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Optical properties of Sm^{3+}-Doped soda-lime siligate Glass System

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Abstract

Physical and optical properties of Sm^{3+} in soda-lime silicate glasses with composition xSm_2O_3: $(65-x)SiO_2$:$25Na_2O$:10CaO are investigated for the composition range $0 \le x \le 2.5$ (in mol%). The glass samples have been prepared using the normal melt-quench technique. The results found that the density, the refractive index and the molar volume of glasses changed with changing Sm_2O_3 concentrations. A total of five absorption bands from the ground state $^6H_{5/2}$ of Sm^{3+} ion have been observed. The absorption bands at 360.0, 403.4, 473.6, 948.9 and 1084.9 nm arises due to $^6H_{5/2} \rightarrow {}^4D_{3/2}$, $^6H_{5/2} \rightarrow {}^4L_{13/2}$, $^6H_{5/2} \rightarrow {}^4I_{11/2}$, $^6H_{5/2} \rightarrow {}^4F_{11/2}$ and $^6H_{5/2} \rightarrow {}^6F_{9/2}$ respectively. The intensity of the absorption peaks was increased with increasing of Sm_2O_3 concentration.

Keywords: Soda-lime glass, Sm^{3+} doping

1. Introduction

The photonic application, based on soda lime glass as a host material, has received great attention because it has superior characteristic. Especially, rare-earth doped soda-lime glasses have been focused on the potential application of optical planar active waveguides [1]. The emission wavelength involved in the intra-4f transitions of trivalent RE ions is relatively insensitive to the host and temperature because the 4f shell is shielded from its surroundings by the filled 5s and 5p shells as the dopant rare earth ions [2]. Rare earth ion-doped glasses have received more attention because of their potential applications towards the development of visible and near-infrared (NIR) optical lasers and amplifiers, sensors and optical switching, etc. [2,3]. The studies on samarium containing glasses have received relatively less attention than other lanthanide ions, despite many features of interest. Samarium containing soda-lime siligate glasses are known as having an unusual elastic behavior due to valance instability [4]. Samarium exhibits promising characteristics for spectral hole burning studies [5,6]. The decay of exited states in Sm^{3+} involves different mechanisms depending on the matrix.

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In this work, Sm^{3+}-doped soda-lime silicate glasses have been synthesized by conventional melt quenching technique and physical and investigated their properties.

2. Methodology

The glass samples were prepared by using high purity SiO_2, Na_2CO_3, CaO and Sm_2O_3 in the composition range of xSm_2O_3:(65-x)SiO_2:25Na_2O:10CaO where x = 0.5, 1.0, 1.5, 2.0 and 2.5 mol%. Each batch weight about 20 g was melt in high alumina crucible by placing them in an electrical furnace for an hour, at 1,100 °C till a bubble free liquid was formed. These melts were quenched at room temperature in air by pouring between the melt on a stainless steel plate and pressing with another stainless steel plate. The quenched glasses were annealed at 450°C for 3 hour for reduce thermal stress [7], and cool down to the room temperature. All glass samples were cut and polish in proper shape for further studies. At the room temperature, densities (ρ) of all glass samples were measured by Archimedes's method using xylene as an immersion liquid. The density is calculated according to the formula;

$$\rho = \frac{w_A}{w_A - w_B} \times \rho_{xylene} \quad \text{g/cm}^3 \qquad (1)$$

Where w_A is the weight of the sample in air, w_B is the weight of the sample in xylene, and density of xylene is 0.8630 g/cm^3. The molar volume (V_M) was calculated using the relation $V_M = M_T/\rho$, where M_T is the total molecular weight of the multi-component system given by;

$$M_T = WM_{(SiO_2)} + XM_{(Na_2O)} + YM_{(CaO)} + ZM_{(Sm_2O_3)} \qquad (2)$$

Where W, *X*, *Y* and *Z* are the mole fractions of the constituent oxides, $M_{(SiO_2)}$, $M_{(Na_2O)}$, $M_{(CaO)}$ and $M_{(Sm_2O_3)}$ are the molecular weights of the different oxides for glasses preparation in this research.

The refractive index (n) of the glasses was measured using abbe refractometer with monobromo naphthalene as the contact layer between the glass and the refractometer prism.The absorption spectra were measured by uv-visible spectrophotometer (Cary 50, Varian) with a spectral range from 200 to 1100 nm.

