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Invited Paper

Physical and Gamma-Ray Shielding Properties of Barium Borosilicate Glasses

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Abstract. Glasses composition of xBaO:(80–x)B_2O_3:20SiO_2 where 45≤x≤70 wt.% were prepared using the melt quenching technique to investigate the physical and gamma-ray shielding properties. The density and hardness of the glasses were measured using Archimedes' principle and Vickers hardness, respectively. The mass attenuation coefficients of glasses have been determined experimentally for the gamma-ray with photon energy 662 keV, the results were compared with theoretical calculations from WinXCom computer software. The reported data is useful for chosen decision of these glasses in the radiation shielding application.

1. Introduction

Barium oxide is one of oxides that have been considerable to be a good candidate for development of radiation shielding glass. Ba-based glasses possess the strong absorption for x-rays and gamma-rays and non-toxicity compared with lead- and bismuth-based glasses [1]. Moreover, it has property to improve the rigidity of glass material [2]. Nowadays, shielding glasses are widely used as the nuclear radiation shielding materials [3] because they can be transparent to visible light and their other properties can be modified by filling some chemicals in the glasses matrix. Borosilicate glass is one of the important glasses in nuclear industries because it is mainly used as a medium for immobilizing the radioactive ions in the waste generated from nuclear reactors [4-6]. So, the purposes of the present work are to prepared a xBaO:(80–x)B_2O_3:20SiO_2 glass and investigate the physical and radiation shielding properties such as density, hardness and mass attenuation coefficients, respectively. The mass attenuation coefficients were investigated at photon energy 662 keV.

2. Experimental

Glasses having the formula xBaO:(80–x)B_2O_3:20SiO_2 where x = 45, 50, 55, 60, 65 and 70 wt.% (BaBS-1 - 6) were prepared from the reagent-grade raw materials of $BaCO_3$, H_3BO_3 and SiO_2 with purities higher than 99 wt.%. After mixing uniformly, the batches were melted with temperature at 1200 ^oC. The resulting liquid was cooled in a stainless steel mould, then transfered to anneal before cooling down to a room temperature. Finally, the glasses were cut into small pieces for test the other properties. The density (ρ) of glasses was determined directly at room temperature using the Archimedes method with xylene as an immersion fluid at least three times of each glass to determine the average value.

The Vickers hardness was determined using a micro hardness tester (Digital Micro Vickers Hardness Tester, Model HVS-1000) equipped after specimens were polished with a Vickers indenter under a 0.981 N load (100 gf). The indentations were examined by an optical microscopy under differential interference contrast. The Vickers hardness was calculated from the standard Vickers formula

$$H_V = 1.8544 \frac{P}{d^2} \qquad (1)$$

Where P is the indentation load and d is the diagonal of the indentation.

The theoretical mass attenuation coefficients of glass have been determined by using WinXCom computer software and the experimental mass attenuation coefficients have been determined by using narrow beam transmission method. The Narrow beam gamma-ray transmission geometry was used for the attenuation measurements of prepared borosilicate glass samples. The diagram of geometry is show in Fig 1. The source was enclosed in a lead container with one face aperture 3 mm. Samples were positioned on a specimen holder at 400 mm. interval from the source. The distance between source and detector is 550 mm. A 2”×2” NaI(Tl) detector crystal with the energy resolution 10.2 % at 662 keV and Multi-Channel Analyzer (MCA) plug-in-card with associated electronics were used to record the pulse-height spectra of ^{137}Cs radioactive source. The radioactive sources were procured from Office of Atom for Peace (OAP), Bangkok, Thailand. The intensities of photon were measured without (I_0) and with (I) placing the sample between source and the detector. Incident and transmitted intensities of photon were measured for a fixed preset time by selecting a narrow symmetrical region with respect to the centroid of the photo peak. The net area under each peak gives the intensity of gamma-rays. The counting time for each measurement was chosen such that 10^5 counts were recorded under each peak given a statistical error less than 0.3 %. The stability and reproducibility of the experimental procedure were tested using lead as a reference absorber at 662 keV.

