Optics & Laser Technology 44 (2012) 1270–1276

Contents lists available at SciVerse ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Spectral dispersion of linear optical properties for Sm_2O_3 doped B_2O_3–PbO–Al_2O_3 glasses

S.Y. El-Zaiat *, M.B. El-Den, S.U. El-Kameesy, Y.A. El-Gammam

Physics Department, Faculty of Science, Ain Shams University, Abbasia, Cairo 11566, Egypt

ARTICLE INFO

Article history:
Received 1 April 2011
Received in revised form
7 December 2011
Accepted 29 December 2011
Available online 17 January 2012

Keywords:
Optical constants
Refractive index dispersion
Optical band gap

ABSTRACT

Glasses having composition $(B_2O_3)_{25}$ $(PbO)_{70}$ $(Al_2O_3)_5$ $(Sm_2O_3)_x$,where x=0, 0.5, 1, 2, 3 and 5 g were prepared using the normal melt quench technique. Spectral reflectance and transmittance at normal incidence of the glass samples are recorded with a spectrophotometer in the spectral range 220–2200 nm. These measured values are introduced into analytical expressions to calculate the real and imaginary parts of the refractive indices. Wemple–DiDomenico single oscillator model and one-term Sellmeier dispersion relations are used to model the real refractive indices. Dispersion parameters such as: single oscillator energy, dispersion energy, lattice oscillating strength, average oscillator wavelength, average oscillator strength and Abbe's number are deduced and compared. Absorption dispersion parameters such as: Fermi energy, optical energy gap for direct and indirect transitions, Urbach energy and steepness parameter are calculated. Effects of doping Sm_2O_3 on these linear optical parameters are investigated and interpreted.

1. Introduction

B_2O_3–PbO–Al_2O_3 glasses possess high mechanical strength, excellent electrical properties and moisture resistant. Also it is optically transparent in a broad band region and has very low thermal expansion. Some electrical and certain optical properties of these glasses have been investigated [1,2]. These glasses are used in variety of applications such as in battery sealing and other microelectronic packaging [3,4]. Physical properties of B_2O_3–PbO–Al_2O_3 glasses doped with MnO [5], Cr_2O_3 [6] and certain rare earth ions [7] have been studied. Heavy metal oxide glasses have high refractive index, high infrared transparency and high density [8,9]. It is used in many optical applications such as optoelectronic devices, lasers and thermoelectric devices [10,11]. Rare earth ions exhibit distinct optical properties and have broad band absorption and emission spectra. Rare earth ions dissolved in B_2O_3–PbO–Al_2O_3 glass matrix [7] strongly influence its physical and optical properties. Sm^{3+} ions possess strong fluorescence intensity, rich energy levels, large emission cross-section and high quantum efficiency. It is suitable to improve properties and develop new optical functions of glasses [12]. Recently, glasses containing samarium ions have stimulated extensive interests due to their potential application for high-density optical memory [13,14].

In this work six B_2O_3–PbO–Al_2O_3–Sm_2O_3 glass samples with different Samarium oxide contents are prepared using high temperature solid-state method. The reflectance and transmittance at normal incidence are measured for the prepared glass samples with a spectrophotometer in the spectral range 220–2200 nm. These measurements are introduced in analytical expressions to extract the glasses refractive indices. Two dispersion relations are fitted to the experimental real refractive indices and their dispersion parameters are calculated. Dispersion parameters for the imaginary refractive indices are also deduced. Effects of doping Sm_2O_3 on different dispersive parameters and some atomic parameters are investigated.

2. Experimental methods

2.1. Glass samples preparation

Glasses having composition $(B_2O_3)_{25}$ $(PbO)_{70}$ $(Al_2O_3)_5$ $(Sm2O3)_x$,where x=0, 0.5, 1, 2, 3 and 5 g, were prepared using the normal melt quench technique from AR grade chemicals of B_2O_3, PbO, Al_2O_3 and Sm_2O_3. The samples were mixed in porcelain crucibles, and then heated at 950 °C for two hours under normal atmospheric conditions. The melt was stirred from time to time to promote complete mixing and finally poured into preheated molds made of stainless steel of radius 1.3 cm. All samples were properly annealed at 350 °C in a muffle furnace to eliminate mechanical and thermal stresses. The composition of the glass samples used in investigated optical properties is shown in

* Corresponding author. Tel.: +20104530267.
E-mail address: syelzaiat@hotmail.com (S.Y. El-Zaiat).

0030-3992/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.optlastec.2011.12.051

Table 1
Compositions and densities of the studied glasses.

Glass no	Composition (%)			(g per batch)	Density (g/cm^3)
	B_2O_3	PbO	Al_2O_3	Sm_2O_3	
G0	25	70	5	0	5.143
G1	25	70	5	0.5	5.025
G2	25	70	5	1	5.081
G3	25	70	5	2	5.131
G4	25	70	5	3	5.257
G5	25	70	5	5	5.291

Table 1. Optical slabs are prepared by grinding and polishing the prepared samples with Paraffin oil and minimum amount of water.

