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) compose of $63.5\text{P}_2\text{O}_5-20\text{MgO}-15\text{ZnSO}_4-1.5\text{Eu}_2\text{O}_3-y\text{AgNps}$ ($y = 0.0, 0.1, 0.3, 0.5, 0.7, 0.9$ and 1.1 g in excess) were prepared via melt-quenching method. As-Quenched glasses were then characterized to establish the relationship between optical and mechanical characteristics. Densities were found to increase 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 value increased from 0.0978 to 0.1416 while values of both Vickers hardness (from 0.0658 to 0.0682 GPa) as well as GC_{12} (from 0.8350 to 0.8916) were increased. This necessitate the evaluation of ultrasonic properties and mechanical properties of the synthesized glasses and further analysed by various analytical tools. The studied glass may be useful for the development of hard surface engineering.

Keywords: Elastic Moduli; Ultrasonic Velocity; Poisson Ratio; Vickers Hardness, Young Modulus.

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. (1) Mechanical properties of glass is dependent on micro structure and phase crystalline assembly (2). Hardness of glass materials usually implied as resistance to abrasion and scratching (3). Glass properties varies significantly with chemical composition. Rare earth doped glasses performed substantial character in development of biocompatible appliances (4). Microscopic cracks or surface layer defects determines glass strength. (5) 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) (6).

Phosphate has excellent features such as higher density and lower refractive index(7)(8). Europium improves absorption property of phosphors (around 400 nm) thereby improving photoluminescence feature (9)(10). 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 30 s (11).

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 $63.5\text{P}_2\text{O}_5-20\text{MgO}-15\text{ZnSO}_4-1.5\text{Eu}_2\text{O}_3-y\text{AgNps}$ ($y = 0.0, 0.1, 0.3, 0.5, 0.7, 0.9$ 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/cm^3) due to large molecular mass Eu_2O_3 than that of phosphate and the decrease in density might be attributed to the Eu^{3+} ions taking part in the glass structure causing density decrease. Figure 1 shows decrease in molar volume ranged (from 43.5682 to 30.8883 cm^3) 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 (12). Molar volume decrease shows increase in oxygen packing density and shrinkage of bonds length (9).

Fig. 1 Density and Molar Volume Against AgNPs Contents

Mechanical Properties

Mechanical properties of glass is dependent on micro structure and phase crystalline assembly(2). Hardness of glass materials usually implied as resistance to abrasion and scratching (3).Glass properties varies significantly with chemical composition (4). Microscopic cracks or surface layer defects determines glass strength.(5) 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) (6).

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The period of pulse reception display were evaluated longitudinal velocity (V_L) and shear velocity (V_S) (13).

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 Δt is period gap.

The elastic modulus expressed using Cauchy relation,

$$L = \rho V_L^2 \quad (3)$$

(L) categorised homogenous isotropic material.

$$G = \rho V_S^2 \quad (4)$$

G represent shear resistance.

Bulk modulus (K) represent hydrostatic pressure incompressibility.

$$K = \frac{3L-4G}{3} \quad (5)$$

Young modulus describes stress and strain uniaxial proportionality.

$$E = 2(1 + \nu)G \quad (6)$$

Poisson ratio identifies ratio of axial strain to radial strain (13).

$$\delta = \frac{L-2G}{2(L-G)} \quad (7)$$

Poisson's ratio (δ) 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 (14).

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 (15)(16). If $GC_{12}=1$ is said to be central when value is 1 and non-central when its $GC_{12} \neq 1$. The observed range of values is from 0.8350 to 0.8916 (Table 2), implying central forces as a result of diminishing bond fraction (11)(17).

Fig. 2. GC_{12} ratio versus Poisson ratio against AgNPs Contents

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 (11). Poisson ratio is calculated from ultrasonic velocity in which they diminution trend as AgNPs contents increases from (0.0978 to 0.1416) as displayed in(Figure 2) (18). Poisson ratio depict obvious connection with cross-link density as portrayed by the amount of bridging bonds per cation (19).

Fig. 3. Shear and longitudinal velocities against AgNPs contents

Fig. 4. Elastic moduli variation with AgNPs contents

Hardness is expressed as the mean pressure a material support under load (20). This is determined by the relation.

$$HV = \alpha \frac{F}{d_2} \quad (8)$$

Where α is the indenter's geometrical constant (0.1891) F is the applied load (N) and d_2 is indenter's diagonals. Fig. 5 shows linear increase of hardness with increase AgNPs contents.

Fig. 5. Hardness against AgNPs content

Table 1. Vickers hardness of the synthesized glasses against AgNPs contents

Glass system	Hardness ±0.0020	D1 ±0.0016	D2 ±0.018	HV(GPa) ±0.004
EPMZAg0.1	360	140	141	0.0658
EPMZAg0.3	361	139	140	0.0663

EPMZAg0.5	363	139	138	0.0672
EPMZAg0.7	370	137	137	0.0677
EPMZAg0.9	373	137	137	0.0678
EPMZAg1.1	386	136	136	0.0682

Table 2. Experimental values of Elastic moduli in comparison with existing literature

Glass Code	V_L (ms ⁻¹)	V_S (ms ⁻¹)	Elastic moduli				σ	GC ₁₂	Ref.
			L GPa	G GPa	K GPa	E GPa			
EPMZAg0.1	5412	3497	89.91	37.54	39.86	85.72	0.1416	0.8350	Present work
EPMZAg0.3	5539	3596	101.85	42.93	44.61	97.52	0.1357	0.8430	Present work
EPMZAg0.5	5603	3682	113.64	49.07	48.21	109.92	0.1200	0.8637	Present work
EPMZAg0.7	5758	3811	127.31	55.77	52.95	123.83	0.1102	0.8761	Present work
EPMZAg0.9	5824	3878	136.35	60.45	55.74	133.21	0.1017	0.8868	Present work
EPMZAg1.1	5967	3984	154.17	68.72	62.53	150.89	0.0978	0.8916	Present work
TiB ₂	-	-	-	-	-	55	0.18	-	(1)
SiO ₂	6440	3923	106.30	39.44	53.70	95.06	-	-	(5)
NPC	4101	2500	48.45	15.69	27.53	39.6	0.261	0.92	(11)
BTDCe4	4476	2230	64.251	15.948	43.040	42.581	0.335	-	(13)
NDF3	-	-	104	-	61	82	-	-	(19)
SHA	-	-	-	-	-	27.3	-	-	(20)

Conclusion

This 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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