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Optical and radiation-induced luminescence properties of Ce-doped magnesium aluminoborate glasses

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ABSTRACT

Optical, radioluminescence (RL) and thermoluminescence (TL) properties of magnesium aluminoborate glasses were evaluated. The samples were synthesized by the conventional melt-quenching technique using an alumina crucible under ambient atmosphere. After polishing, all the samples show good transparency. In photoluminescence, RL and TL, the emission is predominantly due to the 5d-4f transitions of Ce^{3+} appearing as a broad feature peaking around 300–500 nm, and the decay time constants are affected by concentration quenching but on the typical range for the 5d-4f transitions of Ce^{3+}. TL glow curves are characterized as a single but broad glow peak over 100–300 °C, and the TL intensity monotonically increases with the X-ray dose irradiated over 1–10000 mGy.

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1. Introduction

With the increasing demands of radiation detections, inorganic luminescent materials have been attracting much interests as they are used as a main sensing element in many radiation detectors. Among the luminescent materials in such applications, passive-type detectors using inorganic phosphors are mainly categorized into three types: thermoluminescence (TL) [1–3], optically-stimulated luminescence (OSL) [4,5] and radiophotoluminescence (RPL) dosimeters [6], and these materials can be in various material forms including ceramics [1], single crystals [7] and glasses [8]. Passive-type detectors are used in practical applications such as medical imaging [9] and personal dose monitoring [8]. In general, required dosimetric characteristics include suitable sensitivity to radiation dose, the linearity between the irradiation dose and response signal and low fading. Furthermore, to measure a radiation dose absorbed in human body, having low effective atomic number (Z_{eff}) is also one of the requirements for dosimeter materials since interactions of ionizing radiations with matter strongly depend on the effective atomic number (Z_{eff} ~7.42 [10] for human tissue).

Borate compounds have been intensely studied in glass forms since boron trioxide (B_2O_3, Z_{eff}~7.35) is a good glass network former due to its high bond strength and low melting point. Borate glasses have a small Z_{eff} value which is in general very close to that of human tissue and are advantageous for radiation dosimetry applications. Among borate glasses, particularly alkaline earth borates show high TL properties [11–15], so many researchers have studied glasses of alkaline earth borate compounds for TL applications [16–22]. These compounds can have higher sensitivities compared with commercial TL dosimeters such as LiF:Mg, Ti (TLD-100) [1].

The aim of this study is to investigate a new formula of alkaline earth borate glass for radiation measurement applications. Previously, aluminoborate glasses were studied with inclusion of Ca and Sr as a host constitute [21,22] while the current study is to extend the past studies by substituting with Mg. The latter glass composition is advantageous in terms of human body equivalence for its equivalent effective atomic number (Z_{eff}~9.46) compared with other compositions, for example Z_{eff}~12.48 for calcium aluminoborate. In this paper, we synthesized magnesium aluminoborate glasses doped with various concentrations of Ce as luminescent center and evaluated the basic optical, radioluminescence (RL) and TL properties. To the best of our knowledge, this paper is the first investigation of radiation-induced luminescence properties in magnesium aluminoborate glass.

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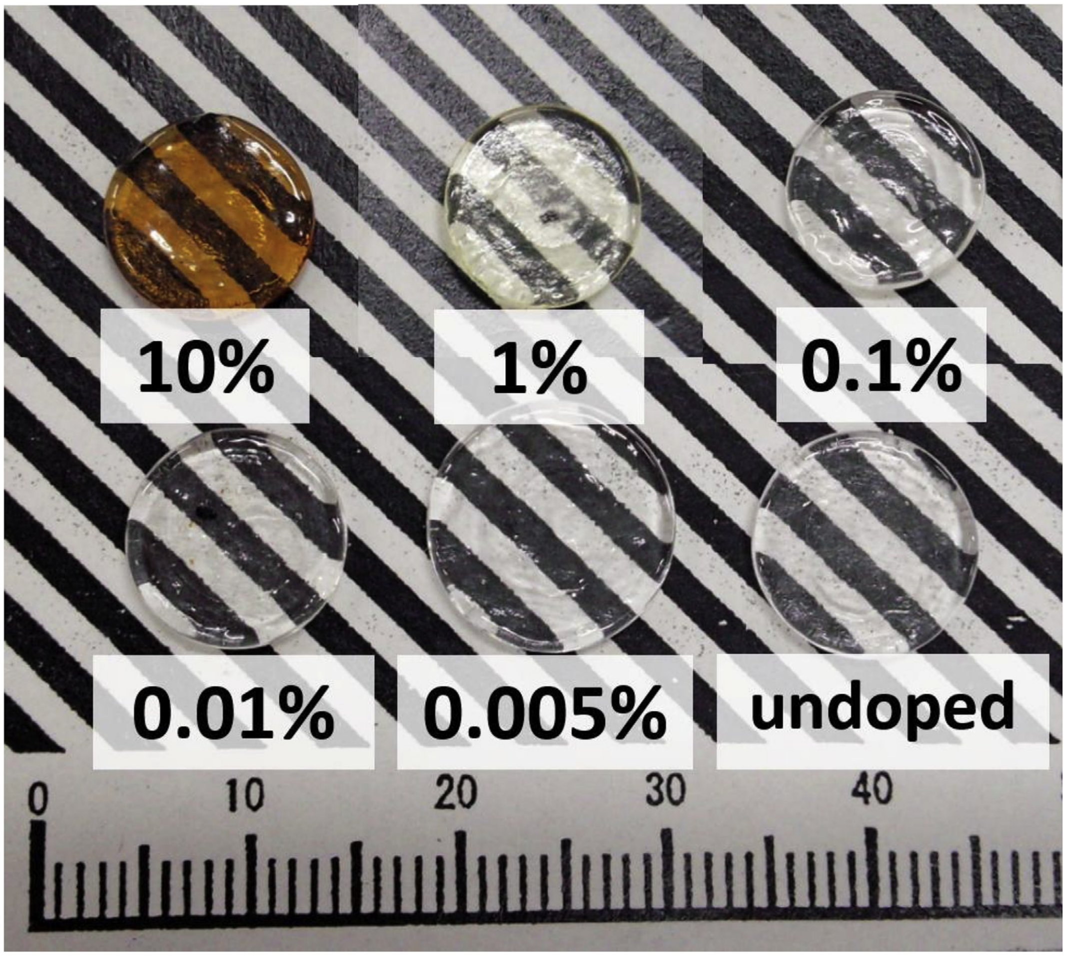

