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A Review on Physical, Optical and Up-Conversion Properties of Lead Borate Glasses Co-Doped with Different Rare Earth Ions

Renuka Bairagi [a], Sukhdev Bairagi [b], M. Y. Lone [a], Ghizal F. Ansari [a*]

[a] Department of Physics, Madhyanchal ProfessionalUniversity, Bhopal-462044, India

[b] Department of Physics, Sardar Vallabhbhai Patel Govt. College Nalkheda-465445, India

*Email: ansarigf@rediffmail.com

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ABSTRACT:

In this paper we review the effect of physical and optical, structural and upconversion properties were determined with different Nd^{3+}-Yb^{3+}Doped Lead Borate of tellurite base glass. The physical properties of the glasses were evaluated and the change in density, molar volume and ionic packing density in these glasses indicates the effect of B_2O_3different content show on the glasses structure. The study of optical properties such as the optical band gap and refractive index of zinc tellurite glass were studied. Lead Borate Tellurite glasses doped with Nd^{3+}-Yb^{3+}ions were synthesized by varies researcher. The glasses were characterized by X-ray diffraction, optical absorption and photoluminescence spectra. The glassy nature of borate tellurite host glass has been confirmed through XRD measurements. The glasses doped or co-doped with rare-earth ions have generated much interest due to the possibility of many potential applications in the field of photonics such as optical communication fibers, up conversion, photonic memories, display systems, X-ray image processing, sensors, optical amplifiers, optoelectronics, magneto-optical devices

Keyword: Lead Borate Tellurite glasses, physical properties, structural properties optical properties, band gap, up conversion.

1. Introduction

The current scientific interest is up conversion materials & process in lanthanide ion doped glasses is primarily motivated by the search of good optical materials for up conversion devices. Glass and Glasses ceramic doped with lanthanide ions materials are attractive because they produce effective up conversion luminescence. In addition, glassy materials are highly transparent from the UV to IR wave-length region and relatively high concentration of trivalent lanthanide ions induced into them in order to work in this area, one takes advantage of the high absorption cross-section for efficient energy transfer rates. It is provided by Yb^{3+} as a sensitizer or donor and to improve substantially the effective up conversion in comparison to single ion (Er^{3+}) systems. Effective Er^{3+} up conversion fluorescence has been observed in fluoride, chalcogenide, chloride, bromide and iodide glasses.

In recent years, there have been many attempts to develop efficient laser devices based on the trivalent ytterbium ion (Yb^{3+}) operating around 980 nm [1–6]. The Yb^{3+} ion presents a very simple energy level structure with only two energy manifolds, the $^2F_{7/2}$ ground state and the $^2F_{5/2}$ excited level, which are separated by an energy gap of around 10,000 cm^{-1}. When a laser system uses Yb3+ as the active ion, this simple scheme is ideal to avoid undesirable effects, such as excited-state absorption, cross-relaxation or upconversion processes that would reduce the effective laser cross-section. An additional advantage is related to the possibility of some tunability in the near-infrared range (NIR) [7–11]. Due to the large number of electrons in the 4f 13 configuration of Yb^{3+} ions, these are less shielded from host interaction than other rare earths, therefore Yb^{3+} exhibits a significant broadening of its optical transitions. The broad emission spectrum provides sufficient bandwidth to generate and amplify ultrashort laser pulses, while the millisecond upper-state lifetime enables free-running lasers and laser diodes for pump sources [12]. This broadening can be further enhanced by the presence of local disorder of the Yb^{3+} environments in a given host. However, some problems must be considered, such as the inherent quasi-three-level nature of the laser transition involved, since pumping and laser emission wavelengths are very close to each other [13,14]. Another important disadvantage of this simple energy level scheme is related to the existence of a single band absorption, which limits the pumping wavelength in the 920–1050 nm region ($\Delta\nu$~1350 cm^{-1}), with a maximum at around 980 nm. An alternative way of exciting Yb^{3+} ions is to take advantage of energy transfer processes from trivalent neodymium (Nd^{3+}) ions. Codoping materials with Nd^{3+} ions as a sensitizer allows a broader spectral range for laser excitation due to the multiple absorption bands in the ultraviolet (UV), visible and NIR regions below 860 nm, with large absorption coefficients [15]. Another interesting advantage of this co-doped system is the possibility of using the 800 nm radiation of AlGaAs laser diodes as pump sources for Nd^{3+} ions as they are generally cheaper and more powerful than the InGaAs laser diodes commonly used to pump Yb^{3+} single-doped materials, which operate at 980 nm [9]. Resonantly exciting the Nd^{3+} ions at 800 nm causes the $^4I_{9/2} \rightarrow {}^4F_{5/2}$ absorption transition to populate the $^4F_{5/2}$ level, from which a fast non-radiative relaxation to the 4 F3/2 metastable emitting state occurs. Subsequently, phonon-assisted energy transfer to Yb^{3+} ions populate the $^2F_{5/2}$ emitting level. These $Nd^{3+} \rightarrow Yb^{3+}$ energy transfer processes have already been studied in several materials for different purposes.

