Characterization of $Gd_3Ga_3Al_2O_{12}$:Ce single crystal scintillators coupled to Silicon-photomultiplier

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Introduction

The nuclear radiation detectors based on inorganic single crystal scintillator have various applications in the field of medical, industrial, academic, security etc. A scintillator converts the high energy radiation into low energy photons (visible in most of the cases) that can be further detected using various photo-sensors. Photomultiplier tubes (PMT) have been primarily used as photo-sensors in most of the applications due to their excellent sensitivity. However, PMT suffers with the disadvantages like bulky size, low quantum efficiency, sensitiveness to magnetic fields, high operating voltages and high cost which make the major limitations of using these in practical applications. Silicon based solid state devices like photodiodes have been considered as promising candidates to replace PMTs. The poor gain of Si(P-I-N) makes researchers to investigate alternate photo-sensors. Recently, silicon photomultiplier (SiPM) has been emerged as promising photo-detectors for many applications, especially which require a compact geometry [1]. SiPM are basically a 2D array of small avalanche photo-diodes (APDs) which are operated in the Geiger mode. The SiPM has several advantages including single photon sensitivity, high gain (~ 10^6) and very low operating voltage (~ 30 V).

Single crystals of Ce doped $Gd_3Ga_3Al_2O_{12}$ (GGAG:Ce) have excellent scintillation properties like high light output (60,000 ph/MeV), high density (6.7gcm^{-3}), good energy resolution, short rise time (~ 8ns), short decay time (~55ns), etc. The emission at 550 nm lies in the best efficiency region of silicon based photo-detectors.

In this communication, we report the scintillation characteristics of GGAG:Ce single crystals coupled to SiPM in order to explore the possibility of making compact detectors.

Experimental

Single crystals of GGAG:Ce were grown under accurately controlled and well-optimized conditions in the Crystal Technology Section (CTS), Technical Physics Division (TPD), BARC, India. Fig.1 shows a photograph of an as-grown single crystal of GGAG:Ce having ~ 25 mm diameter and ~ 60 mm length [2].

Fig.1 Photograph of an as-grown $Gd_3Ga_3Al_2O_{12}$:Ce crystal.

A sample having dimension of 5 x 5 x 5 mm^3 was cut, polished, wrapped with Teflon tape and coupled to an SiPM (manufactured by SenSL) with the help of optical grease. The SiPM with an active area of 6x6 mm^2 that consists of 18980 microcells, was mounted on a board which has two terminal outputs corresponding to the measurement in energy and time modes. The gain at the standard output (energy) was 3x10^5 while it was 4x10^4 at the fast output (time). The SiPM was operated at 28 V (V_{br} + 2.5 V). The energy output signal was given to a shaping amplifier and MCA to record the pulse height spectrum while the output from fast out was given to a fast digital oscilloscope for the timing measurements.

Results and Discussion

Fig.2 shows the pulse height spectra of Cs^{137} and Co^{60} sources measured using a GGAG:Ce crystal coupled to the SiPM. The energy resolution was measured to be ~ 6.5 % at 662 keV gamma radiations from the Cs^{137} source. The small size of the scintillator (5x5x5 mm^3) results in to a high Compton background in the recorded spectra. The over breakdown voltage of SiPM and shaping time of the spectroscopic amplifier was optimized to minimize the effect of dark current, cross-talk, after pulse and nonlinearity problems of the SiPM. Due to the problem of saturation of microcells, the SiPM suffers with the limitation of number of photons and therefore the output becomes nonlinear with increasing number of emitted photons with increase in the incident energy.

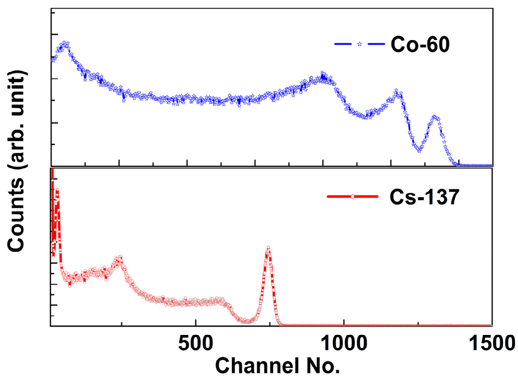

Fig. 2 The pulse height spectra of Co^{60} and Cs^{137} gamma sources measured using a GGAG:Ce single crystal scintillator coupled to an SiPM.

Fig.3 shows the scintillation decay time measured from the fast output terminal. The scintillation decay was fitted exponentially having the average decay times of 38 ns and 360 ns when measured from fast and energy output terminals, respectively. The undershoot observed in fast decay pulse can be minimized with the help of proper matching of impedence. The rise time was measured to be 4 ns and 37 ns, respectively.

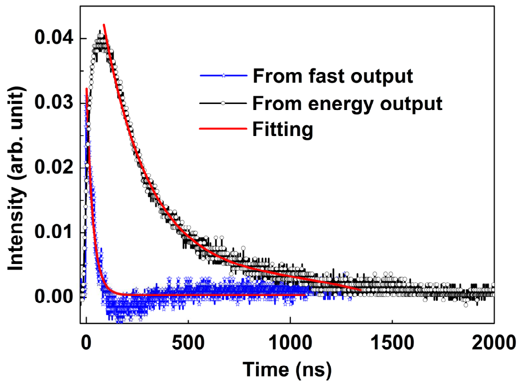

Fig. 3 Scintillation decay of a GGAG:Ce crystal coupled to an SiPM having fast and energy output terminals

The standard output terminal has a higher gain but makes the rise and decay times slower. Therefore the timing application would require the output from the fast terminal.

The measurements exhibited promising scintillating properties of the GGAG:Ce single crystal scintillators when coupled to SiPM. However more experiments with the state-of-art electronics for the SiPM are necessary to explore the potential of these detectors in various applications. Fast rise and decay times and high light output should lead to better coincident timing resolutions of these detectors which is very useful for many timing applications including medical imaging like positron emission tomography (PET).

Experiments to explore the possibility of charged particle identification based on pulse shape discrimination using these detectors are in progress.

References

[1] G. Stewart, L. Wall, and J. C. Jackson, *J. Mod. Opt.* **56,** pp. 240-252, (2009).

[2] M. Tyagi, V. V. Desai, A. K. Singh, S. G. Singh, S. Sen, B. K. Nayak, and S. C. Gadkari, *Phys. Stat solidi A*; DOI: 10.1002/pssa.201532252 (2015).