CHAPTER 1 INTRODUCTION

Glasses, crystal and ceramics are ubiquitous in our daily lives, and are of increasing value in technological advances and for everyday use. Glass, as one of the important artificial materials and a major vehicle for East-West cultural and technical exchange, has played an invaluable role in the course of human civilization. There has been major interest in exploring new possibilities and research has been carried out in search of new glass materials for photonics applications, composites containing small particles, and modifying and tuning glass properties. More recently, advanced knowledge in preparing, producing, and developing new glass applications based on glassy sciences or glassy technology is in line with large scale economies.

1.1 Background

For the past decade, a large amount of luminescence and photogenic equipment research had focused mainly on two aspects. One was a crystal matrix and the other was a glass matrix. Glass was a promising host to investigate the influence of the chemical environment on the optical properties. Glass affords considerable flexibility in size and shape, and can be doped or activated to excellent uniformity. The possibility to control physical properties of glasses, e.g., refractive index, density and molar volume by a proper variation of glass composition suggests the feasibility of a chemical control of the materials according to the needs of respective applications.

Boric oxide (B_2O_3) is one of the most important glass formers and flux materials. Melts with compositions rich in B_2O_3 exhibit rather high viscosity and tend to the formation of glasses. In crystalline form, borates with various compositions are of exceptional importance due to their interesting linear and nonlinear optical properties [1]. It can be found in high technological applications. The boron atom in borate crystal or glass usually coordinates with either three or four oxygen atoms forming $[BO_3]^{3-}$ or $[BO_4]^{5-}$ structural units. Furthermore, these two fundamental units can be arbitrarily combined to form a super structure or different B_xO_y structural groups like boroxol ring, tetraborate, and diborate groups, etc [2]. Among these borates, especially the monoclinic bismuth borate BiB_3O_6 shows up remarkably large linear and nonlinear optical coefficients [3, 4]. Calculations indicate that this can be mainly attributed to the contribution of the $[BiO_4]^{5-}$ anionic group [5, 6]. For the linear properties (refractive index) this anionic group should act in a similar way in an amorphous environment, i.e., in glass. Combining bismuth oxide (Bi_2O_3) with boric oxide was called bismuth borate glass thus allows for tuning the optical properties in a wide range depending on the composition. Moreover, bismuth borate glass is high density materials, and it is a good property to develop as glass scintillation for x-ray luminescence or phosphor materials. Consequently, the properties of glasses of the Bi_2O_3-B_2O_3 system have attracted much interest [7] and are most widely used for various purposes. An important method in modifying and tuning glass properties is rare-earth doped in glasses.

Rare-earth atoms are divided in to two classes. The first one is lanthanides with atomic number 57 through 71 and the second is actinides with atomic number 89 through 103. Rare-earth (RE) ions (4f electronic configuration) doped glasses have been studied and applied for several years in a variety of photonic applications. Rare-earth ions possess unique optical behavior when dope onto glass system and have lead to the way for different objectives and many potential uses including fluorescent lamps, solar control devices, solid laser and optical amplifiers. Rare-earth doped glasses have gained much interest of researchers for the reason that the particular 4f electron configuration of rare -earth in varied glass matrixes. One kind of rare-earth interesting for glass system doping was dysprosium (Dy). The word Dysprosium [dis-pro-zee-uhm], was derived from the Greek word *dysprositos*, meaning 'hard to get'.

