

## Dielectric Dispersion in PbO-Bi<sub>2</sub>O<sub>3</sub>-B<sub>2</sub>O<sub>3</sub> Glasses Mixed with Cr<sub>2</sub>O<sub>3</sub>

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### ABSTRACT

(20-x)PbO · 40Bi<sub>2</sub>O<sub>3</sub> · 40B<sub>2</sub>O<sub>3</sub>:xCr<sub>2</sub>O<sub>3</sub>, 0.0 ≤ x ≤ 1 glasses were prepared. Dielectric properties (dielectric constant ε', loss tan δ and a.c. conductivity σ<sub>ac</sub>, over a wide range of frequency and temperature) of these glass materials have been investigated. The dielectric study has revealed that the glasses possess high insulating strength when Cr<sub>2</sub>O<sub>3</sub> concentration's > 0.8 mol% in the glass matrix.

### 1. Introduction

Bi<sub>2</sub>O<sub>3</sub>-B<sub>2</sub>O<sub>3</sub> glasses exhibit transmission into the far infrared region (0.5–8.7 μm), possess high refractive index and exhibit nonlinear optical behavior. Recently, optical Kerr shutter switching and degenerated fourwave mixing experiments have been performed on bismuth borate glasses using femtosecond pulse lasers [1–3]. In view of these characteristics, Bi<sub>2</sub>O<sub>3</sub> based glasses have potential applications in optoelectronic circuits as ultrafast switches, infrared windows, optical isolators [2, 3]. The nonconventional glass forming oxide Bi<sub>2</sub>O<sub>3</sub>, participates in the glass structure with two possible coordinations [BiO<sub>3</sub>] pyramidal and [BiO<sub>6</sub>] octahedral units [2–4]. Further, bismuth ion was found to be an efficient luminescent activator with applications in lasers as a sensitizer for some rare earth ions [5, 6]. Kityk et al have carried out extensive work on Bi<sub>2</sub>O<sub>3</sub> based glasses along these lines [7] in recent years. The current investigation is aimed at an understanding the influence of the chromium ions on structural aspects of PbO-Bi<sub>2</sub>O<sub>3</sub>-B<sub>2</sub>O<sub>3</sub> glasses by studying their dielectric properties.

### 2. Experimental Methods

Within the glass forming region of PbO-Bi<sub>2</sub>O<sub>3</sub>-B<sub>2</sub>O<sub>3</sub> glass system, the following compositions with successive increase in the concentration of Cr<sub>2</sub>O<sub>3</sub> are chosen for the present study:

- C0: [(PbO)20-x·(Bi<sub>2</sub>O<sub>3</sub>)40·(B<sub>2</sub>O<sub>3</sub>)40]:(Cr<sub>2</sub>O<sub>3</sub>)0  
 C2: [(PbO)19.8·(Bi<sub>2</sub>O<sub>3</sub>)40·(B<sub>2</sub>O<sub>3</sub>)40]:(Cr<sub>2</sub>O<sub>3</sub>)0.2  
 C4: [(PbO)19.6·(Bi<sub>2</sub>O<sub>3</sub>)40·(B<sub>2</sub>O<sub>3</sub>)40]:(Cr<sub>2</sub>O<sub>3</sub>)0.4  
 C6: [(PbO)19.4·(Bi<sub>2</sub>O<sub>3</sub>)40·(B<sub>2</sub>O<sub>3</sub>)40]:(Cr<sub>2</sub>O<sub>3</sub>)0.6  
 C8: [(PbO)19.2·(Bi<sub>2</sub>O<sub>3</sub>)40·(B<sub>2</sub>O<sub>3</sub>)40]:(Cr<sub>2</sub>O<sub>3</sub>)0.8  
 C10: [(PbO)19·(Bi<sub>2</sub>O<sub>3</sub>)40·(B<sub>2</sub>O<sub>3</sub>)40]:(Cr<sub>2</sub>O<sub>3</sub>)1.0

Appropriate amounts (all in mol%) of reagent grades of PbO, Bi<sub>2</sub>O<sub>3</sub>, H<sub>3</sub>BO<sub>3</sub> and Cr<sub>2</sub>O<sub>3</sub> powders were thoroughly mixed in an agate mortar and melted in a platinum crucible in the temperature range 950–1000 °C in a PID temperature controlled furnace for about 1 h until a bubble free transparent liquid was formed. The resultant melt was then poured in a brass mould and subsequently annealed at 300 °C (i.e. below its glass transition temperature).

