DOI: 10.21776/ub.jpacr.2016.005.02.265 J. Pure App. Chem. Res., **2016**, 5 (2), 116-124
26 August 2016

Spectroscopic and Radiative Properties of Several Nd^{3+} Ions in Borate Glass System

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Received 20 May 2016; Revised 24 September 2016; Accepted 26 September 2016

ABSTRACT

Radiative properties and spectroscopic studies of several Nd^{3+} doped borate glass system have been reported. Judd-Ofelt intensity parameter and other parameters like oscillator strength (f), effective bandwidth ($\Delta\lambda_{eff}$), radiative transition probabilities (A_R), stimulated emission cross section (σ), branching ratio (β_R), radiative lifetime (τ_R) and experimental lifetime (τ_{exp}) for the hypersensitive Nd^{3+} doped Borate Glass are listed and discussed. The variation of Ω_2 values for the different host matrix are expressed their covalency among Nd^{3+} ions in the glass matrix. In this study, reported that the hypersensitive transition achieved at $^4I_{9/2} \rightarrow {}^4G_{5/2}, {}^2G_{7/2}$ centered at 580 – 585 nm range.

Keywords: Borate glass, Judd-Ofelt, radiative

INTRODUCTION

In the several years and recently, laser gain medium based on Nd^{3+} doped glasses have been attracted much attention from researchers in the field of photonic and laser. The above related to Nd^{3+} laser application such as optical amplifier, laser pumping, optical communication, optical waveguide, storage data optically, radar and medical instrumentation [1-5]. Medium gain laser characteristics for commercial laser required were must satisfied sharpness fluorescent lines, strong absorption bands and sensible for high quantum efficiency in accordance with the needed transition photon [6].The above requirements have been obtained by a small amount of concentration Nd^{3+} ions-doped glass material, since Nd^{3+} ions were able to produce population inversion for result stimulated emission in the visible range (such as emission transition at $^4G_{7/2} \rightarrow {}^4I_{9/2}$, $^4G_{7/2} \rightarrow {}^4I_{11/2}$, $^4G_{7/2} \rightarrow {}^4I_{13/2}$) [7] and the NIR range (lasing transition $^4F_{3/2} \rightarrow {}^4I_{9/2}$, $^4F_{3/2} \rightarrow {}^4I_{11/2}$, $^4F_{3/2} \rightarrow {}^4I_{13/2}$) [1]. Improved laser performance is strongly influenced by the composition of the host glass matrix and the concentration of doped ions, since the stimulated emission quality depends on host matrix in which the ions are incorporated [7,8]. Several types of commercial glass are generally used as a laser host matrix, i.e silicate, phosphate, borate glasses and several heavy metal oxide glasses [1,2,7,9]. Some of the results showed that the silicate glasses has its advantages as well as high chemical stability, high transparency for UV, low thermal expansion coefficient leading to strong thermal resistance, a small nonlinear refractive index, high surface damage threshold,

The journal homepage www.jpacr.ub.ac.id
p-ISSN : 2302 – 4690 | e-ISSN : 2541 – 0733

large tensile fracture strength and good durability [10-12]. Those advantages made this type of glass are suitable for application as optical fiber or waveguide lasers [13]. Phosphate glass appropriately used as a host matrix for Nd^{3+} ions owned properties are low thermal-optical constants, low melting point, low glass transition temperature and high thermal expansion coefficient [14]. Moreover, the borate glass properties have been reported as well high transparency, high density, appropriate bandwidth, suitable for infrared transmission, high mechanical stability, corrosion resistivity and inexpensive [2,15]. In addition, the other types of glasses and crystals have been reported as well as a host of Nd^{3+} ion laser such as Nd^{3+} doped alkali niobium zinc tellurite glasses [16], Nd^{3+} doped barium titanium silicate glasses [17], Nd^{3+} ions in fluoro-phosphate glasses [18], Nd^{3+} doped lanthanum calcium borate glasses [19] and Nd^{3+} doped alkali boro germanate glasses [20]. In this paper discussed some of the parameters needed in the determination of the glass composition doped Nd^{3+} ion to be used as a laser gain medium. This discussion is limited to the composition of glasses based on borate glass former. As for the parameters that were examined in a laser medium are absorption spectrum, intensity analysis, emission spectrum, energy level, emission cross section, radiative lifetime, etc.