3. Result and discussion

The measured physical and some optical properties of the soda-lime silicate glasses are summarized in Table 1. The density of glass increased with increasing of Sm_2O_3 concentration, because of higher molecular weight of Sm_2O_3 compared with SiO_2. The reflective index of glasses increased with increasing of Sm_2O_3 concentration. The result of refractive index is in good agreement with density result. The variation of density and refractive index of glasses are shown in fig. 1 and fig. 2 respectively.

The molar volume decrease with increasing of Sm_2O_3 concentration is shown in fig. 3. The result indicated that the structure of glass more compacted, with addition of Sm_2O_3. The probable explanation may be that a major part of Sm_2O_3 enters directly into the structure without the introduction of additional non-bridging oxygen.

Table 1. Properties of glasses sample

Properties	**Glass Sample Sm_2O_3 (%mol)**					
	0.00	0.50	1.00	1.50	2.00	2.50
Thickness of the glass, *d* (cm)	0.34	0.34	0.35	0.33	0.35	0.36
Average molecular weight, M(g/mol)	60.16	60.61	61.06	61.51	61.96	62.42
Density, ρ (g/cm^3)	2.54	2.58	2.62	2.68	2.72	2.76
***Molar volume, V_M* (cm^3/mol)**	23.68	23.52	23.30	22.96	22.80	22.59
Refractive index (n)	1.52	1.5271	1.5335	1.5385	1.5427	1.5474

