



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

# IJRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 9, September 2021

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

Impact Factor: 7.569

 9940 572 462

 6381 907 438

 [ijrset@gmail.com](mailto:ijrset@gmail.com)

 [www.ijrset.com](http://www.ijrset.com)



# Spectral and Thermal Properties of $Tm^{3+}$ Doped in Zinc Lithium Lead Alumino Tungsten Borophosphate Glasses

S.L.Meena

Ceramic Laboratory, Department of Physics, Jai Narain Vyas University, Jodhpur (Raj.) India

**ABSTRACT:** Glass sample of Zinc Lithium Lead Alumino Tungsten Borophosphate:  $(35-x) P_2O_5:10ZnO:10Li_2O:10PbO:10Al_2O_3:10WO_3:15B_2O_3:xTm_2O_3$ , (where  $x=1, 1.5$  and  $2$  mol%) have been prepared by melt-quenching technique. The amorphous nature of the prepared glass samples was confirmed by X-ray diffraction. Optical absorption and fluorescence spectra were recorded at room temperature for all glass samples. Judd-Ofelt intensity parameters  $\Omega_\lambda$  ( $\lambda=2, 4$  and  $6$ ) are evaluated from the intensities of various absorption bands of optical absorption spectra. Using these intensity parameters various radiative properties like spontaneous emission probability, branching ratio, radiative life time and stimulated emission cross-section of various emission lines have been evaluated

**KEYWORDS:** ZLLATBP Glasses, Optical Properties, Judd-Ofelt Theory, Rare earth ions.

## I. INTRODUCTION

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 frequency-conversion materials, waveguide laser and optical fiber amplifiers [1-6]. Rare-earth doped glasses are technologically important materials as they find applications in lasers, white light emitting diodes and light converting devices [7-10]. Glasses based on heavy metal oxide have received increased attention due to their manifold possible applications in the field of glass ceramics, layers for optoelectronics devices, thermal and mechanical sensors [11-15]. The host glass materials should have high refractive index with good chemical and thermal stability. Phosphate glasses are promising laser hosts because they are able to accommodate higher content of rare earth ions and still remain amorphous in comparison with other glass systems. The up-conversion of phosphate glasses is also compressed because of their relatively large phonon energy. Phosphate glasses can be a good matrix for fiber lasers because they exhibit good mechanical property [16-25].

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  $Tm^{3+}$  doped zinc lithium lead aluminotungsten borophosphate 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 ( $\beta$ ), radiative life time ( $\tau_R$ ) and stimulated emission cross section ( $\sigma_p$ ) are evaluated using J.O. intensity parameters ( $\Omega_\lambda$ ,  $\lambda=2, 4$  and  $6$ ).

## II. EXPERIMENTAL TECHNIQUES

### Preparation of glasses

The following  $Tm^{3+}$  doped borophosphate glass samples  $(35-x) P_2O_5:10ZnO:10Li_2O:10PbO:10Al_2O_3:10WO_3:15B_2O_3:xTm_2O_3$ , (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  $P_2O_5, ZnO, Li_2O, PbO, Al_2O_3, WO_3, B_2O_3$  and  $Tm_2O_3$ . They were thoroughly mixed by using an agate pestle mortar. then melted at  $965^\circ C$  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  $250^\circ C$  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 %)
ZLLATBP (UD)	30 P <sub>2</sub> O <sub>5</sub> :10ZnO:10Li <sub>2</sub> O:10PbO:10Al <sub>2</sub> O <sub>3</sub> :10WO <sub>3</sub> :15B <sub>2</sub> O <sub>3</sub>
ZLLATBP(TM1)	29 P <sub>2</sub> O <sub>5</sub> :10ZnO:10Li <sub>2</sub> O:10PbO:10Al <sub>2</sub> O <sub>3</sub> :10WO <sub>3</sub> :15B <sub>2</sub> O <sub>3</sub> :1Tm <sub>2</sub> O <sub>3</sub>
ZLLATBP(TM1.5)	28.5 P <sub>2</sub> O <sub>5</sub> :10ZnO:10Li <sub>2</sub> O:10PbO:10Al <sub>2</sub> O <sub>3</sub> :10WO <sub>3</sub> :15B <sub>2</sub> O <sub>3</sub> :1.5Tm <sub>2</sub> O <sub>3</sub>
ZLLATBP(TM2)	28 P <sub>2</sub> O <sub>5</sub> :10ZnO:10Li <sub>2</sub> O:10PbO:10Al <sub>2</sub> O <sub>3</sub> :10WO <sub>3</sub> :15B <sub>2</sub> O <sub>3</sub> :2Tm <sub>2</sub> O <sub>3</sub>

ZLLATBP (UD) -Represents undoped zinc lithium lead aluminotungsten borophosphate glass specimen.

