

Structural and Spectral Analysis of Dy³⁺ ions doped Phosphate Glasses for White Light Laser Applications

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ABSTRACT: Glass of the system: (40-x)P₂O₅: 10ZnO: 10Li₂O: 10Na₂O: 10CaO: 10WO₃: 10Yb₂O₃:xDy₂O₃, (where x=1, 1.5,2 mol %) have been prepared by melt-quenching technique. The amorphous nature of the prepared glass samples was confirmed by X-ray diffraction. Raman, Optical absorption and fluorescence spectra were recorded at room temperature for all glass samples. Judd-Ofelt intensity parameters Ω_λ ($\lambda=2, 4$ and 6) are evaluated from the intensities of various absorption bands of optical absorption spectra. The radiative properties like spontaneous emission probability (A), branching ratio (β), radiative life time(τ_R),stimulated emission cross-section(σ_p)and thermal properties have been evaluated.

KEYWORDS: YZLSLTP Glasses, Optical Properties, Judd-Ofelt Theory, Raman Analysis.

I. INTRODUCTION

Tripositive rare earth ions have several attractive spectroscopic properties which give them wide applicability and versatility for laser action [1-5]. The glasses doped with rare earth elements are widely used in different fields such as fluorescent lamps, displays, lasers and medical diagnostic devices, due to their luminescent properties. Transparent glass-ceramic as host materials for active optical ions have attracted great interest recently due to their potential application in optical devices such as optical fiber amplifiers and frequency-conversion materials [6-8]. Among different host matrices, phosphate glasses are quite prone with the advantages such as low non-linear refractive index, good physical and chemical stability and high transparency from near Ultra Violet to mid-Infrared region [9-11]. Phosphate glasses have a best thermo-optical performance with considerable chemical durability, high gain as with low energy back transfer and weak upconversion [12, 13]. They present superior properties that include high refractive index, high transparency, low melting point, high thermal stability, high gain density and high thermal expansion coefficient [14-16]. Phosphate glasses are very well known for their suitable chemical homogeneity, and excellent optical properties [17-19]. The addition of network modifier (NWF) Li₂O is to improve both electrical and mechanical properties of such glasses. Phosphate glasses also exhibit high RE ions solubility [20].

The present work reports on the preparation and characterization of rare earth doped heavy metal oxide (HMO) glass systems for lasing materials. I have studied on the absorption and emission properties of Dy³⁺ doped Ytterbium zinc lithium sodalime tungsten phosphate glasses. The intensities of the transitions for the rare earth ions have been estimated successfully using the Judd-Ofelt theory, The laser parameters such as radiative probabilities(A),branching ratio (β), radiative life time(τ_R) and stimulated emission cross section(σ_p) are evaluated using J.O.intensity parameters(Ω_λ , $\lambda=2,4$ and 6).

II. EXPERIMENTAL TECHNIQUES

Preparation of glasses

The following Dy³⁺doped borophosphate glass samples (40-x) P₂O₅:10PbO:10Li₂O:10 K₂O: 10Nb₂O₅:20B₂O₃: xDy₂O₃, (where x=1,1.5 and 2 mol%) have been prepared by melt-quenching method. Analytical reagent grade chemical used in the present study consist of P₂O₅, PbO, Li₂O, K₂O, Nb₂O₅, B₂O₃ and Dy₂O₃. They were thoroughly mixed by using an agate pestle mortar. then melted at 1055°C by an electrical muffle furnace for 2h., After complete melting, the melts were quickly poured in to a preheated stainless steel mould and annealed at temperature of 350°C for 2h to remove thermal strains and stresses. Every time fine powder of cerium oxide was used for polishing the samples. The glass

samples so prepared were of good optical quality and were transparent. The chemical compositions of the glasses with the name of samples are summarized in **Table 1**.

Table 1

Chemical composition of the glasses

Sample	Glass composition (mol %)
YZLSLTP (UD)	40P ₂ O ₅ : 10ZnO: 10Li ₂ O: 10Na ₂ O: 10CaO: 10WO ₃ : 10Yb ₂ O ₃
YZLSLTP DY(1.0)	39P ₂ O ₅ : 10ZnO: 10Li ₂ O: 10Na ₂ O: 10CaO: 10WO ₃ : 1 Dy ₂ O ₃ .
YZLSLTP DY(1.5)	38.5P ₂ O ₅ : 10ZnO: 10Li ₂ O: 10Na ₂ O: 10CaO: 10WO ₃ :1.5 Dy ₂ O ₃ .
YZLSLTP DY(2.0)	38P ₂ O ₅ : 10ZnO: 10Li ₂ O: 10Na ₂ O: 10CaO: 10WO ₃ :2Dy ₂ O ₃ .