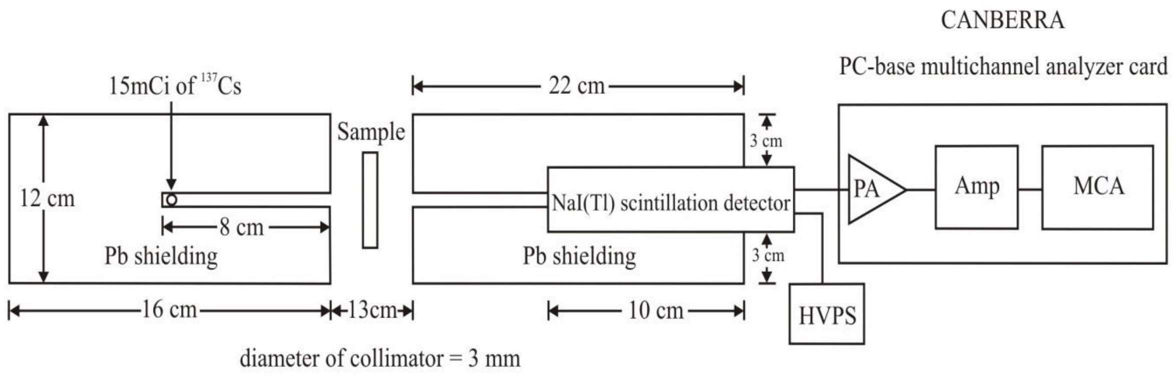

Fig. 1 Experimental setup of narrow beam transmission method

3. Results and Discussion

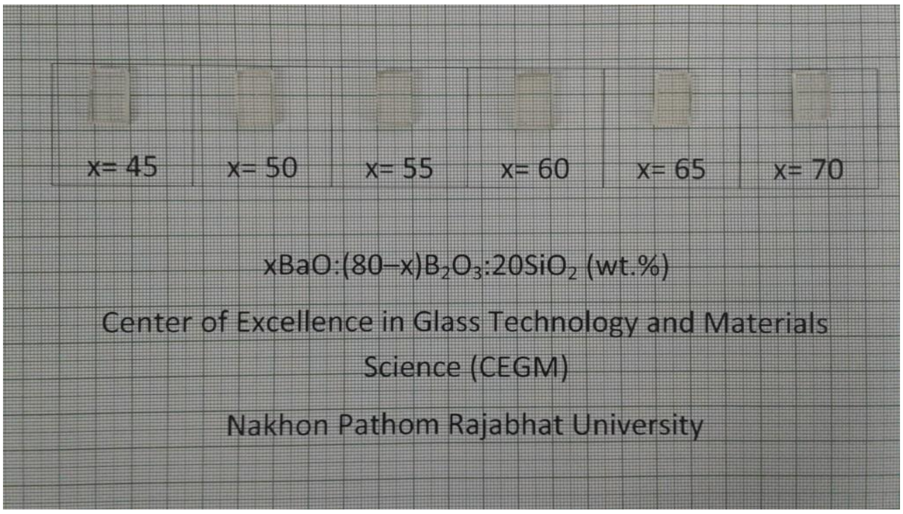

Fig. 2 The glasses after were cut and polished

Table 1. The density, hardness and theoretical and experimental values of total mass attenuation coefficients of BaBS glasses system

Sample	ρ (g/cm^3)	Hardness (Pa)	$(\mu_m)_{th}$ (cm^2/g)	$(\mu_m)_{ex}$ (cm^2/g)	% RD.*
BaBS-1	3.1363±0.0102	1,705.5±284	0.07677	0.07625	0.68
BaBS-2	3.2684±0.0074	1,606.9±23	0.07688	0.07651	0.48
BaBS-3	3.3562±0.0123	1,581.4±142	0.07699	0.07663	0.47
BaBS-4	3.5136±0.0030	1,507.4±30	0.07709	0.07701	0.10
BaBS-5	3.6312±0.0195	1,486.9±115	0.07720	0.07713	0.14
BaBs-6	3.8826±0.0058	1,407.8±227	0.07731	0.07729	0.03

% RD = relative difference of μ_m between experiment and theory

From Table 1, list the density, hardness, theoretical and experimental values of total mass attenuation coefficients for xBaO:(80–x)B_2O_3:20SiO_2 glasses. From the data seen that, the density values of the BaBS-1 - 6 are in the range of 3.1363 ± 0.0102 to 3.8826 ± 0.0058 g/cm^3. The variation of glass density is well understandable from the variation in the molecular weight of the added alkaline earth oxides, as shown in Fig 3. The impact of the BaO content on the hardness are shown in Fig.4. It can be observed that increase in the BaO content lead to decrease in the hardness values of glasses. For shielding property, the mass attenuation coefficients of glasses increase with increasing of BaO concentration. That means the photon interaction probability increases with higher content of BaO. When we checked the mass attenuation coefficient of BaO and B_2O_3 at the same energy (662 keV) found that the mass attenuation coefficient of BaO is more than B_2O_3 (μ_m of BaO = 0.07758 cm^2/g, μ_m of B_2O_3 = 0.07545 cm^2/g). That is the reason why when the amount of BaO increased the mass attenuation coefficient of the glass is increased. In general, the experimental values agree with the theoretical values which are calculated from WinXCom, within relative difference in a range of 0.03 – 0.68 %.

