ACOUSTIC PROPERTIES OF LEAD - VANADATE GLASS SYSTEM

P. Vasantharani* & M. Vijayalakshmi
Department of Physics, Annamalai University, Annamalainagar, 608002. Tamil Nadu, India.
*Corresponding author E-mail address: pvrselvam@yahoo.co.in (P. Vasantharani)

Received 08 November 2011; accepted 18 November 2011

Abstract
Longitudinal and shear ultrasonic velocities were measured in different compositions of glass system (100-x)V₂O₅-xPbO at room temperature and at 10 MHz frequency. The velocity data, the calculated elastic moduli, and Debye temperature have been used to obtain quantitative details about the structure of these glasses. Compositional dependence of ultrasonic velocities, calculated elastic moduli, Debye temperature, and molar volume showed the change in the structure of lead vanadate glasses.

Key words: Glasses; Ultrasonic velocity; Elastic moduli; Debye temperature

Introduction
The propagation of ultrasonic waves in solids provides useful information about the solid state motion in the material. In recent years, the study of glasses has rapidly increased because of their diverse applications in electronics, nuclear and solar energy technologies and acousto-optic devices. The acoustic wave propagation in bulk glasses has been of considerable interest to understand their mechanical properties [1]. The velocity of sound is particularly suitable for characterizing glasses as a function of composition because it gives information about the micro structure and dynamics of the glasses [2]. The study of elastic properties of glasses has inspired many researches [2-6] and significant information about the same has been obtained.

Ultrasonic nondestructive character on materials is a versatile tool for investigating the change in microstructure, deformation process and mechanical properties of materials [7]. This is possible due to the close association of the ultrasonic waves with elastic and inelastic properties of the materials. It is also due to the availability of different frequency range and many modes of vibration of the ultrasonic waves to probe into the macro, micro and submicroscopic levels.

Oxide glasses doped with the transition metal oxides such as CuO, Fe₂O₃, MoO₃, WO₃, V₂O₅, etc. are known to exhibit semiconducting properties [8]. The concentration of transition metal oxide plays an active role in semiconducting glasses. The information such as elastic properties, Debye temperature, acoustic impedance etc., of the glass system will be very much useful to have a complete knowledge of the system.

In this work, the density and ultrasonic velocities of V₂O₅-PbO glass were measured. The experimental results are used to obtain elastic constants. A possible explanation will be discussed in terms of the glass structure rather than disorder itself. They are also elastic moduli as a reliable source to reflect the intrinsic structure of a material.

Experimental studies
Glass samples belonging to (100-x) V2O5-xPbO (x = 40, 45 and 50) were prepared by melt quench technique using starting materials as V₂O₅ and PbO of reagent purity grade. The mixtures corresponding to the desired compositions were melted in silica crucibles in a muffle furnace at 1023 - 1273 K and maintained for few min at this temperature. The molten mixture was cast into a copper mould. Then the glass samples were annealed at 523K for one hour to avoid the mechanical strain developed during the quenching process. The prepared glass samples were polished and the surfaces are made perfectly plane and smoothened by diamond disc and diamond powder. Thickness of the glass samples was measured having the dimension of 10 mm diameter and 6 mm height. All glass samples were shown in Fig. 1.
Density measurements were performed using Archimedes’s method with double distilled water as an immersion liquid.

\[
\rho = \frac{a}{(a-b)} \rho_w \tag{1}
\]

where \(a\) and \(b\) are the weights of the glass samples in air and in distilled water and \(\rho_w\) is the density of distilled water at 303K.

The molar volume was calculated using the relation

\[
V_M = \frac{\sum X_i M_i}{\rho} \tag{2}
\]

where \(X_i\) is the molar fraction of the \(i\)th component and \(M_i\) is the molecular weight of the \(i\)th component.

Ultrasonic velocity measurements were carried out at a frequency of 10 MHz using x-cut and y-cut quartz transducers at room temperature using pulse echo method. The longitudinal \((U_l)\) and transverse \((U_s)\) velocities were calculated using the relation,

\[
U = \frac{2d}{t} \tag{3}
\]

where \(U\), velocity of the specimen (ms\(^{-1}\)), \(d\), thickness of the specimen (mm) and \(t\), transit time in microseconds.

