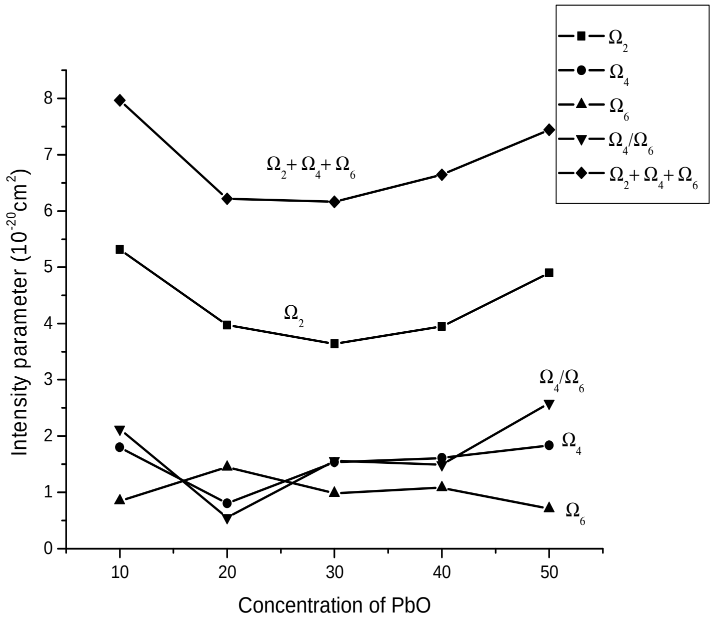


**Fig-4: Variation of J-O parameters & Quality factor with concentration variation**

**Table 4: Judd Ofelt intensity parameters ($\Omega_\lambda$, ($\lambda$ = 2,4,6 ) x $10^{-20}$ $cm^2$) of $Er^{3+}$: BZCAP1-5 glasses**

| Glass/ Parameter | BZCAP1 | BZCAP2 | BZCAP3 | BZCAP4 | BZCAP5 |
|---|---|---|---|---|---|
| $\Omega_2$ | 5.313 | 3.970 | 3.638 | 3.950 | 4.900 |
| $\Omega_4$ | 1.802 | 0.801 | 1.538 | 1.611 | 1.833 |
| $\Omega_6$ | 0.850 | 1.446 | 0.985 | 1.081 | 0.710 |
| $\Omega_4$ / $\Omega_6$ | 2.120 | 0.554 | 1.562 | 1.491 | 2.583 |
| $\Omega_2 + \Omega_4 + \Omega_6$ | 7.965 | 6.217 | 6.160 | 6.642 | 7.443 |

The J-O intensity parameters presented in table-3 are used to estimate the radiative transition probabilities ($A_R$) from excited ($\Psi J$) to particular lower state ($\Psi' J'$) manifolds using the following equations

$$A_R(JJ') = \frac{64\pi^4\nu^3}{3h(2J+1)}\left(\frac{n(n^2+2)^2}{9}S_{ed} + n^3 S_{md}\right) \qquad \longrightarrow \qquad (3)$$

Where $S_{ed}$ and $S_{md}$ are electric and magnetic dipole line strength respectively. The total radiative transition probability ($A_T$) of an excited state is given by the sum of the $A_R$ ($\Psi J$ ; $\Psi' J'$) terms calculated over all the terminal states and is related to radiative life time ($\tau_R$) as

$$\frac{1}{\tau_R} = A_T(\Psi J) = \sum A_R(\Psi J; \Psi J') \qquad \longrightarrow \qquad (4)$$

And branching ratio is given by

$$\beta_R(\psi J;\Psi' J') = \frac{A_R(\Psi J;\Psi' J')}{A_T(\Psi J)} \qquad \longrightarrow \qquad (5)$$

According to J-O theory [18,19] the radiative lifetime $\tau_R$ is inversely proportional to the refractive index ‘n’. The value of ‘n’ monotonically increases with increasing CaO (see table 4), so the value of $\tau_R$ decreases with the increase of CaO content.

