Journal of Nuclear Materials 399 (2010) 38–40

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

Study on borate glass system containing with Bi_2O_3 and BaO for gamma-rays shielding materials: Comparison with PbO

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ARTICLE INFO

Article history:
Received 1 June 2009
Accepted 18 December 2009

ABSTRACT

In this work, the mass attenuation coefficients and shielding parameters of borate glass matrices containing with Bi_2O_3 and BaO have been investigated at 662 keV, and compare with PbO in same glass structure. The theoretical values were calculated by WinXCom software and compare with experiential data. The results found that the mass attenuation coefficients were increased with increasing of Bi_2O_3, BaO and PbO concentration, due to increase photoelectric absorption of all glass samples. However, Compton scattering gives dominant contribution to the total mass attenuation coefficients for studied glass samples. Moreover the half value layers (HVL) of glass samples were also better than ordinary concretes and commercial window glass. These results reflecting that the Bi-based glass can use replace Pb in radiation shielding glass. In the case of Ba, may be can use at appropriate energy such as X-rays or lower.

1. Introduction

Nowadays, glass materials are one of the possible alternatives to concrete because they can be transparent to visible light and their properties can be modified by composition and preparation techniques. Boric oxide, B_2O_3, acts as one of the most important glass formers and flux materials. Melts with compositions rich in B_2O_3 exhibit rather high viscosity and tend to be the formation of glasses. In crystalline form, on the other hand, borates with various compositions are of exceptional importance due to their interesting linear and nonlinear optical properties. The boron atom usually coordinates with either three or four oxygen atoms forming $[BO_3]^{3-}$ or $[BO_4]^{5-}$ structural units. Furthermore, these two fundamental units can be arbitrarily combined to form different B_xO_y structural groups [1]. Good reviews on radiation shielding borate glass development have been published recently by several authors [2–5]. These results show that the borate glass can be used in radiation shielding materials.

Bismuth (Bi) and barium (Ba) are playing on important role in radiation glass shielding and replacing lead (Pb) due to environmental toxicity of Pb and protectionism in world economy. In this work, we have measure the total mass attenuation coefficients of the candidate materials which used for radiation shielding glass development such as Bi_2O_3 and BaO in borate glass system at 662 keV, and compare with PbO in same glass system. Moreover, shielding parameters such as half value layer (HVL) and effective atomic numbers are also determined and compare with ordinary concrete and commercial window for useful of radiation shielding glass design, and investigate influence of Bi_2O_3 and BaO content in xR_mO_n: $(100-x)B_2O_3$ ($R_mO_n = Bi_2O_3$ and BaO and where $x = 30 \leqslant x \leqslant 70\%$ by weight) glass system.

2. Experimental details

The glass samples were prepared by using high purity grade of Bi_2O_3, $BaCO_3$, and H_3BO_3 in the composition range of (weight%) xR_mO_n: $(100-x)B_2O_3$ for $x = 30$–70 (where $R_mO_n = Bi_2O_3$ and BaO). Each batch weighs about 50 g was melt in alumina crucibles by placing them in an electrical furnace for an hour, at 1200 °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 500 °C for 3 h for reduce thermal stress, 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;

$$\rho = \frac{w_A}{w_A - w_B} \times \rho_{\text{xylene}} \quad (1)$$

where w_A the weight of the sample in air, w_B is the weight of the sample in xylene, and density of xylene is 0.863 g/cm^3.

The good geometry of transmission experiment was setup, as show in Fig. 1. The procedure followed for measure mass

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doi:10.1016/j.jnucmat.2009.12.020

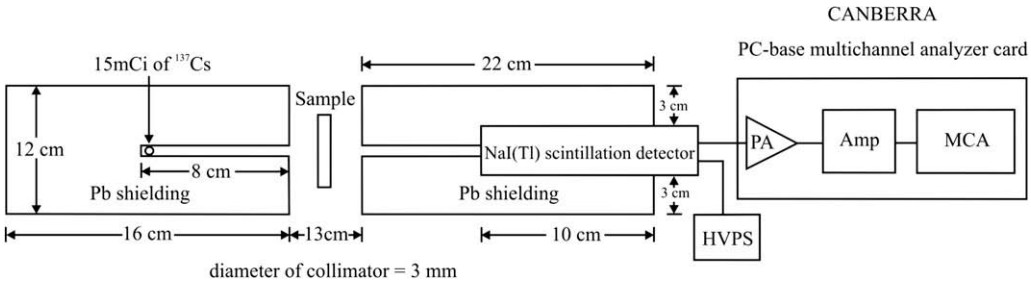

Fig. 1. Experimental setup of transmission method.