YZLSLTP (UD) -Represents undoped Ytterbium zinc lithium sodalime tungsten phosphate glass specimens.

YZLSLTP (DY) -Represents Dy³⁺ doped Ytterbium zinc lithium sodalime tungsten phosphate glass specimens.

III.THEORY

3.1 Oscillator Strength

The intensity of spectral lines are expressed in terms of oscillator strengths using the relation [21].

$$f_{\text{expt.}} = 4.318 \times 10^{-9} \int \epsilon(\nu) d\nu \quad (1)$$

where, $\epsilon(\nu)$ is molar absorption coefficient at a given energy ν (cm⁻¹), to be evaluated from Beer–Lambert law.

Under Gaussian Approximation, using Beer–Lambert law, the observed oscillator strengths of the absorption bands have been experimentally calculated [22], using the modified relation:

$$P_m = 4.6 \times 10^{-9} \times \frac{1}{cl} \log \frac{I_0}{I} \times \Delta\nu_{1/2} \quad (2)$$

where c is the molar concentration of the absorbing ion per unit volume, l is the optical path length, $\log I_0/I$ is optical density and $\Delta\nu_{1/2}$ is half band width.

3.2. Judd-Ofelt Intensity Parameters

According to Judd [23] and Ofelt [24] theory, independently derived expression for the oscillator strength of the induced forced electric dipole transitions between an initial J manifold $|4f^N(S, L) J\rangle$ level and the terminal J' manifold $|4f^N(S', L') J'\rangle$ is given by:

$$\frac{8\pi^2 mc\nu}{3h(2J+1)n} \frac{1}{n} \left[\frac{(n^2+2)^2}{9} \right] \times S(J, J') \quad (3)$$

Where, the line strength $S(J, J')$ is given by the equation

$$S(J, J') = e^2 \sum_{\lambda=2,4,6} \Omega_{\lambda} \langle 4f^N(S, L) J \| U^{(\lambda)} \| 4f^N(S', L') J' \rangle^2 \quad (4)$$

In the above equation m is the mass of an electron, c is the velocity of light, ν is the wave number of the transition, h is Planck's constant, n is the refractive index, J and J' are the total angular momentum of the initial and final level respectively, Ω_{λ} ($\lambda=2,4$ and 6) are known as Judd-Ofelt intensity parameters .

3.3 Radiative Properties

The Ω_λ parameters obtained using the absorption spectral results have been used to predict radiative properties such as spontaneous emission probability (A) and radiative life time (τ_R), and laser parameters like fluorescence branching ratio (β_R) and stimulated emission cross section (σ_p).

The spontaneous emission probability from initial manifold $|4f^N(S', L') J\rangle$ to a final manifold $|4f^N(S, L) J\rangle$ is given by:

$$A[(S', L') J'; (S, L) J] = \frac{64 \pi^2 \nu^3}{3h(2J'+1)} \left[\frac{n(n^2+2)^2}{9} \right] \times S(J', \bar{J}) \quad (5)$$

$$\text{Where, } S(J', J) = e^2 [\Omega_2 \|U^{(2)}\|^2 + \Omega_4 \|U^{(4)}\|^2 + \Omega_6 \|U^{(6)}\|^2]$$

The fluorescence branching ratio for the transitions originating from a specific initial manifold $|4f^N(S', L') J\rangle$ to a final manifold $|4f^N(S, L) J\rangle$ is given by

$$\beta[(S', L') J'; (S, L) J] = \sum_{S, L, J} \quad (6)$$

where, the sum is over all terminal manifolds.

The radiative life time is given by

$$\tau_{rad} = \sum_{S, L, J} A[(S', L') J'; (S, L) J] = \quad (7)$$

where, the sum is over all possible terminal manifolds. The stimulated emission cross-section for a transition from an initial manifold $|4f^N(S', L') J\rangle$ to a final manifold

$|4f^N(S, L) J\rangle$ is expressed as

$$\sigma_p(\lambda_p) = \left[\frac{\lambda_p^4}{8\pi c n^2 \Delta\lambda_{eff}} \right] \times A[(S', L') J'; (\bar{S}, \bar{L}) \bar{J}] \quad (8)$$

where, λ_p the peak fluorescence wavelength of the emission band and $\Delta\lambda_{eff}$ is the effective fluorescence line width.