THEORY

Optical Spectroscopic

The optical spectra of the laser medium affected by the concentration of Nd^{3+} and glass structure as host matrix which the ion in the host matrix have the transition energy level vary with the Nd^{3+} concentration. The energy level depends on covalency and asymmetry of Nd^{3+}-O bond in the host matrix [10,21]. For the Nd^{3+} ions doped some different host material such as glass material can be observed the energy level E_j by a Taylor series expansion [22].

$$E_j = E_{0j} + \sum_{i=2,4,6} \frac{\partial E_j}{\partial P_i} \Delta P_i + \frac{\partial E_j}{\partial F \varsigma_{4f}} \Delta \varsigma_{4f} + \dots \tag{1}$$

Where E_j is the energy levels of the Nd^{3+} ion in the host matrix from the measurement of absorption spectra, E_{0j} is the zero order Energy level of the Nd3+ ion, $(\partial E_j / \partial P_i)$, $\partial E_j / \partial F \varsigma_{4f}$ are the partial derivatives and ΔPi, $\varsigma 4f$ are the variations of the interactions with the host matrix [23]. The experimental energy levels observed, and then obtained the deviation of the levels energy by the equation:

$$\Delta E_{rms} = \sqrt{\frac{\sum_{i=1}^{M} (E_{\exp} - E_{th})^2}{M - J}} \tag{2}$$

Where M is the number of absorption bands and J expresses the number of parameters on the theoretical energy values.

Judd-Ofelt Parameters

The intensity of absorption bands determined by the experimental oscillator strength (f_{exp}) that related to particular transition. Oscillator strengths were determined according to Judd-Ofelt theory [2,24].

$$f_{\exp} = \frac{2.303 mc^2}{N \pi e^2} \int \varepsilon(\upsilon) d\upsilon = 4.32 \times 10^{-9} \int \varepsilon(\upsilon) d\upsilon \tag{3}$$

Where ε is the molar absorption coefficient, υ is energy (cm^{-1}). The area of the absorption curve utilized for calculating the right side of integral, concentration of the Nd^{3+} ion in mole/lit and the optical length of glass in cm. The optical density or absorptivity according to Beer's law discovered by ε(υ) is = (1/cl) log (I_0/I) where c is the concentration of Nd^{3+} ion (mole/lit), l is the optical path in the medium. The theoretical oscillator strength of an induced electric-dipole transition from ground state ΨJ to an excited state Ψ'J' is given by

$$f_{cal} = \frac{8\pi^2 mc\upsilon}{3h(2J+1)} \frac{(n^2+2)^2}{9n} \sum_{\lambda=2,4,6} \Omega_\lambda \left\langle \Psi J \| U^{(\lambda)} \| \Psi' J' \right\rangle^2 \quad (4)$$

Where (2J + 1) is the multiplicity of the lower states, m is the mass of the electron, υ is the setting of absorption peak, Ω_λ (λ = 2,4,6) are JO intensity parameters and the $\langle \| U^{(\lambda)} \| \rangle$ are the doubly reduced unit tensor operations calculated in the intermediate coupling approximation [25,26]. The equation of the root mean square deviation (Δf_{rms}) clarifies the quality of the fit known is given by

$$\Delta f_{rms} = \sqrt{\frac{\sum_{i=1}^{M} (f_i^{\exp} - f_i^{cal})^2}{M}} \quad (5)$$

where f^{exp} and f^{cal} are the experimental and calculated oscillator strengths, respectively, M is the number of absorption bands used in account, *i* and *f* refers the total number of levels included in the fit.

