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Optical and Physical Analysis of Nd^{3+} Doped Borosilicate Glasses

Yogesh Kumar Sharma[1], Priyanka Goyal[1*], Sudha Pal[1] and Umesh Chandra Bind[2]

1. Department of Physics, S.B.S. Govt. P. G. College, Rudrapur, (Kumaun University, Nainital)-263153, Uttarakhand, India

2. Centre of Nano Technology, Indian Institute of Technology, Roorkee, India

Abstract: Nowadays rare earth doped glasses are becoming very interesting among researchers due to their physical and optical properties. In the present work physical and optical parameters were computed for borosilicate glasses doped with Neodymium ion. The glass samples were prepared by conventional melt quenching technique. Their final composition is (50 – x) B_2O_3 - (10 + x) SiO_2 – 10 Na_2O – 20PbO – 10 ZnO- 0.3 Nd_2O_3 (where x = 0, 5, 10, 15, 20, 25, 30, 35 and 40). The amorphous nature of the glass samples was confirmed by XRD (X-ray diffraction). Composition and functional groups of the glass samples were confirmed by EDX (Energy-dispersive X-ray spectroscopy) and FTIR (Fourier transform infrared spectroscopy) respectively. SEM (Scanning Electron microscopy) and TEM (Transmission electron microscope) images were recorded. Absorption spectra have been recorded at room temperature in UV-VIS-NIR region. Energy and intensity parameters were computed for Nd^{3+} doped glasses. Physical parameters were measured for the present glass. The optical energy band gap was computed for all different concentration of SiO_2 contents. It was found that with increasing of the concentration of SiO_2 contents, the values of physical parameters decreases.

Key words: Borosilicate glass, physical parameters, absorption spectra, optical band gap.

1. Introduction

Over the last few decades, rare earth ions doped glasses have drawn much interest among the researchers due to their potential application in the development of various optical and optoelectronic devices such as, solid state laser, optical amplifier, light converters, sensors, electro-chromic display devices, solid state lightning (LED's) etc [1]. Rare earth ions play an important role in much of modern optical technology as the active constituents of materials. There are an amazing number of applications for these rare earth activated materials and much of today's cutting – edge optical technology and future innovations rely on their unique properties [2]. Nd^{3+} doped glass samples are of great interest due to their wide applications as laser materials and luminescent solar concentrators [3]. The Nd^{3+} ion has been used in a number of laser systems due to the relatively wide availability of samples of this ion doped in a range of host materials. In general, the properties of spectral transitions of rare earth ions can be improved by developing novel host materials [4]. Among oxide glasses borosilicate glasses are of growing interest because of their excellent optical properties in the mid infrared region and their stability. In this research paper we have selected silica and borax as host matrix. Borosilicate glasses were prepared by conventional method. We investigated optical and physical properties of Nd^{3+} doped borosilicate glasses. We have computed optical energy band gap, energy parameters (*i.e.* Slater – Condon, Racah and bonding parameters) and intensity (*i.e.* Judd – Ofelt parameters) parameters.

2. Experimental Details

2.1 Glass Preparation

The starting materials silicon dioxide (SiO_2), Borax ($Na_2B_4O_7.10H_2O$), Lead carbonate ($PbCO_3$) and Zinc carbonate $\{ZnCO_3\}_2$ $\{Zn(OH)_2\}_3$ were used of A. R.

*Corresponding author: Priyanka Goyal, research scholar, research fields: laser material, absorption and fluorescence spectra of rare earth doped glasses.

Grade and were procured from E. Merck (India) are 99.99% pure. The glass specimens were prepared by conventional melt quenching technique. The samples were preheated at 300 °C in electric furnace for 1 hour. After that samples were heated by increasing temperature slowly up to 1,000 °C for 3 hours. Homogeneity of the melt was ensured by stirring the melt by platinum rod time to time. Prepared samples were poured into preheated rectangular brass plate and annealed for 6 hours. Prepared samples were cut and polished for optical measurements. The final composition of glass specimens were collected in Table 1.

2.2 Characterization of Glass Samples

The Characterization of the borosilicate glass specimens was done to ensure the glass formation by X-ray diffraction. From Fig. 3 it is clear that there are no crystalline peaks in this, which shows that prepared samples are amorphous in nature. Composition and functional groups are justified by the EDX and FTIR which are shown in Figs. 1 and 2 respectively. Optical absorption spectra were recorded at room temperature using UV-VIS/NIR spectrophotometer model Varian carry with a resolution of 0.5 nm. The density of the glass specimens were calculated using Archimedes principle with toluene as immersion liquid. Formula for calculating density is given in Table 2. Optical path lengths of the glass materials were measured using digital Vernier callipers. SEM image was recorded by using FEI Quanta 200F. TEM image also has been recorded by using Tecnai G2 20.

3. Results and Discussion

3.1 EDX, XRD and FTIR

EDX spectrum for the present glass system is shown in Fig. 1. From Fig. 1 it is clear that the chemicals we have used in our sample preparation are

Table 1 Final composition of borosilicate glass specimens with 0.3 wt% of neodymium ion.

Name of the glass specimens	Composition of glass specimens
A	50 B_2O_3 – 10 SiO_2 – 10Na_2O - 20 PbO – 10 ZnO
B	45 B_2O_3 – 15 SiO_2 – 10Na_2O - 20 PbO – 10 ZnO
C	40 B_2O_3 – 20 SiO_2 – 10Na_2O - 20 PbO – 10 ZnO
D	35 B_2O_3 – 25 SiO_2 – 10Na_2O - 20 PbO – 10 ZnO
E	30 B_2O_3 – 30 SiO_2 – 10Na_2O - 20 PbO – 10 ZnO
F	25 B_2O_3 – 35 SiO_2 – 10Na_2O - 20 PbO – 10 ZnO
G	20 B_2O_3 – 40 SiO_2 – 10Na_2O - 20 PbO – 10 ZnO
H	15 B_2O_3 – 45 SiO_2 – 10Na_2O - 20 PbO – 10 ZnO
I	10 B_2O_3 – 50 SiO_2 – 10Na_2O - 20 PbO – 10 ZnO

Table 2 Formulas for calculating Physical and Optical parameters.