2.2. XRD apparatus setup

The amorphous nature of these glasses was examined by X-ray diffraction analysis at room temperature. The data are collected using Philips (X'pert MPD) diffractometer using the Bragg–Brentano para-focusing technique. Highly monochromated Cu-radiation (wavelength $\lambda = 1.54051$ Å) is used. The step scan mode is applied in the 2θ-range (4–157.4612°). The step size ($\Delta 2\theta = 0.04°$) and the counting time is 10 s for each reading. The corresponding accessible maximum scattering vector magnitude, K, is 8.0 Å^{-1}. The air scattering was avoided by a suitable applied arrangement of XRD system. The receiving and divergence slits were properly chosen in both small and large 2θ-ranges, in order to improve the qualities of data collected as it could as it possible.

2.3. Glass density measurements

The densities of the prepared glass samples at room temperature were measured in indirect method based on Archimedes' principle using a sensitive microbalance with Xylene as immersion liquid. The density is calculated according to the equation:

$$\rho = \frac{wt_a}{wt_a - wt_{lq}} \times \rho_{lq} \mathrm{g/cm^3} \tag{1}$$

where ρ is the required glass sample density, wt_a the weight of the glass sample in air, wt_{lq} the weight of the glass sample in the immersion liquid, ρ_{lq} the density of the immersion liquid. The density is measured three times for each glass sample and the measured error is about ± 0.002 g/cm^3.

2.4. Spectrophotometric measurements

A computer aided two-beam spectrophotometer (JASCO Corp., V-570, UV/VIS/NIR, Japan) is used to record the reflectance, R, and the transmittance, T, data of the slab plane parallel glass samples. The resolution limit of the spectrophotometer is $\delta\lambda = 0.1$ nm. The accuracy of measuring reflectance and transmittance is ± 0.002 with an incidence angle of $5.0° \pm 0.1°$ to the normal to external slab faces. The propagation angle inside the slab samples is reduced below 5° due to refraction. The measurements are carried out at room temperature for the entire spectral range 190–2500 nm.

3. Refractive indices determination

Refractive index is the fundamental optical parameter of all materials. Its real part is inversely proportional to the wave propagation velocity, while its imaginary part is related to the intensity attenuation inside the material. It is closely related to the polarizability of material constituents and the local field inside the material. The determination of the refractive indices of optical materials is crucial for applications in optical devices. The refractive index as a function of the wavelength is a critical design parameter for advanced photonic systems [15,16].

A single transmission approach [17] or iteration procedure for incoherent multiple beam reflections [18] are usually used for extracting the refractive indices from reflectance and transmittance of spectrophotometric measurements. Single transmission is an approximated approach due to the neglecting of multiple reflections inside the sample. Iteration procedure needs time and means for computations. In this work analytical expressions are used for the first time (to our knowledge) to retrieve the real and imaginary refractive indices taking into consideration incoherent multiple reflections inside the sample [19,20]. The relation between the measured reflectance, R, measured transmittance, T, and interface reflectance, R_{as}, is [19,20]:

$$R_{as} = \frac{\left[2+T^2-(1-R)^2\right] - \{\left[2+T^2-(1-R)^2\right]^2 - 4(2-R)R\}^{1/2}}{2(2-R)} \tag{2}$$

The imaginary part of the refractive index is deduced as:

$$k = \frac{\lambda}{4\pi t} \ln\left[\frac{TR_{as}}{(R-R_{as})}\right] \tag{3}$$

The real part of the refractive index is:

$$n = \frac{(1+R_{as})}{(1-R_{as})} + \left[\frac{4R_{as}}{(1-R_{as})^2} - k^2\right]^{1/2} \tag{4}$$

The absorption coefficient of the glass material is:

$$\alpha = \frac{4\pi k}{\lambda} \tag{5}$$

The real part of the dielectric constant of the glass material is:

$$\varepsilon_r = n^2 - k^2 \tag{6}$$

The imaginary part of the dielectric constant of the glass sample is:

$$\varepsilon_i = 2nk \tag{7}$$

The first step is to measure the slab thickness, t, and its spectral reflectance, R, and spectral transmittance, T, with a spectrophotometer. Secondly, R and T are substituted in Eq. (2) to get R_{as}. Thirdly, R, T, λ, R_{as} and t are introduced in Eq. (3) to find k. Finally, n is calculated from Eq. (4) using R_{as} and k. The estimated errors for real refractive index is 0.005 and that for the extinction coefficient is 6×10^{-6}.

4. Experimental results

4.1. X-rays results

The x-ray diffraction spectra of four samples (with $x = 0$, 0.5, 3 and 5 g) are shown in Fig. 1. The spectra show the diffused bands characteristic of the x-ray diffraction pattern of amorphous materials. The spectra did not show any sharp peaks and confirms that the glass samples are amorphous in nature.

4.2. Glass density results

It is well known that, the density is mainly related to the individual ions present and the thermal history of the glass. Table 1 contains the measured values of density for the present glass samples. It can be seen that with sample G_1 there is a decrease in its density than that of sample G_0 due to the insertion