II. Objective of the study

- To investigate the effect of physical and optical, structural and upconversion properties of Lead Borate tellurite glasses doped and co-doped with different rare earth ion have successfully synthesized and prepared by varies researcher
- To investigate the glasses doped or co-doped with different rare-earth ions have generated much interest due to the possibility of many potential applications in the field of photonics.
- Identification of the physical properties of Nd^{3+} and Nd^{3+}/Yb^{3+} doping B_2O_3-TeO_2-Na_2O_3 glasses in term of density and molar volume.
- Determination the thermal stability of Nd^{3+} and Nd^{3+}/Yb^{3+} doping B_2O_3-TeO_2-Na_2O_3 glass in term of melting temperature Tm, crystallization temperature Tc and transition glass temperature Tg using Differential Scanning Calorimeter (DSC).
- Determination the optical properties of Nd^{3+} and Nd^{3+}/Yb^{3+} doping B_2O_3-TeO_2-Na_2O_3 glass in term of refractive index, energy band gap, Urbach energy and refractive index using Ultraviolet-Visible Spectroscopy.

III. Review of Literature

Norihan Yahya et al. have been prepared Nd3+ doped lead borotellurite glasses containing silver by conventional melt-quenching method with the chemical composition (69.5-x)TeO2 -20B2O3 -10PbO-0.5Nd2O3 -xAgNO3 (where x = 0, 0.5, 1.0, 1.5, 2.0 and 2.5 mol %). The density of the glasses increased from 4.969 gcm-3 to 5.053 gcm-3 while their molar volume values decrease from 29.642 cm3 /mol to 29.169 cm3 /mol with respect to AgNO3 content. The oxygen packing density (OPD) show the same trend to the density as they vary from 71.015 g.atom/L to 73.206 g.atom/L with respect to AgNO3 content. The XRD results confirmed fact the glasses obtained are amorphous in nature. The FTIR spectra indicated the presence of Te-O-Te or O-Te-O, Ag-O, Te-O-Pb and B-O functional group of the glass network [16].

B. Sudhakar Reddy et al. have beeninvestigatedthe spectroscopic properties of Nd3+ - doped and Er3+-Yb3+ -codoped borotellurite glasses thoroughly using Judd-Ofelt theory in terms of intensity parameters, radiative transition rates, branching ratios and radiative lifetimes. In addition, the examined glass system shows that, for Nd3+ intense and broad emission bands at 1.06 µm corresponds to 4 F3/2→ 4 I11/2 transition, while those at 1.56 µm for Er3+ corresponds to 4 I13/2→ 4 I15/2 transition. Also large gain bandwidth and high stimulated emission cross-section values are obtained for the 4 F3/2→ 4 I11/2 transition of Nd3+ and the 4 I13/2→ 4 I15/2 transition of Er3+. The results of this analysis indicate that the Nd3+- and Er3+-Yb3+ -doped borotellurite glasses can be useful in the development of lasers and optical fiber amplifiers [17].