The samples were then ground and optically polished. The final dimensions of the samples used for dielectric studies were about 1 cm × 1 cm × 0.2 cm. A thin coating of silver paint was applied (to the larger area faces) on either side of the glasses to serve as electrodes for dielectric measurements. The painted samples were then dried with a hot blower for about 10 minutes on either side. The details of dielectric measurements were given in our earlier reports [8, 9]. Measurement accuracy of the dielectric constant is ~0.001 and that in loss is ~10<sup>-4</sup>.

### 3. Results

Temperature dependence of ε' of the glasses containing different concentrations of Cr<sub>2</sub>O<sub>3</sub> at 1 kHz is shown in Figure 1. The value of ε' is found to exhibit a considerable increase at higher temperatures; the rate with which ε' increases with temperature is found to be the highest for the glass containing 0.6 mol% of Cr<sub>2</sub>O<sub>3</sub>. The values of ε' and tanδ are observed to increase with the concentration of Cr<sub>2</sub>O<sub>3</sub> gradually up to 0.6 mol%; and for further increase of Cr<sub>2</sub>O<sub>3</sub>, these two parameters have been observed to decrease. Temperature dependence of ε' of the glasses containing different concentrations of Cr<sub>2</sub>O<sub>3</sub> at 1 kHz is shown in Figure 1.

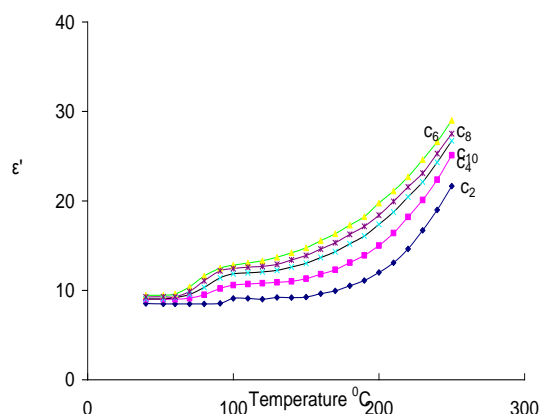


Fig.1 A comparison plot of variation of dielectric constant (1 kHz) with the temperature for PbO-Bi<sub>2</sub>O<sub>3</sub>-B<sub>2</sub>O<sub>3</sub>: Cr<sub>2</sub>O<sub>3</sub> glasses

The value of ε' is found to exhibit a considerable increase at higher temperatures; the rate with which ε' increases with

temperature is found to be the highest for the glass containing 0.6 mol% of Cr<sub>2</sub>O<sub>3</sub>. Temperature dependence of tanδ of all the glasses measured at a frequency of 10 kHz is shown in Figure 2. The dielectric loss curves of Cr<sub>2</sub>O<sub>3</sub>-containing glasses exhibited distinct maxima. With increasing frequency the temperature maximum shifts towards higher temperature, and with increasing temperature the frequency maximum shifts towards higher frequency, indicating the dielectric relaxation character of dielectric losses of these glasses. Additionally, the observations on dielectric loss variation with temperature indicated an increase in the broadness and (tan δ) max of relaxation curves with increase in the concentration of Cr<sub>2</sub>O<sub>3</sub> up to 0.6 mol%. Using the relation  $f=f_0 \exp(-Wd/KT)$ , (1)