Eq. No.	Parameter	Formula	Description
Physical parameters			
1)	Density (ρ)	$\rho = \frac{W_a \rho_t}{W_a \sim W_t}$	W_a – Weight of sample in air W_t - Weight of sample in Toulene ρ_t - Density of Toulene
2)	Molar volume (V_m)	$V_m = \frac{M_{AV}}{\rho}$	M_{AV} – Average molecular weight
3)	Ion concentration (N)	$N = \frac{N_A \rho \, (mol\,\%\, of\ rare\ earth\ ion)}{M_{AV}}$	N_A – Avogadro number
4)	Oxygen packing density (O) [13]	$O = \frac{1000*n*\rho}{M}$	n – No. of oxygen atoms per formula M – Molecular mass ρ – Density
5)	Polaron radius (r_p)	$r_p = \frac{1}{2}\left(\frac{\pi}{6N}\right)^{1/3}$	N – Rare earth ion concentration
6)	Inter nuclear distance (r_i)	$r_i = \left(\frac{1}{N}\right)^{1/3}$	
7)	Field strength (F)	$F = \left(\frac{Z}{r_p^2}\right)$	Z – Atomic mass of Neodymium ion

(Table 2 continued)

Optical parameters			
Eq. No.	Parameter	Formula	Description
8)	Refractive index	$n_d = 1.57376 + \frac{153.137}{\lambda(Å) - 686.2}$	λ(Å) = for peaks
9)	Reflection losses	$R = (\frac{n_d - 1}{n_d + 1})^2$	n_d – Refractive index
10)	Molar refractivity(R_M)	$R_M = V_M (\frac{n_d^2 - 1}{n_d^2 + 2})$	V_M – Molar volume
11)	Molar polarizability (α_M)	$\alpha_e = \frac{3}{4\pi N} R_M$	R_M – Molar refractivity
12)	Dielectric constant(ε)	$\varepsilon = n_d^2$	n_d – Refractive index
13)	Optical dielectric constant	$p\frac{\partial t}{\partial p} = (\varepsilon - 1) = (n_d^2 - 1)$	

Table 3 Physical and Optical Parameters of Nd-ion doped Borosilicate glass.

Parameters		Glass name								
Physical parameters	Unit	A	B	C	D	E	F	G	H	I
Density(ρ)	(gm/cm^3)	6.75	6.68	6.60	6.53	6.45	6.38	6.30	6.22	6.14
Thickness	(cm)	0.10	0.11	0.15	0.10	0.05	0.12	0.11	0.11	0.19
Average molecular weight (M_{AV})	(gm)	100.806	100.329	99.852	99.375	98.898	98.421	97.945	97.468	96.991
Rare earth ion concentration N ($*10^{22}$)	($ions/cm^3$)	1.210	1.203	1.194	1.187	1.178	1.171	1.162	1.153	1.144
Oxygen packing density (OPD)	(g – atom/l)	141.219	137.090	132.791	128.727	124.502	120.50	116.358	112.252	108.188
Polaron radius r_p	(Å)	3.781	3.789	3.798	3.805	3.815	3.823	3.832	3.843	3.853
Inter ionic separation r_i	(Å)	9.385	9.403	9.423	9.444	9.466	9.487	9.512	9.537	9.562
Field strength (F) (10^{16})	(cm^{-2})	10.086	10.047	9.999	9.960	9.910	9.870	9.819	9.767	9.715
Optical parameters										
Refractive index n_d	-	1.615	1.607	1.606	1.603	1.600	1.598	1.596	1.594	1.592
Dielectric constant (Ɛ)	-	2.609	2.584	2.581	2.569	2.561	2.553	2.546	2.540	2.533
Optical dielectric constant	-	1.609	1.584	1.581	1.569	1.561	1.553	1.546	1.540	1.533
Molar volume V_m	(g/cm^3)	14.934	15.019	15.129	15.213	15.333	15.427	15.547	15.670	15.797
Reflection losses R	-	5.536	5.429	5.414	5.362	5.332	5.298	5.265	5.241	5.212
Molar Refractivity R_m	(cm^{-3})	5.214	5.190	5.221	5.225	5.249	5.263	5.287	5.316	5.343
Electronic polarazability (α_e) (10^{-24})	($ions\ cm^{-1}$)	6.894	6.862	6.903	6.908	6.940	6.958	6.990	7.028	7.065
Optical energy band gap (E_o)	(eV)	0.948	0.936	0.952	0.959	0.932	0.930	0.962	0.950	0.951
Urbach energy	(eV)	1.020	1.076	1.075	1.076	1.075	1.076	1.071	1.076	1.055

confirmed by EDX. In this image all the elements are present. FTIR spectra has been Recorded by using OMNIC software in the region (500-4,000 cm^{-1}) as shown in Fig. 2. This spectrum provides the information about the molecular vibrations and rotations related with the covalent bond. The observed bands and their respective description is given in Table 4. X-ray diffraction patterns of the Nd^{3+} doped borosilicate glass system (sample F) have been shown in Fig. 3. The XRD patterns exhibit a broad diffuse scattering at low angles instead of crystalline peaks, which confirms the long range structural disorder

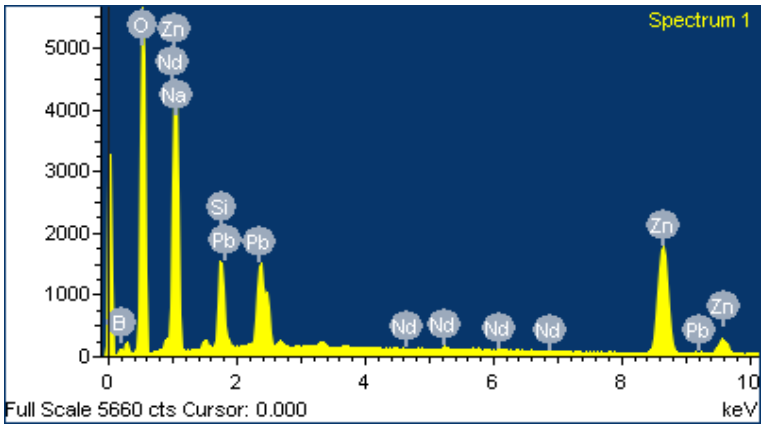

Fig. 1 EDAX of Nd^{3+} doped borosilicate glass of F specimen.