Dysprosium ($^{164}_{66}Dy$) was discovered in 1886 in Paris by Paul Emile Lecoq de Boisbaudran. It occurs along with other so-called rare-earth or lanthanide element groups in a variety of minerals such as xenotime, fergusonite, gadolinite, euxenite, polycrase, and blomstrandine. The most important sources are from monaziate and bastnasite. Dysprosium can be prepared by reduction of the trifluoride with calcium. The element has a metallic, bright silver luster. It is relatively stable at room temperature, and is readily attacked and dissolved by dilute and concentrated mineral acids, to evolve hydrogen. Dysprosium has applications for thermal neutron absorption cross-section and high melting point, suggesting metallurgical uses in nuclear control applications, optic fiber, phosphors or luminescence and for alloying with special stainless steels. Dysprosium oxide is used in the electronics industry and antireflection coating in photoelectric devices. Dysprosium oxide-nickel cement can be used in cooling nuclear reactor rods. This cement absorbs neutrons readily without swelling or contracting under prolonged neutron bombardment. In combination with vanadium and other rare earths, dysprosium has been used in making laser materials. Dysprosium-cadmium chalcogenides, as sources of infrared radiation, have been used for studying chemical reactions [8].

Dy^{3+}(4f electronic configuration) doped glasses have been considered as promising laser active materials able to emit radiation associated with the $^6H_{13/2}\rightarrow{}^6H_{15/2}$ transition of Dy^{3+} ion around 3 μm [9] .The active Dy^{3+} ion provides two typical emission transitions that correspond to $^4F_{9/2}\rightarrow{}^6H_{15/2}$ (magnetic dipole) transition in blue bands (~480 nm) and $^4F_{9/2}\rightarrow{}^6H_{13/2}$ (electric dipole) transition in yellow bands (~570 nm) regions, which are also necessary for full primary color displays [10-13]. The relative intensities of the $^4F_{9/2}\rightarrow{}^6H_{13/2}$ transition to the $^4F_{9/2}\rightarrow{}^6H_{15/2}$ transition known as a yellow-to-blue luminescence intensity ratio Y/B can be modulated by varying the glass host and its chemical composition as well as the excitation wavelengths. This research was a study on optical, physical, structural, photo, x-ray, and proton luminescence properties of Dy^{3+} ions doped bismuth borate glass system with different Dy_2O_3 concentration.

1.2 Motivation

From the view of application, glasses doped with Dy^{3+} ions have been used in optical devices, field emission technology, phosphors and LEDs which exhibit red emission with higher luminescence efficiency and due to high density of bismuth borate glass host, it can be candidate on scintillation materials. From literature reviews, very lack studied on Dy^{3+} doped in bismuth borate glasses. In this research, Dy^{3+} doped bismuth borate glasses were prepared and investigated their optical, physical, and structural properties, photoluminescence, x-ray luminescence, and proton luminescence properties.

1.3 Objectives

The objectives of this dissertation are the following.

1.3.1 To prepare Dy^{3+} doped bismuth borate glasses with various Dy_2O_3 concentrations.

1.3.2 To investigate optical, physical, structural, photo luminescence, x-ray luminescence, and proton luminescence properties of prepared glass.

1.4 Literature Reviews

Zhao, X. et al. [14] reported the data of the average electronic polarizability of the oxide ion α_0^{2-}, optical basicity L, and Yamashita-Kurosawa's interaction parameter A of Bi_2O_3–B_2O_3 glasses in a wavelength range from 404.66 to 1,083.03 nm. The present investigation suggests that both α_0^{2-} and L increase gradually with increasing wave number, and parameter A decreases with increasing wave number. Furthermore, close correlations were studied among α_0^{2-}, L, A, and refractive index n. A quantitative relationship between electronic polarizability and optical basicity was observed in a wavelength range from 404.66 to 1,083.03 nm. The present study extends over a wide range of α_0^{2-}, L and A values.

Pascuta, P. et al. [15] studied glasses of the xEu_2O_3•$(100-x)[2Bi_2O_3-B_2O_3]$ system with $0 \leq x \leq 25$ mol% by x-ray diffraction and FTIR spectroscopy measurements, melting at 1,100 ^{0}C and subjected to rapid cooling at room temperature to obtain glass samples. The glass samples were kept at 625 ^{0}C for 24 hr. After heat treatment two crystalline phases were collected. One of the crystalline phases was observed for the host glass matrix, the x = 0 mol% sample, and belongs to the cubic system. The second one was observed for the x = 25 mol% sample and was found to be orthorhombic with two unit cell parameters very close to each other. FTIR spectroscopy data suggest that both Bi_2O_3 and B_2O_3 play the glass network former role while the europium ions play the network modifier role in the studied glasses.

