Pulse Shape Discrimination for γ and α Detection using Cerium Doped YAG Crystal

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1. Introduction

The Large Acceptance Multipurpose Spectrometer (LAMPS) at RAON is a heavy ion collision experimental facility for studying nuclear symmetry energy using rare isotope beams [1]. The physics goal at LAMPS is to understand the nature of symmetry energy in nuclei and in nuclear matter with nuclei from stable ones to those far from the valley of stability, and to apply our knowledge to related phenomena from the microscopic scale to stellar objects. This experimental setup consists of an array of Si-CsI(Tl) detectors, a CsI(Tl) array to cover backward polar angle, and a forward neutron wall.

Ce doped Yttrium aluminum garnet ($Y_3Al_5O_{12}$:Ce, YAG) has a reasonably fast decay time with a relative light yield of 21% of NaI(Tl). The density of YAG is 4.56 g/cm^3 and its effective Z-number is 35. From these properties, the YAG crystal can replace the CsI(Tl) detector in the LAMPS experiment, as it has a particle identification capability, non-hygroscopic as well as faster decay time than CsI(Tl). In this study, we studied α and γ separation capability which can be used for particle identification.

2. Experiments and Results

2.1 YAG crystal

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 larger and high-optical-quality growing system [2, 3]. However, the growing speed is slower than the Czochralski method.

We obtained 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 for optical transmission characterization.

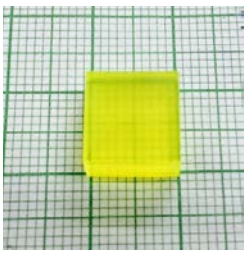

Fig. 1. Developed YAG crystal with sizes of 10 × 10 × 5 mm^3.

2.2 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 [4]. The measured decay time curve of the YAG crystal sample is shown in Fig. 2 (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. Figure 2 (b) presents, the decay time distribution of the YAG crystal that was measured using the ^{241}Am source. The decay time distribution was fitted by assuming three exponential decay components, a short component with a time constant of 161 ns and an intensity equal to 71%, an intermediate component with a time constant of 479 ns and an intensity equal to 11%, and a long component with a time constant of 1182 ns and an intensity equal to 18% of the total light yield.

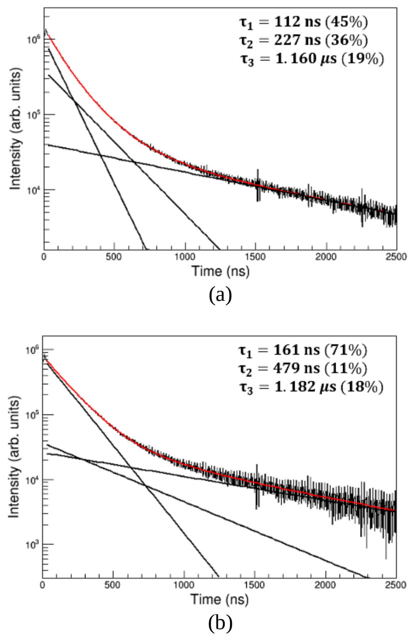

Fig. 2. Decay times of the YAG crystal were measured under (a) ^{137}Cs γ-rays and (b) ^{241}Am α particles.

2.3 Pulse shape discrimination

As shown in section 2.2, the different decay times of α and γ-rays can be used for pulse shape discrimination [5]. We used the mean decay time [6], which is the pulse height weighted time average and is defined as

$$< t > = \frac{\sum t_i \times E_i}{\sum E_i}$$

,where E_i is the amplitude of the pulse at the channel time t_i up to 40.96 μs. It is practically identical to the decay time. In order to separate α and γ, a quantity that is used to represent the discrimination power is called the figure of merit (FOM). The definition of the FOM is given as

$$FOM = \frac{T_{\alpha-\gamma}}{FWHM_\alpha + FWHM_\gamma}$$

,where $T_{\alpha-\gamma}$ is the distance between the γ-ray and α peak, and $FWHM_\alpha$ and $FWHM_\gamma$ are the full widths at half maximum (FWHM) of the α and γ-rays, respectively. The FOM of α and γ discrimination using the mean decay time was calculated for the same energy value. The result is shown in Fig. 3 with FOM = 1.04.

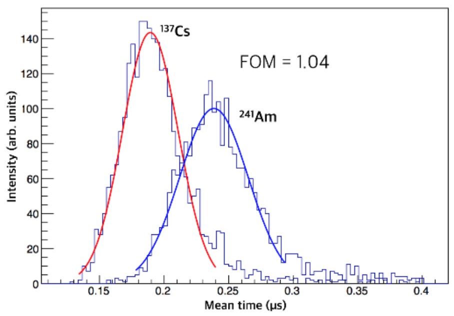

Fig 3. Mean decay time of the YAG crystal with ^{137}Cs (red line) and ^{241}Am (blue line) radioactive sources.

2.4 α/ β ratio

The α/β ratio shows the ratio of the energy released by the charged particles and γ-rays. It is defined as the ratio of the peak position of α particles divided by the energy α to the peak position of the γ-ray divided by the energy β. When α particles interact with the sample, a considerable amount of energy is converted by other ways, instead of scintillation light. We irradiated the YAG crystal with 5.486 MeV of α particles from the ^{241}Am source and 662 keV of γ-rays from ^{137}Cs. These pulse height spectra of the YAG crystal are shown in Fig. 4. The α/β ratio is 0.16, which means that 85% of the light from α particles was quenched.

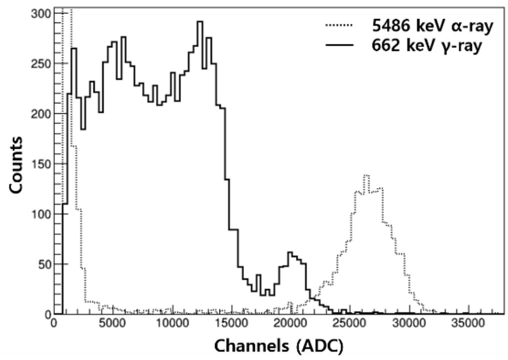

Fig. 4. The pulse height spectra of the YAG:Ce crystal with ^{137}Cs and ^{241}Am radioactive sources for measuring α/β ratio.

3. Conclusions

In this study, we measured the decay time and capability of α particles and γ-rays discrimination of YAG crystal using different pulse shape.

The decay times of the YAG crystal under the ^{137}Cs γ-ray were 112 ns (45%), 227 ns (36%) and 1160 ns (19%). The decay times under the ^{241}Am were 161 ns (71%), 479 ns (11%), and 1182 ns (18%). The α/β ratio of the YAG crystal was 0.16. This can be explained by α quenching mechanism.

In addition, the measured difference in the pulse shape due to α particles and γ-rays with FOM = 1.04 enables the particles to be identified and discriminated. This method can improve α particle detection. Based on these properties, the YAG crystal can be used for particle identification.

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