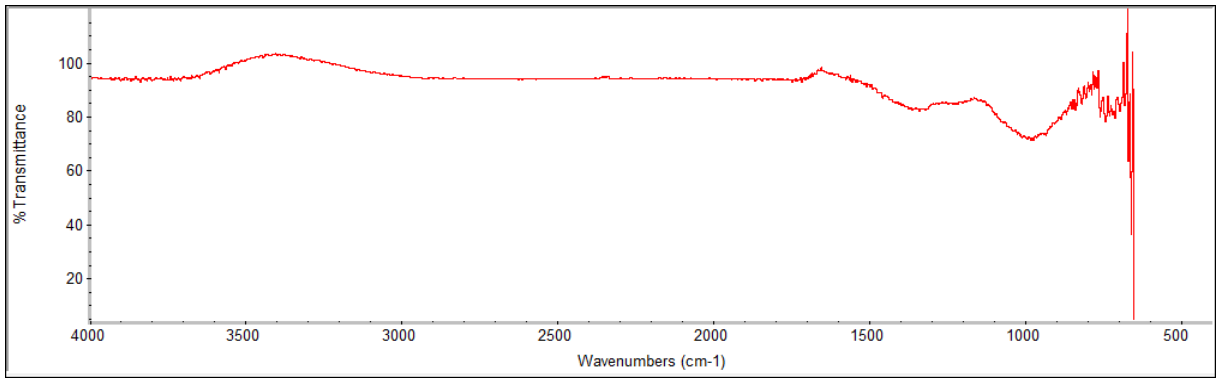

Fig. 2 FTIR spectrum of Nd^{3+} doped borosilicate glass of F specimen.

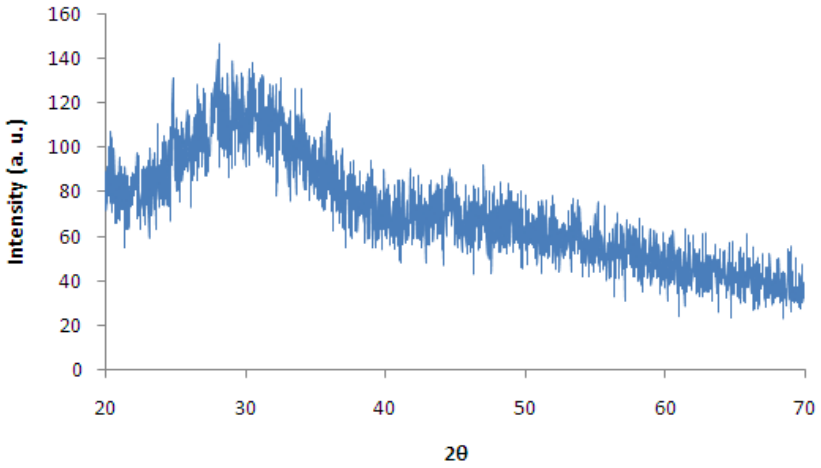

Fig. 3 XRD of Nd^{3+} doped borosilicate glass of F specimen.

characteristic of amorphous network [5]. Absence of the peaks in the graph shows its glassy nature. The angular position for the first halo is at about $2\theta \cong 28.72°$.

3.2 Physical Analysis

The values of the measured density (ρ) and the calculated molar volume are given in Table 3. The respective formula for calculating density and molar volume are given in Table 2. Fig. 4 shows the variation of density and molar volume with SiO_2 content. It is clear from Fig. 4 that density decreases linearly from 6.75 to 6.14 g/cm^3 with increase of SiO_2 concentration while molar volume increases linearly

Table 4 Band positions in FTIR spectra of Nd^{3+} doped borosilicate glass of F specimen.

S. No.	Band position (cm^{-1})	Structural vibrations
1)	~475	Presence of ZnO tetrahedral bond
2)	~ 510	υ_4 vibration of BO_4 tetrahedral
3)	~705	B-O-B bending
4)	~980	Penta borate groups
5)	~1,075	Vibrations of pentaborate along with BO^-_4 tetrahedral
6)	~1,220	Stretching of B – O bonds
7)	~1,302	B – O vibrations of borate group
8)	~1,490	Anti symmetric stretching vibrations with three non bridging oxygens of B – O – B groups