Radiative Properties

Radiative transition of the laser transition $^4F_{3/2} \rightarrow {^4I_{11/2}}$ covered by the transition probability (A_R), radiative lifetime (τ_R), stimulated emission cross section (σ_{em}), Branching ratio (β_R) are calculated by using of the Judd-Ofelt parameters (Ω). The relation of the initial level ΨJ to Ψ'J' with the spontaneous transition probabilities (AR) given as [27]

$$A_R(\Psi J, \Psi' J') = \frac{64\pi^4 \upsilon^3}{3h(2J+1)} \frac{n(n^2+2)}{9} S_{ed} + \frac{64\pi^4 \upsilon^3}{3h(2J+1)} n^3 S_{md} \quad (6)$$

Where S_{ed} and S_{md} are the electric dipole and magnetic dipole line strengths given as

$$S_{ed} = e^2 \sum_{\lambda=2,4,6} \Omega_\lambda \left\langle \Psi J \| U^\lambda \| \Psi' J' \right\rangle^2 \text{ and } S_{md} = \frac{e^2 h^2}{16\pi^2 m^2 c^2} \sum_{\lambda=2,4,6} \Omega_\lambda \left\langle \Psi J \| U^\lambda \| \Psi' J' \right\rangle^2 \quad (7)$$

The quality of the laser transition $^4F_{3/2} \rightarrow {^4I_{11/2}}$ observed by size stimulated emission cross-section and calculated with using of Fuchtbabauer-Ladenburg method.

$$\sigma_{em} = \frac{\lambda_p^4}{8\pi c n^2 \Delta\lambda_{eff}} A(aJ, bJ') \quad (8)$$

Where λ_p is the peak wavelength of the emission peak, c is the speed of light, n is the refractive index, A(*a*J, bJ') is the radiative transition probability and $\Delta\lambda_{eff}$ is an effective line width. The area under of emission peak is used for calculation of full-width at half-maximum. The effective line width of the emission given as

$$\Delta\lambda_{eff} = \frac{\int I(\lambda) d\lambda}{I_{\max}} \quad (9)$$

Where Imax is the maximum intensity at fluorescence emission peaks. Then the radiative life time (τ_R) is given with reverse of the sum A_R(ΨJ, Ψ'J').

$$\tau_R = \frac{1}{\sum_{\psi' J'} A_R(\Psi J, \Psi' J')} \quad (10)$$

DISCUSSIONS
Judd-Ofelt analysis

The oscillator strength (f_{exp}) determined experimentally by substituting of the absorption spectra obtained from the measurement of results. Judd-Ofelt parameters obtained from the absorption spectra have been measured at room temperature. These values used for calculating oscillator strength each of the absorption bands in accordance with eq. (3). The experimental and theoretical oscillator strength of some Nd^{3+}: doped borate glasses former showed in **Table 1**. The value of energy levels, especially at $^4I_{9/2} \rightarrow {}^4G_{5/2}, {}^2G_{7/2}$ transitions for some materials with various concentrations also presented in **Table 1**. In this paper selected Nd^{3+} concentrations that have the best potential for the emission spectra of each reference.

Table 1. Hypersensitive absorption transition (from the ground state, $^4I_{9/2} \rightarrow {}^4G_{5/2}, {}^2G_{7/2}$) for Nd^{3+} : borate glass

Glasses structure	λ_p (nm)	$x Nd^{3+}$ (mole%)	E_{xpt} (cm^{-1})	E_{cal} (cm^{-1})	f_{exp} x 10^{-6}	f_{cal} x10^{-6}
$75B_2O_3.13PbO.5Bi_2O_3.5Al_2O_3$ [2]	580	2.0	17.212	17.199	20.70	20.86
$99Bi_2ZnOB_2O_6$ [27]	585	1.0	17.094	-	20.63	-
$25LiO;25GeO_2;49B_2O_3$ [20]		0.5	19.477	-	-	-
$20CdO.15Bi_2O_3$-$79.5B_2O_3$ [28]	582	0.5	-	-	5.12	5.11
$72.75B_2O_3;4.5CaO$-$22.37La_2O_3$ [29]	583	1.0	-	-	1.1649	1.1642
$20NaF;30PbO;49.5B_2O_3$ [22]	582-585	0.5	17.153	17.123	22.41	22.42
$20NaCl;30PbO;49.5B_2O_3$ [22]	582-585	0.5	17.185	17.220	22.31	22.29
$35Bi_2O_3;30Na_2O;34B_2O_3$[30]	582-585	1.0	17.065	-	16.0	16.2
$35PbO;30Na_2O;34B_2O_3$[30]	582-585	1.0	17.605	-	15.0	15.3
$49.5PbO;30B_2O_3;10TiO_2$-$10AlF_3$ [31]	585	0.5	17.094	17.300	16.090	16.033
$67\ B_2O_3;12Li_2O;20Na_2O$ [32]	582-585	1.0	17.118	-	-	-
$67\ B_2O_3;12Li_2O;20K_2O$ [32]	582-585	1.0	17.089	-	-	-
$49.5\ B_2O_3;49.5Na_2O$ [33]	580	1.0	-	-	26.37	26.31
$49.5B_2O_3;24.75Na_2O;24.75NaF$ [33]	580	1.0	-	-	19.90	19.90
$20B_2O_3;69.5Bi2O_3;10SiO_2$ [34]	586	0.5	-	-	5.53	5.20

