Development of glass for radiation shielding material

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***Abstract*—The investigation of glass for radiation shielding material has been more intense. It occurs because the development of crystal is complicated, inflexible to shape and high-cost production. Meanwhile, glass possesses high refractive index, transparency, easy to fabricate and low-cost production. The glasses development were manufactured by melt and quenching method. The radiation shielding properties were measured by Compton scattering instrument. The addition of metal oxides such as Bi_2O_3, PbO, and BaO in silicate glass improved the density and effective atomic number of the glass sample. Meanwhile, the addition of oxyfluoride in borate glass decreased the mass attenuation coefficient of glass. Both experimental data of effective atomic number and mass attenuation coefficient of glass were compared by theoretical data. The theoretical data was calculated by WinXCom program. The highest of absorption spectra occurred due to the addition of oxyfluoride in glass system. All results showed that glass was a suitable candidate for radiation shielding material. The oxyfluoride glass possessed the more potential for radiation shielding material among glass samples.**

Keywords*— *glass; optical; radiation shielding;

I. Introduction

Nowadays, glass is very important material to develop photonic devices such as white LED, orange emitting devices, scintillator, infrared emission, sensor and radiation shielding material [1]–[6]. Glass is a suitable material to replace crystal. Glasses possess high transparency, good stability of chemical, mechanical and durability. On the other hand, glass is very easy to shape, manufactured, low-cost production and can be doped with high concentration of rare earth. Recently, radioactive materials are used more intense due to the application not only in industry but also medical field. In radiation physics field, glass is developed for radiation shielding material.

The most important parameters of radiation shielding are mass attenuation coefficient and effective atomic number. Several glasses have been investigated for radiation shielding material such as silica, borate, phosphate and fly ash as silica source [7]–[10]. The addition of ZnO, Al_2O_3, and other metal oxides can improve the transparency, chemical and mechanical property of glasses. Oxyfluoride such as calcium fluoride and gadolinium fluoride was mixed in glass system to make glass more compact [11]. The OH compound will be replaced by HF from oxyfluoride and decrease the phonon energy [6], [12]. Replacement Pb (lead) by Bi_2O_3 and BaO in radiation shielding material is more attractive to investigate due to the toxicity of Pb for environmental [13].

In this paper, the properties of glasses such as density, mass attenuation coefficient, effective atomic number and optical property will be discussed to understand the glass nature of radiation shielding material. The glasses were developed by melt and quenching method. The radiation shielding properties were measured by Compton scattering instrument. The experimental data were compared with theoretical, which was calculated by WinXCom program.

II. Manufactured of Glass

Glass systems such as phosphate [6], borate [12], silicate [13], and borosilicate [14] were prepared by melt and quenching technique. The glass sample was melted at 1400 ^{0}C for 3 hours. Thereafter, the glass sample was quenched at room temperature in the rectangular stainless steel. The glass sample then was annealed at 500 ^{0}C for 3 hours to release thermal stress. [15]. After the annealing process, the glass sample can be cooled down at room temperature. Finally, the glass sample was cut and polished around 1.0 x 1.5 x 0.35 cm^3 as shown in Fig. 1. The characterization of glass sample [6], [12]–[14] will be described in the next chapter (III). The characterization consisted of density, mass attenuation coefficient, effective atomic number, and optical property.

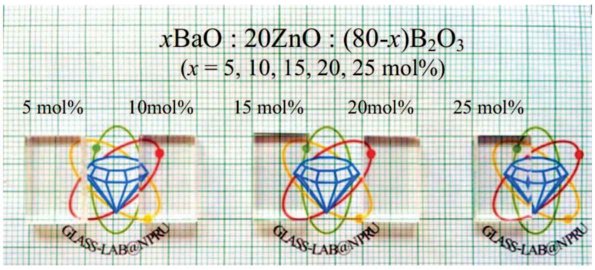

Fig. 1. Cut and polished glass sample for characterization [15].