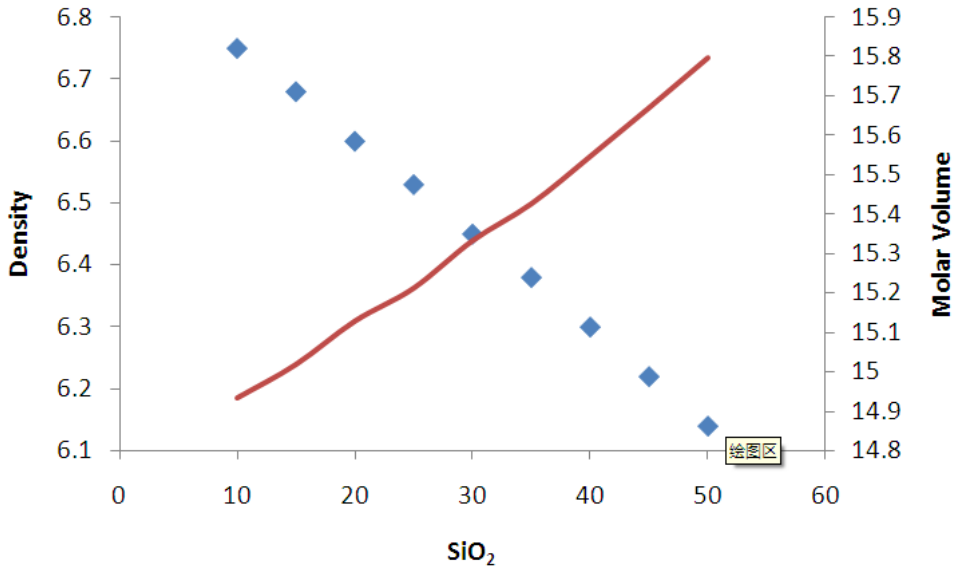

Fig. 4 Variation of density (ρ) and Molar volume (V_m) for borosilicate glasses with Nd_2O_3 ion.

from 14.934 to 15.796 cm^3/mol with SiO_2 concentration. Similar results for density were also observed [6]. Also for molar volume with varying host matrix, molar volume increases is reported [7]. Decrease in density is due to the replacement of B_2O_3 (69.622) by SiO_2 (60.085) as in decrease of the molar mass of SiO_2. In general, it is expected that the density and the molar volume should show opposite behaviour to each other [7] and our present work shows the similar behaviour.

The Nd-ion concentration (N) is of great interest since it affects different properties of the host material. The number of ions per cubic centimetre was calculated according to the Eq. (3) of Table 2 [7]. The calculated values of concentration are collected in Table 3 and corresponding graph is shown in Fig. 5. The data shows that Nd-ion concentration decrease as SiO_2 increased, this is most likely due to the change in density.

Polaron radius and field strength are calculated by the formula given in Table 2. Variation of polaron radius and field strength with SiO_2 concentration is shown in Fig. 6. From Fig. 6, it is clear that polaron radius decreases while field strength increases with increase in SiO_2 content. In general, polaron radius and the field strength show opposite trend which is observed in the present work.

Oxygen packing density (OPD) is a measure of the tightness of the oxide network [7]. It is calculated by the formula given in Table 2. Calculated values of OPD are given Table 3. Fig. 7 shows the dependence of OPD on SiO_2 content. From Fig. 7, it is observed that

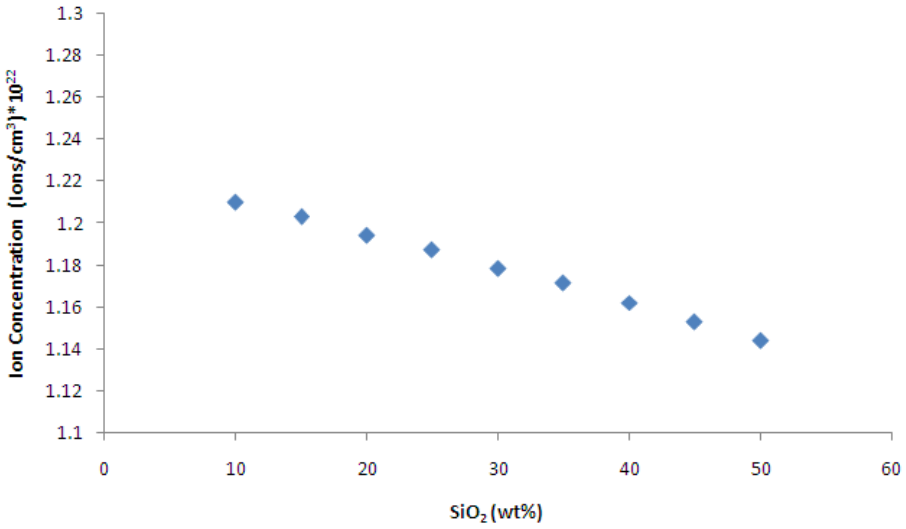

Fig. 5 Composition dependence of rare earth ion concentration (N) on SiO_2 content.

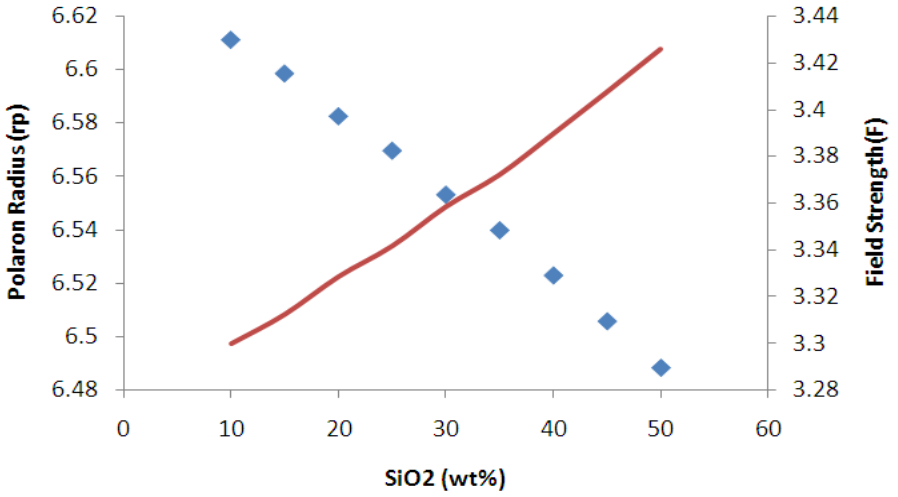

Fig. 6 Dependence of polaron radius (r_p) and field strength on SiO_2 content.

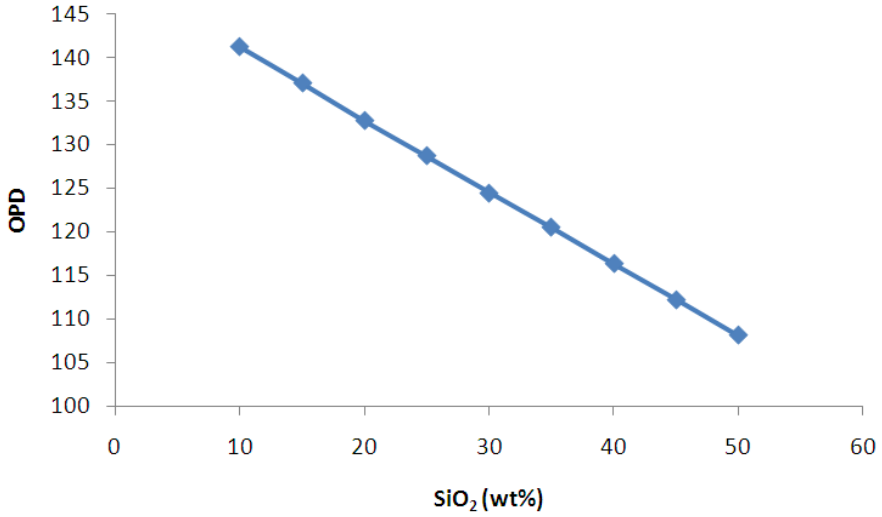

Fig. 7 Variation of Oxygen packing density (O) with on SiO_2 content.

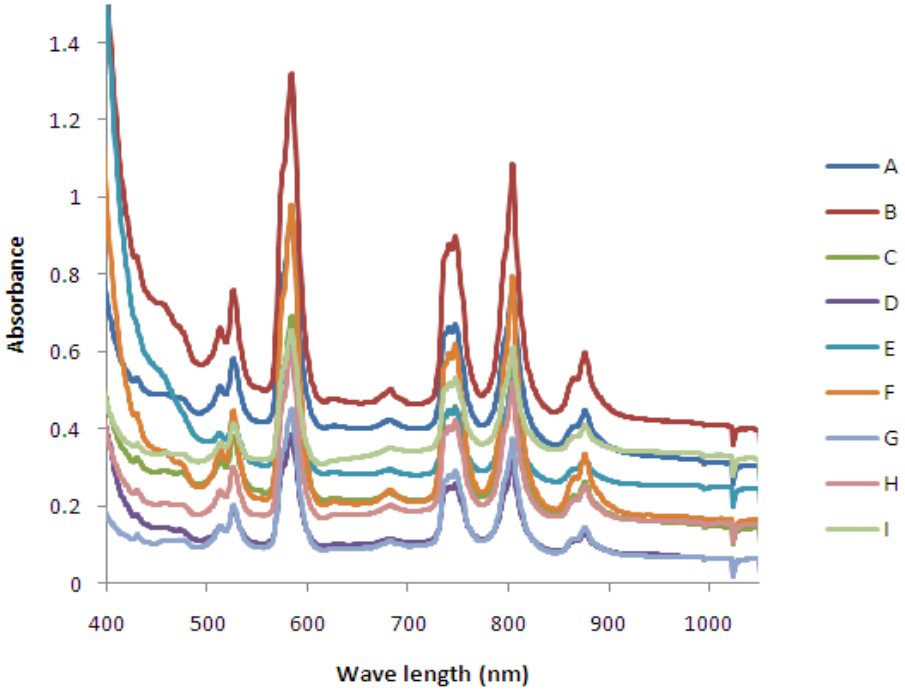

Fig. 8 Absorption spectra of Nd^{3+} doped borosilicate glass specimen at room temperature.

OPD decreases with increase in SiO_2 content. This is the indication that structure is now loosely packed with increase in SiO_2 content. Similar results were also reported [7].

3.3 Optical Analysis

3.3.1 Absorption Spectra

The absorption spectra of Nd^{3+} doped borosilicate glasses were recorded in UV-VIS (300-1,100 nm) region at room temperature and shown in Fig. 8. Room temperature spectra are necessary for the application of Judd – Ofelt theory because this theoretical model assumes that all crystal – field levels of the ground state are equally populated [8]. Nine absorption peaks are observed in this spectra which are at 877($^4F_{3/2}$) , 805($^4F_{5/2}$), 748 ($^4F_{7/2}$), 683($^4F_{9/2}$), 626($^2H_{11/2}$), 584($^4G_{5/2}$), 526($^4G_{7/2}$), 513($^4G_{9/2}$) and 430($^2P_{1/2}$). Absorption is clear in the UV region. If we study this spectra we come to know that all samples with different concentration of SiO_2 follow common pattern, where an absorption edge is observed. The optical absorption edge extended over wide wavelength range i.e. no sharp edge (Urbach edge), which indicates the amorphous nature of the prepared glass samples and agree with the result of XRD. From its linear part we calculated optical energy band gap. The relation between $\alpha(\omega)$ and the photon energy of the incident radiation, is given by:

$$\alpha(\omega) = [B(\hbar\omega - E_g)^n]/\hbar\omega \quad (1)$$

where, B is the tailing parameter, E_g is the energy of the optical band gap, n depends on the type of transition (direct or indirect) taking the values n = 2, 3, 1/2 and 1/3 which corresponds to indirect allowed, indirect forbidden, direct allowed and direct forbidden transitions respectively, n also depends on the nature of the material (crystal or amorphous) [7]. According to Tau relation, for amorphous material n=2. The values of E_0 determined from Fig. 8 (Tau's Plot) by extrapolating the linear parts of the curves to $(\alpha\hbar\omega)^{1/2} = 0$ lie within close limits between 0.93 to 0.98 eV and values of optical energy band gap are given in Table 3.

The relation between $\alpha(\omega)$ and Urbach energy (ΔE) is given by the well known Urbach law given by

the relation:

$$\alpha(\omega) = \text{const.} \exp(\hbar\omega/\Delta E) \quad (2)$$

where, ΔE is usually interpreted as the width of the tail of the localized states in the band gap [9]. Generally Urbach energy values were calculated by taking the log of absorption coefficient (α) and by extrapolating the linear part of the graph (Fig. 10) between log α and photon energy and taking its reciprocal. The values calculated by this method are nearby equal to the reciprocal of optical energy band gap.