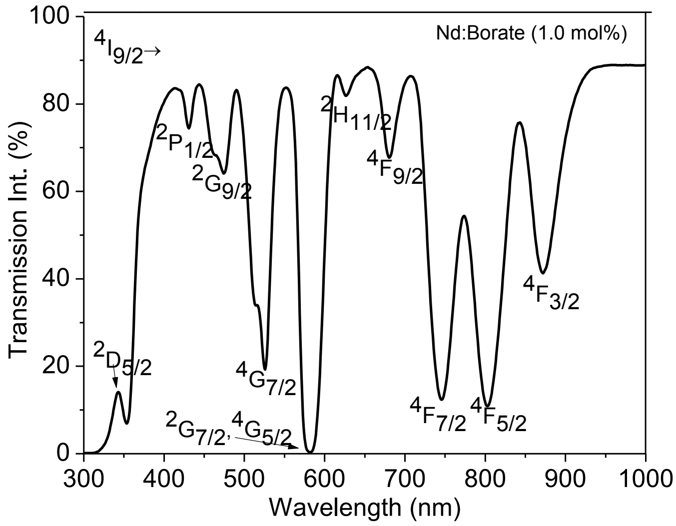

Figure 1. Transmission spectra of 1.0 mole% Nd^{3+} doped borate glass system

Table 1 reflected the hypersensitive absorption band located in the 580-586 nm wavelength range with the Nd^{3+} concentrations to be potential as a laser medium are 0.5; 1.0 and 2,0 mole%. Absorption band due to the content of the composition of Nd^{3+} ions in the glass material, this affects the shape, peak position and intensity of the transition. The difference of hypersensitive wavelength position of several glass mediums are attributed to differences in the crystal field asymmetry which makes the peak position split. In addition, the intensity of the absorption peak of hypersensitivity split was also caused by changes in the content of the composition glass. On the other hand, some medium glasses have the same absorption peak, which splits disappearances have occurred by expansion of homogeneity [33]. The oscillator strength values are strongly influenced by the type and composition of other metal compounds as modifiers of the glass network structure. The high content of the borate not guarantee can increase the value of the oscillator strength, but becomes interesting that the current composition of 49.5 mole% boric produced high oscillator strength values. The transmission spectra of 1.0 mole% Nd^{3+} doped borate glass system in the wavelength range 300-1000 nm is shown in **Figure 1**. The transmission spectra shows ten sensitive bands derived from the state of $^4I_{9/2}$ to various excited states. The transmission peaks centered at 354 nm, 430 nm, 474 nm, 524 nm, 580 nm, 625 nm, 679 nm, 744 nm, 802 nm and 871 nm were attributed to $^2D_{5/2}$, $^2P_{1/2}$, $^2G_{9/2}$, $^4G_{7/2}$, $^2G_{7/2}$+$^4G_{5/2}$, $^2H_{11/2}$, $^4F_{9/2}$, $^4F_{7/2}$, $^4F_{5/2}$, $^4F_{3/2}$ transitions respectively

Table 2. Judd-Ofelt parameters (x 10^{-20}) and spectroscopic quality factor (Ω_4/Ω_6) of the excellent concentration of Nd^{3+} (*x*) : doped borate glasses based

