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Investigation of Dielectric Properties of Synthesized Zno-Na_2o-Bi_2o_3-B_2o_3 Glass System

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Abstract

Glasses, unlike crystalline counter parts, have widely different physical and chemical properties, which are composition dependent. Glasses with varying compositions of zinc sodium bismuth borate were prepared. Glass systems with the compositions xZnO-(30-x) Na_2O-36Bi_2O_3-34B_2O_3 (The values of x ranging from 5 to 25 in mol% in steps of 5) were prepared by using melt quenching technique. We call the glasses of different compositions obtained with five different names G_1, G_2, G_3, G_4, and G_5. In the present paper the dielectric Properties of xZnO-(30-x) Na_2O-36Bi_2O_3-34B_2O_3 glass system were investigated. The dielectric properties of given glasses were determined at room temperature in the frequency range of 40Hz-1MHz using an impedance analyzer.

Keywords: *Capacitance, dielectric constant, permittivity of free space, dielectric loss.*

1. Introduction

Owing to the excellent adjustability of compositions and microstructures, glass-ceramics containing crystalline of high permittivity dispersed within glass phase make these materials strong candidates for the applications in high energy capacitors over the crystalline ferroelectrics. The dielectrics based on glasses have high dielectric constants, associated with low dissipation factor that change very little with frequency and temperature. They do not age (as there are no grain\boundaries and pores) as there is no subsequent chemical reaction taking place, and can be operated at high temperatures without any damage or performance shortfall. They also find applications in temperature sensors, oscillators, filters, and microwave windows.

In dielectric study, the real part of permittivity or dielectric constant (ε') represents the polarizability of the material while the imaginary part (tanδ) represents the energy loss due to polarization and ionic conduction. Dielectric materials have four distinguishable polarization mechanisms, namely electronic, atomic, orientation and interfacial or space charge polarization.

The dielectric constant (ε') of the material is dependent on the porosity, crystalline phase size, direction and distribution of grains and density. The dielectric constant of the ZnO-Na_2O-Bi_2O_3-B_2O_3 glass system is due to the polarization of electron, ion, and dipole orientation contributing to the polarizability. The electronic contributions always present generally. The ionic polarizability arises from the displacement of ions of opposite sign from their regular lattice sites resulting from the relative displacement of the ions. In an ideal capacitor the electric charge adjusts itself instantaneously to any change in the voltage of the applied electric field. In practice, there is a relaxation time for charge transport and the dielectric constant depends on the applied frequency. Sharaf El-Deen et al. [1] studied that the composition dependence of the dielectric constant and tanδ for ZnO-Na_2O-Bi_2O_3-B_2O_3 glass system can be interpreted in terms decreasing cross-linking in the glass network of the

$ZnO-Na_2O-Bi_2O_3-B_2O_3$ glass system with the increasing the amount of ZnO content. The addition of ZnO the polyhedral in the Bi_2O_3 network will transform some of the Bi-O bonds into non-bridging bonds depending upon the amount of ZnO [1]. This effect will decrease the average cross-link density of the glass network. The decreased amount with increasing ZnO content causes the average atomic ring size to increase and both the dielectric constant and tangent loss to decrease since the average Zn-O bond is weaker than Bi-O bond [1].

2. Material And Methods

Each of these compositions $xZnO-(30-x)Na_2O-36Bi_2O_3-34B_2O_3$,(the values of x ranging from 5 to 25 in mol% in steps of 5) were ground in a mortar with a pestle to obtain homogeneous mixture. The batch was melted in a porcelain crucible in an electric furnace at a temperature 1273K for about half an hour to obtain a homogenous melt. The homogeneous melt was rapidly quenched onto a stainless steel mould kept at 473K and pressed with another steel plate maintained at a temperature of 373K. The obtained glasses were annealed for 24 hours at the same temperature to remove mechanical stress.

3. Experimental Procedure:

The dielectric properties of glasses such as capacitance, dielectric constant, permittivity of free space, dielectric loss are found.

Samples of glasses of thickness were measured perfectly by a screw gauge. Each sample was coated with silver paste. The Capacitance-Dielectric loss (C_P-D) and Impedance-Phase angle (Z-θ) of the investigated sample were measured at room temperature and frequency range between 40Hz-1MHz using HP 4294 A Impedance analyzer which is fully automated and can be interfaced to a computer [2].