3.3.2 Energy Parameters

From absorption spectra, the values of various energy interaction parameters viz Slater – Condon (F_k), Racah (E^k) and Lande′(ζ_{4f}) parameters have been computed by using the observed energies of the bands, the values of zero order energies (E_{0j}) [10] and partial derivatives by the help of partial regression method [11].

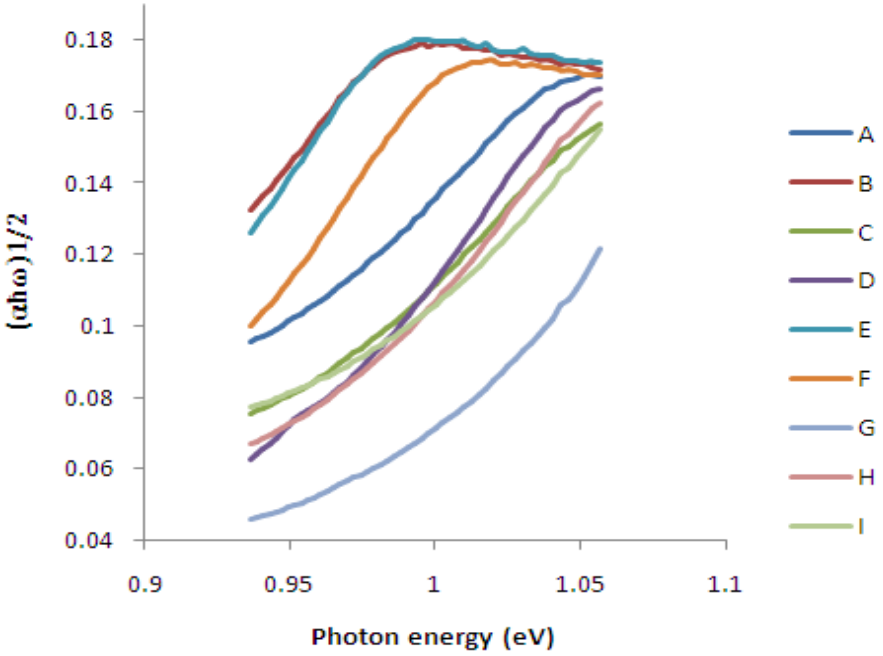

Fig. 9 $(\alpha\hbar\omega)^{1/2}$ as a function of photon energy for Nd^{3+} doped borosilicate glass specimen.

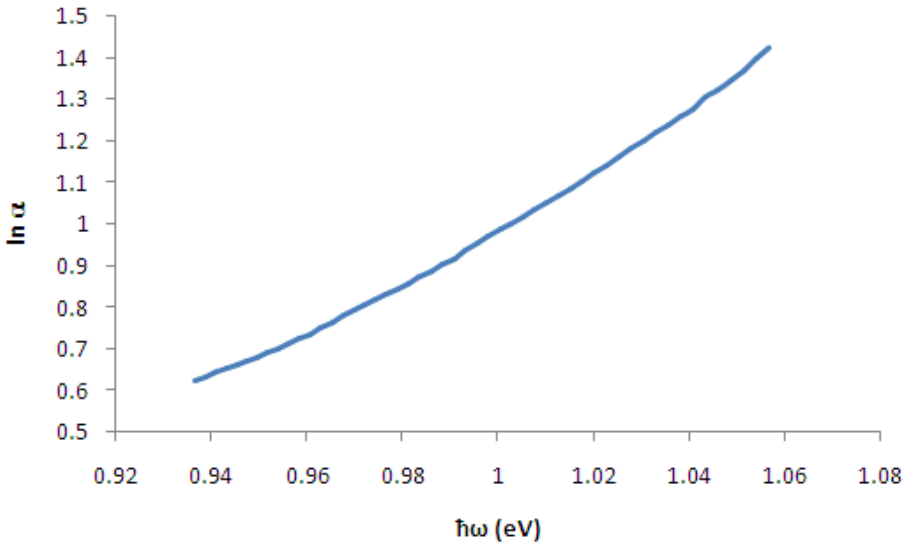

Fig. 10 ln α plotted against photon energy, ħω, for glass sample F.

Table 5 Reported Partial Derivatives and zero order energy value of Nd^{3+} ion for different levels [10].

Absorption levels	E_{Oj}	Partial derivatives			
		E_j/F_2	E_j/F_4	E_j/F_6	E_j/ξ_{4f}
$^4F_{3/2}$	11523.3	35.27	39.90	-588.9	1.02
$^4F_{5/2}$	12606.7	34.93	39.86	-631.4	2.06
$^4F_{7/2}$	13453.7	35.02	41.04	-602.5	3.24
$^4F_{9/2}$	14902.4	28.58	58.06	-382.8	5.06
$^2H_{11/2}$	15980.0	9.26	123.31	406.0	5.22
$^4G_{5/2}$	17357.5	540.98	63.01	-991.2	1.29
$^4G_{7/2}$	19288.9	41.95	101.66	-620.8	4.13
$^4G_{9/2}$	19718.0	43.14	88.67	-723.4	45.12
$^2P_{1/2}$	23147.0	42.63	93.71	226.5	3.56

Table 6 Energy Interaction parameters of Nd^{3+} doped borosilicate glass specimens.

