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Original research article

Gamma irradiation on bismuth borate glasses doped by Eu^{3+} ions: Structural, optical and mechanical investigations

Akshatha Wagh, Kumari Manjunath, Vinod Hegde, Sudha D. Kamath *

Department of Physics, Manipal Institute of Technology, Manipal University, Manipal 576 104, India

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ABSTRACT

The research article concentrates on the effects of gamma rays [50 kGy] over Europium doped bismuth borate glass systems based on 10ZnO-5Na_2O_3-10Bi_2O_3-(75-x)B_2O_3-xEu_2O_3 (where x = 0.1, 0.3, 0.5, 1.0, 1.5), synthesized through melt-quench technique. Structural changes in the glasses after gamma irradiation were probed by measuring the basic parameter density. XRD confirmed amorphous nature of the glasses. Optical properties were investigated for their lasing behavior through spectroscopic technique UV–vis–NIR absorption. Under mechanical characterization, Vickers (H_v) indentation tests were performed with mechanical loads 1000 gf and 500 gf. A theoretical model, Makishima and Mackenzie (M-M), gave reasonable estimation of different constants of elasticity (Young's modulus (E), bulk modulus (K), shear modulus (S), Poisson's ratio (μ)).

1. Introduction

Rare earth doped glasses are attracting attention of the research due to their prominent application in the field of optic and telecommunication [1–5]. Glasses doped with various rare earth ions are promising material for high power lasers, optical amplifiers, three-dimensional displays, planar wave guides, field emission displays, white light emitting diodes, optoelectronic devices such as short wavelength (visible) lasers, and high density frequency domain optical data storage [1–9]. As, boric oxide (B_2O_3) acts as a good glass former and flux material, multi component borate glasses are excellent host matrices for rare earth ions [5,7]. They show attractive properties like good rare earth compatibility, high transparency and low glass transition temperature which make them suitable for device fabrication [5]. Host phonon energy is the major problem in the borate glasses which enhances non radiative path decays thereby lowering the luminescence properties of the glasses [5]. Addition of heavy metal ion like Bi_2O_3 to borate glasses decreases the host phonon energy and thereby improves the chemical durability and optical quality of the glasses [10–12]. As the Bi_2O_3 is not a classical network former, it displays some superior physical properties like high density, high refractive index and exhibits high optical basicity, large polarizability and large nonlinear optical susceptibility [5].

The glass forming ability of the borate glasses can be enhanced by adding an appropriate amount of alkali ions like ZnO, Na_2O, which will improve conversion of borate structural units from BO_3–BO_4 units, thereby improving the optical quality of the glasses [1–5]. Usually high phonon energy, low viscosity and resistance to the moisture content limits the use of conventional borate glasses in opto-electronic devices but incorporation of alkali and heavy metal oxide into the borate network, reduces the negative effects of borate glasses [13–17].

* Corresponding author.
E-mail address: sudha.kamath@manipal.edu (S.D. Kamath).

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Among the given rare earths, triply ionized europium ions has got technological importance due to the prominent red and orange emission peak around 600 nm, used in various field emission displays as well as red light emitting diodes [7,9,15,16]. Several literatures reported that highly sensitive with a simple electronic transition from $^5D_0$ to ^7F_j multiplet state made europium ion as an optical probe to examine the structure and type of chemical bonding with the host around rare earth [5,7,12–17].

Influence of high energy photons (gamma rays, X-rays and UV light) on matter is important and beneficial in photonics, nuclear engineering, space technology, medicinal and healthcare products [18]. Researchers have conducted extensive study over various types of glasses to analyze their behavior to the effect of different irradiation conditions [18–20]. It is well known that the gamma rays induce defects in the glasses which will alter optical, mechanical and electrical properties [18]. Hence, the analysis of the defects formed is in itself a challenging work. Better understanding of microscopic mechanisms for radiation damage is important for safe storage of vitrified radioactive material (material which has been irradiated with electromagnetic or particle radiations). It was studied through survey that, accumulation of radiation damage/radionuclide ions will reduce the ability of the glass structure [18]. The particular concern after irradiation is volatilization (formation and coalescence of O_2 molecule) and devitrification of the matrix. To assess the long-term radiation damage, one needs to know the mechanism of formation and agglomeration of radiation induced lattice defects [18–22].