Table 1
Chemical composition and density of glass samples.

% Weight	Density (g/cm^3)		
	BaO-glass (this work)	Bi_2O_3-glass (This work)	PbO-glass (take from Ref.6)
30	3.17 ± 0.01	4.21 ± 0.02	3.60 ± 0.00
40	3.46 ± 0.01	4.70 ± 0.02	3.97 ± 0.00
50	3.76 ± 0.03	4.88 ± 0.00	4.29 ± 0.01
60	3.76 ± 0.01	4.97 ± 0.02	4.48 ± 0.01
70	3.78 ± 0.01	5.01 ± 0.09	4.77 ± 0.01

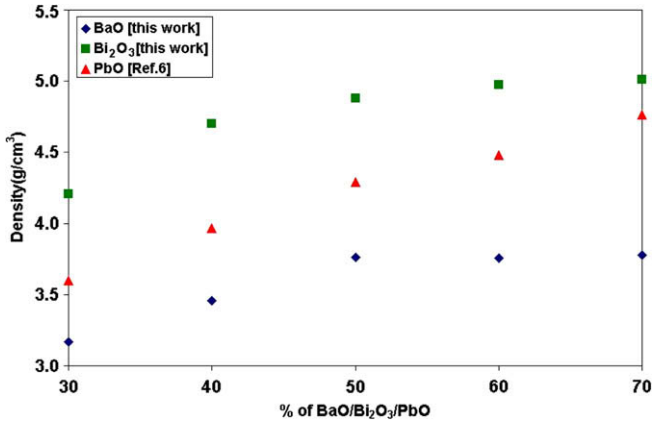

Fig. 2. Density of glass samples.

attenuation coefficients of glass samples are described in previous our work [5,6].

3. Results and discussion

3.1. Glass density

Chemical composition, density and thickness of glass samples are given in Table 1. It is seen that the density of glass samples increase with higher R_mO_n content, due to higher molecular weight of R_mO_n compared to with B_2O_3, therefore it is expected result. The density of Bi_2O_3 glasses more than PbO glasses [6] and BaO glasses respectively. The density of all glass samples are illustrated in Fig. 2 along with their composition.

3.2. Total mass attenuation coefficients and shielding properties

Table 2 lists the experimental and theoretical values of total mass attenuation coefficients glass samples. In general, the experimental values agree with the theoretical values which are calculated from WinXCom [7,8]. The total mass attenuation coefficients of Bi_2O_3 glasses and PbO [6] glasses are comparable, and the both more than BaO glasses, show that more attenuated photon in Bi_2O_3, and PbO glasses than BaO-glass. It was found that the total mass attenuation coefficients of glasses were increased with increasing of Bi_2O_3 and PbO concentration, due to increasing of photoelectric absorption interaction of all glass samples. The Compton scattering are dominant process under total interaction

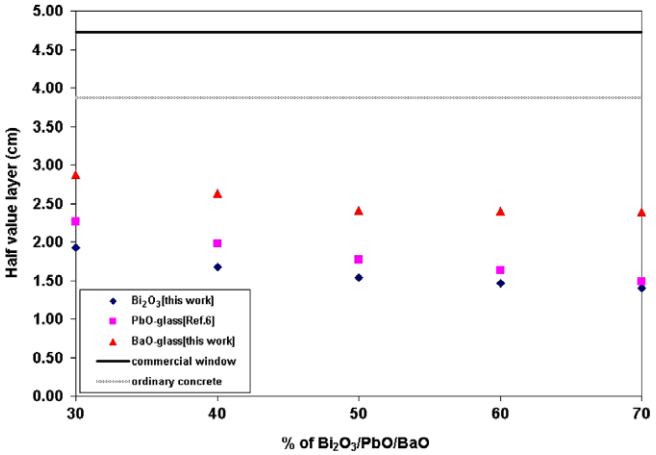

Fig. 3. The half value layer of glass samples compare with ordinary concrete and commercial window (at 662 keV).

Table 2
Total mass attenuation coefficients of glass samples.

