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Third order nonlinear and optical limiting properties of alkaline bismuth borate glasses

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ABSTRACT

Transparent Alkaline Bismuth Borate glasses (10RO-35Bi_2O_3-55B_2O_3, where R = Ba, Ca & Sr) were prepared by melt-quenching method. The optical band gap values of the glasses are obtained from absorption spectra and found to increase due to the presence of alkaline earth ion in the order of Ba < Sr < Ca whereas optical basicity values follows the reverse trend. Nonlinear optical properties and optical limiting properties of the glasses were investigated at wavelengths of 532 and 800 nm for ns and ps and fs time domains respectively by Z-scan technique. Two-photon absorption is regarded as the dominant mechanism in the case of Sr and Ca based glasses whereas glass with Ba exhibit two photon induced three photon mechanism. Optical limiting characteristics are also reported in fs and ns regimes for these glasses.

1. Introduction

High third order nonlinear materials are utmost required to fabricate optical devices, viz., optical switch, wavelength converters, etc. that are used in high complex network structures where these optical devices will manipulate the signals through various processes viz., amplification, modulation, etc. [1–35]. Nonlinear optical properties of a broad range of materials like glasses, glass ceramics, crystals, nanomaterial, thin films, quantum dots and polymers have been studied more comprehensively for optical limiting purpose [28–47]. In this context, glasses are found to be more promising materials for photonic applications [1–25]. Among the glass systems, borate glasses are better known for their nonlinear optical properties and also exhibit good transparency, moderate low melting point, thermal stability and high chemical durability. Nevertheless, borate glasses having the lack of ability to suppress the non-radiative decay process because of high phonon energy. Heavy metal oxide such as Bi^{3+} and Pb^{2+} are incorporated into the borate glasses to diminish the phonon energy and melting temperature [21,44,45]. Especially, bismuth-borate based binary or ternary systems received a great attention due to higher solubility of Bi^{3+} ions, better physical and chemical stabilities [46–50]. At the same time they exhibit high linear refractive index (n) as well as large χ^3 (about 10^{-11} esu) comparable to those of some chalcogenides glasses and ultrafast response time of a few hundred femtoseconds [51,52]. The higher susceptibility associated to the bismuth glass is due to its smaller optical band gap and the presence of $[BiO4]^{5-}$ anionic groups that possess large hyper polarizability [48,53,54]. Nonlinear optical properties of the materials such as nonlinear refraction and nonlinear absorption are measured using Z-scan technique in liquids, liquid solutions and solids [55,56]. This technique is simple and values of the refractive index and/or absorption coefficient can be obtained from the data without resorting to intricate computer fitting [55,56]. Previously Gomes et al. [22,23] and Hasegawa et al. [57] studied the third order nonlinear optical properties and optical limiting of bismuth borate glasses by conventional and thermally managed eclipsed Z-scan methods. Recently, we reported the third order nonlinear optical properties of bismuth zinc borate glasses [17].

In present work, we studied the structural and third order nonlinear optical properties of the alkaline bismuth borate ternary glass (RO-Bi_2O_3-B_2O_3) with various alkaline ions (R = Ba, Ca & Sr) using 800 nm (fs), 532 nm (ps), and (ns) pulses through the standard Z-scan technique.

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2. Experimental details

Transparent alkaline bismuth borate glasses, hereafter called as RBB glasses, with composition 10RO - 35Bi_2O_3 - 55B_2O_3 where R = Ba, Ca & Sr were prepared by melt-quenching method. The required amount of chemicals such as BaO, SrO, CaO, Bi_2O_3 and H_3BO_3 were mixed and melted in a platinum crucible at 1050 °C for 30 min. Melt were quenched by casting on steel plate and pressed with another steel plate to obtain glass samples of desired shape. The prepared glasses were annealed a few degree above the glass transition temperature for 2 h and samples are grounded with various SiC meshes to obtain required thickness. The ground samples with thickness ≈ 1.5 mm were then polished to make them suitable for optical measurements. The photograph of the polished glass samples are shown in Fig. 1 The absorption spectra were recorded using Shimadzu UV–Vis-NIR (Varian 5000) spectrophotometer. The nonlinear optical properties such as nonlinear absorption and refraction of the glasses were studied with 800 nm (fs), 532 nm (ps) and (ns) pulses using standard Z-scan technique [56]. The ns and ps laser with 6 ns and 30 ps pulse duration and a repetition rate of 10 Hz at 532 nm wavelength and fs laser with 110 fs pulse duration and a repetition rate of 1 kHz at 800 nm are used. The Z-scan experiment was repeated more than once and to obtain the nonlinear optical coefficient by using the best data for the best fit.