IV. RESULT AND DISCUSSION

4.1 XRD Measurement

Figure 1 presents the XRD pattern of the sample contain P_2O_5 which is show no sharp Bragg's peak, but only a broad diffuse hump around low angle region. This is the clear indication of amorphous nature within the resolution limit of XRD instrument.

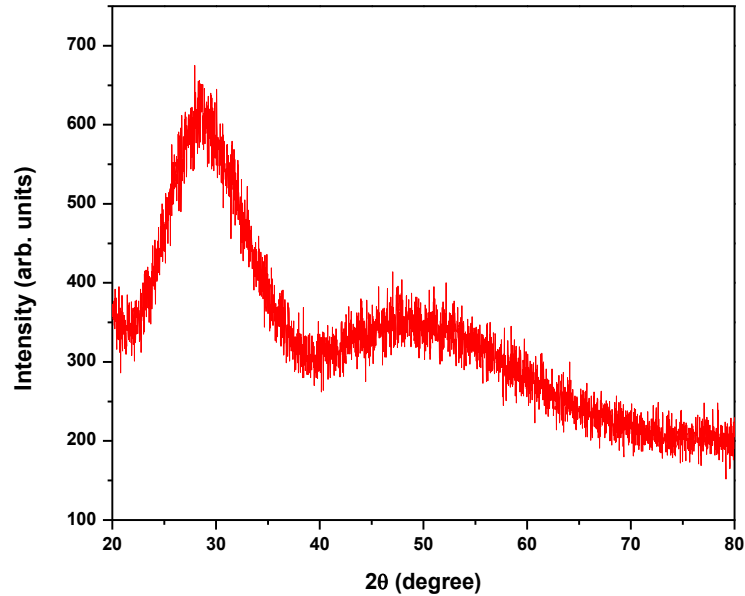


Fig. 1 X-ray diffraction pattern of YZLSLTP DY(1.0) glass.

4.2 Raman Spectrum

Figure 2 shows the thermal properties of YZLSLTP DY(1.0) glass from 300⁰C to 1000⁰C. From the DSC curve of present glasses system, I can find out that no crystallization peak is apparent and the glass transition temperature T_g are 353⁰C, 456⁰C and 586⁰C respectively. The T_g increase with the contents of Dy₂O₃ increase. I could conclude that thermal properties of the YZLSLTP glass are good for fiber drawing from the analysis of DSC curve.

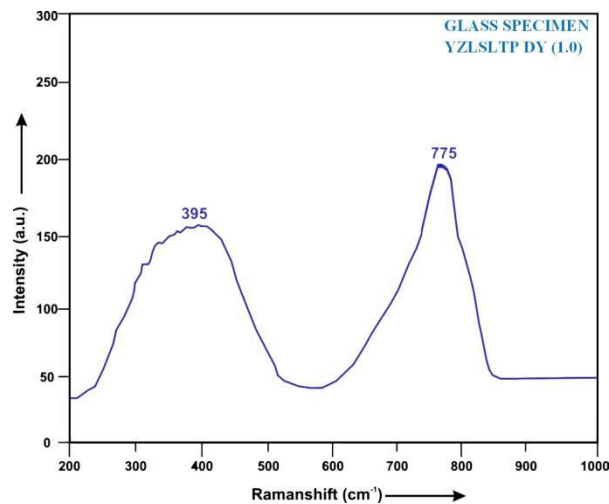


Fig.2: Raman Spectrum of YZLSLTP DY(1.0) glass.

4.3 Absorption Spectrum

The absorption spectra of YZLSLTP DY(1.0) glass specimen has been presented in Figure 3 in terms of Intensity versus wavelength. Thirteen absorption bands have been observed from the ground state ⁶H_{15/2} to excited states ⁶H_{13/2}, ⁶H_{11/2}, ⁶H_{9/2}+⁶F_{11/2}, ⁶H_{7/2}+⁶F_{9/2}, ⁶F_{7/2}+⁶H_{5/2}, ⁶F_{5/2}, ⁶F_{3/2}, ⁶F_{9/2}, ⁴I_{15/2}, ⁴G_{11/2}, ⁶F_{7/2}+⁴I_{13/2}, ⁶M_{19/2}+⁴(P,D)_{3/2} and ⁴G_{9/2}+⁶P_{3/2} for YZLSLTP DY(1.0)glass.

