CORRELATION OF OPTICAL AND MECHANICAL PROPERTIES OF SILVER NANOPARTICLES SENSITIZED EUROPIUM DOPED PHOSPHATE GLASSES

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ABSTRACT

Magnesium-zinc-sulfophosphate glasses with various concentration of Silver nanoparticles (AgNPs) of molar composition 63.5P₂O₅–20MgO–15ZnSO₄–1.5Eu₂O₃–yAgNps (y = 0.0, 0.1, 0.3, 0.5, 0.7, 0.9 and 1.1 g in excess) were prepared via melt-quenching method. As-synthesized glasses were characterized at room temperature to determine the relationship between structural and mechanical properties. Densities of glasses were increased from 3.0720 to 4.3304 g.cm⁻³ with increase in AgNPs embedding levels, suggesting the network shrinkages and enhanced compactness. The Young’s, shear and bulk modulus of glasses were observed to enhance with the increase in AgNPs contents. The Poisson’s ratio of the studied glasses was increased from (0.0978 to 0.1416) while the values of both Vickers hardness (from 0.0658 to 0.0682 GPa) as well as G{sub C}₁₂ (from 0.8350 to 0.8916) were increased. The proposed glass composition may be useful for the development of hard surface engineering.

INTRODUCTION

In recent times, oxide glasses have received wide attention largely due to superior mechanical properties of these alloys which include high elastic strain limit, high hardness, abrasion resistance and great strength.(Yonezu, Xu, & Chen, 2009) Mechanical properties of glass is dependent on micro structure and phase crystalline assembly (Yang et al., 2019). Hardness of glass materials usually implied as resistance to abrasion and scratching (Al-Amri & Evans, 1994). Glass properties varies significantly with chemical composition. Rare earth doped glasses performed...
substantial character in development of biocompatible appliances (Jupri, Ghoshal, Omar, & Yusof, 2018). Microscopic cracks or surface layer defects determines glass strength. (Laopaiboon & Bootjomchai, 2015) Exceptional properties of glasses which include high resistance, high hardness, low toughness fracture which shows manifold technological application in building of houses, bridges and medicine (biocompatibility, prosthetic dentistry) (Sawamura & Wondraczek, 2018).

Phosphate has excellent features such as higher density and lower refractive index(Yu, 2014)(Gopi et al., 2018). Europium improves absorption property of phosphors (around 400 nm) thereby improving photoluminescence feature (Danmallam, Ghoshal, Ariffin, Jupri, Sharma, et al., 2019)(Danmallam, Ghoshal, Ariffin, Jupri, & Sharma, 2019). A suitable method of studying mechanical features of small volume materials is via indentation hardness where a fixed load on the diamond indenter is applied and measured using a microscope. Vickers hardness is the most widely used among several geometry indenters in hardness testing. The diamond pyramid hardness number HV is the ratio of applied load to contact surface (area). Low load hardness test was conducted with load levels ranging from 5 to 50 N with dwell period of 30s (Marzouk, 2009).

Considering the above mentioned scientific and engineering benefits, this study evaluates the optical and mechanical traits of phosphate glass. The glasses were synthesized by melt-quenching technique and analyzed with several investigative instruments. A link between optical and mechanical attributes was developed.

**EXPERIMENTAL PROCEDURES**

Reagents from Sigma Aldrich were used as raw materials for the synthesis of glasses with molar concentration 63.5P₂O₅–20MgO –15ZnSO₄–1.5Eu₂O₃ –yAgNps (y = 0.0, 0.1, 0.3, 0.5, 0.7, 0.9 and 1.1 g in excess). 15 g of batch composition was placed in crucible then placed in furnace (1100 °C) for 90 minutes. Samples were analysed to measure optical and mechanical features using RIGOL DS202 digital oscilloscope and Vickers indenter.

**RESULTS AND DISCUSSION**

**Physical Traits of the Studied Glasses**

Densities increased (from 3.0720 to 4.3304 g/cm³) due to large molecular mass Eu₂O₃ than that of phosphate and the decrease in density might be attributed to the Eu³⁺ ions taking part in the glass structure causing density decrease. Figure 1 shows decrease in molar volume ranged (from 43.5682 to 30.8883 cm³) with proportionate increase in AgNPs contents. The inverse trend of molar volume to density is due to change in structure with increase compactness and rigidity of the glasses (Mohammed, Krishna, & Ariffin, 2018). Molar volume decrease shows increase in oxygen packing density and shrinkage of bonds length (Danmallam, Ghoshal, Ariffin, Jupri, Sharma, et al., 2019).
MECHANICAL PROPERTIES

Mechanical properties of glass is dependent on micro structure and phase crystalline assembly (Yang et al., 2019). Hardness of glass materials usually implied as resistance to abrasion and scratching (Al-Amri & Evans, 1994). Glass properties varies significantly with chemical composition (Jupri et al., 2018). Microscopic cracks or surface layer defects determines glass strength (Laopaiboon & Bootjomchai, 2015). Exceptional properties of glasses which include high resistance, high hardness, low toughness fracture which shows manifold technological application in building of houses, bridges and medicine (biocompatibility, prosthetic dentistry) (Sawamura & Wondraczek, 2018).