3.1 IMPEDANCE ANALYSIS: Figure 1 shows the variation of the real part of impedance (*Z'*) with the variation in frequency at room temperature. It is observed that the magnitude of *Z*' decreases with the increase in frequency. The curves display single relaxation process and indicate an increase in AC conductivity with frequency [2]. Figure 2 shows a set of impedance data taken over a wide frequency range (40 Hz- 1 MHz) at room temperature and do not take the shape of a semi-circle in the Nyquist frequency plot rather presents a straight line, suggesting the insulating behavior of $5ZnO-25Na_2O-36Bi_2O_3-34B_2O_3$ glass at room temperature [2].

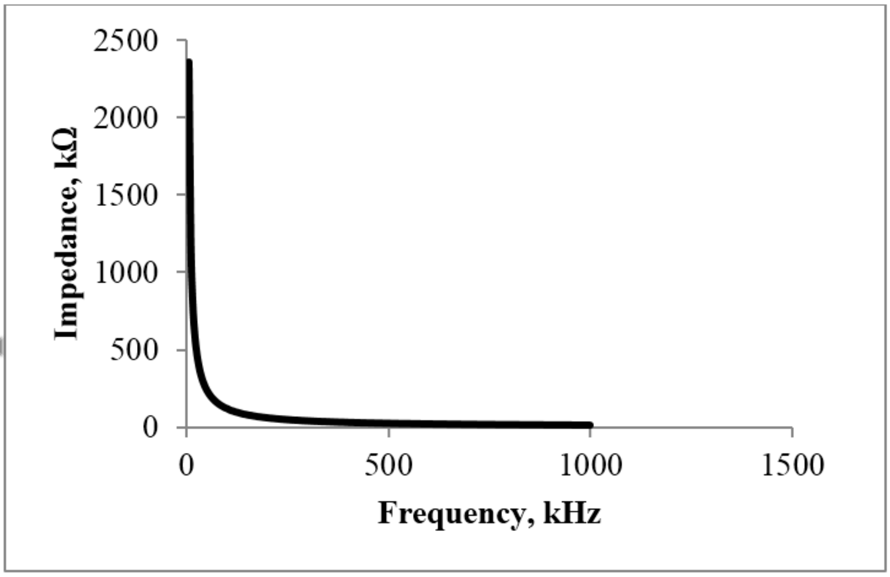

Figure 1: Variation of real part of impedance of $5ZnO-25Na_2O-36Bi_2O_3-34B_2O_3$ glass system with frequency at room temperature.

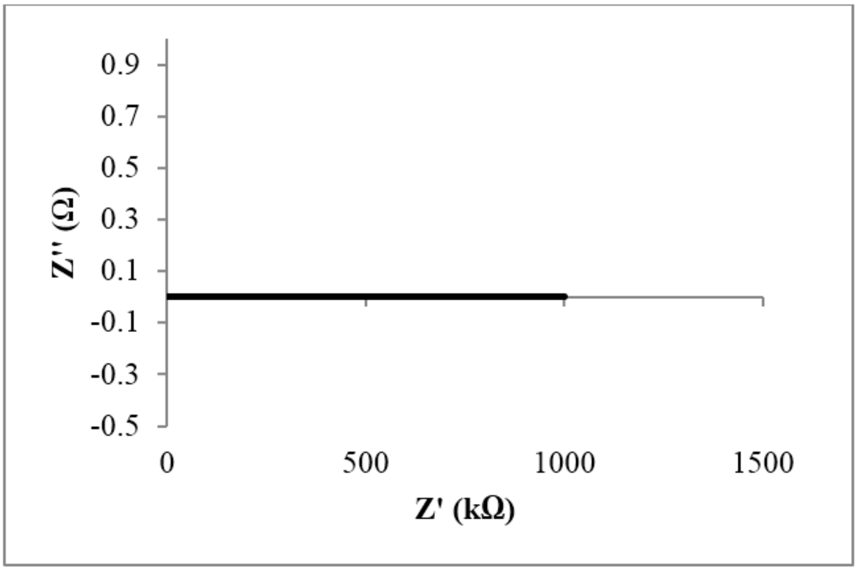

Figure 2: Nyquist frequency diagram for $5ZnO-25Na_2O-36Bi_2O_3-34B_2O_3$ glass at room temperature

The Bode plots (Figures 3 and 4) at room temperature suggests the capacitive behavior of electrode as log|Z| varies linearly with logf with a slope of -1.018, which is very close to the theoretical value of -1 for a pure capacitor. Also the value of θ increases with the increase in frequency and it lies in the range of -95^0 to -89^0 under these conditions, |Z| is related with frequency as equation (1) below

Log |Z| = - log f-log C_{bl}, -------------------------------- (1)

Where C_{bl} represents the barrier layer capacitance. The value of – log C_{bl} obtained from figure 4.12 is 10.18 Farad. The value of log |Z| and θ at 10 kHz were found respectively to be 6.07 and -90.10 ^{0}C at room temperature.