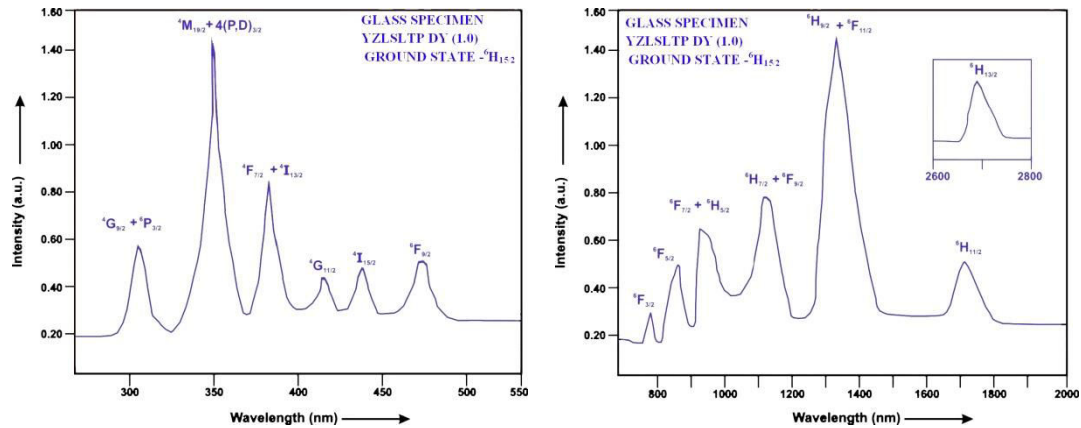


Fig (3) Absorption spectrum of YZLSLTP DY(1.0)glass.

The experimental and calculated oscillator strength for Dy³⁺ ions in YZLSLTP glasses are given in Table 2.

Table 2: Measured and calculated oscillator strength ($P_m \times 10^6$) of Dy³⁺ ions in YZLSLTP glasses.

Energy level from ⁶ H _{15/2}	Glass YZLSLTP DY(1.0)		Glass YZLSLTP DY(1.5)		Glass YZLSLTPDY(2.0)	
	P _{exp.}	P _{cal.}	P _{exp.}	P _{cal.}	P _{exp.}	P _{cal.}
⁶ H _{13/2}	3.46	3.14	3.42	3.12	3.39	3.11
⁶ H _{11/2}	2.74	3.17	2.71	3.14	2.69	3.13
⁶ H _{9/2} + ⁶ F _{11/2}	11.92	11.96	11.89	11.93	11.86	11.90
⁶ H _{7/2} + ⁶ F _{9/2}	6.96	6.68	6.92	6.64	6.90	6.62
⁶ F _{7/2} + ⁶ H _{5/2}	5.99	5.80	5.97	5.75	5.95	5.73
⁶ F _{5/2}	2.87	2.91	2.84	2.88	2.81	2.86
⁶ F _{3/2}	1.09	0.55	1.07	0.54	1.05	0.54
⁶ F _{9/2}	1.12	0.45	1.08	0.44	1.06	0.44
⁴ I _{15/2}	1.17	1.14	1.15	1.13	1.12	1.12
⁴ G _{11/2}	0.99	0.14	0.96	0.14	0.92	0.14
⁶ F _{7/2} + ⁴ I _{13/2}	4.90	5.14	4.87	5.10	4.84	5.08
⁶ M _{19/2} + 4(P,D)3/2	8.98	10.49	8.96	10.47	8.92	10.46
⁴ G _{9/2} + ⁶ P _{3/2}	2.85	3.12	2.82	3.09	2.78	3.08
r.m.s. deviation	0.5745		0.5663		0.5669	

The values of Judd-Ofelt intensity parameters are given in Table 3.

