Dy$^{3+}$ Doped Glasses For White Light Applications: A Short Review


Abstract: Recently published various Dy$^{3+}$ ions doped glass materials were taken for analysis to understand their white light emission behavior and to correlate that behavior with their optical properties. The structural properties of the materials were analyzed using their Judd-Ofelt (JO) intensity parameters. All the selected glasses have shown coherent nature for the Dy$^{3+}$-Oxygen bond and low symmetry around Dy$^{3+}$ ion sites. The colour coordinates (X, Y) which are crucial in understanding white light behavior have found a relation with the optical property stimulated emission cross-section of the selected glasses. The glasses with higher $\sigma_\alpha$ values have the colour coordinates of X and Y > 0.4 which are far from the standard colour coordinates (X=0.333, Y=0.333) and the glasses with lesser $\sigma_\alpha$ values have the colour coordinates of X and Y < 0.4 which are nearer to the standard colour coordinates (X=0.333, Y=0.333).

Index Terms: Colour coordinates, Covalent nature, Dy$^{3+}$ ions doped glasses, Judd-Ofelt intensity parameters, Low symmetry, Stimulated emission cross-section, Y/B ratio.

1. INTRODUCTION

Under the Solid-State Lightening (SSL) devices category, Dy$^{3+}$ ions doped glasses have been investigating for white light emitting material applications as the SSL devices have enormous advantages in the field of lightening devices such as low energy consumption, ease of control, small in size, reduced carbon emission, unidirectional distribution, cool beam and colour rendering that can be very high and comparable to high fluorescent lamps with high colour rendering index (CRI), long life and high performance in cold environmental conditions etc. [1-9]. Among the available Rare Earth (RE) ions, especially Dy$^{3+}$ ion can produce white light through combination of its intense yellow and blue emissions. The yellow to blue intensity (Y/B) ratio from emission transitions $^4F_{9/2} \rightarrow ^6H_{13/2}$ (electric dipole) and $^4F_{9/2} \rightarrow ^6H_{15/2}$ (magnetic dipole) of Dy$^{3+}$ ions in a glass system can influence the quality of emitting white light from the glass material [10-12]. Particularly, the intensity of the hypersensitive emission transition $^4F_{9/2} \rightarrow ^6H_{13/2}$ which obeys the selection rule $|\Delta L| \leq 2$ and $|\Delta J| \leq 2$ depends on the nature of the glass system and the ligand environment around the Dy$^{3+}$ ion in that glass system. So, the generation of white light from Dy$^{3+}$ ions doped glasses can be manipulated or tuned by altering the combinations of chemical compositions of the glass system [10-15].

As the white light emission from Dy$^{3+}$ glasses can be greatly altered by the selected glass composition, we have vast variety of glass bases to tailor the white light emission from Dy$^{3+}$ ions [1,8,16-25]. The glasses like Borate glasses, Phosphate glasses, Silicate glasses, Boro-Silicate glasses, Oxide glasses, Oxyfluoride glasses, Tellurite glasses, Boro-Tellurite glasses, Boro-Aluminate glasses etc. have their own advantages as well as disadvantages in case of properties like Phonon energy, Optical stability, Chemical durability, Physical strength etc [9,11,26-30]. In this study, we have selected a set of available Dy$^{3+}$ ions doped glasses from the literature to analyse the white light emission capabilities with help of their optical properties and to compare them with our earlier study of AEBTDy1.0 glass [1].

2 METHOD OF SYNTHESIS

All the glasses that are chosen for this analysis are prepared by simple conventional melt quenching technique. In melt quenching technique the glasses are usually prepared by melting the homogeneous mixture of selected chemical compositions in an electrical furnace and after air quenching the melts by pouring on the pre heated moulds.

3 ANALYSIS OF DIFFERENT DY$^{3+}$ DOPED GLASSES FOR WHITE LIGHT APPLICATIONS

A set of glasses doped with Dy$^{3+}$ ions from various published studies are taken to compare their fitness as white light emitting materials with our recently published AEBTDy1.0 glass [1]. The selected glass compositions for this analysis are as follows:

AEBTDy1.0 [1] = 60B$_2$O$_3$-15TeO$_2$-9CaO-5MgO-5Al$_2$O$_3$-5TiO$_2$-1Dy$_2$O$_3$ (Alkaline-Earth Boro Tellurite glass)

G2 glass [2] = 20La$_2$O$_3$-10CaF$_2$-69P$_2$O$_5$-1Dy$_2$O$_3$ (Lanthanum Calcium Phosphate oxyfluoride glass)