**3. Radiative and non-radiative transition rates**

Using J-O intensity parameter $\Omega_\lambda$ determined from the measured oscillator strengths of the absorption bands, the radiative lifetime $\tau_R$ and branching ratios $\beta_R$ for certain excited levels have been calculated using eqs 4 & 5 [26] and are listed in table-5. The trend of $\tau_R$ for the excited levels in all the five glasses are found to increase in order

$$^4I_{13/2} > {}^4I_{11/2} > {}^4I_{9/2} > {}^4F_{9/2} > {}^4S_{3/2} > {}^2H_{11/2} > {}^4F_{7/2} > {}^4F_{5/2}$$

**Table-5: Computed Radiative lifetimes $\tau_R$ (in μ sec) and Branching ratios (β) of certain lasing transitions of $Er^{3+}$: BZCAP 1-5 glasses**

| SLJ | S'L'J' | BZCAP1 | | BZCAP2 | | BZCAP3 | | BZCAP4 | | BZCAP5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\tau_R$ | β | $\tau_R$ | β | $\tau_R$ | β | $\tau_R$ | B | $\tau_R$ | β |
| $^4F_{3/2}$ | $^4I_{15/2}$ | 45175 | 0.01 | 45424 | 0.01 | 40198 | 0.01 | 38797 | 0.01 | 36474 | 0.01 |
| | $^4I_{13/2}$ | 2149 | 0.13 | 2161 | 0.10 | 1913 | 0.11 | 1846 | 0.10 | 1735 | 0.10 |
| | $^4I_{11/2}$ | 404 | 0.57 | 379 | 0.52 | 336 | 0.52 | 323 | 0.52 | 302 | 0.51 |
| | $^4I_{9/2}$ | 283 | 0.30 | 238 | 0.37 | 211 | 0.37 | 203 | 0.37 | 188 | 0.38 |

Similar trends have been observed for various other $Er^{3+}$ doped glasses [27,28]. The electric dipole line strength ($S_{ed}$) and magnetic dipole line strength ($S_{md}$) for these band is related to the J-O parameters by the following eqs

The electric dipole line strength ($S_{ed}$) is given by

$$S_{ed}(JJ') = e^2 \sum \Omega_\lambda (\Psi J \| U^\lambda \| \Psi' J') \quad \longrightarrow \quad (6)$$

The magnetic dipole line strength ($S_{md}$) is given by

$$S_{md}(JJ') = \left(\frac{e\hbar}{4\pi mc}\right)^2 (\Psi J \| L + 2S \| \Psi' J')^2 \quad \longrightarrow \quad (7)$$

Table-6 shows that the values of $\Delta\lambda_{eff}$ of all the BZCAP 1-5 glasses. A large stimulated emission cross- section is related with low threshold and high gain amplifier applications. The stimulated emission cross- section can be calculated by the following eq

$$\sigma_{e=} \frac{\lambda_P^4}{8\pi c n^2} A(a_j, b_j) \quad \longrightarrow \quad (8)$$

**Table -6: Emission peak wavelengths ($\lambda_P$, nm),effective line widths ($\Delta\lambda_{eff}$, nm) and stimulated emission cross sections ($\sigma_e$, x$10^{-20}$cm$^2$) of $Er^{3+}$: BZCAP 1-5 glasses**

| Level | BZCAP1 | | | BZCAP2 | | | BZCAP3 | | | BZCAP4 | | | BZCAP5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $^4F_{3/2} \rightarrow$ | $\lambda_P$ | $\Delta\lambda_{eff}$ | $\sigma_e$ | $\lambda_P$ | $\Delta\lambda_{eff}$ | $\sigma_e$ | $\lambda_P$ | $\Delta\lambda_{eff}$ | $\sigma_e$ | $\lambda_P$ | $\Delta\lambda_{eff}$ | $\sigma_e$ | $\lambda_P$ | $\Delta\lambda_{eff}$ | $\sigma_e$ |
| $^4I_{13/2}$ | 1334 | 51.14 | 1.20 | 1331 | 54.44 | 1.11 | 1328 | 59.24 | 1.14 | 1331 | 56.57 | 1.25 | 1330 | 52.79 | 1.42 |
| $^4I_{11/2}$ | 1060 | 5.69 | 19.51 | 1063 | 8.86 | 13.73 | 1065 | 13.17 | 10.45 | 1060 | 33.59 | 4.18 | 1065 | 25.67 | 5.96 |
| $^4I_{9/2}$ | 900 | 56.10 | 0.55 | 904 | 54.442 | 0.84 | 904 | 54.30 | 0.94 | 907 | 45.08 | 1.21 | 909 | 41.24 | 1.45 |

The values of σe is dependent on the composition of the glasses considering into account the relation between the radiative lifetime $\tau_R$ and the refractive index [29], the σe increases with the magnetic transition. From Eqs 8 it is observed that σe is directly proportional to the spontaneous emission probability, $A_T$ and inversely proportional to the effective band width, $\Delta\lambda_{eff}$. It has been reported by Becker [30] that the refractive index increases with an increase CaO content. In the present work, the increase in the value of n (table-2) and $A_T$ (table-7) decreases in $\Delta\lambda_{eff}$ satisfies Eqs 8 which provides large σe