Table 3: Judd-Ofelt intensity parameters for Dy³⁺ doped YZLSLTP glass specimens

Glass Specimen	$\Omega_2(\text{pm}^2)$	$\Omega_4(\text{pm}^2)$	$\Omega_6(\text{pm}^2)$	Ω_4 / Ω_6
YZLSLTP DY(1.0)	3.645	1.307	2.448	0.5339
YZLSLTP DY(1.5)	3.629	1.313	2.422	0.5421
YZLSLTP DY(2.0)	3.613	1.317	2.406	0.5474

4.4 Excitation Spectrum

The Excitation spectra of YZLSLTP DY(1.0)glass specimens have been presented in Figure 4 in terms of Excitation Intensity versus wavelength. The excitation spectrum was recorded in the spectral region 315–465 nm fluorescence at 575nm having different excitation band centered at 321,354, 365, 385, 425, 455 and 473 nm are attributed to the ⁶P_{3/2},

${}^6P_{7/2}$, ${}^4P_{3/2}$, ${}^4I_{13/2}$, ${}^4G_{11/2}$, ${}^4I_{15/2}$ and ${}^4F_{9/2}$ transitions, respectively. The highest absorption level is ${}^4I_{13/2}$ and is at 385nm. So this is to be chosen for excitation wavelength.

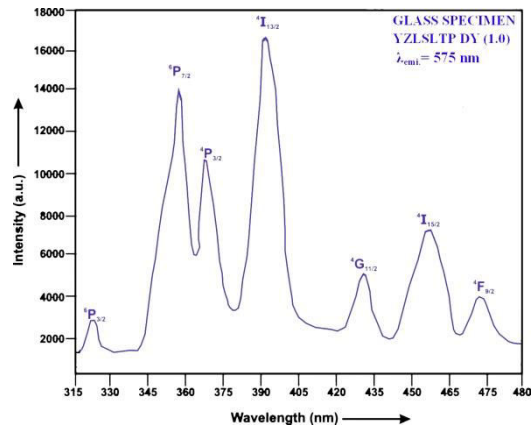


Fig (4) Excitation spectrum of YZLSLTP DY(1.0) glass.

4.5. Fluorescence Spectrum

The fluorescence spectrum of YZLSLTP DY(1.0) glass is shown in Figure 5. There are four broad bands observed in the Fluorescence spectrum of YZLSLTP DY(1.0) Ytterbium zinc lithium sodalime tungsten phosphate glass. The wavelengths of these bands along with their assignments are given in Table 4. The peak with maximum emission intensity appears at 485nm, 575 nm, 665nm and 752 nm and corresponds to the (${}^4F_{9/2} \rightarrow {}^6H_{15/2}$), (${}^4F_{9/2} \rightarrow {}^6H_{13/2}$), (${}^4F_{9/2} \rightarrow {}^6H_{11/2}$) and (${}^4F_{9/2} \rightarrow {}^6H_{9/2}$) transitions.

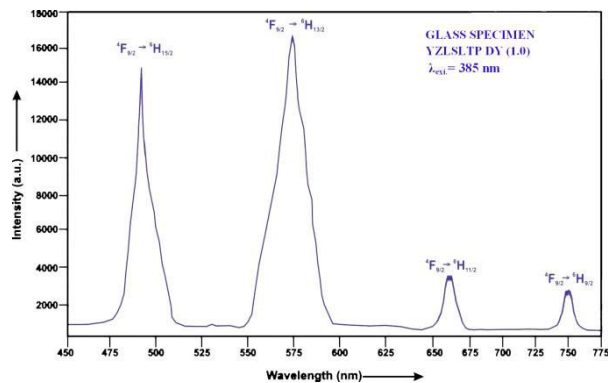


Fig (5) Fluorescence spectrum of doped YZLSLTP DY(1.0) glass.

Table4: Emission peak wave lengths (λ_p),radiative transition probability (A_{rad}),branching ratio (β),stimulated emission cross-section(σ_p) and radiative life time(τ_R) for various transitions in Dy³⁺ doped YZLSLTP glasses.