A. Madhua **et al.** have been investigated erbium doped lithium bismuth boro tellurite glasses using melt-quenching technique. The prepared glasses were extensively characterized through, XRD, DSC, UV–Vis-NIR and also Luminescence and Decay techniques to study the concentration dependent structural, optical and luminescence properties. Prepared glasses are amorphous in nature and the corresponding band gap energy decreases with erbium concentration indicates increase of metallicity of the glasses. FTIR studies show different vibration modes majorly borate groups. Estimated values of Stimulated emission, effective band width and gain band width values found higher when compared with other host glasses. Results also show that, 100% branching ratio is obtained for the highest intense peaks corresponds to the transition 4 I13/2 → 4 I15/2 in NIR luminescence spectra for 1.53 µm broad band. For power dependent 980 nm excitation, up-conversion spectra shows two transitions, namely 4 S3/2 → 4 I15/2 and 4 F9/2 → 4 I15/2 at 541 and 655 nm corresponds to green and red emission respectivelyThe results suggests that, the prepated glasses are the potential candidates for optical fiber applications [18].

A.Madhu et al. have been prepared Samarium doped lanthanum- lead- boro-tellurite glasses (TS series) using melt quenching technique and the effect of gamma irradiation on the structural, optical and luminescence studies are evaluated before and after irradiation. Soon after gamma irradiation, the change in the physical appearance of glasses is observed, as evidenced in the colour change from pale yellow to dark red colour due to the generation of radiation induced defects. XRD reveals the amorphous nature of prepared glasses even after irradiation. Majorly borate glasses related functional groups were observed in both complimentary techniques FTIR and Raman spectra. Also, IR active transitions are majorly observed in UV-Vis-NIR spectra. Further, the energy band gap and Urbach energy values are estimated using Tauc's plots. The estimated indirect band gap decreases with incorporation of samarium, Sm2O3, due to the breaking of Te–O–Te linkages creates non-bridging oxygen's. Even though no peaks are t observed even after irradiation in UV-Vis spectra, which is attributed to up shift of absorbance intensity. The energy band gap and Urbach energy estimation reveals that, irradiation has induces slight structural changes in present glasses. Gamma irradiation of the high PbO and varied TeO2 glasses shows some minor variations due to the shielding behaviour of heavy Pb2+ and Te2+ ions. Luminescence spectra reveals that TS2 proves to be better sample as even after subjection of gamma irradiation, the emission property is unaltered, which exhibits shielding property. Further, luminescence decay for all the samples exhibit single exponential behaviour, which is evident to know that, between Sm3+ ions, the energy transfer is not so dominant. Also the lifetime decreases with increase is Sm3+ concentration (decrease in TeO2 concentration) [19].

Ansari G. F. et al. (2021) has been found the Optical and upconversion properties of bismuth tellurite glasses compositionsTeO_2-Bi_2O_3-Na_2O co-doped with rare earth ions Er^{3+}-Yb^{3+} ions by melt- quench and press method. The batch composition is taken (80-x-y)%TeO_2-10% Bi_2O_3-10%Na_2O-x%Er_2O_3-y%Yb_2O_3, (x, y) are (0.1, 0) and (0.5, 0.5). Thermal study of the synthesized sample is done by Differential Scanning Calorimetry (DSC). Amorphous nature of samples is characterized by X-Ray diffractogram. Heaviness of the samples justifies by the calculated densities of the glass sampleis 5.26 gm/cc and Refractive index (R.I.) of samples 2.05, Their optical band gap and Urbatch's energies are respectively are order of 3 eV and 300 meV, justify its candidature for photonic devices. Upconversion luminescence in the synthesized TBNEY glass is the attribution of Er^{3+}-Yb^{3+} ions. Excellent green and red upconversion emissions were observe under excitation of 980 nm [20].

A. Madhua et al. have been preparedEr doped lithium-bismuth-boro-phosphate glasses using melt quenching technique and their structural, thermal, absorption and luminescence studies were carried out in detail. The estimation of physical parameters reveals that the obtained glasses are having low loss and high refractive index which are feasible for fibre fabrication. XRD analysis confirms the amorphous nature of the prepared glasses. The FTIR structural analysis reveals the different vibration modes corresponding to major borate and phosphate groups along with presence of metal oxides. The presence of lesser OH– group in FTIR spectra indicates the possibility of enhancement in luminescence. Thermal (DSC) analysis provides the information of increase in glass transition temperature even for small variation of Er3+-ions in the host glass matrix. The gradual increase in indirect band gap and decrease in Urbach energy values with Er concentration is observed in the prepared glasses, which was attributed to the formation of NBO's in the matrix. The MC theory explained the spectral broadening of luminescence spectra and the peak emission values well matched with σ(λp). The gain coefficient spectra explained population inversion obtained for present glass system is about 40% and lies in the range of C band (1530-1565 nm) which in turn proves that the present systems are promising candidates for the broadband amplifiers. Finally the UC process for power dependence shows the 4 F9/2– 4 I15/2 transition is responsible for the observed red emission and two photon mechanisms were well matched for the present system [21].