Fig. 1. Picture of undoped and Ce-doped 30MgO-20Al_2O_3-50B_2O_3 glasses.

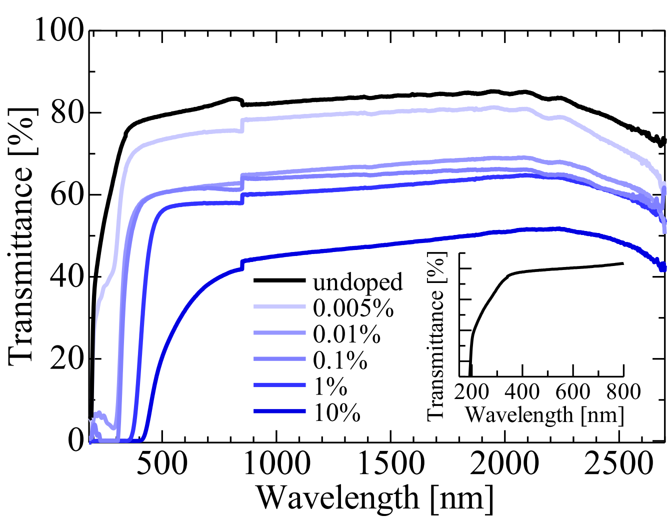

Fig. 2. In-line transmittance spectra of the samples. The inset enlarges the spectrum of undoped sample in the 180 to 800 nm range.

2. Experimental

Ce-doped magnesium aluminoborate ($xCeO_2$-30MgO-20Al_2O_3-50B_2O_3, x = 0–10) glasses doped with different concentrations of Ce were synthesized by the conventional melt-quenching technique. We used CeO_2 (99.99%, Furuuchi Chemical), $MgCO_3$ (99.99%, High Purity Chemicals), Al_2O_3 (99.99%, High Purity Chemicals), and B_2O_3 (99.999%, Furuuchi Chemical) powders as the starting raw materials. The starting materials were homogeneously mixed first, and the mixture was melted in an alumina crucible inside an electric furnace heated at 1300 °C for 30 min under ambient atmosphere. The melt was then quenched on a preheated stainless plate at 300 °C. The obtained glass samples were mechanically polished and characterized by the following experiments.

The optical in-line transmittance spectrum was measured by using a spectrometer (V670, JASCO), in which the spectral region covers from 190 to 1500 nm. The photoluminescence (PL), PL excitation (PLE) and PL quantum yield (QY) were measured by using Quantaurus-QY (C11347-01, Hamamatsu Photonics). The PL decay time profile was evaluated by using Quantaurus-τ (C11367, Hamamatsu Photonics).

As scintillation properties, X-ray-induced RL spectrum was measured by utilizing our original setup [23]. The X-ray generator (XRB80P&N200X4550, Spellman) was equipped with an ordinary X-ray tube having a tungsten anode target and beryllium window. For irradiation, the X-ray tube was operated by applying the bias voltage of 40 kV and tube current of 5.2 mA. The RL emission from the sample was collected and guided to the spectrometer (Andor DU-420-BU2 CCD with Shamrock SR163 monochromator) through a 2 m optical fiber to measure the spectrum. The detector was cooled down to 188 K by a Peltier module to reduce the thermal noise. Further, we have measured the RL decay time profiles using a pulse X-ray source equipped afterglow characterization system

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