**Table-7: Electric dipole line strengths (S'$_{ed}$ cm$^2$ (x10$^{-22}$) and radiative transition probabilities A (s$^{-1}$) of certain lasing transitions of $Er^{3+}$: BZCAP1-5 glasses**

| Transition | | BZCAP1 | | BZCAP2 | | BZCAP3 | | BZCAP4 | | BZCAP5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | S'$_{ed}$ | A | S'$_{ed}$ | A | S'$_{ed}$ | A | S'$_{ed}$ | A | S'$_{ed}$ | A |
| $^4G_{11/2}$ | $^2H_{9/2}$ | 214 | 5 | 202 | 5 | 169 | 4 | 184 | 5 | 194 | 5 |
| | $^4F_{3/2}$ | 16 | 4 | 12 | 3 | 15 | 3 | 16 | 4 | 16 | 4 |
| | $^4F_{5/2}$ | 15 | 4 | 14 | 4 | 15 | 4 | 16 | 5 | 14 | 4 |
| | $^4F_{7/2}$ | 115 | 82 | 75 | 53 | 86 | 61 | 92 | 66 | 110 | 78 |
| | $_2H_{11/2}$ | 27 | 29 | 17 | 18 | 24 | 26 | 25 | 28 | 26 | 29 |
| | $_4S_{3/2}$ | 14 | 25 | 7 | 12 | 12 | 21 | 13 | 22 | 15 | 25 |
| | $^4F_{9/2}$ | 213 | 906 | 156 | 661 | 148 | 630 | 161 | 683 | 198 | 841 |
| | $^4I_{9/2}$ | 60 | 493 | 45 | 368 | 42 | 341 | 45 | 370 | 56 | 455 |
| | $^4I_{11/2}$ | 8 | 102 | 8 | 98 | 8 | 99 | 9 | 106 | 8 | 96 |
| | $^4I_{13/2}$ | 123 | 2775 | 99 | 2228 | 103 | 2319 | 110 | 2490 | 116 | 2618 |
| | $^4I_{15/2}$ | 589 | 31194 | 421 | 22307 | 424 | 22449 | 457 | 24220 | 551 | 29197 |
| $^2H_{9/2}$ | $^4F_{3/2}$ | 5 | 0 | 7 | 0 | 5 | 0 | 6 | 0 | 4 | 0 |
| | $^4F_{5/2}$ | 36 | 2 | 27 | 2 | 30 | 2 | 32 | 2 | 34 | 2 |
| | $^4F_{7/2}$ | 7 | 2 | 6 | 1 | 6 | 1 | 6 | 2 | 6 | 2 |
| | $^2H_{11/2}$ | 55 | 27 | 35 | 17 | 45 | 22 | 48 | 23 | 53 | 26 |
| | $^4S_{3/2}$ | 4 | 4 | 2 | 2 | 3 | 3 | 4 | 3 | 4 | 4 |
| | $^4F_{9/2}$ | 45 | 126 | 38 | 108 | 33 | 94 | 36 | 102 | 41 | 115 |
| | $^4I_{9/2}$ | 1 | 6 | 1 | 6 | 1 | 5 | 1 | 6 | 1 | 5 |
| | $^4I_{11/2}$ | 101 | 995 | 76 | 750 | 78 | 773 | 84 | 832 | 95 | 936 |
| | $^4I_{13/2}$ | 94 | 1830 | 92 | 1803 | 82 | 1599 | 89 | 1731 | 86 | 1675 |
| | $^4I_{15/2}$ | 22 | 1095 | 34 | 1673 | 25 | 1222 | 27 | 1336 | 19 | 942 |
| $^4F_{5/2}$ | $^4F_{7/2}$ | 59 | 1 | 48 | 1 | 45 | 1 | 49 | 1 | 55 | 1 |
| | $^2H_{11/2}$ | 27 | 3 | 32 | 3 | 28 | 3 | 30 | 3 | 25 | 3 |
| | $^4S_{3/2}$ | 7 | 2 | 5 | 1 | 5 | 2 | 6 | 2 | 7 | 2 |
| | $^4F_{9/2}$ | 78 | 137 | 77 | 136 | 77 | 135 | 83 | 145 | 73 | 129 |
| | $^4I_{9/2}$ | 22 | 109 | 20 | 98 | 20 | 98 | 21 | 105 | 21 | 102 |
| | $^4I_{11/2}$ | 25 | 226 | 14 | 123 | 22 | 198 | 23 | 209 | 25 | 227 |
| | $^4I_{13/2}$ | 61 | 1238 | 64 | 1289 | 61 | 1236 | 66 | 1329 | 57 | 1153 |
| | $^4I_{15/2}$ | 19 | 1122 | 32 | 1910 | 22 | 1300 | 24 | 1428 | 16 | 937 |
| $^4S_{3/2}$ | $^4F_{9/2}$ | 3 | 1 | 5 | 1 | 4 | 1 | 4 | 1 | 3 | 1 |
| | $^4I_{9/2}$ | 34 | 55 | 41 | 66 | 36 | 57 | 38 | 62 | 31 | 50 |
| | $^4I_{11/2}$ | 8 | 31 | 12 | 50 | 9 | 35 | 10 | 39 | 6 | 26 |
| | $^4I_{13/2}$ | 29 | 374 | 50 | 637 | 34 | 434 | 37 | 476 | 24 | 313 |
| | $^4I_{15/2}$ | 19 | 953 | 33 | 1622 | 22 | 1104 | 24 | 1212 | 16 | 796 |
| $^4F_{9/2}$ | $^4I_{9/2}$ | 55 | 3 | 41 | 2 | 38 | 2 | 41 | 2 | 51 | 3 |
| | $^4I_{11/2}$ | 102 | 35 | 171 | 58 | 117 | 40 | 128 | 44 | 85 | 29 |
| | $^4I_{13/2}$ | 37 | 72 | 24 | 46 | 32 | 63 | 34 | 66 | 37 | 71 |
| | $^4I_{15/2}$ | 131 | 1457 | 107 | 1195 | 123 | 1376 | 132 | 1467 | 126 | 1403 |
| $^4I_{9/2}$ | $^4I_{11/2}$ | 30 | 1 | 27 | 1 | 29 | 1 | 31 | 1 | 28 | 1 |
| | $^4I_{13/2}$ | 66 | 42 | 108 | 69 | 75 | 48 | 82 | 53 | 55 | 35 |
| | $^4I_{15/2}$ | 38 | 241 | 19 | 118 | 33 | 208 | 35 | 219 | 38 | 243 |
| $^4I_{11/2}$ | $^4I_{13/2}$ | 95 | 13 | 140 | 19 | 103 | 14 | 113 | 15 | 82 | 11 |
| | $^4I_{15/2}$ | 60 | 182 | 85 | 255 | 64 | 192 | 69 | 209 | 53 | 159 |
| $^4I_{13/2}$ | $^4I_{15/2}$ | 153 | 105 | 224 | 154 | 166 | 114 | 181 | 125 | 133 | 91 |