Qui, Y.Q. et al. [16] reported the results of the investigation on the optical properties of the bismuth borate glass ($75B_2O_3$-$25Bi_2O_3$). Unusual near-infrared (NIR) and visible band luminescence was observed when the sample was excited by lasers working at 532 and 808 nm. The NIR fluorescent lifetime of the sample measured at room temperature was longer than two hundred microseconds. This indicated that this glass system could be a new candidate for the broadband optical amplification and laser material covering the wavelength from 1,100 to 1,300 nm. The influences of preparation conditions and glass compositions on the luminescence properties of glasses were investigated. It was found that heat treatment under air and hydrogen atom sphere can weaken the infrared luminescence of the materials. All the results indicated that the infrared luminescence center should be Bi^+ ions.

Oprea, I. et al. [17] studied the optical properties of glasses in the binary system bismuth oxide (Bi_2O_3) - boric oxide (B_2O_3), and measured for the composition range 25-65 mol% Bi_2O_3. Both refractive indices and ultraviolet absorption edge show an expressed dependence on composition. A generalized Sellmeier formula was derived to describe the refractive indices for the whole composition range and a wide wavelength range.

Honma, T. et al. [18] proposed the new optical nonlinear transparent surface crystallized glasses in the system of Ln_2O_3-Bi_2O_3-B_2O_3 (Ln = La, Sm, Gd). The second harmonic (SH) generation from the crystalline phases at the surface layers had been confirmed from Maker fringe measurements. It was suggested that the optical nonlinear crystals precipitated through the crystallization of Ln_2O_3-Bi_2O_3-B2O3 glasses would be new metastable $Bi_xLn_{1-x}BO_3$ phases in which Bi^{3+} ions in $BiBO_3$ were substituted by Ln^{3+} ions. The thickness of crystallized surface was approximately 5 lm and SH intensity was 0.02 compared with that of the Z-cut a-quartz with a thickness of 0.6 mm. In $12.5Sm_2O_3$ $•30Bi_2O_3•57.5B_2O_3$ glass, the crystalline dots with diameters of 5-65 lm were formed by the irradiation of CW YAG laser with a wavelength of 1,064 nm (at 0.6 and 0.7 W, for 1-240 s).

Chen, Y. et al. [19] analyzed an absorption spectra, fluorescence spectra, and fluorescence decay curves at room temperature. Spectroscopic and laser performance parameters of Yb^{3+} in bismuth borate glasses with different compositions and $Yb^{3\ +}$ concentrations were calculated. The effects of the host glasses compositions and Yb^{3+} concentration on the spectroscopic and laser performance parameters were analyzed. The effect of radiation trapping on the spectroscopic properties was also discussed. The results show that the Yb^{3+} doped bismuth borate glass was a promising laser material.

Liu, Y.H. et al. [20] measured the effect of Bi_2O_3 on the optical absorption and emission, energy transfer, and gain property of Yb^{3+}–Er^{3+}-co-doped bismuth borate glasses. An increase of the emission cross-section and fluorescence lifetime of Er^{3+} ions of around 1.5 lm with Bi_2O_3 content was indicated. The increase of Bi_2O_3 content was also beneficial in obtaining a large absorption cross-section at 980 nm and increasing the energy transfer from Yb^{3+} to Er^{3+}. Furthermore, in the $45Bi_2O_3$-$55B_2O_3$ glass, gain curve was almost flat in the range from 1.53 to 1.60 lm. The results indicate that the Yb^{3+}–Er^{3+}-co-doped bismuth borate glasses had good prospects as a candidate of gain medium for 1.5 lm broadband amplifier.

