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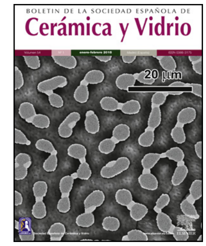

Properties and structure of Faraday rotating glasses for magneto optical current transducer

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ABSTRACT

High heavy metal oxides (60–100 mol.%) ternary $PbO–Bi_2O_3–B_2O_3$ (PBB) glasses were fabricated and characterized. Using a homemade single lightway DC magnetic setup, Verdet constants of PBB glasses were measured to be 0.0923–0.1664 min/G cm at 633 nm wavelengths. Glasses with substitution of PbO by Bi_2O_3 were studied in terms of their Faraday effects. $PbO–Bi_2O_3–B_2O_3$ = 50–40–10 mol.% exhibited good thermal stability, high Verdet constant (0.1503 min/G cm) and good figure of merit (0.071). Based on this glass, a magneto optical current sensor prototype was constructed and its sensitivity at different currents was evaluated to be 8.31 nW/A.

Propiedades y estructura de los vidrios rotadores de Faraday del transductor de corriente magneto-óptico

Palabras clave:
Vidrio de óxidos de metales pesados
Efecto Faraday
Constante de Verdet

RESUMEN

Se fabricaron y se calificaron vidrios ternarios $PbO-Bi_2O_3-B_2O_3$ (PBB) de óxidos metálicos muy pesados (60-100 mol%). Con una sencilla y simple instalación magnética de corriente continua se midieron las constantes de Verdet de los vidrios de PBB de 0,0923-0,1664 min/G cm, a longitudes de onda de 633 nm. Se estudiaron los efectos Faraday en los vidrios con una sustitución de PbO por Bi_2O_3. $PbO-Bi_2O_3-B_2O_3$ = 50-40-10 mol% mostró una buena estabilidad térmica, una constante de Verdet elevada (0,1503 min/G cm) y un buen factor de mérito (0,071). Sobre la base de este vidrio se construyó un prototipo de sensor de corriente magneto-óptico y se evaluó su sensibilidad a diferentes corrientes para llegar a 8,31 nW/A.

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Introduction

Magneto-optical current transducers (MOCT) based on Faraday effect have been developed worldwide as alternative to conventional optical ones [1] because MOCTs are compact and lightweight, immune to electromagnetic noise, and they offer a wide measurement range and long distance signal transmission [2]. Based on principle of Faraday effect, high rotation material is fundamental for getting a high sensitivity. Currently used high rotation materials are crystals (Bi:YIG etc.), or garnets and rare earth doped paramagnetic glasses, However, these expensive materials have limited magneto optical response to currents due to their temperature-dependent property [3–5].

Unlike its paramagnetic counterpart, diamagnetic heavy metal oxide (HMO) glasses, such as Bi_2O_3 and PbO, due to their mass and high polarizability of ions Pb^{2+} and Bi^{3+}, are appealing for magneto optical sensors because of their temperature-independent Faraday effect, small phonon energy, large refractive index and low-melting properties [6].

Bi_2O_3-based glasses have attracted a great deal of research interest because of their high optical transmission into the far-infrared region (in the range 0.5–8.7 mm), non-linear optical behavior and efficient luminescent applications in lasers. The modifier oxide, PbO, when added to bismuth borate glasses, the glasses are expected to become highly stable against devitrification and chemically inert [7] since PbO, in contrast with the conventional alkali/alkaline earth oxide/halide modifiers, form the stable glasses due to its dual role—modifier (with PbO_6 structural units) and glass network former in both covalent and ionic bonding with $PbO_4/2$ pyramidal units connected in puckered layers or frame structure [7,8]. Although Bi_2O_3 and PbO do not form glass by their own, they modify a vitreous network to form glass when they were combined with B_2O_3 [9,10] which is a good glass forming oxide for technological applications.