A suitable method of studying mechanical properties of small volume materials is via indentation hardness where a fixed load on the diamond indenter is applied and measured using a microscope. Vickers hardness is the most widely used among several geometry indenters in hardness testing. The diamond pyramid hardness number HV is the ratio of applied load to contact surface (area). Low load hardness test were conducted with load levels of 50 N with dwell period of 30s (Marzouk, 2009).

The period of pulse reception display were evaluated longitudinal velocity ($V_L$) and shear velocity ($V_S$) (Bulus, Hussin, Ghoshal, Tamuri, & Jupri, 2019).

This relation was used to obtain the ultrasonic velocity

$$V_L = \frac{2d}{\Delta t} \quad (1)$$

$$V_S = \frac{2d}{\Delta t} \quad (2)$$

Glass width is symbolized with $d$ and $\Delta t$ is period gap.

The elastic modulus expressed using Cauchy relation,

$$L = \rho V_L^2 \quad (3)$$
(L) categorised homogenous isotropic material.

\[ G = \rho V_s^2 \]  \hspace{1cm} (4)

G represent shear resistance.

Bulk modulus (K) represent hydrostatic pressure incompressibility.

\[ K = \frac{3L-4G}{3} \]  \hspace{1cm} (5)

Young modulus describes stress and strain uniaxial proportionality.

\[ E = 2(1 + \delta)G \]  \hspace{1cm} (6)

Poisson ratio identifies ratio of axial strain to radial strain (Bulus et al., 2019).

\[ \delta = \frac{L-2G}{2(L-G)} \]  \hspace{1cm} (7)

Poisson’s ratio (\( \delta \)) were analysed via equation (7).

Table 2 depicts ultrasonic values increasing with proportionate increase in AgNPs contents ascribed to reduction in non-bridging oxygen and glass connectivity network rise (Gong, Wu, & Guan, 1999).

The rise in elastic moduli through increase AgNPs contents reveals shift in network bonds per unit volume presence. GC\(_{12}\) ratio describes dimensionality of glass system and field force character (Saddeek, 2004)(Renjo, Ćurković, Štefančić, & Ćorić, 2014). If GC\(_{12}\) = is said to be central when value is 1 and non-central when its GC\(_{12}\) ≠1. The observed range of values is from 0.8350 to 0.8916 (Table 2), implying central forces as a result of diminishing bond fraction (Marzouk, 2009)(Li, Subhash, Kecskes, & Dowding, 2005).

The Poisson ratio from (0.1 to 0.2) indicate higher cross-link density but (0.3 to 0.5 ) reveal lower cross-link density (Marzouk, 2009). Poisson ratio is calculated from

\[ \delta = \frac{L-2G}{2(L-G)} \]
ultrasonic velocity in which they diminution trend as AgNPs contents increases from (0.0978 to 0.1416) as displayed in( Figure 2) (Bridge & Higazy, 1986). Poisson ratio depict obvious connection with cross-link density as portrayed by the amount of bridging bonds per cation (Marzouk, Zobaidi, Okasha, & Gaafar, 2018).

![Graph showing ultrasonic velocity and AgNPs content](image1)

**Fig. 3.** Shear and longitudinal velocities against AgNPs contents

![Graph showing elastic moduli and AgNPs content](image2)

**Fig. 4.** Elastic moduli variation with AgNPs contents

Hardness is express as the mean pressure a material support under load (Roop Kumar & Wang, 2002). This is determined by the relation.

\[ HV = \alpha \frac{F}{d_2^2} \]

(8)

Where is the indenters geometrical constant (0.1891) F is the applied load (N) and d2 is indenters diagonals. Fig. 5 shows linear increase of hardness with increase AgNPs contents.
Fig. 5. Hardness against AgNPs content