Fig. 2 presents the experimental set up of Compton scattering instrument for measuring the mass attenuation coefficient and effective atomic number. Many research in Nakhon Pathom Rajabat University, Thailand used this instrument to measure radiation shielding parameters [16]–

[18]. The source of the instrument was 15mCi of 137 Cs and used aluminium rod as scattering rod. The adjustable detector, which was mounted 20 cm from scattering rod, was 2" x 2" NaI(TI) with resolution 8% at 662 keV (BIRCON model 2M2/2). The signal was recorded by CANBERRA PC-base multichannel analyzer. For generating alteration of gamma energy, the angle (θ) of the detector was adjustable. The experimental result of mass attenuation coefficient and effective number atomic were compared with the theoretical which was calculated by WinXCom program.

samples [13]. The mass molecular of Bi_2O_3, PbO and BaO are 153.33, 223.20 and 224.98 g/mol respectively. Other parameters of radiation shielding properties are mass attenuation coefficient (μ/ρ) and effective atomic number (Z_{eff}). The mass attenuation coefficient shows the ability of a material to be penetrated by a beam of light, sound, particles, or other energy or matter.

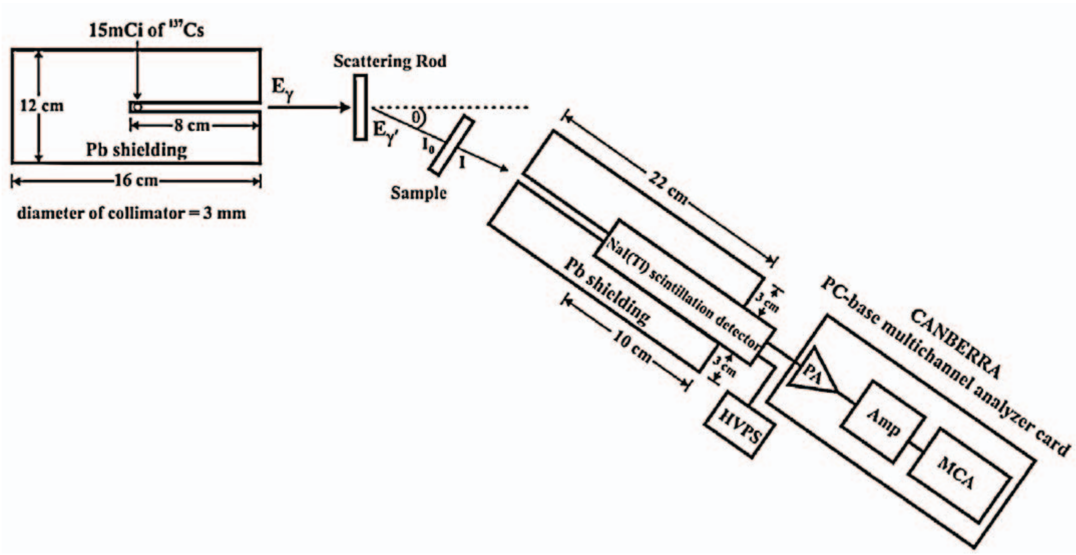

Fig. 2. Experiment set up for radiation shielding measurement [19].

III. Glass Properties

A. Radiation Shielding Properties

Kirdsiri et al. have investigated the comparative study of Bi_2O_3, PbO and BaO (R_mO_n) addition in the silicate glass. The formula of glass system was xR_mO_n:(100-x)SiO_2 where x was 30, 40, 50, 60 and 70 mol%. Fig. 3 presents the density of glass sample as a function of Bi_2O_3, PbO, and BaO (R_mO_n) concentration.

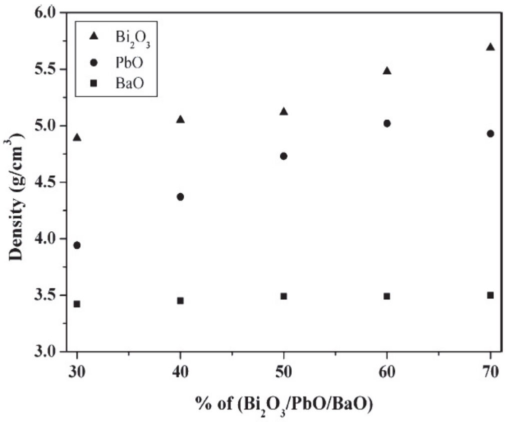

Fig. 3. The density of 30 to 70 mol% of Bi_2O_3, PbO, and BaO in glass system [13].

The density of Bi_2O_3 sample was higher than PbO and BaO due to the higher mass molecular of Bi_2O_3 among the glass

Shamshad et al. have studied the comparative of gadolinium oxide (LSGB1) and gadolinium oxyfluoride (LSGB2) in borate glass. Fig. 4 shows the theoretical and experimental of mass attenuation coefficient for LSGB1 and LSGB2 glass. As can be seen from Fig. 4, both mass attenuation coefficient of LSGB1 and LSGB2 exponentially decreased with increasing concentration of oxide and oxyfluoride. On the other hand, the mass attenuation coefficient of oxyfluoride was lower than oxide glass.

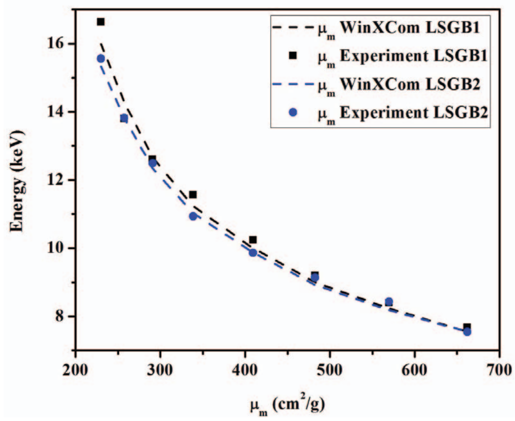

Fig. 4. Mass attenuation coefficient of LSGB1 and LSGB2 [12].

The theoretical and experimental of the mass attenuation coefficient of LSGB1 and LSGB2 were close each other [12].

Ruengsri et al. have developed glass material for radiation shielding from husk ash (RHA) as a silica source. The glass formula was $xBaO:(80-x)B_2O_3:20RHA$ (for x = 30, 35, 40 and 45 wt%). Fig. 5 shows the theoretical and experimental of effective atomic numbers (Z_{eff}) for glass sample. The graph shows that Z_{eff} theory is near Z_{eff} experiment. The scattered gamma rays energy were varied around 200 to 700 keV. The effective atomic number of glasses decreased by increasing the concentration of BaO and scattered gamma rays energy [14].

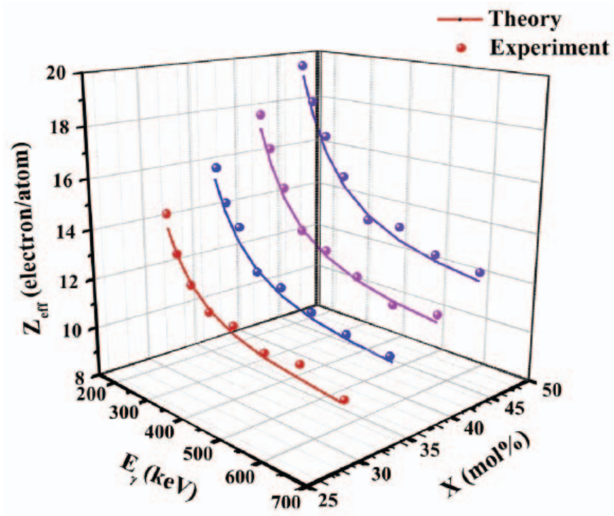

Fig. 5. The effective atomic number of 30 to 45% of BaO in RHA as a silica source [14].

