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NaBr Transparent Ceramics for γ-ray Detection Scintillator

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Scintillators have become essential materials in modern society since they find applications in diverse fields such as security screening, resource exploration, and medical imaging. NaI is widely used as a host material for scintillators, but its strong hygroscopicity limits long-term use. In this study, we evaluated the scintillation properties of NaBr, which exhibits lower hygroscopicity than NaI. In scintillation spectra, NaBr transparent ceramics exhibit some emission peaks due to self-trapped excitons and some lattice defects. The light yield of NaBr transparent ceramics is estimated to be 1,000 photons/MeV.

1. Introduction

Scintillators are optical materials that convert ionizing radiation into low-energy photons in the UV–Vis range. They underpin a wide range of technologies, including security,[1] resource exploration,[2] and medical imaging.[3] The performance requirements for scintillators depend on the applications, but several key characteristics are required for scintillators: chemical stability, a large effective atomic number (Z_{eff}), high density, fast decay time, and high light yield (LY). Because none of the known scintillators exhibit all the desired properties, extensive efforts have been devoted to developing new materials in various forms, including glasses,[4–6] transparent ceramics,[7–10] and single crystals.[11–17]

NaI is a representative host material for γ-ray detectors,[7] including γ-ray spectrometers. Although it has a relatively high Z_{eff}, its strong hygroscopicity leads to poor chemical stability, making long-term use challenging. To address this challenge, we focused on NaBr. NaBr has a lower Z_{eff} (32.9) than NaI but exhibits much lower hygroscopicity.[18] Therefore, compared with NaI, NaBr is expected to be more suitable for long-term use. However, its scintillation properties remain largely unexplored, indicating significant potential for further investigation.

Recently, transparent ceramic (TC) scintillators have emerged as a promising alternative to conventional single-crystal materials.[19] Single crystals require lengthy fabrication, are difficult to produce in large sizes, and involve high manufacturing costs. However, transparent ceramics

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can be fabricated relatively quickly at temperatures below their melting points and offer greater flexibility in shaping. For the above reasons, we fabricated NaBr transparent ceramics and evaluated their scintillation properties.

2. Experimental Methods

A NaBr TC was synthesized by the spark plasma sintering (SPS) method. NaBr (4N, Fujifilm) was dried in a silica ampule (300ND, Sun-yell) under vacuum at 400 °C for 3 h. The dried powder was sintered in an SPS furnace (LaBOX100, Sinterland). First, the sintering temperature was raised to 200 °C at a rate of 10 °C/min and held for 10 min under a pressure of 6 MPa. Then, the temperature was increased to 500 °C at a rate of 10 °C/min and kept for 20 min under a pressure of 33 MPa. The surface of the synthesized sample was polished with sandpaper (300–3000 grits). The diffuse transmission spectrum was evaluated using a spectrophotometer (SolidSpec-3700, Shimadzu). The emission spectrum under vacuum UV (VUV) excitation was evaluated at the BL-7B in the ultraviolet synchrotron radiation facility (UVsor). The scintillation spectrum, decay curve, and pulse height spectra (PHS) under γ-rays from ^{137}Cs were evaluated with our original setups.[20,21]

3. Results

Figure 1(a) shows a photograph and diffuse transmittance spectrum of NaBr TC. The thickness/diameter of the sample is 1 mm/10 mm, and the sample looks colorless and transparent. The diffuse transmittance is about 80% between 230 and 850 nm, while there is the optical absorption edge below ~200 nm. Figure 1(b) shows the emission spectra under VUV excitation. When monitoring at 480 nm, the excitation peaks are observed at ~200 and 56 nm. The excitation peak at ~200 nm originates from the fundamental absorption edge, given that the band gap is approximately 6.1 eV.[22] This result is consistent with the diffuse transmittance spectrum. Additionally, the peak at 56 nm is of unknown origin at present, and further investigation is required to clarify its origin. Under excitation at 56 and 200 nm, NaBr TC has the emission band in the range of 350–800 nm. This emission band would originate from the lattice defects.[7]