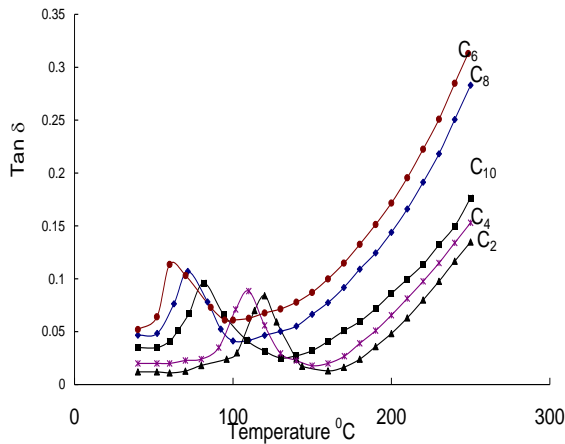


Fig.2 A comparison plot of variation of dielectric loss ( at 10kHz) with the temperature for PbO-Bi<sub>2</sub> O<sub>3</sub>-B<sub>2</sub>O<sub>3</sub> : Cr<sub>2</sub>O<sub>3</sub> glasses.

the effective activation energy Wd for the dipoles is calculated for different concentrations of Cr<sub>2</sub>O<sub>3</sub>; the activation energy is found to increase with increase in the concentration of Cr<sub>2</sub>O<sub>3</sub> beyond 0.6 mol% (inset of Figure 3 and Table 1).

The a.c. conductivity σ<sub>ac</sub> is calculated at different temperatures using the equation

$$\sigma_{ac} = \omega \epsilon'' \epsilon_0 \tan \delta \quad (2)$$

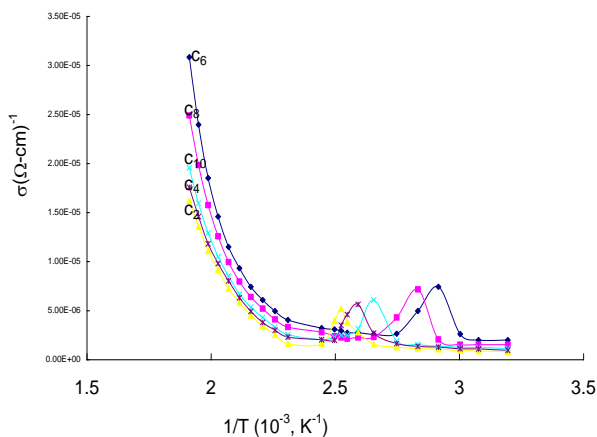


Fig.3. A comparison plot of variation of a.c. conductivity σ<sub>ac</sub> ( at 100kHz) with the temperature for PbO-Bi<sub>2</sub> O<sub>3</sub>-B<sub>2</sub>O<sub>3</sub> : Cr<sub>2</sub>O<sub>3</sub> glasses

A plot of log σ<sub>ac</sub> against 1/T for all the glasses at 100 kHz is shown in Figure 3. The conductivity is found to increase considerably at any given frequency and temperature with increase in the concentration of Cr<sub>2</sub>O<sub>3</sub> from 0.2 to 0.6 mol%. From these plots the activation energy for conduction in high temperature region over which a near linear dependence of log σ<sub>ac</sub> with 1/T could be observed is evaluated and its variation with the concentration of Cr<sub>2</sub>O<sub>3</sub>. The curve exhibits a minimum at 0.6 mol% of Cr<sub>2</sub>O<sub>3</sub>.

Glass	(Tanδ)max	A.E. for dipoles (eV)	A.E. for Conduction (eV)
C <sub>2</sub>	0.084	3.25	0.372
C <sub>4</sub>	0.090	3.15	0.364
C <sub>6</sub>	0.125	2.79	0.286
C <sub>8</sub>	0.113	2.86	0.298
C <sub>10</sub>	0.099	3.02	0.358

#### 4. Conclusion

The dielectric parameters ε', tanδ and σ<sub>ac</sub> are found to increase and the activation energy for AC conduction is found to decrease with a increase in the concentration of Cr<sub>2</sub>O<sub>3</sub> up to 0.6 mol% ,indicating an increase in the concentration of chromium ions that take part modifying positions in this concentration range.

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