Table I. Vickers hardness of the synthesized glasses against AgNPs contents

<table>
<thead>
<tr>
<th>Glass system</th>
<th>Hardness</th>
<th>±0.0020</th>
<th>D1 ±0.0016</th>
<th>D2 ±0.018</th>
<th>HV(GPa) ±0.004</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPMZAg0.1</td>
<td>360</td>
<td>140</td>
<td>141</td>
<td></td>
<td>0.0658</td>
</tr>
<tr>
<td>EPMZAg0.3</td>
<td>361</td>
<td>139</td>
<td>140</td>
<td></td>
<td>0.0663</td>
</tr>
<tr>
<td>EPMZAg0.5</td>
<td>363</td>
<td>139</td>
<td>138</td>
<td></td>
<td>0.0672</td>
</tr>
<tr>
<td>EPMZAg0.7</td>
<td>370</td>
<td>137</td>
<td>137</td>
<td></td>
<td>0.0677</td>
</tr>
<tr>
<td>EPMZAg0.9</td>
<td>373</td>
<td>137</td>
<td>137</td>
<td></td>
<td>0.0678</td>
</tr>
<tr>
<td>EPMZAg1.1</td>
<td>386</td>
<td>136</td>
<td>136</td>
<td></td>
<td>0.0682</td>
</tr>
</tbody>
</table>

Table II. Experimental values of Elastic moduli in comparison with existing literature

<table>
<thead>
<tr>
<th>Glass Code</th>
<th>$V_L$ (ms$^{-1}$)</th>
<th>$V_S$ (ms$^{-1}$)</th>
<th>L GPa</th>
<th>G GPa</th>
<th>K GPa</th>
<th>E GPa</th>
<th>$\sigma$</th>
<th>$G_{12}$</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPMZAg0.1</td>
<td>5412</td>
<td>3497</td>
<td>89.91</td>
<td>37.54</td>
<td>39.86</td>
<td>85.72</td>
<td>0.1416</td>
<td>0.8350</td>
<td>Present work</td>
</tr>
<tr>
<td>EPMZAg0.3</td>
<td>5539</td>
<td>3596</td>
<td>101.85</td>
<td>42.93</td>
<td>44.61</td>
<td>97.52</td>
<td>0.1357</td>
<td>0.8430</td>
<td>Present work</td>
</tr>
<tr>
<td>EPMZAg0.5</td>
<td>5603</td>
<td>3682</td>
<td>113.64</td>
<td>49.07</td>
<td>48.21</td>
<td>109.92</td>
<td>0.1200</td>
<td>0.8637</td>
<td>Present work</td>
</tr>
<tr>
<td>EPMZAg0.7</td>
<td>5758</td>
<td>3811</td>
<td>127.31</td>
<td>55.77</td>
<td>52.95</td>
<td>123.83</td>
<td>0.1102</td>
<td>0.8761</td>
<td>Present work</td>
</tr>
<tr>
<td>EPMZAg0.9</td>
<td>5824</td>
<td>3878</td>
<td>136.35</td>
<td>60.45</td>
<td>55.74</td>
<td>133.21</td>
<td>0.1017</td>
<td>0.8868</td>
<td>Present work</td>
</tr>
<tr>
<td>EPMZAg1.1</td>
<td>5967</td>
<td>3984</td>
<td>154.17</td>
<td>68.72</td>
<td>62.53</td>
<td>150.89</td>
<td>0.0978</td>
<td>0.8916</td>
<td>Present work</td>
</tr>
<tr>
<td>TiB$_2$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>(Yonezu et al., 2009)</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>6440</td>
<td>3923</td>
<td>106.30</td>
<td>39.44</td>
<td>53.70</td>
<td>95.06</td>
<td>-</td>
<td>-</td>
<td>(Laopaiboon &amp; Bootjomchhai, 2015)</td>
</tr>
<tr>
<td>NPC</td>
<td>4101</td>
<td>2500</td>
<td>48.45</td>
<td>15.69</td>
<td>27.53</td>
<td>39.6</td>
<td>0.261</td>
<td>0.92</td>
<td>(Marzouk, 2009)</td>
</tr>
<tr>
<td>BTDCe4</td>
<td>4476</td>
<td>2230</td>
<td>64.251</td>
<td>15.948</td>
<td>43.040</td>
<td>42.581</td>
<td>0.335</td>
<td>-</td>
<td>(Marzouk et al., 2018)</td>
</tr>
<tr>
<td>NDF3</td>
<td>-</td>
<td>-</td>
<td>104</td>
<td>-</td>
<td>61</td>
<td>82</td>
<td>-</td>
<td>-</td>
<td>(Roop Kumar &amp; Wang, 2002)</td>
</tr>
<tr>
<td>SHA</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>27.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

CONCLUSION

This is about the first-time a connection between mechanical and optical properties of silver nanoparticle sensitized phosphate glasses. The monitored rising trend of
longitudinal velocities and shear velocities were ascribed to glass compactness and network structure. The increasing nanoparticles contents attribute the rise in Poisson’s ratio, elastic moduli, and density cross link, this signify rigidity rise in the glass network matrix further revealing high stability and appreciable mechanical trait in the glass matrix.

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Reference:


