Journal of Physics and Chemistry of Solids 112 (2018) 185–189

Contents lists available at ScienceDirect

Journal of Physics and Chemistry of Solids

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

Elevated gamma-rays shielding property in lead-free bismuth tungstate by nanofabricating structures

Jun-Hua Liu [a], Quan-Ping Zhang [a,*], Nan Sun [b], Yang Zhao [a], Rui Shi [c], Yuan-Lin Zhou [a], Jian Zheng [a]

[a] State Key Laboratory Cultivation Base for Nonmetal Composites and Functional Materials, Southwest University of Science and Technology, Mianyang 621010, China
[b] Institute of Materials, China Academy of Engineering Physics, Jiangyou 621908, China
[c] Fundamental Science on Nuclear Wastes and Environmental Safety Laboratory, Southwest University of Science and Technology, Mianyang 621010, China

ARTICLE INFO

Keywords:
Gamma-rays shielding
Environment-friendly
Bismuth tungstate
Nanosheets

ABSTRACT

Radiation shielding materials have attracted much attention across academia and industry because of the increasing of nuclear activities. To achieve the materials with low toxicity but good protective capability is one of the most significant goals for personal protective articles. Here, bismuth tungstate nanostructures are controllably fabricated by a versatile hydrothermal treatment under various temperatures. The crystals structure and morphology of products are detailedly characterized with X-ray diffraction, electron microscope and specific surface area. It is noteworthy that desired Bi_2WO_6 nanosheets treated with 190 °C show the higher specific surface area (19.5 m^2g^{-1}) than that of the other two products. Importantly, it has a close attenuating property to lead based counterpart for low energy gamma-rays. Due to the less toxicity, Bi_2WO_6 nanosheets are more suitable than lead based materials to fabricate personal protective articles for shielding low energy radiations and have great application prospect as well as market potential.

1. Introduction

Bismuth tungstate (Bi_2WO_6) nanostructures have been extensively studied due to their fascinating physical and chemical properties, which have been applied widespread fields, such as photocatalysis, solar cell and chemical sensors [1–5]. It should be noted that Bi_2WO_6 are also a kind of promising radiation shielding materials due to high density and atomic number with strong gamma-rays attenuation [6,7]. Importantly, Bi_2WO_6 particles have less toxicity than lead based materials. This trait is a crucial factor for some environment-friendly applications, such as personal protective articles [8]. Furthermore, the interaction of gamma-rays with matter gives rise to photoelectric, Compton scattering and other effects that result in the radiation attenuation [9,10]. According to the conventional theory of radiation shielding, the ability to attenuate gamma-rays mainly depends on the density and atomic number of materials and there is no obvious relationship with its size or morphology [11]. However, it has been intensively reported that nanostructures contribute to gamma-rays shielding without consolidated interpretations in recent years [12–19]. Therefore, the investigation of Bi_2WO_6 nanostructures for gamma-rays shielding is a topic of great significance both in theory and in practice.

Controllable synthesis of Bi_2WO_6 nanostructures is an important link with their particular application and then various synthetic methods have been developed [20–23]. Hydrothermal method is one of the most versatilely applied routes to controllably fabricate inorganic particles with desired structure and morphology [24,25]. Usually, the crystals growth and nucleation of Bi_2WO_6 particles can be tailored using specific solvent that can affect their resulted structure and morphology. Second, the viscosity of system decreases with the increasing temperature that leads to promote the mobility of dissolved ions and molecules. Third, the pH value in the reaction system has been found to play an important role in the development of anisotropic nanostructures. Hence, the formation of Bi_2WO_6 nanostructures strongly depends on multiple factors, including the interior reaction system conditions (such as concentration, pH value, time, organic additives or templates) and the exterior reaction environment conditions (such as temperature, microwave or magnetic field) [24,25].

Besides, the materials applied for radiation shielding should perform more than just the sole function [26]. Usually, there is also the need for materials capable of surviving temperature extremes and withstanding mechanical loading [9,10]. Given the requirements, the wanted radiation shielding materials should be equipped with good thermal conductivity, mechanical properties, flame retardancy, and so on [15,27–31]. Much

* Corresponding author.
E-mail address: zhangqp@swust.edu.cn (Q.-P. Zhang).

http://dx.doi.org/10.1016/j.jpcs.2017.09.007
Received 17 July 2017; Received in revised form 22 August 2017; Accepted 9 September 2017
Available online 11 September 2017

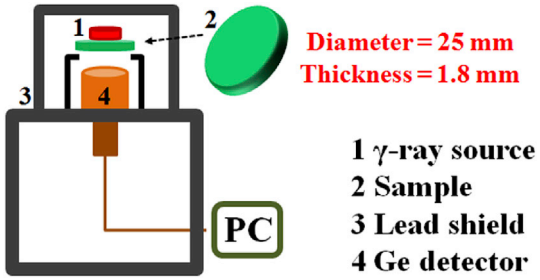

Fig. 1. Diagram of testing set-up for γ-rays shielding.