M.R.S. Nasuha et al. have been determine theNd3+ ions doped yttrium lead borotellurite glasses physical and also optical properties. Glass density shows the increasing trend while the molar volume shows decreasing results with increasing concentration of Nd.3+ ions. However, the result of OPD of the yttrium lead borotellurite glass samples are found to increase from 88.508 g.atm/L to 96.469 g.atm/L with increasing concentration of Nd2O3. Optical results show that, the pure sample has no absorption peaks while the other sample exhibited several absorption peaks due to the addition of concentration Nd3+ ions. Both direct and indirect optical band gap were successfully attained. Both the direct as well as indirect band gap show a variation of results with respect to Nd2O3 content. The values of Urbach energy are found to vary from 0.219 eV to 0.517 eV with mol% of Nd.3+ ions content [22].

A. Madhu et al. have been investigatedNd3+-doped lanthanum lead boro-tellurite glass samples structural, thermal, fluorescence, and decay times. Prepared glass samples exhibits amorphous nature and shows good thermal stability in the temperature range of 100e800 C. Judd-Ofelt (JO) analysis was carried out and the intensity parameters (Ul ¼ 2, 4, 6) also spontaneous radiative probability and stimulated-.emission cross-sections were estimated. The magnitude of Ul confirms the covalency nature. The near infrared emission spectra were measured by 808 nm excitation in which the emission intensity is found to be high at 1060 nm for the 4 F3/2 / 4 F11/2 transition. The derived gain bandwidth, figure of merit, threshold and saturation intensity found to be comparable to some of the glass systems. Furthermore, the time decay rate found to decrease from 100 ms to 27 ms when the concentration increased from 0.1 to 3.0 mol% of Nd3þ ions and also all follow the single exponential behaviour which is attributed to the self quenching effect due to the cross-relaxation channels [23].

K. Siva Rama Krishna Reddya et al.have been studied and reportedthe structural and yellowish white light emission characteristics of the titled glasses. The presence of various structural units such as TeO3, TeO4 and BO4 were identified through the Raman spectral analysis. The J-O parameter followed the trend Ω2 > Ω4 > Ω6 for all the prepared glasses and higher Ω2 values indicated the lower symmetry and high covalency around the Dy3+ ion site. This trend may indicate the good quality of a glass hosts for using optoelectronic devices applications. The luminescence quenching has been experienced in PL studies for glasses having Dy3+ ion concentration beyond 1.0 mol% and is due to RET and cross relaxation (CR) process. This luminescence quenching was also confirmed by the decay profiles of titled glasses and the corresponding CR channels causing luminescence quenching were identified and reported. The decay curves of the 4 F9/2 level exhibited almost single exponential for lower concentrations and shifted to non-exponential for higher concentrations of Dy3+ ions indicating the possible energy transfer between Dy3+- Dy3+ ions. Fitting the non-exponential decay curves using IeH model indicated the dipole-dipole nature of the energy transfer between Dy3+ ions [24].

Joao Azevedo et al. have been analysed A transparent and little violet coloured neodymium oxide doped lithium boro-tellurite (LBT) optical glass was prepared and characterized by XRD, FTIR, SEM, absorption, NIR emission and time-resolved decay. Judd–Ofelt theory has been applied to evaluate the best fit intensity parameters, and used to calculate the radiative lifetime and stimulated emission cross section of the lasing transitions. The reported glass shows a smaller spectroscopic quality factor and exhibits an intense and sharp laser emission band 4 F3/2-4 I11/2 at 1065 nm. It is a well known fact that, a good candidate of laser material should have a large FWHM, long lifetime, high stimulated emission cross section and high branching ratio. Hence, the present reported 1 Nd glass is also obeying the above characteristic parameters along with supported literature values. Therefore, lithium boro-tellurite host glass doped with neodymium oxide is a good candidate for laser applications at 1.06 mm [25].