3. Results and discussion

3.1. Z scan measurements

The Z scan signals are recorded in both the open and closed aperture methods. In the open aperture method, the aperture, which is placed in front of the detector, kept open and the transmitted light is completely allowed to reach the detector. In the case of closed aperture, the intensity of the transmitted light is controlled by varying the aperture size (S). Thus open aperture can be considered as normalized transmittance where S = 1 while the value of S lies between 0.1 < S < 0.5 for closed aperture.

Nonlinear absorption is more direct and accurately determined from the open aperture Z-scan [58]. The open aperture Z-scans recorded at wavelength 800 nm (fs), and 532 nm (ps) for RBB glasses are shown in Fig. 2(a–c) respectively.

The light attenuation through the sample for measuring the nonlinear absorption coefficient is given by [17]

$$\frac{dI(Z)}{dZ} = -\alpha_o I(Z) - \beta I^2(Z) - \gamma I^3(Z) \quad (1)$$

Fig. 1. Photograph of the polished RBB (where R = Cs, Sr, & Ba) glasses.

where

$$I(Z,t) = I_{oo}\left(\frac{\omega_o^2}{\omega^2(Z)}\right)\cdot exp\left(\frac{-2r^2}{\omega^2(Z)}\right)\cdot exp\left(\frac{-t^2}{\tau_p^2}\right)$$

$$\omega(Z) = \omega_o\left[1+\left(\frac{Z}{Z_o}\right)^2\right]^{\frac{1}{2}}$$

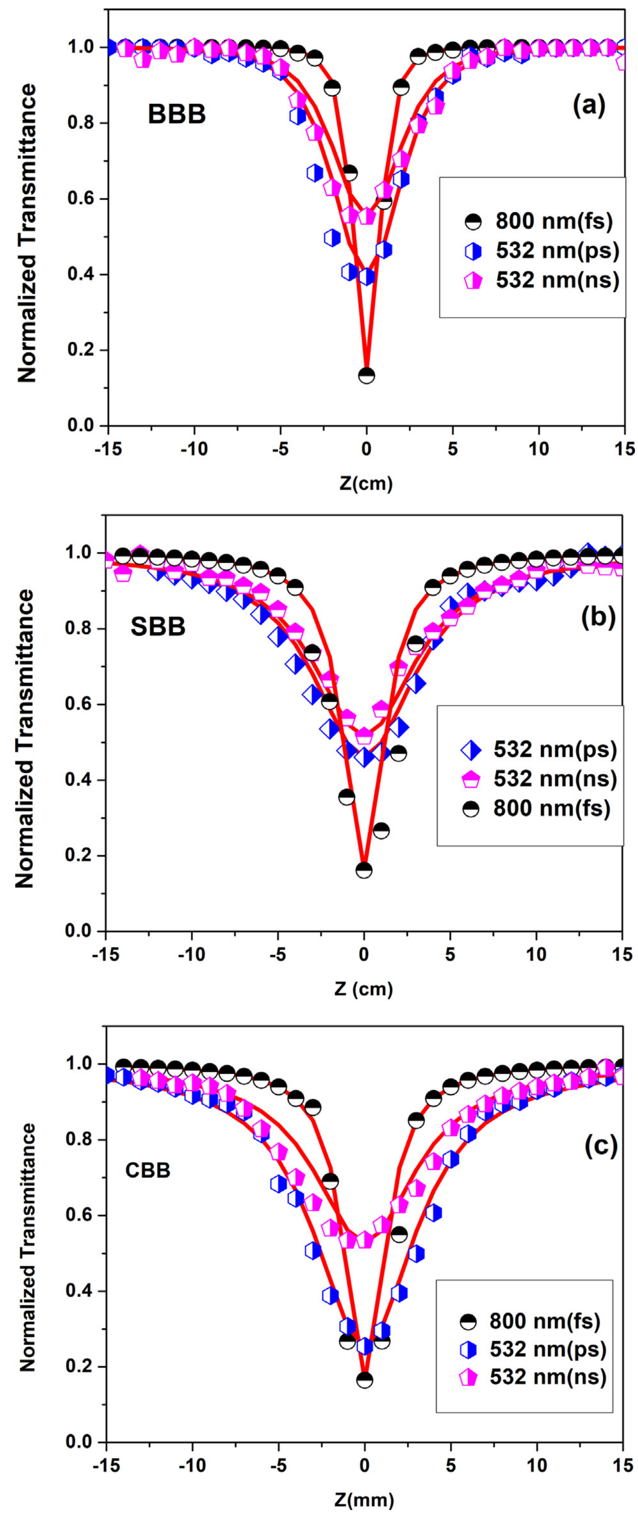

Fig. 2. Open aperture Z-scan curves with 800 nm, 110 fs pulses, 532 nm, 30 ps pulses and 532 nm, 6 ns pulses for (a) BBB (b) SBB & (c) CBB glasses respectively. Solid curves are the theoretical fit to the experimental data.