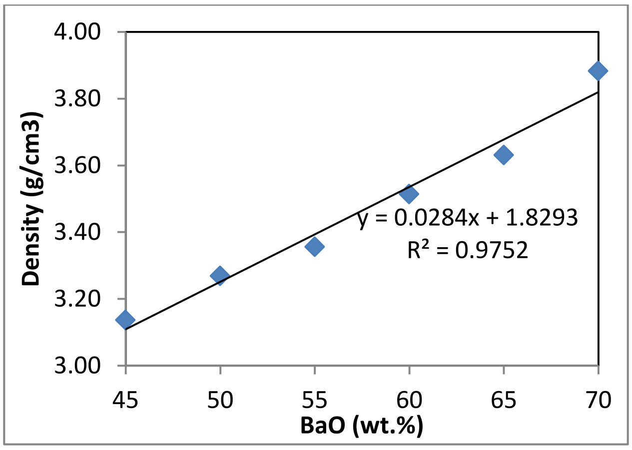

Fig. 3 The variation of density of barium borosilicate glasses depended on concentration

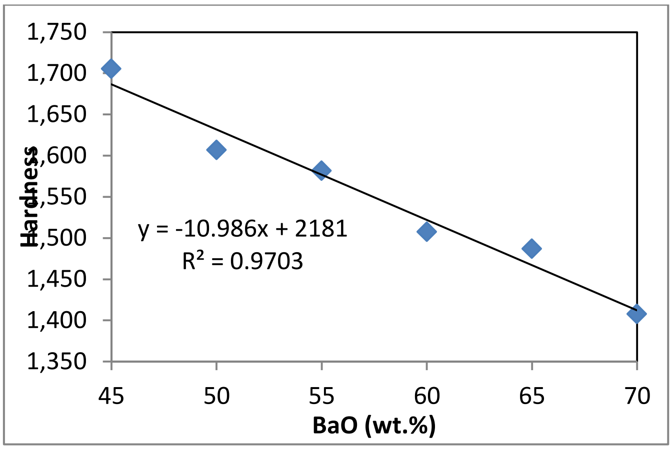

Fig.4 The variation of hardness of barium borosilicate glasses depended on concentration

4. Conclusions

In conclusion, we give the values for gamma-ray mass attenuation coefficients for the xBaO:(80–x)B_2O_3:20SiO_2 glass system at photon energy 662 keV, from the data found that when the concentration of barium oxide increase, the hardness is decreased but the density and the mass attenuation coefficients are increased.

5. Acknowledgements

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6. References

[1] Grelowska, I., Roben, M., Burtan, B., Sitarz, M., Cisowski, J., Sayed, Y.E., Knapik, A. and Dodek, M., 2016, "Structural and optical study of tellurite-barium glasses", Journal of Molecular structure, Vol.1126, pp. 219-225.
[2] Maiti, P.K., Mallik, A., Basumajumdar, A. and Guha, P., 2012, "Influence of barium oxide on the crystallization, microstructure and mechanical properties of potassium fluorophlogopite glass-ceramics", Journal of Ceramics International, Vol.38, pp. 251-258.
[3] Singh, N., Singh, K.J., Singh, K. and Singh, H., 2006, "Gamma-ray attenuation studies of PbO-BaO-B_2O_3 glass system", Radiation Measurement, Vol.41, pp. 84- 88.
[4] Kumar, S., Mishra, R.K., Tomar, B.S., Tyagi, A.K., Kaushik, C.P., 2008, "Heavy ion Rutherford backscattering spectrometry (HIRBS) Study of barium diffusion in borosilicate glass", Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms. Vol 266 (4), pp. 649–652.
[5] Mishra, R.K., Kumar, S., Tomar, B.S., Tayagi, A.K., Kaushik, C.P., Raj, K., Manchada, V.K., 2008, "Effect of barium on diffusion of sodium in borosilicate glass", Journal of Hazard Materials, Vol 156 (1–3), pp. 129–134.
[6] Tomar, B.S., Kumar, S., Shrikhande, V.K., Kothiyal, G.P., 2005, "Study of cesium diffusion in borosilicate glass by heavy ion Rutherford backscattering spectrometry", Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atom, Vol 227 (3), pp. 391–396.