Timing characteristics of Ce doped $Gd_3Ga_3Al_2O_{12}$ single crystals; A promising scintillator

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Introduction

The single crystal scintillators have been a key component in development of various radiation detectors having applications, including high-energy physics, medical imaging, geological exploration, nuclear industry, and national security. Due to increasing applications, there is continuous demand and interest for new scintillating materials with improved performance. In recent years, Ce doped scintillator materials have attracted the attention of many researchers due to their excellent combination of light output and decay time.

Crystals of $Gd_3(Ga,Al)_5O_{12}$ (GGAG) have proven to be promising host materials due to their high density, broad transmission range and easy doping with rare earth elements like Ce [1]. In many applications, these crystals have many advantages over CsI(Tl), including high density of 6.7g/cm^3, fast decay time of 55 ns and non-hygroscopic nature. The broad emission at about 550 nm allows the use of Si-photodiodes to make compact nuclear detectors.

In this communication, we report results on our investigation of timing characteristics of GGAG (Ce) crystal. The time resolutions of GGAG (Ce) crystals coupled with PMT and Si (PIN) have been measured in coincidence with a BaF_2 detector and compared to that of CsI(Tl) detector.

Experiment

Single crystals of Ce (0.2at%) doped $Gd_3Ga_3Al_2O_{12}$ were successfully grown using the Czochralski technique. Scintillation light output and energy resolution measurements were made on 5x5x5 mm^3 samples using a pulse processing chain consisting of PMT, pre-Amp, shaping amp, and an 8k MCA. The scintillation decay time was measured using a Tektronix MDO3102 DSO having 1 GHz bandwidth.

Two samples having dimension of 18x18x10 mm^3 and 10x10x10 mm^3 were coupled to PMT and Si (PIN) photodiodes to measure the time resolution. The start signal was taken from a 6 inch BaF_2 crystal coupled with Hamamatsu PMT; Model: E2979-500. The start signal from BaF_2 and the stop signal from GGAG(Ce)-PMT was given to the time to amplitude converter (TAC) through a constant fraction discriminator (CFD). The stop signal from the GGAG (Ce)-Si (PIN) detector was taken through a timing filter amplifier (TFA) due to a slow rising time caused from pre-amp and junction capacitance of the photodiode. Data were collected in event-by-event mode using a CAMAC based multi-parameter data acquisition system.

Results and Discussion

Fig.1 shows photographs of an as-grown GGAG:Ce crystal having dimension of 25 mm diameter and 60 mm length. The crystal gives a green fluorescence under the UV illumination due to an efficient emission from Ce^{3+} ions and therefore can be efficiently coupled to Si-PIN.

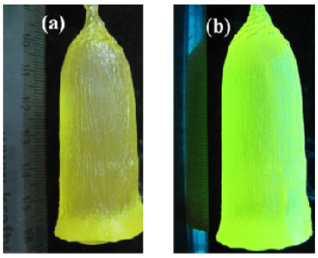

Fig. 1 As-grown single crystal of GGAG:Ce in (a) day-light and (b) under UV illumination.

Fig. 2 shows the pulse height spectrum measured for 10×10×5 mm^3 GGAG crystals coupled to the photodiode and using a ^{60}Co source. The energy resolution was measured to be about 4 % at 1332 keV. The Compton scattered events seems to have a significant contribution due to the small thickness of the crystal (5 mm). The scintillation decay was measured to have two decay component of 55 ns (70%) and 370 ns (30%).

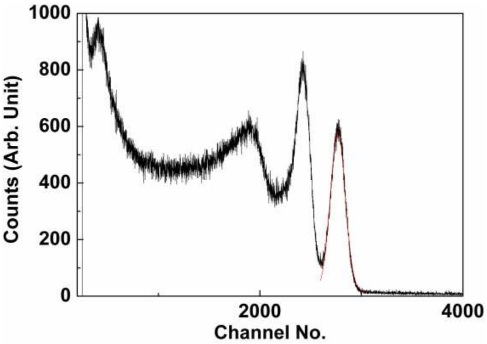

Fig. 2 Pulse height spectrum of a ^{60}Co source measured with the GGAG:Ce crystal coupled to a photodiode.

A two-dimensional plot of time versus energy of the gamma-rays (from ^{60}Co) is shown in Fig.3. The continuous band extending up to maximum in energy scale in the Fig.3 is due to the direct detection of gamma-ray photons by photo-diode. Two photo-peaks and Compton scattered events detected in GGAG (Ce) crystals are seen in a slightly higher time scale comparison to direct photo-diode events.

The time projection of the time-energy correlation measured with GGAG(Ce) crystals coupled to a photodiode is shown in the inset of figure. The timing resolution of the crystal has been calculated using following equation:

$$FWHM^2 = \Delta t_{GGAG(Ce)}{}^2 + \Delta t_{BaF2}{}^2 + \Delta t_{elec}{}^2$$

The resolving time for BaF_2, Δt_{BaF2}, was taken as 120 ps as reported in the literature. The electronic time resolution for the photodiode setup was measured to be ~ 3 ns due to the involvement of TFA. However it was found to be very low (in few ps range) when the similar measurements were carried out with a PMT.

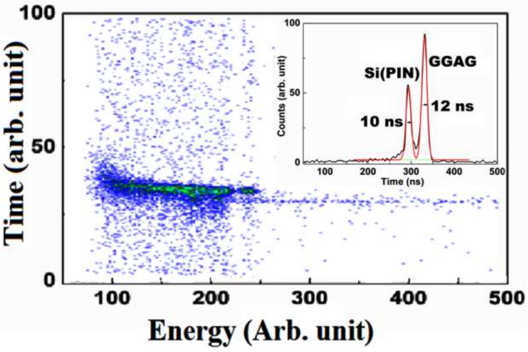

Fig. 3 A two-dimensional plot of time versus energy of a ^{60}Co source measured with the GGAG:Ce crystal coupled to a photodiode. Time projection is shown in the inset.

Time resolutions for the GGAG(Ce) crystals are obtained to be 12 ns and 950 ps when coupled to photodiode and PMT, respectively in the present measurements. Since the PMT used in the experiment (Hamamatsu R6095) has poor transit and rise times, we hope to improve the timing resolution further with a proper choice of PMTs. The time resolution for CsI(Tl) crystals has been reported to be 130 ns and 13 ns, when coupled to Si(PIN) and PMT respectively [2]. Faster rise time (8 ns), decay time (55 ns) and comparable light output (50,000 ph/MeV) ensure better timing resolution of GGAG:Ce crystals.

Conclusion

Single crystals of GGAG:Ce coupled to PMT or photodiode, exhibited promising time resolution compared to CsI:Tl crystals. Therefore these crystals are potential candidates to fabricate compact radiation detectors useful in various fields including timing applications.

References

[1] Mohit Tyagi et al., J. Phys. D: Appl. Phys. **46** (2013) 475302.

[2] Y.K. Gupta et al. Nucl. Inst. And Meth. A **629** (2011)149.