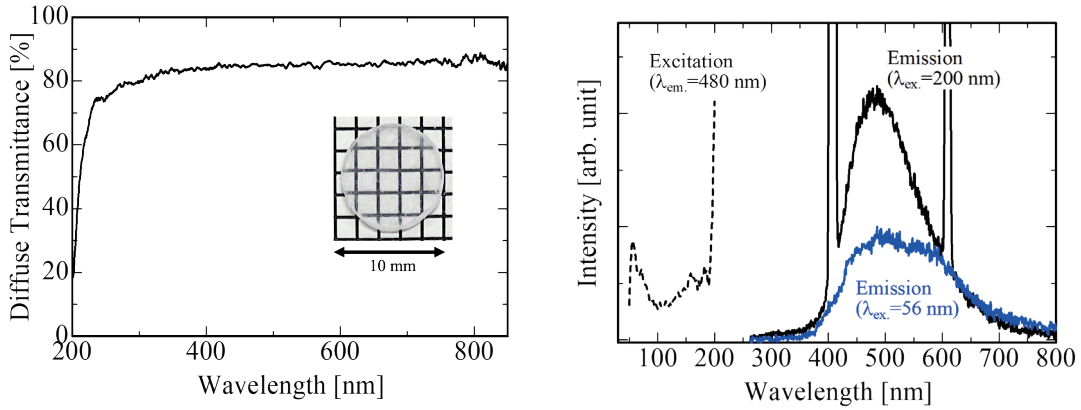

Fig. 1. (a) Photograph and diffuse transmittance spectrum and (b) emission spectra under VUV excitation of NaBr TC.

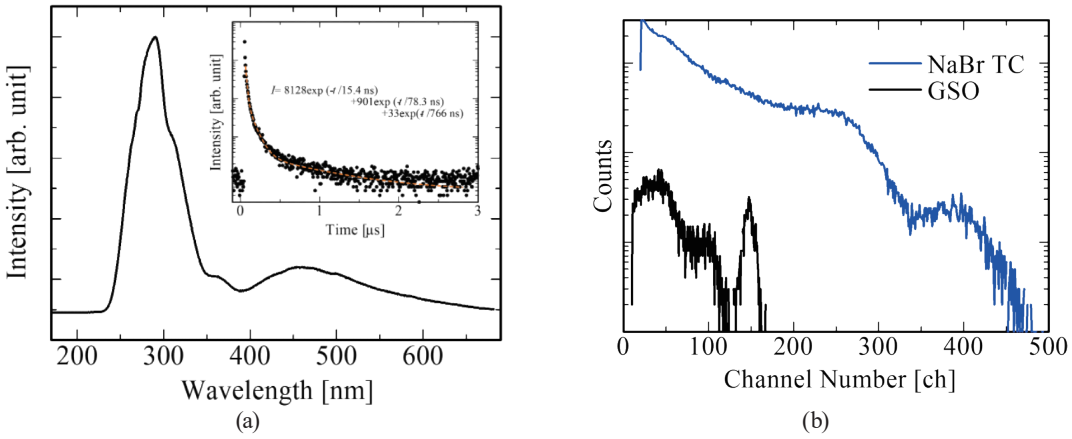

Fig. 2. (a) Scintillation spectrum, decay curve, and (b) PHS of NaBr TC.

Figure 2(a) shows the scintillation spectrum and decay curve of NaBr TC. The scintillation spectrum of NaBr TC exhibits emission peaks at 290, 350, and 460 nm. Since the observed emission peaks are similar to those reported for undoped NaI,[7] the peak at 290 nm is attributed to self-trapped excitons (STEs), whereas those at 350 and 460 nm are likely due to lattice defects. In the scintillation decay curve, the obtained signal is well fitted by the sum of three exponential functions, and the obtained decay time constants are 15.4, 78.3, and 766 ns. Each intensity is 8128 for the first component, 901 for the second component, and 33 for the third component. By comparison with the scintillation spectrum and decay curve, the first component is likely attributable to STEs, since the STE-related emission shows the highest intensity. By exclusion, the second and third components are considered to originate from lattice defects. Figure 2(b) shows the PHS of NaBr TC and Gd_2SiO_5 (GSO) as a reference sample. GSO is a commercial scintillator with 7,000 photons/MeV. The NaBr TC shows a clear photoabsorption peak at 385 ch, and its *LY*, estimated by comparison with that of the GSOs, is 1,000 photons/MeV.

4. Conclusions

In this study, we evaluated the performance of NaBr TC as a scintillator. The scintillation spectrum exhibits some emission peaks at 290, 350, and 460 nm, originating from STEs (290 nm) and lattice defects (350, 460 nm). The *LY* is estimated to be 1,000 photons/MeV on the basis of the result of PHS. The *LY* is considerably lower than that of commercial scintillators such as GSO, making its current application as a scintillator challenging. Therefore, the introduction of emission centers such as Eu^{2+} or Tl^{+} would be required to enhance the *LY*.

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