Glasses	*x*Nd^{3+} (mole%)	Parameter			
		Ω_2	Ω_4	Ω_6	χ
$99Bi_2ZnOB_2O_6$ [27]	1.0	2.67	3.31	3.98	0.83
$25LiO;25GeO_2;49B_2O_3$ [20]	0.5	4.84	5.97	4.59	1.22
$25NaO;25GeO_2;49B_2O_3$ [20]	0.5	5.75	3.44	3.73	0.92
$25KO;25GeO_2;49B_2O_3$ [20]	0.5	5.89	3.95	2.85	1.38
$25RbO;25GeO_2;49B_2O_3$ [20]	0.5	6.18	3.63	2.45	1.48
$20NaF;30PbO;49.5B_2O_3$ [22]	0.5	4.69	5.09	6.50	0.78
$20NaCl;30PbO;49.5B_2O_3$ [22]	0.5	4.84	5.31	6.32	0.84
$75B_2O_3.13PbO.5Bi_2O_3.5Al_2O_3$ [2]	2.0	4.53	4.17	6.44	0.65
$20CdO.15Bi_2O_3$-$79.5B_2O_3$ [28]	0.5	1.44	3.42	2.89	1.18
$35Bi_2O_3;30Na_2O;34B_2O_3$[30]	1.0	4.72	2.12	3.93	0.54
$35PbO;30Na_2O;34B_2O_3$[30]	1.0	4.81	1.97	3.94	0.50
$49.5PbO;30B_2O_3;10TiO_2$-$10AlF_3$ [31]	0.5	5.82	1.88	4.74	0.21
$67\ B_2O_3;12Li_2O;20Na_2O$ [32]	1.0	5.95	7.82	9.84	0.79
$67\ B_2O_3;12Li_2O;20K_2O$ [32]	1.0	10.83	7.73	9.04	0.85
$49.5B_2O_3;49.5Na_2O$ [33]	1.0	7.79	3.03	2.80	1.055
$49.5B_2O_3;24.75Na_2O;24.75NaF$ [33]	1.0	5.33	2.84	4.90	0.579
$20B_2O_3;69.5Bi2O_3;10SiO_2$ [34]	0.5	3.52	4.19	3.86	1.01

The oscillator strength values as shown in **Table 1** were used to determine of Judd-Ofelt parameters, Ω_2, Ω_4, and Ω_6 by using of least-square fitting method in eq. (4). Judd-Ofelt parameters of several Nd^{3+} doped glasses for hypersensitive transition given in **Table 2**. There is one material [28] shown that intensity parameters $\Omega_2 < 2$, this condition represent the high covalent bonding that means there was broadening asymmetry around the environments glass [18]. **Table 2** showed generally was observed that $\Omega_2 > \Omega_{4,6}$ [2,20,30,31,31,33] indicate the higher covalency of the ion-ligand bond lower symmetry of the Nd^{3+} ion site. This result also explained that the higher intensity of hypersensitive transition and the *nephelauxetic* effect possessed by these glass [22]. The higher values of Ω_4 and Ω_6 [20,22,28,32,34] for the glasses indicated their mechanics have higher rigidity. Then, the spectroscopic quality factor known from χ = (Ω_4/Ω_6 for to find the channel through which the excited metastable state to the ground state [2].

Radiative Properties

The Judd-Ofelt parameters (Ω_λ) used for determining of various spectroscopic parameters such as effective bandwidth ($\Delta\lambda_{eff}$), fluorescence lifetime (τ_R), radiative transition probabilities (A_R), stimulated emission cross section (σ) and branching ratio (β_R) as given in **Table 3**. These parameters are calculated using the eq. (6)–(10) for N^{3+} : borate glass of $^4F_{3/2} \rightarrow ^4I_{11/2}$ level transition. Refer to the reported by Q. Nie *et al* [35] that the materials suitable to be used as a laser medium is supposed to have some requirements such as large effective bandwidth, long fluorescence lifetime, high stimulated emission cross-section and high branching ratio. In **Table 3** shown that the value of these parameters is almost equal to each other of the glass material then stated that borate glasses which contained Nd^{3+} potentially be used as a laser gain medium.