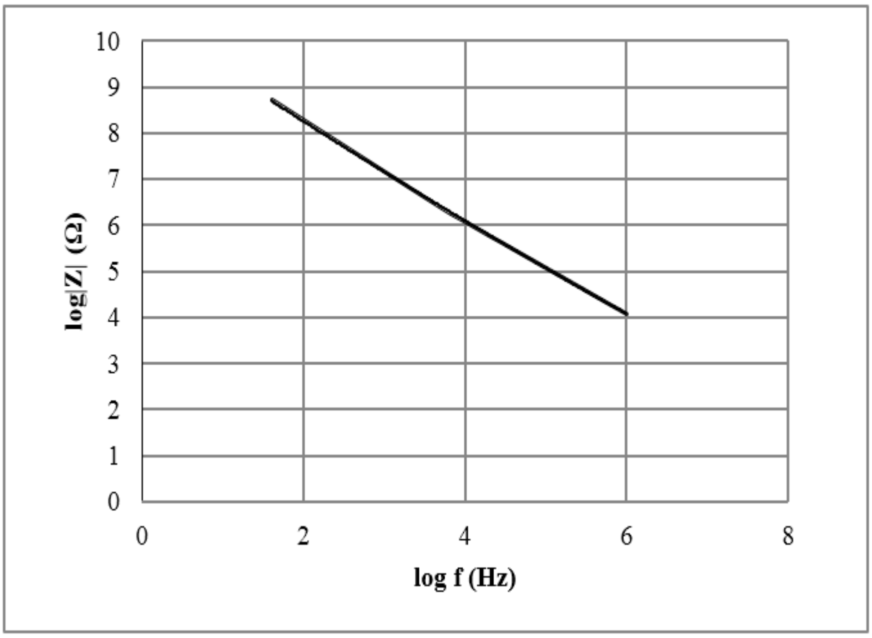

Figure 3: Variation of real part of log |Z| of glass G1 with Frequency at room temperature

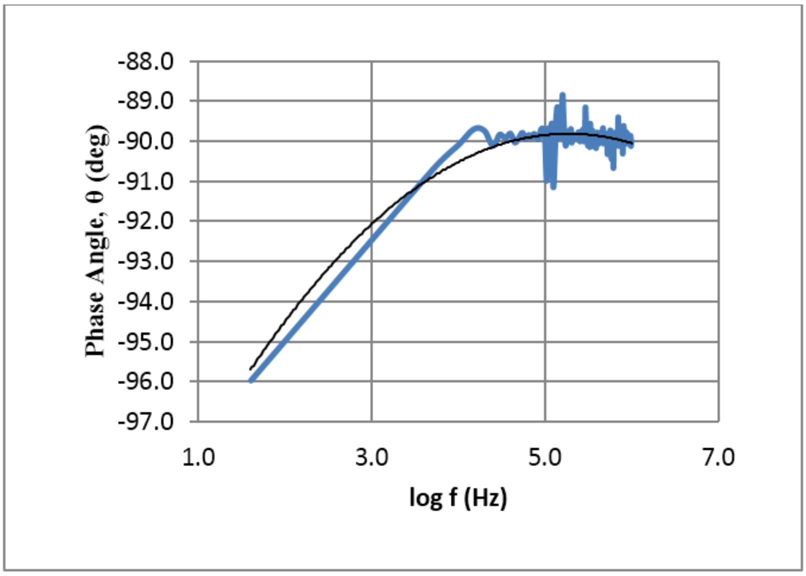

Figure 4: Variation of Phase angle (θ) of glass G1 with Frequency at room temperature.