ZLLATBP (TM) -Represents Tm<sup>3+</sup> doped zinc lithium lead aluminotungsten borophosphate glass specimens.

### III. THEORY

#### 3.1 Oscillator Strength

The intensity of spectral lines are expressed in terms of oscillator strengths using the relation [26].

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

where,  $\epsilon(\nu)$  is molar absorption coefficient at a given energy  $\nu$  (cm<sup>-1</sup>), 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 [27], using the modified relation:

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

where c is the molar concentration of the absorbing ion per unit volume, l is the optical path length, log I<sub>0</sub>/I is optical density and  $\Delta\nu_{1/2}$  is half band width.

#### 3.2. Judd-Ofelt Intensity Parameters

According to Judd[28] and Ofelt[29] theory, independently derived expression for the oscillator strength of the induced forced electric dipole transitions between an initial J manifold |4f<sup>N</sup>(S, L) J> level and the terminal J' manifold |4f<sup>N</sup>(S', L') J'> is given by:

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

Where, the line

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

$$S(S', L') = e^2 \sum \Omega_\lambda < 4f^N(S, L) J || U^{(\lambda)} || 4f^N(S', L') J' >^2 \tag{4}$$

$\lambda = 2, 4, 6$

In the above equation m is the mass of an electron, c is the velocity of light,  $\nu$  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,  $\Omega_\lambda$  ( $\lambda=2, 4$  and 6) are known as Judd-Ofelt intensity parameters.

#### 3.3 Radiative Properties

The  $\Omega_\lambda$  parameters obtained using the absorption spectral results have been used to predict radiative properties such as spontaneous emission probability (A) and radiative life time ( $\tau_R$ ), and laser parameters like fluorescence branching ratio ( $\beta_R$ ) and stimulated emission cross section ( $\sigma_p$ ).

The spontaneous emission probability from initial manifold |4f<sup>N</sup>(S', L') J'> to a final manifold |4f<sup>N</sup>(S, L) J> is given by:

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

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

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

S L J

where, the sum is over all terminal manifolds.

The radiative life time is given by

$$\tau_{rad} = \sum_{A[(S', L') J'; (S, L) J]} A[(S', L') J'; (S, L) J] = A_{Total}^{-1} \quad (7)$$

S L J

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,  $\lambda_p$  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<sub>2</sub>O<sub>5</sub> 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

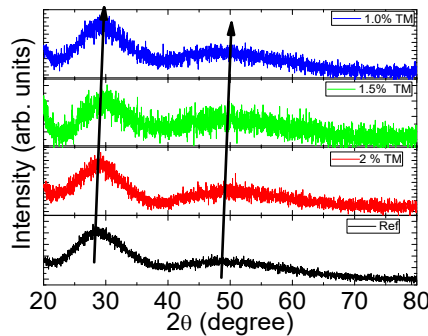


Fig. 1 X-ray diffraction pattern of P<sub>2</sub>O<sub>5</sub>:ZnO:Li<sub>2</sub>O:PbO:Al<sub>2</sub>O<sub>3</sub>:WO<sub>3</sub>:B<sub>2</sub>O<sub>3</sub>:Tm<sub>2</sub>O<sub>3</sub>.

##### 4.2 Thermal Property

Figure 2, shows the thermal properties of ZLLATBP glass from 300<sup>0</sup>C to 1000<sup>0</sup>C. From the DSC curve of present glasses system, I can find out that no crystallization peak is apparent and the glass transition temperature T<sub>g</sub> are 355,450 and 585 respectively. The T<sub>g</sub> increase with the contents of Tm<sub>2</sub>O<sub>3</sub> increase. I could conclude that thermal properties of the ZLLATBP glass are good for fiber drawing from the analysis of DSC curve.