BPB0.5D [3] = 30B$_2$O$_3$-24.5P$_2$O$_5$-5Al$_2$O$_3$-10PbO-10ZnF$_2$-20Bi$_2$O$_3$-0.5Dy$_2$O$_3$ (Oxyfluoro-borophosphate glass)

TJKCDy05 [4] = 61.5TeO$_2$-25ZnO-8K$_2$O-5CaO-0.5Dy$_2$O$_3$ (Tellurite glass)

TBZnD [5] = 30TeO$_2$-29.5B$_2$O$_3$-20ZnO-20ZnF$_2$-0.5Dy$_2$O$_3$ (Telluroborate Glass)

LBGS-0.5Dy [6] = 40La$_2$O$_3$-0.5BaO-0.5Gd$_2$O$_3$-49.5SiO$_2$-0.5Dy$_2$O$_3$ (LBGS glass)

BGGD1.00 [7] = 30B$_2$O$_3$-40GeO$_2$-29Gd$_2$O$_3$-1Dy$_2$O$_3$ (Gadolinium Borogermanate glass)

Dy:BaAS [8] = 35BaO-10Al$_2$O$_3$-55SiO$_2$, 1x10$^{20}$ Dy$^{3+}$/cm$^3$ (Alkaline-Earth Alumino Silicate glass)

TBZDy0.5 [9] = 69.5TeO$_2$-20B$_2$O$_3$-10ZnO-0.5Dy$_2$O$_3$ (Zinc Borotellurite glass)

Glass B [10] = 10Li$_2$O-10PbO-9.5Al$_2$O$_3$-70B$_2$O$_3$-0.5Dy$_2$O$_3$ (Lithium Lead Alumino Borate glass)

BPA0.5D [11] = 45H$_3$BO$_3$-24.5H$_2$NO$_3$P-15K$_2$CO$_3$-10ZnF$_2$...
5Al₂O₃-0.5Dy₂O₃ (Aluminofluoroborophosphate glass)
BiNFB0.5D [12] = 41Bi₂O₃·20Bi₂O₃·19.5Na₂O·19CaF₂·0.5Dy₂O₃ (Bismuth Sodiumfluoroborate glass)

Various properties of the above-mentioned glasses are tabulated in Table.1 and Table.2.

**TABLE 1**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ω₂</th>
<th>Ω₄</th>
<th>Ω₆</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEBT-Dy1.0</td>
<td>497</td>
<td>296</td>
<td>157</td>
<td>Ω₂ &gt; Ω₄ &gt; Ω₆</td>
</tr>
<tr>
<td>G2 glass</td>
<td>1725</td>
<td>462</td>
<td>460</td>
<td>Ω₂ &gt; Ω₄ &gt; Ω₆</td>
</tr>
<tr>
<td>BPB0.5D</td>
<td>500</td>
<td>144</td>
<td>106</td>
<td>Ω₂ &gt; Ω₄ &gt; Ω₆</td>
</tr>
<tr>
<td>TBZnD</td>
<td>500</td>
<td>43</td>
<td>15</td>
<td>Ω₂ &gt; Ω₄ &gt; Ω₆</td>
</tr>
<tr>
<td>LBGS-0.5Dy</td>
<td>832</td>
<td>214</td>
<td>275</td>
<td>Ω₂ &gt; Ω₄ &gt; Ω₆</td>
</tr>
<tr>
<td>LBGS0.5Dy</td>
<td>365</td>
<td>65</td>
<td>157</td>
<td>Ω₂ &gt; Ω₄ &gt; Ω₆</td>
</tr>
<tr>
<td>DyBaAS [8]</td>
<td>753</td>
<td>50</td>
<td>115</td>
<td>Ω₂ &gt; Ω₄ &gt; Ω₆</td>
</tr>
<tr>
<td>TBZDy0.5</td>
<td>1432</td>
<td>564</td>
<td>264</td>
<td>Ω₂ &gt; Ω₄ &gt; Ω₆</td>
</tr>
</tbody>
</table>

