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# Scintillation Properties of Ce doped $Y_3Al_5O_{12}$ Crystal Grown by the Kyropoulos Method

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## 1. Introduction

Inorganic scintillators play a leading part in radiation detection in high energy physics, applied research, and development. Especially, Ce-doped inorganic scintillators were widely studied in the literature [1, 2]. The allowed 5d–4f transition makes the response times in the 10–100 ns range possible. A host material must have a high density and Z-number, and it should have a relatively small band gap.

In this study, we developed the Ce doped Yttrium Aluminum Garnet ($Y_3Al_5O_{12}$:Ce, YAG) crystal using the Kyropoulos technique, which was introduced in the 1930s. Many papers demonstrate a good means of modeling oxide crystal growth using the Czochralski [3] and Bridgman techniques [4]. However, there is a lack of research on large crystal growth using the Kyropoulos method. We tested the scintillation properties of the developed YAG crystal such as X-ray induced emission spectrum, energy resolution, light yield, and decay time.

## 2. Experiments and Results

### *2.1 YAG crystal growth*

The YAG single crystal was grown using the Kyropoulos method with $Y_2O_3$ (99.99%), $Al_2O_3$ (99.99%), and 1 wt.% of $CeO_2$ (99.9%) powders. The growing process was performed without rotation with a pulling rate of 0.4 mm/h. The Kyropoulos technique is similar to the Czochralski method and is a good commercial method for growing the larger, high-optical-quality growing system [5, 6]. However, the growing speed is slower than the Czochralski method.

We obtained the cylindrical YAG crystals, and cut them into 10 × 10 × 5 $mm^3$ to test their scintillation properties, as shown in Fig. 1. The sample was polished with mixed $Al_2O_3$ powder (grain size of 0.02 μm) in mineral oil with a polishing cloth (Buehler, No. 40-7218) for optical transmission characterization.

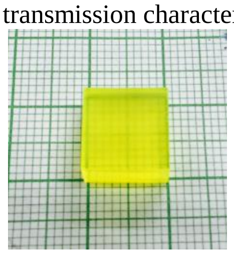

Fig. 1. Developed YAG crystal with sizes of 10 × 10 × 5 $mm^3$.

### *2.2 X-ray induced emission spectrum*

The investigated YAG crystal sample was irradiated with an X-ray tube (DRGEM. Co.) using a tungsten anode at 100 kV and 1 mA. The crystal was wrapped with several layers of Teflon tape except for the one attached to an optical fiber with a holder.

The emission spectrum was measured using a QE65000 spectrometer from Ocean Optics. The X-ray induced emission spectrum of the YAG crystal recorded at room temperature is presented in Fig. 3. The spectrum shows a simple emission that contains a broadband between 500 and 700 nm. The peak is at around 540 nm, which is attributed to the parity-allowed 5d–4f transition of the $Ce^{3+}$ ion.

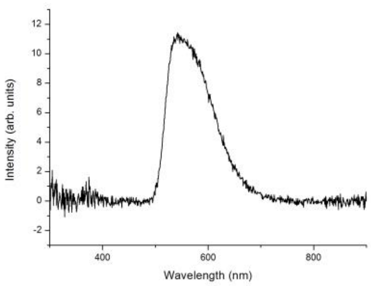


Fig. 3. X-ray induced emission spectrum of the YAG crystal.

### *2.3 Energy resolution and relative light yield*

We studied the scintillation properties, such as light yield, energy resolution, and decay time of the YAG crystal. The signal from a photomultiplier tube (PMT) was fed to a 400 MHz flash analog-to-digital converter (FADC).

Figure 4 presents the energy resolution and relative light yield of the YAG crystal for 662 keV from the $^{137}Cs$ radioactive source. The energy resolution of the YAG crystal was determined to be 14% (FWHM). The relative light yield of the YAG crystal was about 40% of that of the CsI(Tl) crystal [7, 8]. We can measure the absolute light yield of the scintillation crystal using the 16 mm Large Area Avalanche Photodiode (LAAPD) [8]. The light yield of the CsI(Tl) crystal in Ref [9] was 52000 ph/MeV and that of the YAG crystal was estimated to be 20800 ± 4000 ph/MeV.

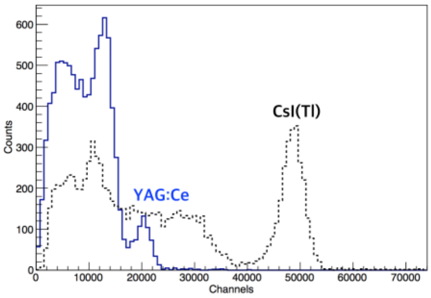


Fig. 4. Relative light yield of YAG and CsI(Tl) crystal for 662 keV from $^{137}$Cs radioactive source.

In Ref. [9], the energy resolution of the YAG crystal made by Preciosa Co. (Czech Republic) was measured to be 11.7% and a light yield of 20300 ± 2000 ph/MeV was determined. The energy resolution and light yield of the grown crystal are comparable to that of the commercial crystal.

### *2.4 Decay time*

The decay times of the YAG crystal were measured at room temperature under $^{137}$Cs γ-rays by using a single-photon counting technique. The measured decay time curve of the YAG crystal sample is shown in Fig. 6 (a). The decay time curve was fitted by assuming three exponential decay components, a short component with a time constant of 112 ns and an intensity equal to 45%, an intermediate component with a time constant of 227 ns and an intensity equal to 36%, and a long component with a time constant of 1160 ns and an intensity equal to 19% of the total light yield.

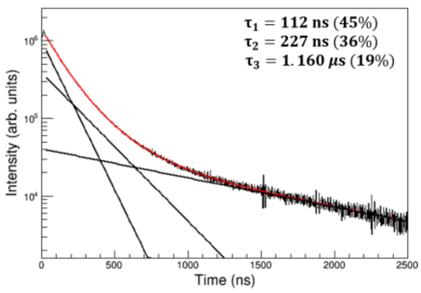


Fig. 5. Decay times of the YAG crystal were measured under $^{137}$Cs γ-rays.

## 3. Conclusions

In this study, we developed a YAG crystal using the Kyropoulos technique and measured the scintillation properties of the YAG crystal such as the X-ray emission spectrum, light yield, and decay time.

The X-ray emission spectrum shows a broadband between 500 and 700 nm with a peak at around 540 nm, which is attributed to the parity-allowed 5d−4f transition of the $Ce^{3+}$ ion. The energy resolution of the YAG crystal was determined to be 14% (FWHM). It can be improved by optimizing the crystal growth. The relative light yield of the YAG crystal was about 40% of that of the CsI(Tl) crystal, and the light yield of the YAG crystal was estimated to be 20800 ± 4000 ph/MeV from the light yield of the CsI(Tl) crystal. The decay times of the YAG crystal under the $^{137}$Cs γ-ray were 112 ns (45%), 227 ns (36%), and 1160 ns (19%). Based on these properties, the YAG crystal can be used for radiation detector.

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