3.2 DIELECTRIC MEASUREMENTS

At room temperature the dielectric constant (ε') and loss tangent (tanδ) were estimated in the frequency range between 40Hz-1MHz using the following relation (2).

$$\varepsilon' = \frac{(C - C0)*t}{\varepsilon 0 * A} \text{ -------------------- (2)}$$

Where C is the capacitance of the glass sample, C_0 (= 6 pF) is the capacitance in air, ε_0 is the permittivity of free space, $\varepsilon_0 = 8.854\text{x}10^{-12}$ F/m, t is the thickness and A is the surface area of the glass sample [4]. The dielectric constant (ε') decreases with increasing porosity in the materials because the dielectric constant (ε') of a pore is 1. In general, the quality factor is affected mainly by the pore size, the crystal phase, the mean crystal size and the crystallinity [5].

3.3 THE MEASUREMENT OF THE DIELECTRIC CONSTANT:

The frequency dependence of the capacitance and dielectric constant was measured for the glassy ZnO-Na_2O-Bi_2O_3-B_2O_3 within the frequency range 40Hz- 1MHz. From figures 5 and 6 it is observed that at room temperature for all compositions the capacitance and dielectric constant start as a high value and decreases by a fast rate at low frequencies and decreases by slow rate with increasing the frequency.

When the frequency is increased, the dipoles are no longer able to rotate sufficiently rapidly so that their oscillations begin to lag behind those of the field so explaining the observed decrease in the dielectric constant may be attributed at low frequency to multi component contribution to the polarizability of the glassy material. As the frequency becomes higher, higher ionic and orientation sources of polarizability decreases and finally disappear due the inertia of the molecules and ions.

The electric polarizability, α_e is the only process sufficiently rapid to follow alternative fields in the visible part of the spectrum. Ionic polarization, $\alpha_{i,}$ contribute to the dielectric constant ε' at high frequencies up to infrared region of the spectrum. Orientation, α_o and space charge polarization, α_s participate only at lower frequencies (1 kHz). So, the electronic contribution is always present and it is main contributors in the optical frequency range and in studied range. So, the dielectric increases due to increase of the α_e and α_s in addition to $\alpha_{o.}$

The room temperature dielectric constant ε' of these glasses varies from 16.26 to 33.28 for x values varying from 5 to 10 then ε' decreases from 33.28 to 26.33 for x varying from 10 to 25 at a frequency of 100 kHz. Since dielectric constant is composed of individual polarizability contributions from dipoles in a material, the effect of a small increment in density is twofold. It increases the number of dipoles per unit volume, an effect that always increases ε' if individual bond contributions are unaffected. However, it may also alter bond lengths and perturb the chemical nature and polarizability of individual bonds.

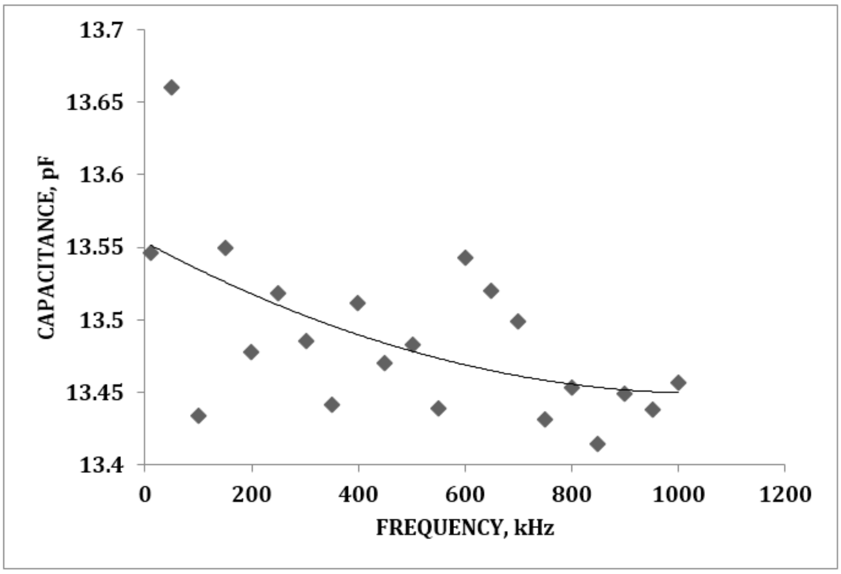

Figure 5: Capacitance in the frequency range of (10-1000 kHz) for $5ZnO$-$25Na_2O$-$36Bi_2O_3$-$34B_2O_3$