Table.1 represents the Judd-Ofelt (J-O) intensity parameters and their trend of various Dy³⁺ doped glasses [1-9] which were derived from the absorption spectra of the glasses that are mentioned in Figure.1. The intensity parameters share the information about structural environment and bonding around Dy³⁺ ion. Here, all the selected glasses have the larger Ω₂ values compared to other two Ω₄ and Ω₆. This domination of Ω₂ over Ω₄ and Ω₆ reveals the covalent nature of the ligand and Dy³⁺ bond as well as low symmetry around Dy³⁺ ion sites. The obtained Ω₂ values reveal that the selected glasses have low symmetry around the Dy³⁺ ions and covalent bond between Dy³⁺ ion and oxygen. The important optical properties such as stimulated emission cross-section (σₑ), gain band width (σₑ × Δλₑ), optical gain (σₑ × τₑ), experimental lifetimes (τₑ), radiative lifetimes (τᵣ), quantum efficiencies (η), non-radiative relaxation rates (WNR) of ⁴F₃/₂ → ⁴I₅/₂ level and CIE Chromaticity coordinates (X and Y), Y/B ratios of various Dy³⁺ doped glasses are presented in Table.2 [1,3,5-12]. The emission spectra, Decay spectra and the colour coordinate diagrams of the selected glass systems are represented in Figure.2, Figure.3 and Figure.4 respectively. The white light emission capability of Dy³⁺ doped glasses can be related to few important optical parameters such as chromaticity coordinates (X, Y), Y/B ratios, quantum efficiency.
and stimulated emission cross-section etc. For a good white light emitting material, the coordinates should be (0.333, 0.333). The higher magnitudes of Y/B ratios indicate lower symmetry around the Dy³⁺ ion sites and high covalency of the Dy-O bond. The higher values of stimulated emission cross-section and quantum efficiency indicate good lasing potentialities of the material. If we observe the Table.2, the Alkaline-Earth Boro tellurite glass AEBTDy1.0 of our previous study attained the colour coordinates as (0.362, 0.387), Y/B ratio as 3.20, \( \sigma_{se} \) as 36.59 \( \times 10^{-22} \) cm\(^2\) and \( \eta \) as 85%. Compared to other selected glasses such as BPB0.5D (Oxyfluoro-borophosphate glass), LBGS-0.5Dy (LBGS glass), BGGD1.00 (Gadolinium Borogermanate glass), Dy:BaAS (Alkaline-Earth Aluminosilicate glass), TBZDy0.5 (Zinc Borotellurite glass), BPA0.5D (Aluminofluoroborophosphate glass) and BiNFB0.5D (Bismuth Sodiumfluoroborate glass), the AEBTDy1.0 glass has better colour coordinates that are nearer to standard coordinates (0.333, 0.333) and the same glass has lower stimulated emission cross-section value compared to BPB0.5D (Oxyfluoro-borophosphate glass), LBGS-0.5Dy (LBGS glass), TBZDy0.5 (Zinc Borotellurite glass), BPA0.5D (Aluminofluoroborophosphate glass) and BiNFB0.5D (Bismuth Sodiumfluoroborate glass). If we keenly observe the Table.2, the glasses with colour coordinates of \( X > 0.4 \) and \( Y > 0.4 \) have higher \( \sigma_{se} \) values and the glasses with colour coordinates of \( X < 0.4 \) and \( Y < 0.4 \) have lesser \( \sigma_{se} \) values. So, from this trend of selected glasses, the stimulated emission cross-section and the colour coordinates of the selected glasses are inversely proportional. Since, the higher value \( \sigma_{se} \) gives the better lasing potentialities to the material, we can draw a conclusion that the glasses may yield better white light emission with low lasing potentialities i.e. low \( \sigma_{se} \) values.

### 4 CONCLUSIONS

Hence, various reported Dy³⁺ doped glasses were analyzed using their optical properties to understand their white light emission behavior. The glasses taken for analysis displayed low symmetry around Dy³⁺ ion and covalent nature for Dy³⁺-O bond. The glasses with colour coordinates of \( X \) and \( Y > 0.4 \) have larger \( \sigma_{se} \) values and the glasses with colour coordinates of \( X \) and \( Y < 0.4 \) have lesser \( \sigma_{se} \) values. Thus, from the trend of \((X, Y)\) coordinates and \( \sigma_{se} \) values of the selected glasses, we may conclude that the both parameters are inversely proportional and the glasses with less \( \sigma_{se} \) values may emit pure white light.

### REFERENCES


[19] A. Venkateswara Rao, B.R. Kumar, S.D. Ramarao, Structural, microstructural and electrochemical studies on LiMn$_{1-x}$(GdAl)$_x$O$_4$ with spinel structure as cathode material for Li-ion batteries, Ceramics International. 44 (2018) 15116–15123.

[20] A. Ramakrishna, N. Murali, S.J. Margarette, T. Wegayehu Mammo, N. Krishna Jyothi, B. Sailaja, Ch.C. Sailaja Kumari, K. Samatha, V. Veeraiah, Studies on structural, magnetic, and DC electrical resistivity of Cobalts substituted Co0.5Mo0.37Cu0.13Fe$_{4-x}$O$_{4}$ (M = Ni, Zn and Mg) ferrite nanoparticle systems, Advanced Powder Technology. 29 (2018) 2601–2607.