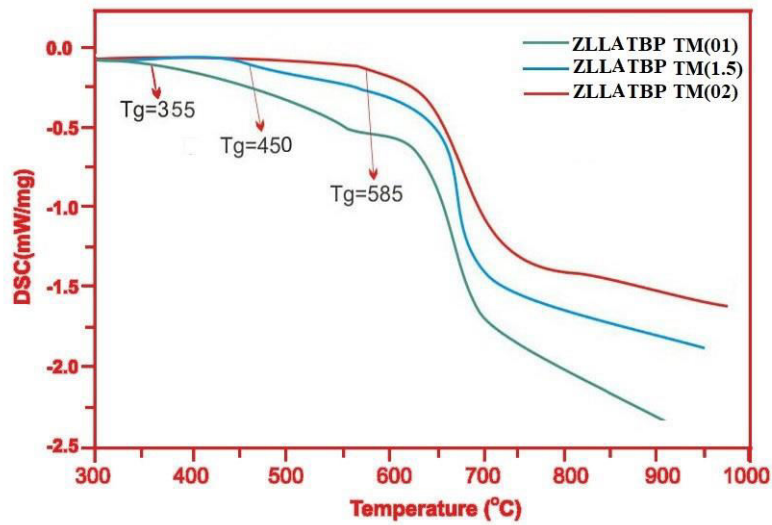


Fig.2: DSC curve of ZLLATBPTM (01) glasses.

### 4.3 Absorption Spectrum

The absorption spectra of  $Tm^{3+}$  doped ZLLATBP glass specimens have been presented in Figure 3 in terms of optical density versus wavelength. Five absorption bands have been observed from the ground state  $^3H_6$  to excited states  $^3F_4$ ,  $^3H_5$ ,  $^3H_4$ ,  $^3F_3$  and  $^1G_4$  for  $Tm^{3+}$  doped ZLLATBP glasses.

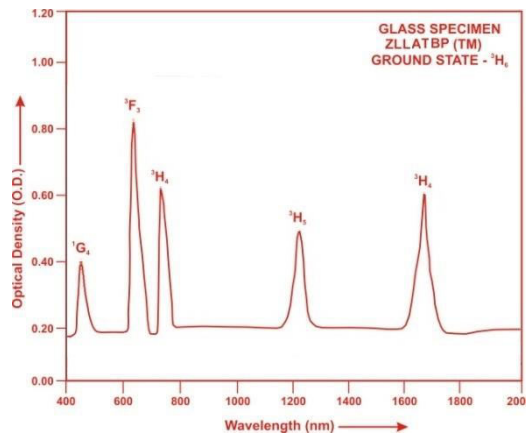


Fig. (3) Absorption spectrum of ZLLATBP TM (01) glass.

The experimental and calculated oscillator strength for  $Tm^{3+}$  ions in ZLLATBP glasses are given in Table 2.

Table 2: Measured and calculated oscillator strength ( $P_m \times 10^{+6}$ ) of  $Tm^{3+}$  ions in ZLLATBP glasses.

Energy level from $^3H_6$	Glass ZLLATBP(TM01)		Glass ZLLATBP(TM1.5)		Glass ZLLATBP(TM02)	
	$P_{exp}$	$P_{cal}$	$P_{exp}$	$P_{cal}$	$P_{exp}$	$P_{cal}$
$^3F_4$	1.80	1.84	1.78	1.83	1.80	1.75
$^3H_5$	1.35	1.44	1.32	1.43	1.41	1.28
$^3H_4$	1.97	2.04	1.95	2.03	2.01	1.92
$^3F_3$	2.95	3.02	2.91	2.99	2.96	2.87
$^1G_4$	0.75	0.89	0.72	0.88	0.87	0.69
r.m.s. deviation	±0.08894		±0.1037		±0.1180	



\*Low r.m.s.deviation values clearly indicate the accuracy of fitting.

In the Zinc Lithium Lead Alumino Tungsten Borophosphate glasses (ZLLATBP)  $\Omega_2$ ,  $\Omega_4$  and  $\Omega_6$  parameters decrease with the increase of x from 1 to 2 mol%. The order of magnitude of Judd-Ofelt intensity parameters is  $\Omega_4 > \Omega_2 > \Omega_6$  for all the glass specimens. The spectroscopic quality factor ( $\Omega_4/\Omega_6$ ) related with the rigidity of the glass system has been found to lie between 1.439 and 1.459 in the present glasses.