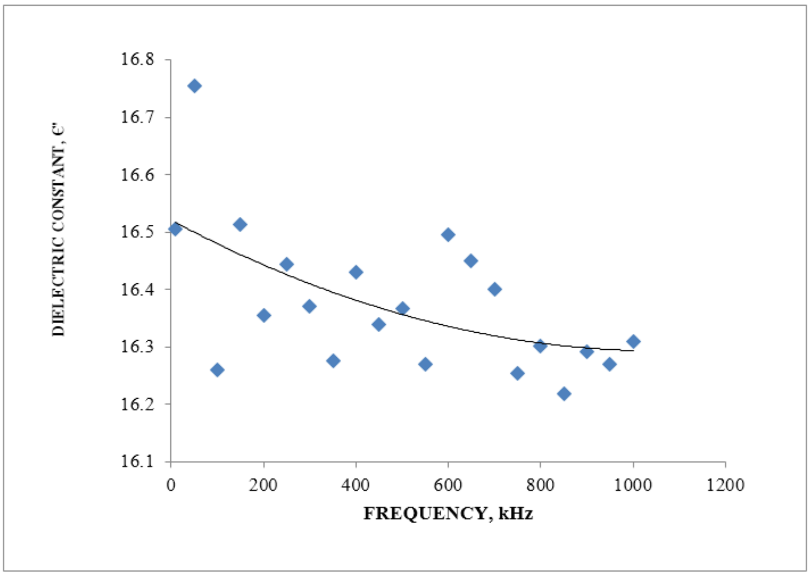

Figure 6: The frequency (10-1000 kHz) dependence of Dielectric Constant (ε') for G1

3.4 THE MEASUREMENT OF THE DIELECTRIC LOSS:

The dielectric loss factors, tanδ, of the glass system ZnO-Na_2O-Bi_2O_3-B_2O_3 were recorded as a function of frequency. The frequency dependence of tanδ at room temperature was recorded in frequency range 40 Hz-1MHz. Fig.7 shows that the dielectric loss has the highest value at low frequency. It decreases with fast rate at low and moderate frequencies, and then the decreasing rate becomes slow at high frequency region. This is because the migration of ions in glass is the main source of dielectric loss at low frequency. Accordingly, the dielectric loss at low and moderate frequencies characterized by high values due to the contribution of both wings (ion jump and conduction loss) of ion migration loss, in addition to the electron polarization loss. At high frequency values the ion vibrations may be the only source of dielectric loss.

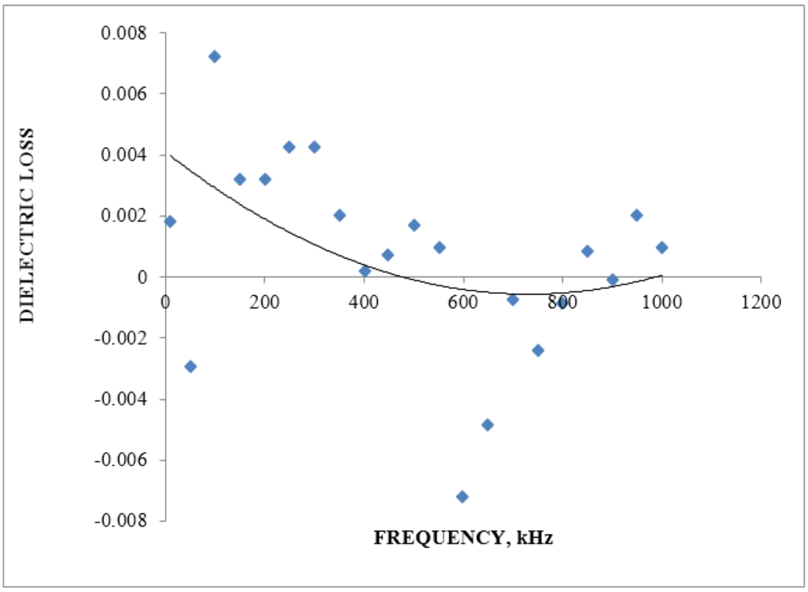

Figure 7: Dielectric loss in the frequency domain (10 - 1000 kHz), for G1 glass system.