Parameters	Free ions	A	B	C	D	E	F	G	H	I
$F_2(cm^{-1})$	331.16	335.412	336.25	338.447	338.102	338.103	336.822	335.453	335.444	338.124
$F_4(cm^{-1})$	50.72	48.560	48.791	46.761	46.899	46.899	48.711	48.223	48.835	47.172
$F_6(cm^{-1})$	5.15	5.524	5.589	5.566	5.550	5.550	5.580	5.468	5.530	5.560
$\zeta_{4F}(cm^{-1})$	884.00	881.805	879.362	886.281	886.935	886.935	871.391	885.941	874.708	879.375
$E^1(cm^{-1})$	5024.00	5084.025	5111.003	5070.811	5068.047	5068.047	5111.376	5063.183	5092.661	5077.44
$E^2(cm^{-1})$	23.90	25.378	25.444	26.347	26.250	26.250	25.528	24.451	25.294	26.170
$E^3(cm^{-1})$	497.00	488.562	488.445	488.752	488.948	488.946	489.510	489.668	488.990	489.378
F4 / F2	0.15	0.145	0.145	0.138	0.138	0.139	0.145	0.144	0.145	0.139
F6 / F2	0.02	0.01647	0.01662	0.01644	0.01641	0.01641	0.01657	0.01630	0.01649	0.01644
E^1/E^3	10.11	10.406	10.463	10.375	10.365	10.365	10.442	10.340	10.415	10.378
E^2/E^3	0.05	5.194	5.209	5.390	5.368	5.369	5.215	5.198	5.173	5.349
β’	----	1.012	1.015	1.022	1.020	1.021	1.017	1.013	1.013	1.021
$b_{1/2}$	-----	0.080	0.0876	0.104	0.102	0.102	0.092	0.080	0.080	0.102

The partial derivatives of the present glass system have been given in Table 5. The values of F_k, E^k and ζ_{4f} parameters have been collected in Table 6. In the present glass specimen, the relation among different F_k parameters found as $F_2 > F_4 > F_6$. It is interesting to note that the observed values of $F_4/F_2 \sim 0.138$ and $F_6/F_2 \sim 0.015$ are nearly same as calculated considering radial eigen function to be hydrogenic ($F_4/F_2 \sim 0.14$ and $F_6/F_2 \sim 0.015$) [12]. The ratio of E^1/E^3 and E^2/E^3 are about 9.890 and 0.052 respectively, which are almost equal to the hydrogenic ratio[13]. The values of nephlauxetic ratio (β′) and bonding parameter ($b^{1/2}$) are 1.20 and 0.056 respectively (Table 6).

3.3.3 Judd – Ofelt Intensity Parameters

The experimental intensity of the absorption bands have been computed in terms of line strengths (S_{exp}). The U matrix elements and oscillator strengths for the present glass system has been given in Table 7.The values of Judd-Ofelt intensity [14, 15] parameters (Ω_λ, $\lambda = 2, 4, 6$) have been computed using line strengths by partial regression method and have been collected in Table 8. The calculated line strength agrees very well with the experimental values. The spectroscopic quality parameters (Ω_4 / Ω_6) have been found to be 0.343 in specimens. The low value of the goodness of fit (0.43) shows the applicability of Judd – Ofelt theory. All these parameters first increases as the SiO_2 concentration decreases till mid concentration of SiO_2. These parameters show the trend $\Omega_6 > \Omega_2 > \Omega_4$.

SEM and TEM image have been shown in Figs. 11 and 12 for Nd^{3+} doped borosilicate glass specimens. From SEM image the size of the samples were verified. Also from this image it is concluded that present glass is amorphous in nature because image did not have grains.

Table 7 U matrix elements and Oscillator strength for Nd^{3+} doped borosilicate glass specimens.

Absorption levels	wavelength (nm)	U matrix			Oscillator strength(10^{-6})								
		$\|\|U^2\|\|^2$	$\|\|U^4\|\|^2$	$\|\|U^6\|\|^2$	A	B	C	D	E	F	G	H	I
$^4F_{3/2}$	873	0.0000	0.2239	0.0549	1.171	1.501	0.665	0.264	0.607	0.769	0.367	0.504	0.557
$^4F_{5/2}$	799	0.0010	0.2371	0.3970	2.037	2.964	1.463	0.870	1.511	2.272	1.068	1.359	0.835
$^4F_{7/2}$	742	0.0000	0.0027	0.2352	2.428	3.366	1.667	0.959	1.705	2.320	1.003	1.585	0.955
$^4F_{9/2}$	682	0.0009	0.0092	0.0417	1.363	1.648	0.694	0.398	0.863	0.788	0.283	0.556	0.482
$^2H_{11/2}$	623	0.0001	0.0027	0.0104	0.750	0.977	----	----	----	0.433	----	0.361	----
$^4G_{5/2}$	584	0.8979	0.4093	0.0359	5.220	7.491	3.805	2.183	3.595	5.557	2.460	3.419	1.785
$^4G_{7/2}$	526	0.0550	0.1570	0.0553	1.343	1.760	0.893	0.493	0.983	1.038	0.472	0.784	0.539
$^4G_{9/2}$	472	0.0046	0.0608	0.0406	0.935	1.411	0.586	0.313	0.714	0.744	0.271	0.512	0.388
$^2P_{1/2}$	430	0.0000	0.0367	0.0000	0.692	0.738	0.571	0.153	0.867	0.383	0.219	0.313	0.314

Table 8 Optical energy band gap and Omega parameters of Nd^{3+} doped borosilicate glass specimens.

