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Thermoluminescence behavior of Sm^{3+} activated ZnB_2O_4 phosphors synthesized using low temperature chemical synthesis method

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ABSTRACT

This study is mainly centered on thermoluminescence (TL) behavior under beta excitation at room temperature (RT) of Sm^{3+} activated ZnB_2O_4 phosphors synthesized by low temperature chemical synthesis method. The prepared phosphors were characterized by the X-ray powder diffraction (XRD) method. The effects of dopant concentration, beta radiation dose (0.115–69 Gy) and heating rate (0.5–10 °C/s) on TL intensity of Sm^{3+} doped ZnB_2O_4 phosphors and reproducibility are investigated using a lexsyg smart TL/OSL reader system. The activation energy values, E obtained from the analysis of the TL glow curve were calculated with initial rise (IR) method and peak shape (PS) method over the deconvoluted glow curves. The E_a–T_{stop} and CGCD methods indicated that the glow curve of this phosphor is the superposition of at least six components, which were called to as P1–P6, in the temperature range between RT and 400 °C. The results reveal that 2% Sm^{3+} doped ZnB_2O_4 gives optimum TL response, the relative intensity of the glow peak increases linearly with increase of beta dose and, the peaks of TL glow curves shift towards the higher temperature side with increase in heating rate as the total area under the glow peak remains the same. The maximum variation of reproducibility for ten successive irradiation cycles of 20.7 Gy is less than 3% from the average value and the sample doped 2% Sm^{3+} shows a good stability for the reusability. Additionally, the results obtained from IR and PS methods indicates that the complex glow curve is composed of six distinguishable peaks.

1. Introduction

Since 1960, there has been extensive research regarding borate compounds for their luminescence properties. Borate compounds have become a major academic research frontier and have been applied to nonlinear optics and thermo-stimulated luminescence (TL) based radiation dosimeters. On borate compounds, TL studies were commenced by the work of Schulman et al. in 1967 [1]. In the majority of cases, phosphor compounds consist of two indispensable components, namely, hosts and activators. The host is usually an inorganic matrix and activator refers to the activator doping ions which can be divalent or trivalent lanthanides, comprising atomic numbers 57–71 of the periodic table (such as Eu^{2+}, Eu^{3+}, Gd^{3+}, Nd^{3+}, Tb^{3+}, Sm^{3+} etc., mainly the so-called Ln^{3+} or Ln^{2+} ions) and several main group elements (such as Bi^{3+}). Potentially, the activator can act as emitter or trap: the emitter is emitting radiation in the wavelength of interest after the excitation while the trap stores the excitation energy, releases light gradually and dominates the duration time of afterglow [2].

In recent years, ZnB_2O_4 is attracting considerable attention, especially in phosphor luminescence application as a host material [3–10]. Mu et al. prepared Bi^{3+} and Gd^{3+} doped ZnB_2O_4 phosphors using solid state reaction method and found that these phosphors co-doped with Gd^{3+} and trivalent rare earth ions can be potential material for display applications [3]. Li et al. investigated photoluminescence (PL), TL spectrum and dosimetric characteristic of Tb doped ZnB_2O_4 and suggested it has a potential use for clinical dosimetry. Li et al. also studied on Dy doped ZnB_2O_4. TL dose response of powder samples to gamma ranging from 1 to 100 Gy was observed as almost linear [4,5]. Zheng