Table 3. Excitation wavelength (λ_{exc}), wavelength peak (λ_p), effective bandwidth ($\Delta\lambda_{eff}$), radiative transition probabilities (A_R), stimulated emission cross section (σ), branching ratio (β_R), radiative lifetime (τ_R) and experimental lifetime (τ_{exp}) for the hypersensitive Nd^{3+} doped Borate Glass and emission transition $^4F_{3/2} \rightarrow ^4I_{11/2}$

Glasses structure	λ_{ex} (nm)	λ_p (nm)	$\Delta\lambda_{eff}$ (nm)	A_R (s^{-1})	$\sigma(\lambda_p)$ x10^{-20} (cm^2)	β_R	τ_R (μs)	τ_{exp} (μs)
$99Bi_2ZnOB_2O_6$ [27]	808	1063	29.00	3407	4.33	0.04	145	62.0
$75B_2O_3.13PbO.5Bi_2O_3.5Al_2O_3$ [2]	580	1065	18.81		7.89	0.74	264	-
$20CdO.15Bi_2O_3$-$79.5B_2O_3$ [28]		1064	-	1696	-	0.543	-	-
$20NaF;30PbO;49.5B_2O_3$ [22]		1063	-	2077	-	0.494	238	-
$20NaCl;30PbO;49.5B_2O_3$ [22]		1063	-	2070	-	0.487	235	-
$35Bi_2O_3;30Na_2O;34B_2O_3$[30]	808	1067	43	1581	2.0	0.552	349	
$35PbO;30Na_2O;34B_2O_3$[30]	808	1065	43	1285	1.8	0.548	426	
$49.5PbO;30B_2O_3;10TiO_2$-$10AlF_3$ [31]	805	1070	34	1184	2.6	0.52	470	230
$67\ B_2O_3;12Li_2O;20Na_2O$ [32]	514	1069		3092	6.16	0.499	26	-
$67\ B_2O_3;12Li_2O;20K_2O$ [32]	514	1050		4110	8.84	0.512	21	-
$49.5\ B_2O_3;49.5Na_2O$ [33]	800	1067	18.83		4.24	0.443	470	153
$49.5B_2O_3;24.75Na_2O;24.75NaF$ [33]	800	1062	17.84		4.18	0.378	347	151
$20B_2O_3;69.5Bi2O_3;10SiO_2$ [34]	800	1075		1130	2.20	0.536		

The composition of glass structure in the **Table 3** is the optimum value selected from each reference. So the quality of the materials is also influenced by the amount of the glass composition in the host matrix. Kumar K *et al* [2] report that the fluorescence radiative lifetime optimum obtained when 75 mole% of B_2O_3 (BINLAB2), the higher emission cross section of $^4F_{3/2} \rightarrow ^4I_{11/2}$ level obtained at 8 mole% PbO (BINLAB3). The difference shown by branching ratio, which were the greatest results given by BINLAB2, followed BINLAB3 and the next BINLAB1. The intensity of the Nd^{3+} ion at $^4F_{3/2} \rightarrow ^4I_{11/2}$ transition level so important to consider in a laser medium therefore the addition of SiO_2 content could be increased of the intensity and lifetime level [35]. The highest of the radiative transition probabilities at $^4F_{3/2} \rightarrow ^4I_{11/2}$ level transition in **Table 3** are given by Nd^{3+} doped $67B_2O_3;12Li_2O;20K_2O$ and

$67B_2O_3;12Li_2O;20Na_2O$ glasses [32]. It is claimed the radiative lifetime both glasses are lower than others and according to reported of Y.Chen et.al [36] that the high radiative transition probability and low radiative lifetime are considered to improve the radiative quantum efficiency of the laser medium.