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

Table 3: Judd-Ofelt intensity parameters for  $Tm^{3+}$  doped ZLLATBP glass specimens.

Glass Specimen	$\Omega_2(\text{pm}^2)$	$\Omega_4(\text{pm}^2)$	$\Omega_6(\text{pm}^2)$	$\Omega_4 / \Omega_6$
ZLLATBP (TM 01)	6.633	8.299	5.688	1.459
ZLLATBP B(TM 1.5)	6.671	8.163	5.645	1.446
ZLLATBP(TM 02)	6.592	8.037	5.586	1.439

#### 4.4. Fluorescence Spectrum

The fluorescence spectrum of  $Tm^{3+}$  doped in zinc lithium lead aluminotungsten borophosphate glass is shown in Figure 4. There are seven broad bands observed in the Fluorescence spectrum of  $Tm^{3+}$  doped zinc lithium lead aluminotungsten borophosphate glass. The wavelengths of these bands along with their assignments are given in Table 5. The peak with maximum emission intensity appears at 798nm and corresponds to the ( $^3H_4 \rightarrow ^3H_6$ ) transition.

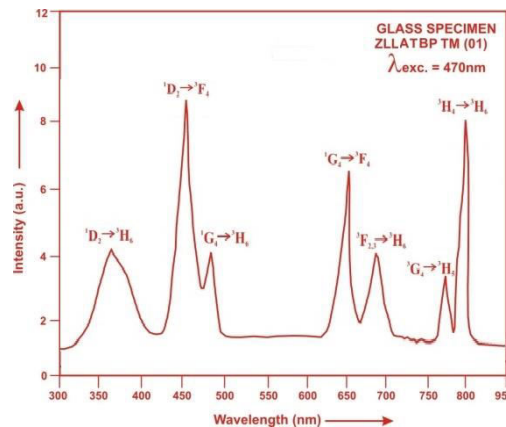


Fig. (4). Fluorescence spectrum of ZLLATBP TM (01) glass.

Table 4: Emission peak wave lengths ( $\lambda_p$ ), radiative transition probability ( $A_{rad}$ ), branching ratio ( $\beta$ ), stimulated emission cross-section ( $\sigma_p$ ) and radiative life time ( $\tau_R$ ) for various transitions in  $Tm^{3+}$  doped ZLLATBP glasses

Transition	ZLLATBP(TM01)					ZLLATBP(TM1.5)					ZLLATBP(TM 02)				
	$\lambda_{max}$ (nm)	$A_{rad}(s^{-1})$	$\beta$	$\sigma_p (10^{-20} \text{cm}^2)$	$\tau_R(\mu s)$	$A_{rad}(s^{-1})$	$\beta$	$\sigma_p (10^{-20} \text{cm}^2)$	$\tau_R(\mu s)$	$A_{rad}(s^{-1})$	$\beta$	$\sigma_p (10^{-20} \text{cm}^2)$	$\tau_R(10^{-20} \text{cm}^2)$		
$^1D_2 \rightarrow ^3H_6$	365	54552.2	0.6370	1.469	11.6775	53871.10	0.6342	1.509	11.7728	53273.10	0.6341	1.547	11.9031		
$^1D_2 \rightarrow ^3F_4$	455	17578.6	0.2053	2.230		17653.80	0.2078	2.419		17457.90	0.2078	2.586			
$^1G_4 \rightarrow ^3H_6$	480	2242.64	0.0262	0.535		2227.31	0.0262	0.581		2200.65	0.0262	0.633			
$^1G_4 \rightarrow ^3F_4$	651	736.44	0.0086	1.344		730.11	0.0086	1.655		723.21	0.0086	2.163			
$^3F_{4,3} \rightarrow ^3H_6$	689	5572.44	0.0651	2.274		5523.98	0.0650	2.352		5467.46	0.0651	2.444			
$^1G_4 \rightarrow ^3H_3$	785	2133.59	0.0249	2.397		2126.11	0.0250	2.581		2106.74	0.0251	2.764			
$^3H_4 \rightarrow ^3H_6$	798	2818.93	0.0329	4.206		2809.40	0.0331	4.506		2782.36	0.0331	4.962			

## V. CONCLUSION

In the present study, the glass samples of composition (35-x)  $P_2O_5:10ZnO:10Li_2O:10PbO:10Al_2O_3:10WO_3:15B_2O_3:xTm_2O_3$  (where  $x = 1, 1.5$  and  $2$  mol %) have been prepared by melt-quenching method. The value of stimulated emission cross-section ( $\sigma_p$ ) is found to be maximum for the transition ( $^3H_4 \rightarrow ^3H_6$ ) for glass ZLLATBP(TM 01), suggesting that glass ZLLATBP(TM 01) is better compared to the other two glass systems ZLLATBP(TM1.5) and ZLLATBP(TM02).