Oprea, I. et al. [21] measured the absorption and luminescence properties of erbium ions in the binary glass system bismuth oxide (Bi_2O_3) - boric oxide (B_2O_3) for the composition range 25–65 mol% Bi_2O_3. A Judd-Ofelt analysis of the typical erbium bands in the absorption spectra reveals comparably high Judd-Ofelt coefficients. This indicates a substantial mixing of other electronic configurations into the $4f^N$ configuration by the random crystal fields in the glasses. All coefficients decrease with increasing Bi_2O_3 content, this effect being most pronounced with Ω_2. Luminescence decay times and radiative efficiencies show an expressed dependence on the glass composition. Radiative efficiencies of all luminescence bands increase with increasing Bi_2O_3 content.

Khonthon, S. et al. [22] studied the relationship between factors affecting redox equilibrium, melting temperature, glass composition and carbon addition, and near infrared luminescence (NIR) characteristics of Bi-containing glasses. The color center and luminescent center of these glasses were discussed based on redox equilibrium. It was found that the coloration and NIR luminescent characteristics of Bi-containing glasses were strongly affected by redox equilibrium. It was confirmed that the darkening effect (black coloration) of Bi-containing glasses originated from the formation process of metallic Bi colloids. The highest NIR luminescent intensity was obtained in glasses just before the beginning of darkening effect. Absorption and luminescence measurements suggest that there were fewer color centers and luminescent centers in those glasses.

Yousef, E.S. et al. [23] analyzed the bismuth borate glasses doped with some rare-earth ions. Glasses were studied with respect to the density, molar volume and the elastic moduli, Poisson's ratio, Debye temperature, microhardness, softening temperature, acoustic impedance, diffusion constant, and the latent heat of melting. Ultrasonic velocities were measured by the pulse echo overlap technique at a frequency of 10 MHz and at room temperature. The derived experimental values of shear modulus, bulk modulus, Young's modulus, and Poisson's ratio for glasses were compared with the theoretically calculated values in terms of the bond compression model and Makishima-Mackenize theory.

Yasser, B. et al. [24] studied glasses with compositions $Li_{0.5}B_{1.5-2x}Bi_{2x}O_{2.5}$, $0 \leq x \leq 0.4$. Glasses were prepared using the normal melt quenching technique. The density and the molar volume was then determined. Infrared (IR) spectroscopy was used as a structural probe of the nearest neighbor environment in the glass network. The optical transmittance and reflectance spectrum of the glasses was recorded in the wavelength range of 300–1,100 nm. The values of the optical band gap E_g^{opt} for indirect transition and refractive index were determined for different compositions of the amorphous glass. The average electronic polarizability of the oxide ion α_0^{2-} and the optical basicity was estimated from the values of calculated refractive indices. The compositional dependence of different physical parameters such as the density, the molar volume, the optical band gap, the refractive index, the average electronic polarizability of the oxide ion, and the optical basicity on Bi_2O_3 content was analyzed and discussed.

Borodi, Gh. et al. [25] studied the formation of a layered structure on the bismuth borate glass surface. X-ray diffraction analysis shows that the transformation during heat treatment from amorphous to crystalline phases of bismuth borate glass samples takes place in sequences. After a short heat treatment, 5 min at 550 ^{0}C, a layered structure with a preferred orientation of crystallites on the surface was observed. After a long heat treatment, 8 hr at the same temperature, normal polycrystalline bulk samples were obtained.

Doweidar, H. and Saddeek, Y.B. [26] proposed $xRO \bullet 30Bi_2O_3 \bullet (70-x)B_2O_3$ glasses and doped with R oxides (R = Zn, Ba) for $0 \leq x \leq 30$ mol%. Elastic properties and Debye temperature were investigated using sound velocity measurements at 4 MHz. The ultrasonic parameters along with the IR spectroscopic studies were employed to explore the role of divalent cations in the structure of the studied glasses. Analysis of infrared spectra indicates that RO was preferentially incorporated into the borate network, forming BO_4 units. It was assumed that Bi_2O_3 enters the structure in the form of BiO_6 only. The change of density and molar volume with RO content reveals that BO_4 units linked to R^{2+} cations were more dense than those linked to positive sites in the Bi_2O_3 network.