Glass system	Ω_2 (10^{-20})	Ω_4 (10^{-20})	Ω_6 (10^{-20})	Trend	Ω_4/Ω_6
A	1.197	0.580	1.220	$\Omega_6 > \Omega_2 > \Omega_4$.	0.475
B	1.706	0.975	1.812	$\Omega_6 > \Omega_2 > \Omega_4$.	0.538
C	0.920	0.440	0.925	$\Omega_6 > \Omega_2 > \Omega_4$.	0.475
D	0.587	0.183	0.597	$\Omega_6 > \Omega_2 > \Omega_4$.	0.306
E	0.942	0.147	0.899	$\Omega_2 > \Omega_6 > \Omega_4$.	0.163
F	1.322	0.837	1.845	$\Omega_6 > \Omega_2 > \Omega_4$.	0.454
G	0.486	0.579	0.670	$\Omega_6 > \Omega_2 > \Omega_4$.	0.864
H	0.887	0.318	0.944	$\Omega_6 > \Omega_2 > \Omega_4$.	0.337
I	0.254	0.435	0.465	$\Omega_6 > \Omega_2 > \Omega_4$.	0.935

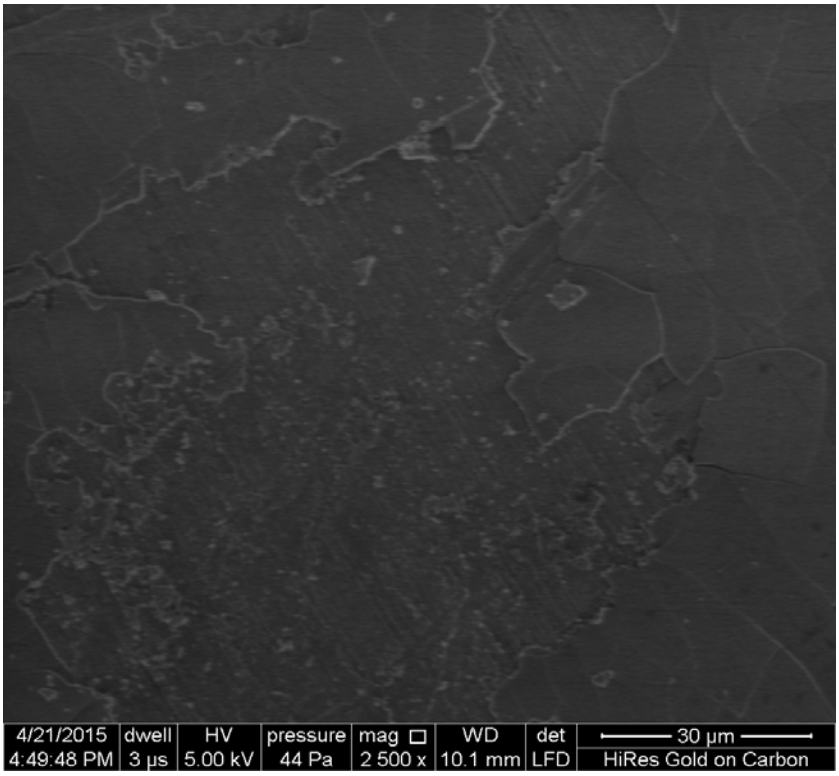

Fig. 11 SEM image of Nd^{3+} ion doped Borosilicate glass of F specimen.

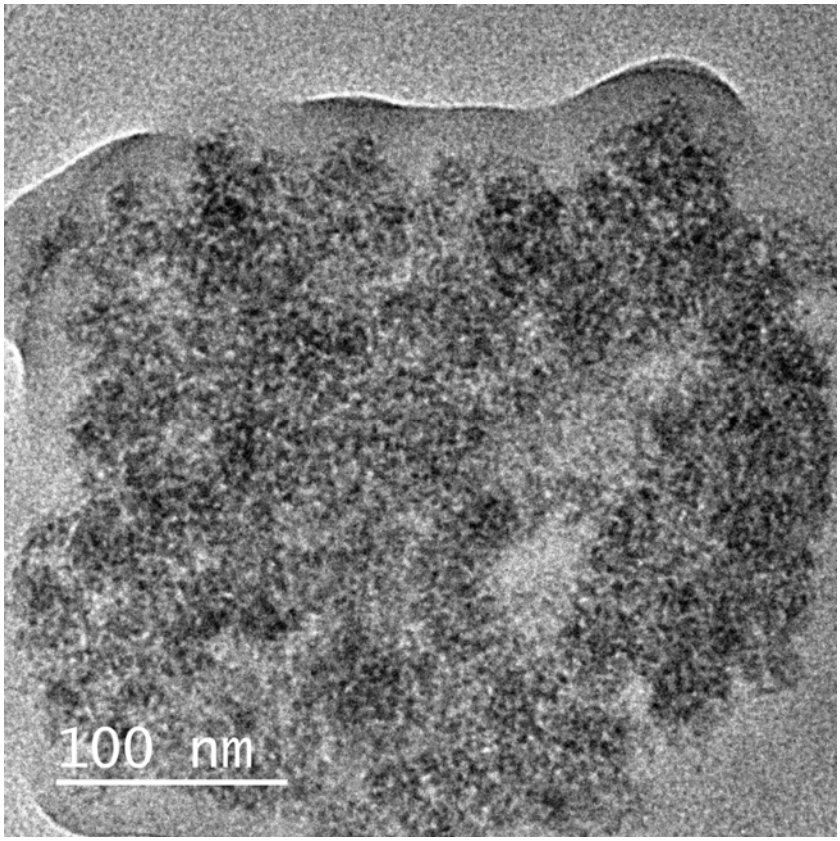

Fig. 12 TEM image of Nd^{3+} ion doped Borosilicate glass of F specimen.

4. Conclusions

New borosilicate glass sample of (50 – x) B_2O_3 – (10 + x) SiO_2 – 10Na_2O – 20 PbO – 10 ZnO has been prepared by doping of neodymium ion and their final composition is done by EDAX and FTIR. From FTIR the band positions of the present glass system are collected. XRD verifies its amorphous nature. Various physical properties were calculated and these increases on increasing the concentration of SiO_2 and their variation are shown with the respective graph. Racah, Slater-Condon, bonding parameters first increases till mid concentration of SiO_2 then decreases and on last concentration it increases again. Judd-Ofelt parameters shows the general trend $\Omega_6 > \Omega_2 > \Omega_4$. Energy parameters (*i.e.* Slater – Condon, Racah and bonding parameters) have been computed and which first increases till mid concentration and then decreases, after that it again increases on last concentration. SEM and TEM images are also given.

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