## REFERENCES

- [1]. Marzuki, A., Pramuda, A. and Fausta D. E. (2020). Effect of  $Nd_2O_3$  and  $Na_2O$  concentration on physical and spectroscopic properties of  $TeO_2-Bi_2O_3-ZnO-Na_2O-Nd_2O_3$  glasses. *Mater. Res. Express* 7, 065201, 1-12.
- [2]. Murthy Goud, K. K., Ramesh, C.H. and Appa Rao, B. (2017). Up conversion and Spectroscopic Properties of Rare Earth Codoped Lead Borate Glass Matrix. *Material Science Research India*, 14, 140-145.
- [3]. Yang, G. F., Shi, D. M., Zhang, Q. Y. and Jiang, Z. H. (2008). Spectroscopic properties of  $Er^{3+}/Yb^{3+}$  codoped  $PbO$  glasses. *J. Fluorescence* 18, 131-137.
- [4]. Fujimoto, Y., Ishii, O. and Yamazaki, M. (2010). Yellow laser oscillation in  $Dy^{3+}$ -doped waterproof fluoro-aluminate glass fibre pumped by 398.8 nm GaN laser diodes. *Electron. Lett.* 46, 1285.
- [5]. Reddy, M. S., Uchil, J. and Reddy, C. N. (2014). Thermal and Optical properties of Sodium-Phospho-Zinc-Neodymium oxide glass system. *J. of Adv. Sci. Research*, 5(2), 32-39.
- [6]. Zhang, L., Lu, Z., Song, Y., Zhao, L., Bhatia, B., Bagnall, K.R. and Wang, E. N. (2019). Thermal Expansion Coefficient of Monolayer Molybdenum Disulfide Using Micro-Raman Spectroscopy. *Nano Letters*, 19, 4745-4751.
- [7]. Seshadri, M., Rao, K., Rao, J. and Ratnakaram, Y. (2009). Spectroscopic and laser properties of  $Sm^{3+}$  doped different phosphate glasses. *J. Alloys Compd.* 476, 263.
- [8]. Zhang, L., Peng, M., Dong, G. and Qiu, J. (2012). Spectroscopic properties of  $Sm^{3+}$  doped phosphate glasses. *J. Mater. Res.*, 27, 16, 2111-2115.
- [9]. Bentouila, O., Eddine Aiadi, K., Rehouma, F. and Poulain, M. (2013). Spectroscopic studies of rare earth-doped halogeno-phosphate glasses. *J. Opt. and Advan. Mat.* 15, 11 - 12, 1204-1208.
- [10]. Shih, P. Y. (2004). Thermal, chemical and structural characteristics of erbium-doped sodium phosphate glasses. *Materials Chemistry and Physics*, 84, 151-156.
- [11]. Moustafa, Y. and El-Egili, K. (1998). Infrared spectra of sodium phosphate glasses. *Journal of Non-Crystalline Solids*, 240, 13, 144-153.
- [12]. Pugliese, D., Boetti N. G. and Lousteau, J. (2016). Concentration quenching in an  $Er^{3+}$ -doped phosphate glass for compact optical lasers and amplifiers. *Journal of Alloys and compounds*, 657, 678-683.
- [13]. Balakrishnaiah, R., Babu, P., Jayasankar, C. K., Joshi, A. S., Speghini, A. and Bettinelli, M. (2006). Optical and Luminescence properties of Nd ions in K-Ba-Al phosphate and fluorophosphate glasses. *Journal of Physics: Condensed Matter*, 18, 165 -179.
- [14]. Dai, S., Yu, C., Zhou, G., Zhang, J., Wang, G. and Hu, L. (2006). Concentration quenching in erbium doped tellurite glasses. *Journal of Luminescence*, 117, 39-45.
- [15]. Mandlule, A., Döhler, F., Wüllen, L. v., Kasuga T. and Brauer, D. S. (2014). Changes in structure and thermal properties with phosphate content of ternary calcium sodium phosphate glasses. *Journal of Non-Crystalline Solids*, 392-393, 31-38.
- [16]. Reddy, A. A., Babu, S. S., Pradesssh, K., Otton C. J. and Prakash, G. v. (2011). Optical properties of highly Er doped sodium aluminium phosphate glasses for broadband 1.5 micron emission. *Journal of Alloys and compounds*, 509, 4047 - 4052.
- [17]. Narro-Garcia, R., Desirena, H., Lopez-Luke, T., Guerrero-Contreras, J., Jayasankar, C.K., Quintero-Torres, R. and De la Rosa, E. (2015). Spectroscopic properties of  $Eu^{3+}/Nd^{3+}$  co-doped phosphate glasses and opaque glass-ceramics. *Optical Materials* 46, 34-39.
- [18]. Pisarska, J., Soltys, M., Zur, L., Pisarski, W.A. and Jayasankar, C.K. (2014). Excitation and luminescence of rare earth-doped lead phosphate glasses. *Appl. Phys. B.*, 116, 837-845.
- [19]. Marzouk, M.A., ElBatal, H.A., Hamdy, Y.M. and Ezz-Eldin, F.M. (2019). Collective Optical, FTIR, and Photoluminescence Spectra of  $CeO_2$  and/or  $Sm_2O_3$ -Doped  $Na_2O-ZnO-P_2O_5$  Glasses. *International Journal of Optics*, 1-11.
- [20]. Ehrt, D. (2015). Phosphate and fluoride phosphate optical glasses - Properties, structure and applications. *Physics and Chemistry of Glasses, European Journal of Glass Science and Technology Part B*, 56, 6, 217-234.