V. Bhingarkar at al. have been conformed the low transition temperature synthesized telluride glasses by DSC. Amorphous nature of synthesized glass samples was confirmed by XRD spectra. For TBB glasses, the higher density and maximum measured refractive index are 5.345 g/cm3 and 2.383 g/cm3 respectively. Although density is observed to increase as Bi_2O_3content increased but the OPD is observed to decrease. With increasing Bi_2O_3 concentration the expected reduction in rp and ri is shown. Through UV-VIS-NIR spectroscopy the samples' optical absorption behaviour is measured. Both the band gap, Urbach energy and the refraction index of the glass decreased with Bi_2O_3 composition increased. At a concentration of Bi_2O_3 of 5%, the maximum observed values of the optical band gap and Urbach energy are Eopt. = 3.18 eV and E = 0.70 eV, respectively. The study showed that optical parameters like refractive index and forbidden energy gap are unchanged by sample thickness. Due to its good thermal stability glass is a suitable material for optical fibre devices [26].

P. Gayathri Pavani at el. have been carried out the different optical, physical and structural analysis of each glass sample. It could be concluded that increase of ZnO results in decrease of optical energy gap owing to increase in Non-bridging oxygen ions shifting the band edge to longer wavelength.

Refractive index increases with increase of ZnO due to decrease in optical energy gap. The optical basicity values are found to be in range 0.707–0.775 for the present glass system. Density of boro-zinc tellurite glasses is decreased with the addition of ZnO as lower molecular weight (ZnO 81.35 gm) is substituted by a higher molecular weight (TeO2–159.599 gm). IR studies revealed that the incorporation of modifier oxide (ZnO) in place of TeO2 increased the number of non-bridging oxygens by gradually replacing trigonal bipyramids [TeO4] units with trigonal pyramids [TeO3] through [TeO3+1]. Also BO4 units are replaced by BO3 units. At 30 mol% of ZnO, ZnO4 units are observed and in all other glasses this group is absent concluding that zinc lattice is completely broken [27].

Agata Górny et al. have been studied the glass systems using excitation and luminescence spectroscopy. The registered excitation bands are assigned to the characteristic transitions of thulium and dysprosium ions in lead borate glasses. The luminescence bands originating to both transitions of thulium and dysprosium ions are present on emission spectra under direct excitation of Tm3+. Moreover, the spectra show the blue wide emission band from overlapped electronic transitions of Tm3+ and Dy3+ ions, which were found to be strongly influenced by the concentration of trivalent dysprosium. The intensities of the bands corresponding to transitions of dysprosium ions increase with increasing concentration of Dy2O3. Luminescence lifetimes for the excited states of rare earth ions were also determined based on decay measurements. The efficiencies of energy transfer from Tm3+ to Dy3+ ions in lead borate glass were estimated. The obtained results show that the Dy3+ ions can accept the excitation energy from Tm3+ ions through the energy transfer process from 1 G4 level (Tm3+) to 4 F9/2 level (Dy3+). Also, our experimental investigations suggest that lead borate glasses are good hosts for Tm3+ and Dy3+ ions in relation to tuned multicolor luminescence applications [28].

H. O. Tekin at el. have been investigated the influence of Nd3+ ion-reinforced yttrium lead borotellurite glasses based on (49-x)B2O3-35TeO2-15PbO-1.0Y2O3-xNd2O3 (where x = 0.0, 0.5, 1.0, 1.5, 2.0, and 2.5% mol) was invstigated in terms of their optical (linear and nonlinear) and gamma-ray attenuation properties. The values of the nlinear were varied from 2.482 (S1 sample) to 2.421 (S6 sample). Our findings showed that Rmolar (19.134–17.259 cm3 /mol) and amolar (7.593–6.848) 9 10–24 cm3 have direct relationship on studied glasses. The Rloss (0.1811–0.1725) and Toptical (0.6932–0.7057) were in inverse behavior with the increasing Nd3? ions in glasses. Our findings also showed that Mcriterion was varied from 0.2793 to 0.2914, while the eoptical was varied from 6.160 to 5.861. Moreover, the highest mass attenuation coefficients values were reported for S6 glass sample with the highest Nd2O3 additive (i.e., 2.5 mol%) in terms of gamma-ray attenuation competencies of studied glasses. The minimum EBF and EABF values were reported for the S6 sample, while S1 sample was reported with its maximum EBF and EABF values. Results revealed that S glasses have suitable properties for optical applications. It can be concluded that S6 sample has superior gamma-ray attenuation properties among the investigated glasses [29].