The compositional dependence of both dielectric constant and tanδ for $ZnO-Na_2O-Bi_2O_3-B_2O_3$ glass system are presented in figures 8 and 9 respectively. The observation of figure 8, one can notice the increasing of the dielectric constant with increasing zinc-oxide content and ε' reaches to maximum value at 10 mole% of ZnO and then decreases with increasing zinc-oxide content in the frequency range 40 Hz-1MHz.The tangent loss has nearly the same trend as the dielectric constant which decreased with increasing zinc-oxide concentration as shown in figure 9.

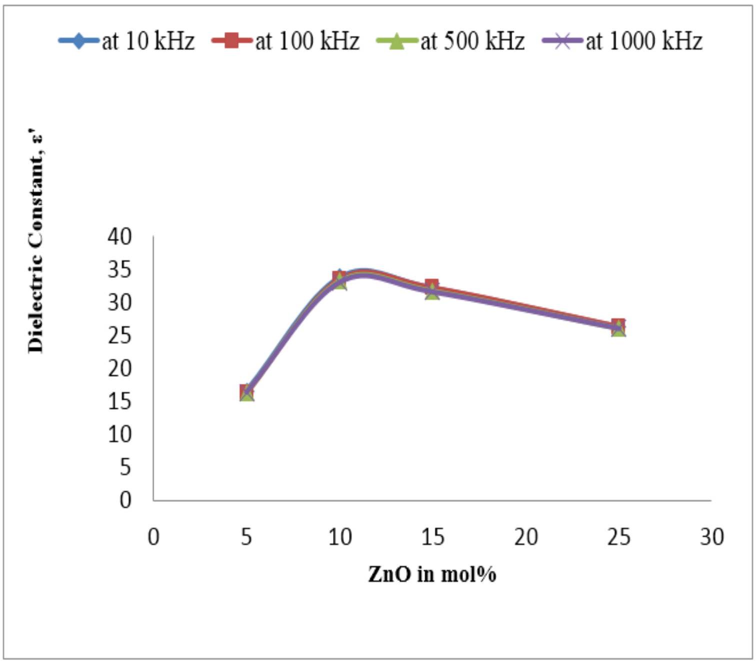

Figure 8: Composition dependence of the Dielectric constant (ε') measured at 10 kHz, 100 kHz, 500 kHz and 1000 kHz at room temperature for $ZnO-Na_2O-Bi_2O_3-B_2O_3$ glasses.

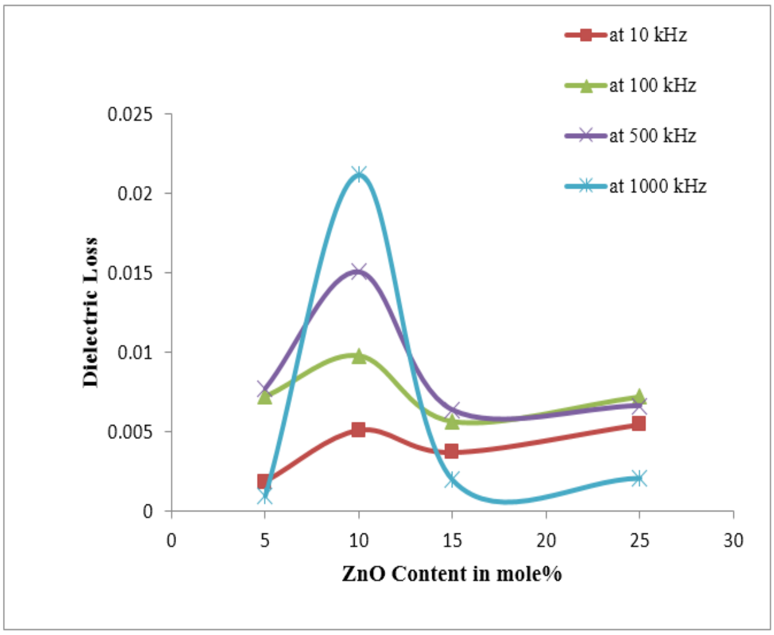

Figure 9: Composition dependence of the Dielectric Loss (tanδ) measured at 10 kHz, 100 kHz, 500 kHz and 1000 kHz at room temperature for $ZnO-Na_2O-Bi_2O_3-B_2O_3$ glasses.

Conclusions

The physical properties that were studied on these glasses may shed light on their potential use in high frequency circuit elements in conventional semiconductor industries. The investigated dielectric properties of these glasses have been reported.

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