- [21]. Elbatal, F.H., Marzouk, M.A. and Abdelghany, A.M. (2011). UV-visible and infrared absorption spectra of gamma irradiated  $V_2O_5$ -doped in sodium phosphate, lead phosphate, zinc phosphate glasses: A comparative study, *Journal of Non-Crystalline Solids*, 357, 3, 1027–1036.
- [22] Mohan Babu, A., Jamalalah, B. C., Sasikala, T., Saleem, S. A. and Rama Moorthy, L. (2011). Absorption and emission spectral studies of  $Sm^{3+}$ -doped lead tungstate tellurite glasses, *Journal of Alloys and Compounds*, 509, 14, 4743–4747.
- [23] Praveena, R., Venkatramu, V., Babu, P. and Jayasankar, C. K. (2008). Fluorescence spectroscopy of  $Sm^{3+}$  ions in  $P_2O_5$ -PbO- $Nb_2O_5$  glasses, *Physica B: Condensed Matter*, 403, 19-20, 3527–3534.
- [24] Marzouk, M. A., Fayad, A. M. and ElBatal, H. A. (2017). Correlation between luminescence and crystallization characteristics of  $Dy^{3+}$  doped  $P_2O_5$ -BaO- $SeO_2$  glasses for white LED applications, *Journal of Materials Science: Materials in Electronics*, 28, 17, 13101–13111.
- [25] Moncke, M. D. (2015). Photo-ionization of 3d-ions in fluoride-phosphate glasses, *International Journal of Applied Glass Science*, 6, 249–267.
- [26]. 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.
- [27]. Sharma, Y.K., Surana, S.S.L. and Singh, R.K. (2009). Spectroscopic Investigations and Luminescence Spectra of  $Sm^{3+}$  Doped Soda Lime Silicate Glasses. *Journal of Rare Earths*, 27, 773.
- [28]. Judd, B.R. (1962). Optical Absorption Intensities of Rare Earth Ions. *Physical Review*, 127, 750.
- [29]. Ofelt, G.S. (1962). Intensities of Crystal Spectra of Rare Earth Ions. *The Journal of Chemical Physics*, 37, 511.





**Impact Factor:  
7.569**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 9940 572 462  6381 907 438  [ijirset@gmail.com](mailto:ijirset@gmail.com)



[www.ijirset.com](http://www.ijirset.com)

Scan to save the contact details