Agarwal, A. et al. [27] prepared glass composition of $20ZnO\bullet xBi_2O_3\bullet(79 - x)B_2O_3$ ($15 \leq x \leq 35$ mol%) and doped with 1 mol% Sm^{3+} ions by melt quench technique. Optical absorption and fluorescence spectra were recorded. Judd-Ofelt approach were applied for the fMf transition of Sm^{3+} ions to evaluate various intensity parameters $(\Omega_2, \Omega_4, \Omega_6)$. The variations in intensity parameters, radiative transition probabilities and hypersensitive band positions with composition. The variation of Ω_2 with Bi_2O_3 content had been attributed to a change in the asymmetry of the ligand field at the rare-earth ion site and to the changes in their rare-earth-oxygen (RE-O) covalency, whereas the variation of Ω_6 was found to be strongly dependent on nephlauxetic effect. The shift of the hypersensitive band shows that the covalency of the RE-O bond increases with increase of Bi_2O_3 content due to increased interaction between the Sm^{3+} ion and non-bridging oxygen (NBOs). The radiative transition probabilities for the Sm^{3+} ions were large in zinc bismuth borate glasses, suggesting their suitability as laser material.

Bajaj, A. et al. [28] reported on the glasses system: $xBi_2O_3–(100-x)B_2O_3$ (x = 20 to 66 mol%) and characterized by density, DSC, UV-visible absorption and ^{11}B MAS-NMR spectroscopy. Glass molar volume increases while the glass transition temperature decreases with Bi_2O_3 concentration. Densities of some bismuth borate glasses were found to be greater or very close to those of single crystal phases with equal composition. ^{11}B MAS-NMR studies determined that the fraction of tetrahedrally coordinated boron (N_4) is maximum at 42 mol% of Bi_2O_3 and that there was a local maxima in N_4 at Bi_2O_3 concentration of 50 mol%. Glasses containing Bi_2O_3 concentration of 33 mol% and higher show an unusual, intense absorption band just below the optical band gap. Two crystalline phases: $Bi_3B_5O_{12}$ and $Bi_4B_2O_9$ were prepared by devitrification of glasses and characterized by x-ray diffraction, FTIR and ^{11}B MAS-NMR studies. Both crystalline phases contained significantly lower N_4 than glasses with equal composition.

Hussin, R. et al. [29] showed the luminescence properties of Dy^{3+} (1.0 mol%) doped $30SrO-30MgO-40P_2O_5$, which had been prepared by solid state reaction. The crystalline phases were identified using x-ray diffraction (XRD) and their luminescence properties were studied using excitation and emission spectra obtained from photoluminescence spectroscopy. The results of XRD patterns indicate that the prepared sample contained $Mg_2P_4O_{12}$ and $SrMgP_2O_7$ crystalline phase. The excitation spectrum of $30SrO-30MgO-40P_2O_5$: Dy^{3+} consist many dominant broad bands' center at ~280, 310 and 400-600 nm. The broad band excitation spectrum associated with defects and vacancies of host material through two different crystalline phases present in host material. The other feature of sharp peaks was very similar and belongs to Dy^{3+} ions. The observed f-f transitions in the range of 417-475 nm correspond to the transitions from $^6H_{15/2}$ to $^4K_{17/2} + {}^4M_{19/2,\ 21/2} + {}^4I_{13/2} + {}^4F_{7/2}$, $^4G_{11/2}$, $^4I_{15/2}$, and $^4F_{9/2}$, in the range of 392 nm to $^6P_{3/2} + {}^6P_{5/2}$, and in the range of 312-370 nm to $^4K_{15/2}$, $^6P_{7/2} + {}^4M_{15/2}$, and $^4I_{11/2}$ respectively. The sharp emission peaks like at 482, 465 and 455 nm could be assigned to the transition of $^4F_{9/2} \rightarrow {}^6H_{15/2}$, $^4I_{15/2} \rightarrow {}^6H_{15/2}$, and $^4G_{11/2} \rightarrow {}^6H_{15/2}$ of Dy^{3+} respectively. Dy^{3+} had emissions due to the atomic energy levels of itself and emissions due to the acceptor levels of defect sites formed by Dy^{3+}. In addition, the $SrO-MgO-P_2O_5$ was found a new self-active luminescent material.