B. Optical property

Absorption spectra describe the optical property of glasses. Meejitpaisan et al. have observed the optical property of Sm^{3+} doped oxide and oxyfluoride phosphate glasses. Fig. 6 shows the absorption spectra of the glass system. The composition of developed glass can be seen in Table I.

TABLE I. COMPOUND COMPISITION OF SM^{3+} DOPED OXIDE AND OXYFLORIDE GLASSES [6]

Glass ID	Glass composition (mol%)
S1	$69P_2O_5$: 10CaO: $20Gd_2O_3$: $1.0Sm_2O_3$
S2	$69P_2O_5$: $10CaF_2$: $20Gd_2O_3$: $1.0Sm_2O_3$
S3	$69P_2O_5$: 10CaO: $20GdF_3$: $1.0Sm_2O_3$
S4	$69P_2O_5$: 10 CaF_2: $20GdF_3$: $1.0Sm_2O_3$

The absorption spectra were monitored at the wavelength range of 900 to 1800 nm. It showed several transitions from the ground state of $^6H_{5/2}$ state to higher state such as $^6H_{11/2}$, $^6F_{9/2}$, $^6F_{7/2}$, $^6F_{5/2}$, $^6F_{3/2}$, $^6H_{15/2}$ and $^6F_{1/2}$ state. These transitions were corresponded by the wavelength of 944, 1077, 1227, 1373, 1474, 1529 and 1585 nm. The highest peak was due to the $^6H_{5/2}\rightarrow{}^6F_{7/2}$ transition centered at 1227 nm. Meanwhile, the highest intensity of absorption spectra was come from the S4 glass. This glass consisted of CaF_2 and GdF_3. The addition of oxyfluoride in glass system increased the absorption intensity of glass. In addition, the optical property of Dy^{3+} doped borate glass has been studied by Djamal et al. and absorption intensity increased by increasing Dy_2O_3 concentration from 0.1 to 2.5 mol% [5].

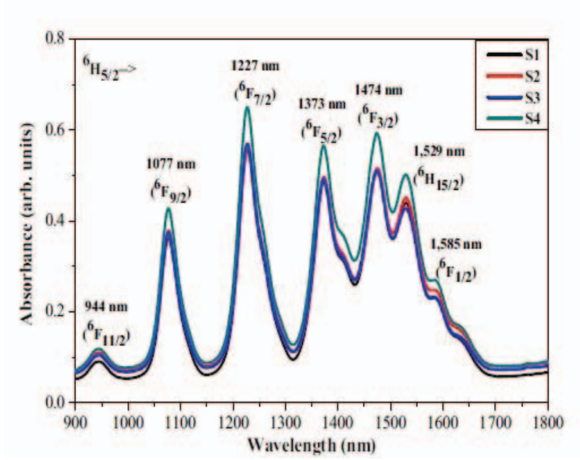

Fig. 6. The absorption spectra of Sm^{3+} doped oxide and oxyfluoride glasses [6].

IV. CONCLUSION

The glasses for radiation shielding material can be developed by melt and quenching method. The radiation shielding properties were measured by Compton scattering instrument. The density of glass system increased by the addition of metal oxides such as Bi_2O_3, PbO, and BaO from 30 to 70 mol%. The addition of oxyfluoride such as GdF_3 and CaF_2 in the glass system decreased the mass attenuation coefficient of glass sample and increased the absorption intensity. Meanwhile, the effective atomic number (Z_{eff}) decreased with the addition of BaO in RHA glass system. The data of radiation shielding properties were compared with theoretical data, which were calculated by WinXCom program. The theoretical data of mass attenuation coefficient and effective number atomic was near the experimental data. From all results show that glass was good material for radiation shielding material especially oxyfluoride glasses.

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