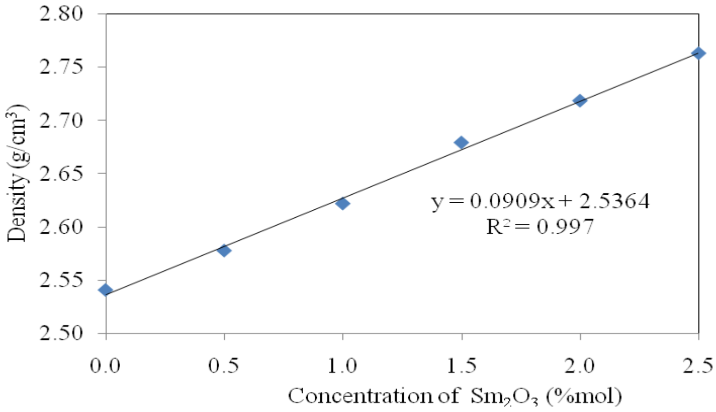

Fig. 1. The variation of density values over the Sm^{3+} concentration

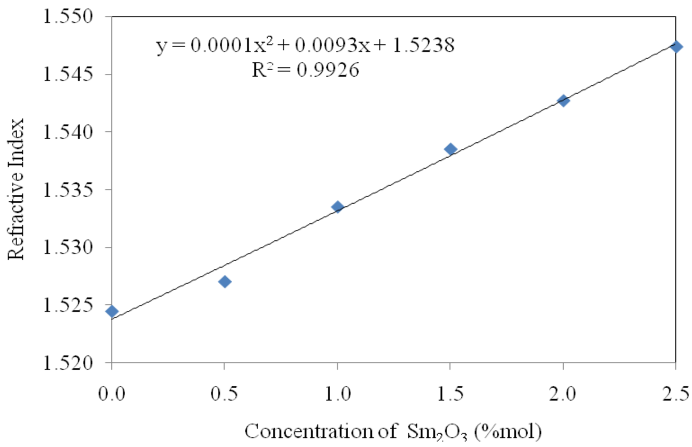

Fig. 2. The variation of refractive index values over the Sm^{3+} concentration

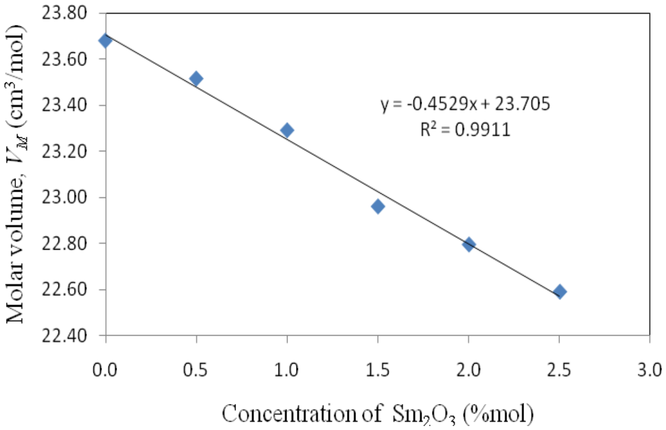

Fig. 3. The variation of molar volume over the Sm^{3+} concentration

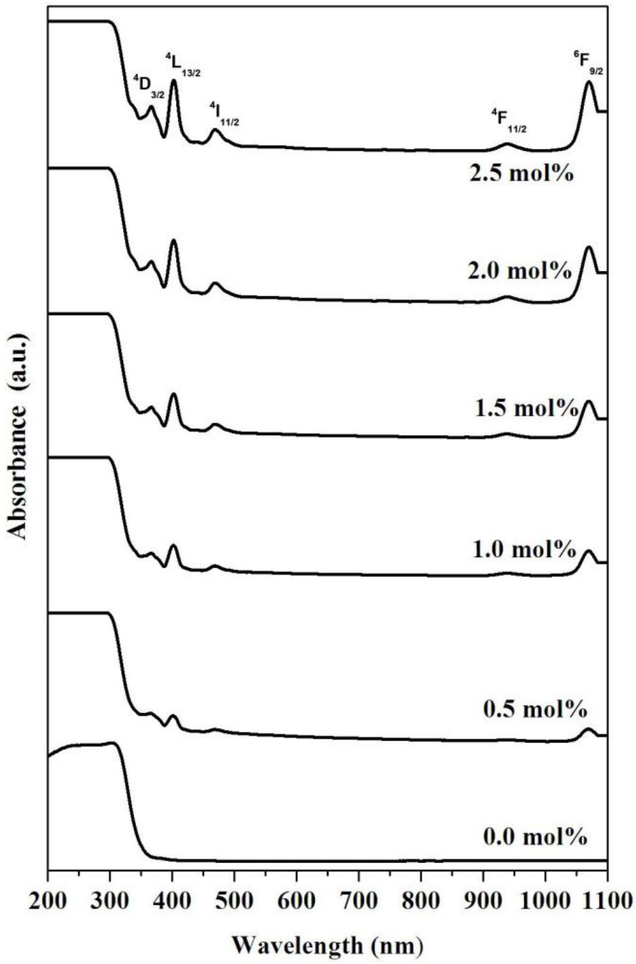

Fig. 4. Optical absorption spectra of glasses

The absorption spectra of Sm^{3+} doped soda-lime siligate glasses in the UV-VIS region at room temperature are shown in Fig. 4. Five absorption bands from the ground state $^6H_{5/2}$ of Sm^{3+} ion have been observed. The absorption bands at 360.0, 403.4, 473.6, 948.9 and 1084.9 nm arises due to $^6H_{5/2} \rightarrow {}^4D_{3/2}$, $^6H_{5/2} \rightarrow {}^4L_{13/2}$, $^6H_{5/2} \rightarrow {}^4I_{11/2}$, $^6H_{5/2} \rightarrow {}^4F_{11/2}$ and $^6H_{5/2} \rightarrow {}^6F_{9/2}$ respectively. All absorption band spectra are characteristic of sm^{3+} - doped oxide glasses [1,2,8]. In accordance with energy level diagram and literature data [8], all the observed absorption band were assigned to appropriate *f-f* electronic transitions of sm^{3+} ion from the ground state to the excited state. The ascending order of intensity of the absorption peaks is $^4F_{11/2} < {}^4I_{11/2} < {}^4D_{3/2} < {}^4F_{9/2} < {}^4L_{13/2}$.

4. Conclusion

Sm^{3+} doped soda-lime silicate glasses with different concentrations of Sm_2O_3 $0 \leq x \leq 2.5$ (in mol%) have been prepared and their physical and optical properties were measured. The density and refractive index of glasses increased with increasing of Sm_2O_3 concentration. The molar volume decreased with increasing of Sm_2O_3 concentration. The result indicated that the structure of glass more compacted, with addition of Sm_2O_3. The absorption bands at 360.0, 403.4, 473.6, 948.9 and 1084.9 nm arises due to $^6H_{5/2} \rightarrow {}^4D_{3/2}$, $^6H_{5/2} \rightarrow {}^4L_{13/2}$, $^6H_{5/2} \rightarrow {}^4I_{11/2}$, $^6H_{5/2} \rightarrow {}^4F_{11/2}$ and $^6H_{5/2} \rightarrow {}^6F_{9/2}$ respectively. The intensity of the absorption peaks was increased with increasing of Sm_2O_3 concentration.

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