Emission spectrum

The shapes and position emission spectra were recorded for the NIR range transition shown in **Figure 2**. According to the energy level diagram of Nd^{3+} in glass, the NIR emission located at around 940-946, 1060-1070 and 1335-1346 nm that are attributed to the $^4F_{3/2} \rightarrow ^4I_{9/2}$, $^4I_{13/2}$, and $^4I_{11/2}$ transition respectively. Furthermore, the shape and peak position emission spectra of Nd^{3+} doped glass borate by exciting at 582 nm and 0.50 mole% Nd^{3+} content shown in **Figure 3.**

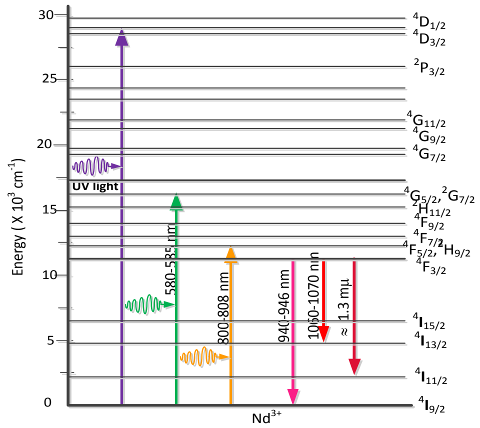

Figure 2 Energy level diagram of Nd^{3+}

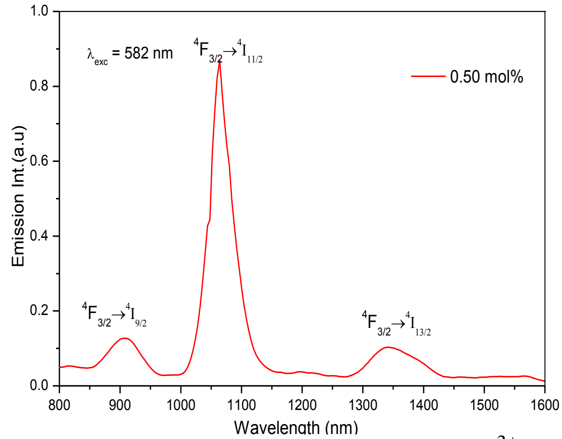

Figure 3 NIR Emission spectra of Nd^{3+}

The position of emission peak wavelength of the $^4F_{3/2} \rightarrow ^4I_{11/2}$ transition shifted a few nanometers due the electric dipole transition of Nd^{3+} ions are very sensitive to the surrounding. This transition assigned as hypersensitive effect and can used to figure out of Nd^{3+}-O covalency bond [30]. The peak wavelength shifted when the Nd^{3+} doped into the host glass due the nephelauxetic effect [37-38], this occurs due to electron orbitals with 4f configuration disabled in the host ligand field [39]. The intensity of the $^4I_{9/2} \rightarrow ^4G_{5/2}+ ^2G_{7/2}$ level transition for Nd^{3+} is higher than the other transition and this is in accordance with the hypersensitive regulations of the transitions such as $J \leq 2$; $\Delta L \leq 2$ and $\Delta S = 0$ [38]. The energy level structure of Nd^{3+} ion will be contracted with the increase in the intersection of the both oxygen and 4f orbitals leading to the wavelength shift. From the emission spectra transition in **Table 3** observed that the peak emission of the $20B_2O_3;69.5Bi2O_3;10SiO_2$ glasses[34] higher than others glass because this glass has a higher polarizability of the Bi-O bond. The emission spectra depends on Ω_4 and Ω_6 parameters because have related to the rigidity of the host glass. In **Table 3** there are three types of glass composition which have the signifies a higher stimulated emission cross section [2,32] and the consequence is the increase of the branching ratio percentage.

CONCLUSIONS

It has been observed the performance of the Nd^{3+} doped borate glass former. This paper focused to discuss of optical properties such as absorption spectra, oscillator strength f, Jud-Ofelt parameters $\Omega_{2,4,6}$, branching ratio β_R, radiative transition probabilities A_R, emission spectra and radiative lifetime τ_R for special of the hypersensitive transition Nd^{3+} from $^4F_{3/2}$

level to $^4I_{11/2}$ level. The highest of the oscillator strength obtained when the current of 49,5 mol% boric nevertheless the high content of borate not guarantee can increase the value of the oscillator strength. The quality of the materials is also influenced by the amount of the glass composition in the host matrix, but for to obtain the high of radiative transition, such as σ_{em}, A_R and τ_R of the laser medium proposed to use of borate-lithium-potassium oxide glass. So, each glass materials have the advantages of each in accordance with the expected parameters.

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