M. R. S. Nasuha et al.exhibited the inclusion of Y2O3 in (49 - x)H3BO3–35TeO2– 15PbO–1.0Nd2O3–xY2O3 glasses marked effect on their physical, elastic, and structural properties. The density and molar volume varies with the Y2O3 concentration. The OPD exhibited the same trend as the density, ranging from 88.999 to 94.506 g atom/L concerning Y2O3 content. The elastic moduli increase due to the enhanced rigidity of the prepared glass samples. X-ray diffraction analysis confirmed the amorphous nature of glasses. The FTIR spectra revealed the presence of Te–O bond in TeO3, TeO4 and B–O bond in BO3 and BO4 functional group of the glass system [30].

K. Azman et al.have been obtained the glasses in a good quality since it shows no sign of devitrification. There are six significant absorption peaks that corresponds to 525 nm, 584 nm, 683 nm, 747 nm, 805 nm and 878 nm wavelength have been observed with the most predominant peak to be used as excitation wavelength is found centered at 584 nm. From the UV-vis measurement, the results of optical energy band gaps as well as the refractive indices were found to vary from 2.50eV to 2.59eV and from 1.89 to 1.96 with mol% of Nd content respectively. Meanwhile, the polarizability shows a similar trend of results to refractive indices as it varies from 5.56 x 10-24 cm3 to 5.63 x 10-24 cm3 [31] .

H. Kumari at el. have been investigatedhigh tungsten content glasses for use in nonlinear optics, near-infrared transmission, and as lanthanide ion hosts in optical devices.Thermal and functional studies of the prepared specimence were carried by differential scanning calorimetry (DSC) and Raman spectroscopy. The luminescence analysis of Er^{3+} and Er^{3+}/Yb^{3+} co-doped in a novel TeO_2-WO_3-Na_2O glass system is reported in this work. UV-VIS-IR absorption was studied to know the different levels of Er^{3+}/Yb^{3+}. The green and red zones show discernible up-conversion emissions, which are amplified when the samples are co-doped with Yb3+. Emissions in the near-infrared range have good quantum efficiency [32].

4. Conclusion

In this review report many other researchers prepared the Boro-tellurite based glasses with different mole percent batch composition by the melt quenching technique. The prepared glasses were extensively characterized through, XRD, DSC, UV–Vis-NIR and also Luminescence and Decay techniques to study the concentration dependent physical, structural, optical and luminescence properties. Determination of the amorphous phase of the obtained glass using X-ray diffraction (XRD). Thermal properties studied by DSC.Other author also reported the Glass density shows the increasing trend while the molar volume shows decreasing results with increasing concentration of Nd.3+ ions. However, the result of OPD of the yttrium lead borotellurite glass samples are found to increase also in Optical results show that, the pure sample has no absorption peaks while the other sample exhibited several absorption peaks due to the addition of concentration Nd3+ ions. Both direct and indirect optical band gap were successfully attained. Both the direct as well as indirect band gap show a variation of results with respect to Nd2O3 content. Other properties as molar mass, molar volume, poleron radius, inter molecular distance, radius of metal ion etc. measured. Another reason to select these glass compositions is that barium has some properties which good for development of Borate based radiation shielding glass because of high absorption of X-rays, gamma rays and non-toxicity compared with lead. The short-range structure of Nd^{3+} and Nd^{3+}/Yb^{3+} doping B_2O_3-TeO_2-Na_2O_3 tellurite glasses, and the effects of rare earth ions on the optical and thermal properties of glasses. UV–visible absorption and photoluminescence spectroscopy are used to study the optical properties.

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