The various elastic properties of the glasses were calculated using the following standard relations.

\[
\text{Longitudinal modulus} \quad L = \rho U_l^2 \tag{4}
\]

\[
\text{Shear modulus} \quad G = \rho U_s^2 \tag{5}
\]

\[
\text{Bulk modulus} \quad K = L - \left(\frac{4}{3}\right)G \tag{6}
\]

\[
\text{Young’s modulus} \quad E = 2(1+\sigma)G \tag{7}
\]

\[
\text{Acoustic impedance} \quad Z = U_l \rho \tag{8}
\]

\[
\text{Debye temperature} \quad \theta_D = \frac{h}{3K} \left(\frac{9N}{4\pi V_{ir}}\right) U_m \tag{9}
\]

where \(L, K, G\) and \(E\) are longitudinal, shear, bulk, Young’s modulus respectively, \(\rho\), the density, \(\theta_D\), the Debye temperature, \(h\), the Planck’s constant, \(K\), the Boltzmann’s constant and \(N\), the Avogadro number.

**Results and discussion**

The variation in density and molar volumes of the glass samples are shown in Table 1. It is well known that density is an important tool [10] to explore the structural compactness/softening, the change in geometrical configurations, coordination number and cross-link density etc. Thus, it helps to reveal the degree of change in the structure with change in composition in any glass systems. Generally, when metal oxides are added into the glass network either a decrease in density or an increase in density will be noticed. The increase in density with addition of PbO content leads to a decrease in density or an increase in density will be noticed. The increase in density with addition of PbO content leads to a decrease in volume due to the charge polarity of the atoms resulting in compactness of the glass network.

It is also observed from the Table 1 that both longitudinal and shear velocity increase linearly with increase in mol% of PbO in VP glass system, but the rate of increase of \(U_l\) is greater than of \(U_s\). The increase in ultrasonic velocity is attributed to increase in packing density because of the transformation of coordination of vanadium ion. Due to this increase in packing density, the rigidity of the glass system increases.

The elastic properties of the glass sample are increased if the content of PbO is increased as shown in Figs. 1-4. The large difference between \(L\) and \(G\) arises from volume effects. The change in volume due to compressions and expansions involved in longitudinal strain is pronounced while no change in volume is involved in shear strain. The obvious increase in elastic moduli is due to an increase in the rigidity of glass samples.
Table 1: Nomenclature, density, molar volume and velocity of VP glasses

<table>
<thead>
<tr>
<th>Glass name</th>
<th>Composition (mol. %)</th>
<th>( \rho ) (g cm(^{-3}))</th>
<th>( V_m ) (cm(^3))</th>
<th>( U_l ) (m s(^{-1}))</th>
<th>( U_s ) (m s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP 1</td>
<td>( V_2 O_5 ) 60 PbO 40</td>
<td>4.7048</td>
<td>42.17</td>
<td>3243.2</td>
<td>1538.5</td>
</tr>
<tr>
<td>VP 2</td>
<td>( V_2 O_5 ) 55 PbO 45</td>
<td>4.9047</td>
<td>40.87</td>
<td>3389.8</td>
<td>1621.6</td>
</tr>
<tr>
<td>VP 3</td>
<td>( V_2 O_5 ) 50 PbO 50</td>
<td>5.3589</td>
<td>37.79</td>
<td>3586.6</td>
<td>1638.8</td>
</tr>
</tbody>
</table>

Fig. 1. Plot of longitudinal modulus with change in PbO content.  
Fig. 2. Plot of shear modulus with change in PbO content. 
Fig. 3. Plot of bulk modulus with change in PbO content. 
Fig. 4. Plot of Young’s modulus with change in PbO content. 
Fig. 5. Plot of Acoustic impedance with change in PbO content. 
Fig. 6. Plot of Debye temperature with change in PbO content.
The acoustic impedance was found to increase from 1.5258 to 1.9220 \( \text{kg m}^{-2} \text{s}^{-1} \) with PbO increased as shown Fig. 5. The variation of the acoustic impedance indicates that the addition of PbO causes increase in the propagation of ultrasonic waves in the specimen [11].

Debye temperature represents the temperature at which nearly all modes of vibration in a solid are excited and its increase implies an increase in the rigidity of the glass [12]. Fig. 6 describes the variation of Debye temperature with lead oxide content. The gradual increase of Debye temperature from 167K to 185K indicates the increase in the rigidity of these glasses. The increase in Debye temperature is attributed to the increase in the number of atoms in the chemical formula of the glass and there is an increase in the mean ultrasonic velocity [13]. It indicates the strengthening in the glass structure which is due to the creation of bridging oxygen [14].

**Conclusion**

The density of this glass system increases with increase in mole percentage of PbO is due to the atomic weight and size of the constituent oxide. The increase in ultrasonic velocity reveals that adding of PbO in the glass system causes an easy movement for the ultrasonic waves inside the network of the glass structure and hence the ultrasonic velocity increases as PbO content increases. The results of the elastic moduli and of Debye temperature shows tightening and increase in rigidity of the glass structure. The VP glasses possess higher rigidity, strength and compactness.

**Reference**


Source of support: Nil; Conflict of interest: None declared