The study of such changes leads to defect centers in glasses which is necessary to be researched over, to examine their appropriateness for nuclear shielding purposes and radiation dosimetry applications [18–22].

The present paper reports the effects of gamma irradiation on physical, optical, mechanical and morphological properties of Eu_2O_3 doped bismuth borate glasses. The paper mainly focusses the role of ZnO-Na_2CO_3-Bi_2O_3–B_2O_3–Eu_2O_3 on the constants of elasticity [Young's modulus, Bulk modulus, Shear modulus, packing density, Poisson's ratio). A theoretical approach, Makishima-Mackenzie model [M-M] [21], is used to calculate constants of elasticity [Young's modulus, bulk modulus, shear modulus, packing density, Poisson's ratio).

2. Experimental

2.1. Sample preparation

Following chemical composition will be used to make Eu^{3+} doped zinc bismuth borate glasses: 10ZnO-5Na_2O_3-10Bi_2O_3-(75-x) B_2O_3-xEu_2O_3 (where x = 0.1, 0.3, 0.5, 1.0, 1.5).

Initially, the Na_2CO_3 powder was decarbonized by heating it in a porcelain crucible (in air) at 450 °C for 30 min to get Na_2O compound. The final five [ZnO-Na_2O–Bi_2O_3-B_2O_3–Eu_2O_3] components in appropriate proportion mixed thoroughly in an agate mortar and the glasses are prepared using melt quench technique. Melt quench technique is explained in detail elsewhere [5,7,13–18]. The chemicals were procured from Sigma Aldrich with a high purity (>99.9%).The raw glasses prepared using melt quench technique were annealed at 350 °C glass transition temperature for 3 h to remove the thermal stresses induced in the glass matrix due to the rapid quenching process [5]. Different silicon carbide water proof abrasive papers (120 Cw, 180 Cw, 220 Cw, 320 Cw, 400 Cw, 600 Cw, 800 Cw, 1000 Cw, 1500 Cw, 2000 Cw) electro-coated obtained from Chennai Metco were used to polish the glasses to get transparent bubble free europium doped glasses. Different grain size emery sheets were used to polish the glasses to get transparent bubble free europium doped glasses for further characterization [5].

The density (ρ) of the glass samples was determined by the standard Archimedes principle using a density kit [Contech Analytical Balance with accuracy of 0.0001 g]. Powder X-Ray Diffraction (XRD) spectra of these glass samples were recorded using a Rigaku Miniflex 600 X-Ray Diffractometer with Cu Kα radiation (40 KV & 15 mA) and a graphite monochromator with 2Θ (Θ being Bragg angle) from 5° to 80°. UV–vis–NIR absorption spectra of the samples were recorded using Perkin Elmer Lambda -750 spectrophotometer with 1 nm resolution, in the wavelength region 250–2500 nm. Hardness of the material (H) is obtained from Vickers micro-hardness tester through H_v values for the loads: 1000 gf & 500 gf, with Dwell time: 10 s, Objective: 400×, Magnification: 40× and Eyepiece: 10×). For gamma rays study, a ^{60}Co gamma cell (2000 Ci) was used as a gamma-ray source with a dose rate of 1.5 Gy/s (150 rad/s) at room temperature (30 °C). The glass samples were placed in the gamma cell in the manner that each sample was subjected to the same gamma dose. Each glass was subjected to a gamma dose of 10, 20, 30, 40 kGy and 50 kGy.

2.1.1. Effects of gamma radiation

Exposure of glasses by high energy radiation (Gamma-rays, X-ray, UV light) produces various changes in their properties including chemical, optical, electrical, magnetic and mechanical properties. [18,22,23]. Gamma rays being an ionizing radiatin, produces mostly induced absorption bands in the visible and UV part of the spectrum. This is due to the creation of defect centres generated as a result of capture of liberated pairs of electrons and positive holes during irradiation process. However, some authours [18,22,23] have arrived to the conclusion that glasses containing heavy metals like (PbO, Bi_2O_3, MO_3 etc) show shielding begaviour towards successive gamma irradiation [22,23].

2.1.2. Gamma rays irradiation

Polished samples were irradiated at Centre for Application of Radioisotopes and Radiation Technology [CARRT], Mangalagangotri, Mangalore University, Mangalore, using Gamma Chamber-5000 radiation source. A typical gamma cell with ^{60}Co