One of most important parameters influencing the laser performance of a material is the emission cross- section. When emission transition bridges the first excited multiplet it can be conveniently evaluated by reciprocity method which relates absorption cross-section and emission cross-section. To assess the emission cross-section for transition ending on the excited multiplets the Fuchtbauer- Laden-burg method is commonly used [31].

**FTIR Spectral Analysis**

Vibrational Spectra of lead calcium zinc borate glasses (BZCAP 1-5) are shown in fig-2. The present work explains about the weak peak at 476,491 cm-1 is due to the stretching vibration in Pbo4, B-O-B and Pb-O-B bending vibration as well as borate ring deformation of $Pb^{2+}$ ions in the glasses. All these Assignments agree well with the literature values [32- 35]. The peaks of FTIR spectra are presented in table-1.

## CONCLUSION

A novel multi component Erbium doped lead borate glasses were developed by compositionally varying the constituent heavy metal oxides PbO and CaO. The measured oscillator strengths (f) have been studied within the frame work of J-O theory to determine the J-O parameters $\Omega_2$, $\Omega_4$ and $\Omega_6$. The large $\Omega_2$ values (table-4) are probably due to the covalent nature of the lead borate glasses. Using the J-O parameters the total radiative transition rates, radiative lifetimes, branching ratios have been theoretically calculated for all the excited states. The inter electronic repulsion parameter ratios E1/E3 and E2/E3 observed in all the compositionally varied glasses do not deviate much from the hydrogenic ratios and indicate that the radial properties (radial distribution function) of all these glasses are similar. The higher values obtained for $\Omega_2$ in all glasses indicate that the $Er^{3+}$ ion is subjected to higher covalency with low asymmetry. From our analysis it is suggested that the BZCAP 2 glass is a good lasing candidature among all the other glasses.

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