Transition	YZLSLTP DY(1.0)					YZLSLTP DY (1.5)				YZLSLTP DY (2.0)			
	λ_{max} (nm)	$A_{rad}(s^{-1})$	β	$\sigma_p (10^{-20} cm^2)$	$\tau_R(\mu s)$	$A_{rad}(s^{-1})$	β	$\sigma_p (10^{-20} cm^2)$	$\tau_R (\mu s)$	$A_{rad}(s^{-1})$	β	$\sigma_p (10^{-20} cm^2)$	$\tau_R (10^{-20} cm^2)$
⁴ F _{9/2} → ⁶ H _{15/2}	485	127.06	0.2237	0.226	1760.49	126.11	0.2231	0.218	1769.10	125.63	0.2229	0.213	1774.36
⁴ F _{9/2} → ⁶ H _{13/2}	575	374.97	0.6601	1.360		373.35	0.6605	1.316		372.31	0.6606	1.277	
⁴ F _{9/2} → ⁶ H _{11/2}	665	37.60	0.0662	0.166		37.48	0.0663	0.163		37.39	0.0663	0.160	
⁴ F _{9/2} → ⁶ H _{9/2}	752	28.40	0.0499	0.171		28.31	0.0501	0.168		28.26	0.0502	0.164	

V. CONCLUSION

In the present study, the glass samples of composition (40-x)P2O5: 10ZnO: 10Li2O: 10Na2O: 10CaO: 10WO3: 10Yb2O3:xDy2O3 (where x =1, 1.5and 2mol %) have been prepared by melt-quenching method. The value of stimulated emission cross-section (σ_p) is found to be maximum for the transition (4F9/2→6H13/2) for all glass specimens. This shows that (4F9/2→6H13/2) transition is most probable transition and useful for White Light Laser Applications.

REFERENCES

- Meena,S.L.(2026). Spectral, Transmittance and Thermal Analysis of Tb³⁺ doped Ytterbium Zinc Lithium Calcium Borogermanate glasses, IOSR Appl.Phys.18,31-18.
- Kaur,R.B.R.,Kumar,A.(2021).Physical,optical,structural and thermoluminescence behavior of borosilicate glass doped with trivalent neodymium ions,Opt.Mat.117,1-13.
- Elias,A.M.,Mwanga,S.F.,Mwankcmwa,B.,Anjaiah,J.,Laxmikanth,C.(2022).Influence of Bi⁺ ions on photoluminescence properties of Tm₂O₃ doped borotellurite glasses for the near-infrared emission applications,Opt.Mat.125,112140.
- Gowda,G.V.J.,Reddy,G.V.A.,Eraiah,B.,Devaraja,C.R.(2023).Investigation of structural modification,physical and optical properties of lead boro-tellurite glasses doped with europium trioxide for possible optical switching applications,J.Met.Min.33,65-74.
- Meena,S.L.(2025). Spectral and Thermal properties of Eu³⁺ doped Ytterium Zinc Lithium Alumina Tungsten Potassiumniobate Bismuth Borate Glasses with low Hruby’s criterion, IOSR Appl.Phys.17,48-54
- Meena, S.L.(2026).Spectral, Thermal and Raman analysis of Tm³⁺ doped in phosphate glasses for optical temperature sensor applications, IOSR Appl.Phys.18,42-30.
- Zhang,L.,Peng,M.,Dong,G.,Qiu,J.(2012).Spectroscopic properties of Sm³⁺ doped phosphate glasses,J.Mater.Res.,27,16,2111-2115.
- Deepa,A.V., Vinothkumar,P., Sathya Moorthy, K., Murlimanohar, P., Mohapatra, M., praveenkumar S. and murugasen, p.(2020).Optical, electrical, mechanical properties of Pr³⁺ and Yb³⁺ doped phosphate glass, Optical and Quantum Electronics,52,483.
- Durga, D.K. and Veeraiah, N. (2003). Role of manganese ions on the stability of ZnF₂-P₂O₅-TeO₂ glass system by the study of dielectric dispersion and some other physical properties. J. Phys. Chem. Solids, 64, 133–146.
- Meena,S.L.(2026).Spectral,Thermal and Luminescent properties of Nd³⁺ doped borophosphate glasses for 1075 nm NIR Photonic broad band Applications,IOSR Appl.Phys.18,16-23.
- Dousti,M.R., Poirier, G.Y., de Camargo, A.S.S.(2020).Tungsten Sodium Phosphate glasses doped with trivalent rare earth ions (Eu³⁺, Tb³⁺, Nd³⁺, Er³⁺) for visible and near infrared applications, Journal of Non- Crystalline Solids 530, 119838.