Most studies on PbO, Bi_2O_3 based glasses are multicomponents. Reports on PBB glass doped with other elements, such as SiO_2, Er/Yb [11–13], Tm, Tb/Ce [14], V_2O_5 Tb/Dy [15] and TiO_2 [16] etc. can be found for laser, luminescence [17], photosensitivity, non-linearity and dielectric dispersion applications [18]. Magneto-optical properties of multicomponents PbO–Bi_2O_3 doped with GeO_2 [6,19], ferrimagnetic FeO [20]/Fe_3O_4 [21], TeO_2 [22], CdO/MnO and Ga_2O_3 [23] etc. were reported. Spectral study of binary glass system PbO–B_2O_3, Bi_2O_3–B_2O_3 and PbO–Bi_2O_3 [24] can be found as gamma-radiation shielding materials [25] and ion conductor.

Till now, two literature reported on Raman spectra/optical [26] and dispersion [27] property of ternary PbO–Bi_2O_3–B_2O_3 for non-linear and optical coating application, respectively. The magneto-optical properties of ternary PBB glass were investigated by a new Faraday measurement method by this group [28]. Further study such as doping Fe_3O_4 nanoparticles [21] and GeO_2 [29] into ternary PBB glass were continued. Detailed study on this system is of big interests because this system has many potential applications in photonics and magneto-optical fields. The main challenge is the synthesis of PBB glass, because it is known that Bi_2O_3 and PbO are not traditional glass former, but Bi^{3+} and Pb^{2+} are highly polarizable ions and the asymmetry of their polyhedral inhibits the crystallization processes in the melts in PBB system [14]. Also the processing conditions of the HMO glasses influence the optical quality and color of samples [30]. In addition, the steep viscosity–temperature relationship and high thermal expansion in high lead/bismuth glasses [31] also hinder the study on ternary PBB glass.

Based on our previous study [21,22,28–30] on the processing condition and Faraday rotation measurement method, in this article, we directed a more systematically study on PBB glasses with a high HMO concentrations ranging from 60% to 90% in mol., and focus on their Faraday rotation in magneto optical sensors application. The aim of this study is to find a PBB with the best thermal and magneto optical performance for MOCT prototype construction. The sensitivity of MOCT was evaluated under different currents to verify the Faraday performance of selected glass.

Experiment

Glasses of nominal compositions were fabricated by melt-quenching method. Optical grade reagents (Aldrich, purity 99.9%) PbO, B_2O_3 and Bi_2O_3 were weighted and mixed in Al_2O_3 crucibles at melting temperatures ranging from 900 °C to 1100 °C for 1 h and were cast on a 200 °C preheated brass plate. The cast bulk glasses were annealed for 2 h at temperature ranging from 300 °C to 350 °C at 1 °C/min heating/cooling rate. The fabricated glasses were bubble-free, highly homogeneous and transparent with a yellow color. The sample with the optimum composition, assuring the best glass forming and physical properties, was chosen as sensing element for MOCT. The annealed glasses were cut into parallel slabs with a thickness of 2.5 mm and optically polished using a polishing instrument (λ – Logitech PM5).

Glass transition temperature (T_g) and crystallization temperature (T_x) were determined by differential scanning calorimetry (Perkin-Elmer DSC7), under N_2 atmosphere at a heating rate of 10 °C/min. The density was calculated at room temperature following the Archimedes' principle using water as immersion liquid. The refractive index (n) was measured under different wavelengths by the prism coupling method using Metricon 2010. The UV absorption spectra were recorded in the wavelength range of 200–800 nm by means of a UV-VIS spectrophotometer (Varian Cary 500) using optically polished samples with a thickness of 2.5 mm. Using samples thickness, the absorption coefficient can be calculated by equation: $\alpha = \log(I_0/I)/z = A/z$, where α is the absorption coefficient, A is the absorbance obtained from UV spectra, z is the sample thickness ($z = 2.5$ mm). The cut off is defined as the wavelength at which light ceases to propagate in the medium, it is normally calculated as the one at which the transmission decreases to 50% of its maximum. Fourier transforms infrared spectra (FT-IR) measurements from 1500 to 4000 cm^{-1} wave number were carried out using a Varian Cary 500 spectrophotometer.

The Verdet constants of glasses were measured using a home-made optical bench as shown in Fig. 1. A He–Ne laser, emitting 1.8 mW in a linearly polarized laser beam about 1 mm

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