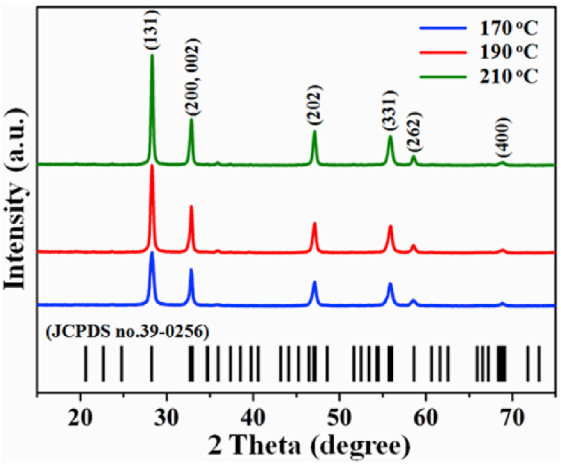

Fig. 2. XRD profiles of the products with various treatment temperatures.

work has proved that anisotropic structures (such as graphene, boron nitride and carbon nanotube) contribute to constructing firm network structures in composites and exhibiting superior integrated performance [32,33].

In this work, wanted Bi_2WO_6 nanosheets and other nanostructures have been successfully fabricated with a versatile hydrothermal treatment under various temperatures. The techniques with XRD, SEM, TEM and specific surface area are provided to determine the products. Gamma-rays shielding properties and its relationship with the structure and morphology of products are also explored. The possibility of using Bi_2WO_6 nanosheets in place of lead based particles in terms of radiation shielding materials is presented.

2. Experimental technique

2.1. Synthesis of Bi_2WO_6 nanosheets

The synthesis of product was similar to other hydrothermal methods. Typically, 5 mmol $Na_2WO_4{\cdot}2H_2O$ was dissolved in 20 ml polyethylene glycol. Second, it was added into 5 ml of 10% nitric acid solution with 10 mmol $Bi(NO_3)_3{\cdot}5H_2O$ under vigorous stir for 1 h. Then, the PH value of mixture with metastable precursors was adjusted to about 7.5 using 10% NaOH solution. Third, the mixture was transferred to a Teflon-lined stainless-steel autoclave to perform hydrothermal process at 170, 190 and 210 °C for 3 h, respectively. After cooled to ambient temperature, a white precipitate was collected and washed several times with distilled water and absolute ethanol. Finally, the product was treated with freeze dry method for further characterization.

2.2. Structure characterization

The structure of product was determined by powder X-ray diffraction (XRD, anode material was Cu, $K_{\alpha2}/K_{\alpha1} = 0.5$, no monochromator used). Morphology observation was performed by field-emission scanning electron microscopy (SEM, ZEISS EVO18) operated at an acceleration voltage of 15.0 kV and transmission electron microscopy. And, the product was ultrasonically dispersed in ethanol solution and dropped onto a carbon coated copper grid for transmission electron microscopy (TEM, JEOL JEM-2100 microscope, 200 kV) detection. The specific surface area was determined using an automated gas-sorption apparatus (Quantachrome Autosorb-1MP, N_2, 105 °C).

2.3. Performance testing

According to Nordfors criteria [34,35], an optimum sample thickness of ($0.5 \leq \mu a \leq 5.0$, μ and a is the mass attenuation coefficient and mass fraction of product in sample, respectively) was applied in this experiment. 2 g product and 0.3 g 10% polyethylene glycol solution were first mixed with grind. Then, the mixture was added into 25 mm diameter of mold for mould pressing under 2 MPa. After vacuum drying under 60 °C for 72 h, the sample with about 1.8 mm of thickness was labeled as Bi_2WO_6-170 °C, Bi_2WO_6-190 °C and Bi_2WO_6-210 °C, respectively. For comparison, lead based materials ($PbWO_4$) were prepared with the same scheme. γ-rays shielding testing of samples was performed on a high-purity germanium γ spectrometer, as depicted in Fig. 1. And various γ-rays sources (mixed Na-22 and Eu-155 with average 86, 105, 511 and 1274 KeV, Cs-137 with average 661 and 1240 KeV) were used. The data analysis was refered to the reported work [36,6].

3. Results and discussion

3.1. Crystal structure

The structural characteristics of the as-synthesized products have been examined with XRD, as shown in Fig. 2. Each of the diffraction pattern can be indexed to the orthorhombic Bi_2WO_6 (JCPDS no.39-0256, a = 5.457 Å, b = 16.435 Å, c = 5.438 Å). No obvious characteristic peaks for other impurities are found among the patterns. However, it exhibits

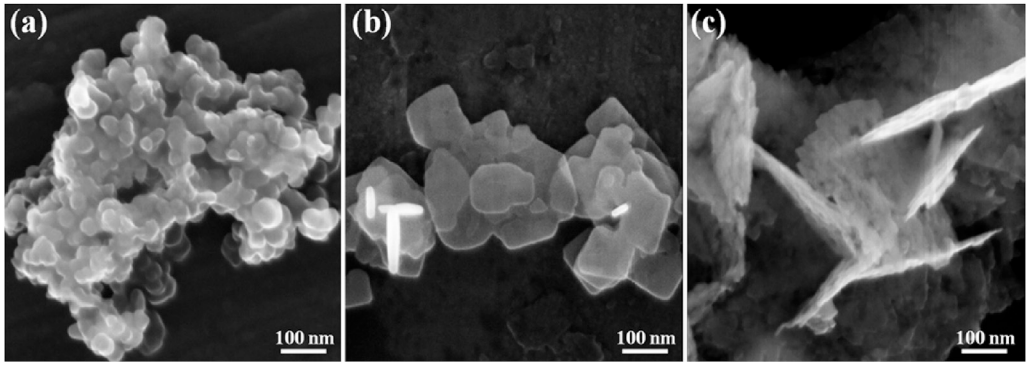

Fig. 3. SEM pictures of Bi_2WO_6 with various treatment temperatures, (a) 170 °C, (b) 190 °C and (c) 210 °C.