% Weight	BaO-glass (this work)			Bi_2O_3-glass (this work)			PbO-glass (take from Ref. [6])		
	$(\mu_m)_{th} \times 10^{-2}$ (cm^2/g)	$(\mu_m)_{ex} \times 10^{-2}$ (cm^2/g)	% RD	$(\mu_m)_{th} \times 10^{-2}$ (cm^2/g)	$(\mu_m)_{ex} \times 10^{-2}$ (cm^2/g)	% RD	$(\mu_m)_{th} \times 10^{-2}$ (cm^2/g)	$(\mu_m)_{ex} \times 10^{-2}$ (cm^2/g)	% RD
30	7.61	7.59 ± 0.15	0.26	8.55	8.98 ± 0.11	5.03	8.51	8.31 ± 0.18	2.35
40	7.63	7.11 ± 0.10	6.81	8.88	8.68 ± 0.10	2.25	8.84	8.93 ± 0.17	1.01
50	7.65	7.93 ± 0.19	3.66	9.22	8.71 ± 0.09	5.53	9.16	8.87 ± 0.10	3.16
60	7.67	7.31 ± 0.13	4.69	9.55	9.57 ± 0.15	0.21	9.48	9.12 ± 0.16	3.80
70	7.69	7.21 ± 0.14	6.24	9.89	10.27 ± 0.12	3.84	9.81	9.96 ± 0.14	1.53

*RD = Relative difference of μ_m between experiment and theory.

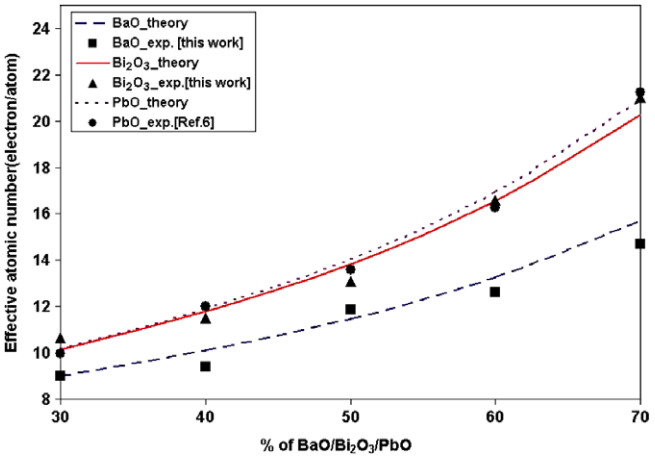

Fig. 4. The effective atomic number of glass samples.

in this work. However, it has very small effect of BaO concentration to total mass attenuation coefficients of borate glass in this energy. This result is in good agreement with published literature by S. Singh et al. for the case of barium borate fly-ash glass at 662 keV [9]. In addition, some data in Table 2 shows that the differences between experiment and theory are about 5%, indicating systematic errors, this is may be due to non-stoichiometry of glass formula ratio after melting at high temperature.

Fig. 3 show the half value layers (HVL) of glass samples were compared with ordinary concrete [2] and commercial window [6]. All glass samples are better HVL than ordinary concrete and commercial window. Furthermore, the effective atomic numbers are also calculated [5]. The result shows that the effective atomic numbers of Bi_2O_3 glasses comparable with PbO glasses and both are greater than BaO glasses. In addition, the effective atomic numbers are increase with higher Bi_2O_3, PbO and BaO concentration, as shown in Fig. 4.

4. Conclusions

In this work, the mass attenuation coefficients, half value layer and effective atomic numbers of Bi_2O_3 and BaO compared with PbO in xR_mO_n: $(100 - x)B_2O_3$ where $x = 30 \leqslant x \leqslant 70$ (% by weight) glass system at 662 keV have been investigated at 662 keV by transmission experiment, and compared with theoretical ones using WinXCom software. The results found that the experimental values agree with the theoretical values. The total mass attenuation coefficients of glasses were increased with increasing of Bi_2O_3 and BaO concentration, due to increasing of photoelectric absorption interaction of all glass samples. The effect of BaO concentration to total mass attenuation coefficients of borate glass at this energy is very small. From the HVL and effective atomic number results show reflecting that the Bi can replace Pb at this energy. In the case of Ba, may be can use at appropriate energy such as X-rays or lower.

Acknowledgements

The authors would like to thank to National Research Council of Thailand (NRCT) and Commission of Higher Education under National Research University (NRU) Project, for funding this research. Thanks are also due to Professor L. Gerward of Department of Physics, Technical University of Denmark for providing the WinXCom program. J. Kaewkhao is gratefully expresses his appreciation to Research and Development Institute NPRU for facilities.

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