Lakshminarayana, G. et al. [30] reported spectral analytical results of Sm^{3+} and Dy^{3+} (1.0 mol%) ions doped in B_2O_3-ZnO-PbO (BZP) glasses. Measurements of x-ray diffraction (XRD), differential scanning calorimeter (DSC) profiles of those rare-earth ion doped glasses were determined. From the DSC thermograms, glass transition (T_g), crystallization (T_c) and melting (T_m) temperatures were evaluated. Direct and indirect optical band gaps were calculated based on the glass UV absorption spectra. Those glasses showed strong absorption bands in the near-infrared (NIR) region and their oscillator strengths were computed. Emission bands of $^4G_{5/2}$-$^6H_{5/2}$ (564 nm), $^4G_{5/2}$-$^6H_{7/2}$ (602 nm), $^4G_{5/2}$-$^6H_{9/2}$ (647 nm) and $^4G_{5/2}$ -$^6H_{11/2}$ (710 nm) for the Sm^{3+}: glass, with excitation at $^6H_{5/2}$-$^4I_{9/2}$ (484 nm) were recorded. Of them, $^4G_{5/2}$-$^6H_{7/2}$ (602 nm) showed a bright emission. With regard to the Dy^{3+}: glass, a bright fluorescent yellow emission at 576 nm ($^4F_{9/2}$-$^6H_{13/2}$) observation apart from $^4F_{9/2}$-$^6H_{15/2}$ (484 nm) and $^4F_{9/2}$-$^6H_{11/2}$ (666 nm) emission transitions with excitation at 450 nm ($^6H_{15/2}$-$^4I_{15/2}$) excitation wavelength. Stimulated emission cross-sections of all the emission bands of Sm^{3+} and Dy^{3+}: BZP glasses were computed based on their measured $\Delta\lambda$ (FWHM) and measured lifetimes (τ_m).

Pisarska, J. et al. [31] reported the visible luminescence of Dy^{3+} ions in oxyhalide lead borate glasses. Luminescence spectra show two intense bands at 480 nm and 573 nm due to $^4F_{9/2}\rightarrow{}^6H_{15/2}$ (blue band) and $^4F_{9/2}\rightarrow{}^6H_{13/2}$ (yellow band) transitions of Dy^{3+}. Luminescence decays from $^4F_{9/2}$ state and yellow-to-blue luminescence intensity ratios (Y/B) were analyzed with PbX_2 (X = F, Cl) content. An introduction of PbX_2 to the borate glass results in the increasing of $^4F_{9/2}$ lifetime and the decreasing of yellow-to-blue luminescence intensity ratio, which was due to reduction of covalency between Dy^{3+} and O^{2-}/X^- ions.

Table 1.1 Summary table of literature reviews.