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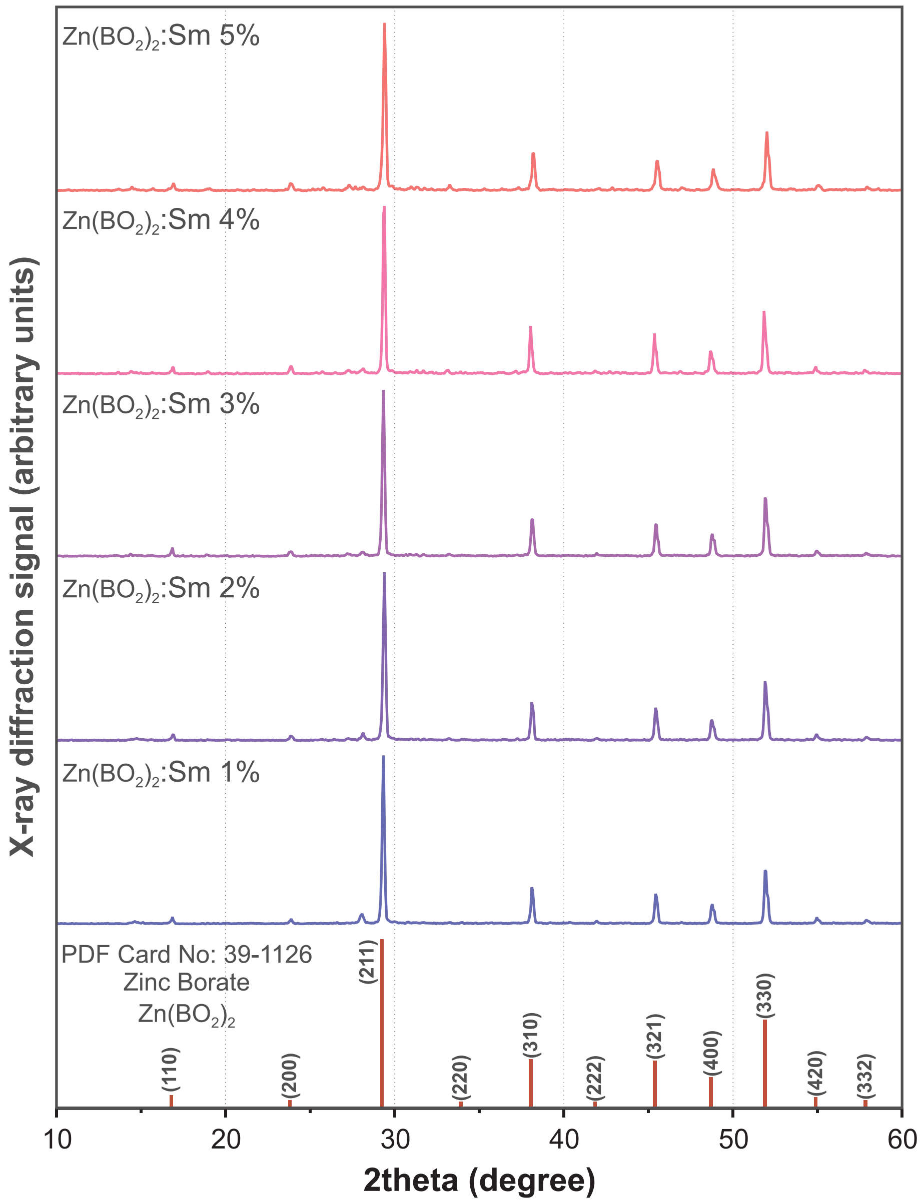

Fig. 1. Powder XRD patterns of prepared samples and PDF card no. 39-1126.

et al. reported that luminescence intensity of ZnB_2O_4 nanocrystalline powders activated with Eu^{3+} ions prepared via co-precipitation method were enhanced greatly [6]. Liu et al. proposed that the novel red emitting phosphor of Eu^{3+}-Bi^{3+} co-activated ZnB_2O_4 would be useful for white light emitting diodes [7]. Balci-Yegen et al. studied on TL behavior of Dy^{3+} doped zinc borate phosphor material and calculated trapping level parameters using different methods (i.e. peak shape (PS), various heating rates (VHR), computerized glow curve deconvolution (CGCD)). Trap depths assigned to the TL glow peak at 180 °C were found to be 0.93, 0.92 and 1.05 [8]. Portakal et al. reported luminescence characteristic in ZnB_2O_4:Dy^{3+} [9]. IR method was used to determine activation energy and frequency factor. The glow peak located at 96 °C was assigned to trap depths between 0.77 and 0.90 eV. Kucuk et al. reported radioluminescence (RL) and Cathodoluminescence (CL) characteristics of ZnB_2O_4:Ce, La prepared by nitric acid method and a new luminescence band was observed in the red region of the spectrum [10]. Consequently, this host material is capable of creating appropriate traps or defects for several activators.

Kucuk et al. evaluated the structural and CL properties of Sm^{3+} doped ZnB_2O_4 phosphors recently [11]. The doping concentration of Sm^{3+} has been found to be 2 mol% at which CL intensity that initially increases with concentration level eventually begins to decrease. A literature survey on $ZnB_2O_4:Sm^{3+}$ phosphor reveals that no studies were performed on its dosimetric characterization. In this work, TL response of ZnB_2O_4:$0.02Sm^{3+}$ phosphors synthesized via low temperature chemical synthesis method irradiated by beta rays are studied and also some dosimetric characteristics like effects of heating rate, and reproducibility are also investigated.

2. Experimental details

2.1. Materials preparation

A series of ZnB_2O_4:xSm^{3+} phosphors with various Sm^{3+} concentrations (x = 0.01, 0.02, 0.03, 0.04, 0.05 mol) were prepared by the low temperature chemical synthesis method [8,11,12]. Zinc oxide (ZnO, 99.99% purity, Alfa Aesar), boric acid (H_3BO_3, 99.99% purity, Alfa Aesar) and samarium oxide (Sm_2O_3, 99.9% purity, Alfa Aesar) were severally weighted in appropriate amounts to prepare ZnB_2O_4:Sm^{3+} phosphors. These powdered materials were mixed, while