12. Areej ,S. Alqarni, R. Hussin, S.N. Alamri and Ghoshal, Ghoshal, S.K.(2020).Tailored structures and dielectric traits of holmium ion-doped zinc-sulpho-boro-phosphate glass ceramics,Ceramics International 46(3),3282-3291.
13. Kolobkova,E.,Grabtchikov,A.,Khodasevich,I.(2021).Upconversion luminescence and energy transfer in the fluorphosphate glasses with low phosphate content doped with Tm³⁺ and Yb³⁺ ions,J.Non Cryst.Solids,11-12,100065.
14. Hao,L., Pei, M., Yang, T. and Ming, C.(2020).Double sensitivity temperature sensor based on excitation intensity ratio of Eu³⁺ doped phosphate glass ceramic, Optik 204,164188.
15. Li,H.,Zou,H.,Sun,Z.,Xu.Yi,Wang,C.,Xie,X.,Yi,J.,Zhao,F.(2022).Spectroscopic and Surface crystallization characterizations of yttrium doped phosphate glasses,Cryst.12,109,1-9.
16. Meena,S.L.(2021). Spectral and Thermal properties of Pr³⁺ doped lead lithium sodium tungsten borophosphate glasses,IOSR Appl.Phys.13,1-7.
17. Mitra,S. and Jana, S.(2015).Intense orange emission in Pr³⁺ doped lead phosphate glass, Journal of physics and chemistry of solids 85,245-253.
18. Haijian Li, Jianhua Yi, Zhao Qin, Zhihua Sun, Yi Xu, Changjian Wang, Fengqi Zhao, Yucheng Hao, Xiaofeng L.(2019). Structures, Thermal expansion, chemical stability and crystallization behavior of phosphate based glasses by influence of rare earth, Journal of Non- Crystalline Solids 522,119602.
19. Meena,S.L.(2025).Spectral, Thermal and Photoluminescence Analysis of Phosphate Glasses with Trivalent Holmium for 2.0 μm optoelectronic applications, IOSR Appl.Phys.18,01-08.
20. Marzouk,M.A.,Ali,I.S.(2024).Enhancing the luminescent properties of strontium phosphate glass via controlled crystallization and rare earth dopant,35:1767,1-18.
21. Meena,S.L.(2021). Spectral and Thermal properties of Pr³⁺ doped lead lithium sodium tungsten borophosphate glasses,IOSR Appl.Phys.13,1-7.
22. Meena,S.L.(2021). Spectral and Raman Analysis of Er³⁺ doped Zinc Lithium Antimony Sodalime Tellurite Glasses,Int.J.Eng.Sci.Inv.10,09-15.
23. Judd, B.R. (1962). Optical Absorption Intensities of Rare Earth Ions. Physical Review, 127, 750.
24. Ofelt, G.S. (1962). Intensities of Crystal Spectra of Rare Earth Ions. The J. Chem. Phys., 37, 511.
25. Marzouk,M.A.,Ali,I.S.(2024).Enhancing the luminescent properties of strontium phosphate glass via controlled crystallization and rare earth dopant,35:1767,1-18.
26. Saisudha, M.B. and Ramakrishna J. (2002). Optical absorption of Nd³⁺, Sm³⁺ and Dy³⁺ in bismuth borate glasses with large radiative transition probabilities. Opt. Mater. 18,403.
27. Kaewkhao, J., Wantana, N., Kaewjaeng, S., Kothan, S. and Kim. H.J. (2000). Luminescence characteristics of Dy³⁺ doped Gd₂O₃-CaO-SiO₂-B₂O₃ scintillating glasses. J. Rare Earths 34 (6), 583.
28. Jing, Li., Chen, Li., Zhang, J. Hao, Z. Yongshi, H., Luo, Y. and Zhang L. (2016). Photoluminescence properties of a novel red-emitting phosphor Eu³⁺ activated scandium molybdate for white light emitting diodes Mat. Res. Bull. 83,290-293.
29. Rao, K.J. (2002). Structural Chemistry of Glasses. Elsevier Science and Technology Books.
30. Xie, J., Zhang, Q., Zhuang, Y., Liu, X., Guan, M., Zhu, B., Yang, R. and Qiu, J. (2011). Enhanced mid-IR emission in Yb³⁺-Tm³⁺ co-doped oxyfluoride glass-ceramics, J. Alloy. Compd. 509, 3032-3037.
31. Hatefi, Y., Shahtahmasebi, N., Moghimi, A. and Attaran, E. (2011).Ultraviolet to visible frequency-conversion properties of rare earths doped glass-ceramics, J. Rare Earths 29 , 484-488.
32. Yu, X., Duan, L., Ni, L. and Wang, Z. (2012).Fabrication and luminescence behavior of phosphate glass-ceramics co-doped with Er³⁺ and Yb³⁺, Opt. Commun. 285, 3805-3808.
33. Lisiecki, R., Augustyn, E., Ryba-Romanowski, W. and elechower, M. Z(2011).Er-doped and Er, Yb co-doped oxyfluoride glasses and glass-ceramics, structural and optical properties, Opt. Mater. 33, 1630-1637.
34. Lakshman S.V.J. and Ratnakaram, Y.C. (1998).Phys. Chem. Glasses, 29, 26.
35. Viana, B., Palazzi M. and LeFol, O. (1997).Non-Cryst, Solids, 215, 96.
36. Jiang, S., Luo, T., Hwang, B.C., Smekatala, F., Seneschal,K., Lucas J. and Peyghambarian, N. (2000).J. Non-Cryst, Solids, 263-264, 364.
37. Liu, Y., Ren, J., Tong, Y., Wang, T., Xu, W. and Chen, G. (2012).Observation of Intra-and Inter-Configurational Luminescence of Pr³⁺-Doped Strontium Phosphate Glasses, Journal of the American Ceramic Society 95, 41.
38. Rasool, N., Moorthy, L. R. and Jayasankar, C. (2013). Spectroscopic Investigation of Sm³⁺ doped phosphate based glasses for reddish-orange emission, Optics Communications 311, 156.
39. Jayasimhadri, M., Jang, K., Lee, H. S., Chen, B., Yi, S.S. and Jeong, J.H. (2009).White light generation fromDy³⁺doped ZnO-B₂O₃-P₂O₅ glasses, Journal of Applied Physics 106, 013105.