Glass System	**Doped**	**Properties**						**Ref.**
		Optical properties	**Structural properties**	**Luminescence properties**	**Thermal properties**	**Physical properties**	**etc.**	
Bi_2O_3-B_2O_3	-	• Refractive index • Polarizability • Basicity	-	-	-	-	-	Zhao, X. et al. [14]
$x$$Eu_2O_3$:(100-$x$)[$Bi_2O_3$:$B_2O_3$]	Eu 0≤x≤25 mol%	-	• XRD • FTIR	-	-	-	-	Pascuta, P. et al. [15]
25Bi_2O_3-75B_2O_3	-	• Absorption spectra	-	• NIR fluorescence	-	-	-	Qiu, Y.Q. et al. [16]
Bi_2O_3-B_2O_3 (range 25 to 65 mol%)	-	• Refractive index • UV-absorption	-	-	-	-	-	Oprea, I. et al. [17]
Ln_2O_3-Bi_2O_3-B_2O_3	(Ln=La, Sm, Gd)	• Refractive index	• XRD	-	-	-	• CW YAG laser irradiation	Honma, T. et al. [18]
Bi_2O_3-B_2O_3	Yb^{3+}	• Absorption spectra	-	• Fluorescence	-	-	-	Chen, Y. et al. [19]
Bi_2O_3	Yb^{3+}-Er^{3+}-co-doped	• Optical absorption and emission	-	• Fluorescence	-	-	-	Liu, Y.H. et al. [20]

Table 1.1 Summary table of literature reviews (cont'd).

Glass System	Doped	Properties						Ref.
		Optical properties	Structural properties	Luminescence properties	Thermal properties	Physical properties	etc.	
Bi_2O_3-B_2O_3	Er (25-65 mol%)	-	-	• Luminescence	-	-	-	Oprea, I. et al. [21]
Bi_2O_3-containing glasses	-	• UV-absorption	• XRD	• NIR luminescence	• Melting temperature	-	-	Khonthon, S. et al. [22]
RE_2O_3-Bi_2O_3-B_2O_3	Pr_2O_3, Nd_2O_3, Sm_2O_3, Eu_2O_3, Gd_2O_3 and Er_2O_3	-	-	-	• Debye temperature • Softening temperature • Latent heat	• Density • Molar volume • Modulus	• Acoustic impedance	Yousef, E. et al. [23]
Bi_2O_3-Li_2O-B_2O_3	Li_2O	• Polarizability • Refractive index	-	-	-	• Density • Molar volume • Basicity	• IR-optical band gap	Saddeek, Y. et al. [24]
$95[xB_2O_3:(100-x)Bi_2O_3]5MnO$ with $x = 7, 10, 20, 33$ and 80 mol%	B_2O_3	-	• XRD	-	-	-	-	Borodi, Gh. et al. [25]

Table 1.1 Summary table of literature reviews (cont'd).

Glass System	**Doped**	**Properties**						**Ref.**
		Optical properties	**Structural properties**	**Luminescence properties**	**Thermal properties**	**Physical properties**	**etc.**	
xRO:30Bi_2O_3:(70-x)B_2O_3	R=Zn, Ba	-	• FTIR	-	• Debye temperature	• Density • Molar volume • Modulus	• IR-optical band gap	Doweidar, H. et al. [26]
20ZnO:$x$$Bi_2O_3$:(79-$x$)$B_2O_3$ (15≤x≤35 mol%)	Sm^{3+} (1.0 mol%)	• Optical absorption spectra	-	• Fluorescence spectra	-	-	-	Agarwal, A. et al. [27]
xBi_2O_3:100-x)B_2O_3 (x=20 to 66 mol%)	-	• UV-visible absorption	• XRD • FTIR	-	• Differential scanning calorimeter (DSC)	• Molar volume	• Optical band gap • NMR	Bajaj, A. et al. [28]
30SrO-30MgO-40P_2O_5	Dy_2O_3 (1.0 mol%)	-	• XRD	• Photo luminescence	-	-	-	Hussin, R. et al. [29]
B_2O_3-ZnO-PbO (BZP)	Sm^{3+} and Dy^{3+}	• UV-absorption	• XRD	• Photo luminescence	• Melting temperature • Differential scanning calorimeter	-	• Optical band gap	Lakshminarayana, G. et al. [30]
B_2O_3-PbO-PbX_2 (X= F, Cl)	Dy^{3+}	• UV-absorption	-	• Visible luminescence	-	-	• Lifetime	Pisarska, J. et al. [31]