40. Linganna, K., Rao, C. S. and Jayasankar, C. (2013). Optical properties and generation of white light in Dy³⁺-doped lead phosphate glasses, *Journal of Quantitative Spectroscopy and Radiative Transfer* 118, 40 .
41. Milankovic, A.M., Gajovic, A. and Day, D.E. (2003). Spectroscopic investigation of MoO₃-Fe₂O₃-P₂O₅ and SrO-Fe₂O₃-P₂O₅ glasses. *J of Non-Crystalline Solids*. 325:76-84.
42. Campbell, J.H. and Suratwala, T.I. (2000). Nd-doped phosphate glasses for high-energy/high-peak-power lasers. *J. Non-Cryst. Solids*, 263-264, 318-341.
43. Jiang, S., Myers, M.J., Rhonehouse, D.L., Hamlin, S.J., Myers, J.D., Griebner, U., Koch, R. and Schonngel, H. (1997). Ytterbium-doped phosphate laser glasses. *Solid State Lasers VI*, 10-15.
44. Jiang, S., Myers, M. and Peyghambarian, N. (1998). Er³⁺ doped phosphate glasses and lasers. *J. Non-Cryst. Solids*, 239, 143-148.
45. Weber, M.J. (1990). Science and technology of laser glass. *J. Non-Cryst. Solids*, 123, 208-222.
46. Gorller-Walrand, C. and Binnemans, K. (1988). Spectral Intensities of f-f Transition. In: Gshneidner Jr., K.A. and Eyring, L., Eds., *Handbook on the Physics and Chemistry of Rare Earths*, Vol. 25, Chap. 167, North-Holland, Amsterdam, 101-264.
47. Sharma, Y.K., Surana, S.S.L. and Singh, R.K. (2009) Spectroscopic Investigations and Luminescence Spectra of Sm³⁺ Doped Soda Lime Silicate Glasses. *Journal of Rare Earths*, 27, 773.
48. Judd, B.R. (1962). Optical Absorption Intensities of Rare Earth Ions. *Physical Review*, 127, 750.
49. Ofelt, G.S. (1962). Intensities of Crystal Spectra of Rare Earth Ions. *The Journal of Chemical Physics*, 37, 511.
50. Ngoc, T. (2015). Optical Properties of Dy³⁺ and Ce³⁺ in Borate Glass. *J.Sci.-Math.-Phy.*, 31, 1, 52-62.
51. Tanabe, S., Kang, J., Hanada, T. and Soga, N. (1998). Yellow/blue luminescences of Dy³⁺-doped borate glasses and their anomalous temperature variations. *J Non-Cryst Solids*, 239, 170-5.





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