Studies on Pulse Shape Discrimination and Efficiency of GGAG:Ce Scintillators

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Introduction

Until the discovery of SrI_2:Eu and KSr_2I_5:Eu scintillators in 2008 and 2015 respectively, the best performing scintillator has been $LaBr_3$:Ce with an excellent resolution of 2.6% and light yield of about 60,000 ph/MeV [1-2]. The relatively weak (1 0 0) cleavage plane, hexagonal crystal structure with considerable anisotropy in properties like thermal expansion, make the growth of large volume crystals very tricky. With the advancement in technology, it is now possible to design a scintillator for specific purpose. There is a choice for bandgap adjustment and introduction of activator energy levels. Cerium doped Gadolinium gallium aluminium garnet (GGAG:Ce) single crystal scintillator is a consequence of such bandgap engineering resulting from the substitution of Gd and Ga in YAG:Ce, LuAG:Ce single crystals [3]. The GGAG:Ce single crystal scintillator's optical, scintillation and electronic properties have been finely tuned by doping and co-doping concentrations. The effect of co-dopants such as boron, calcium, barium, magnesium in GGAG:Ce single crystal has been widely studied in terms of its scintillation and optical characteristics. The research is going on to improve the light output, energy resolution, scintillation decay time and coincidence timing resolution of GGAG:Ce scintillator [4].

In the present thesis work, we have made extensive studies on pulse shape discrimination (PSD) and detection efficiency of GGAG:Ce scintillator. The present thesis work have employed Czochralski technique to grow garnet based single crystal scintillators. Based on the research work, this recently developed oxide single crystal scintillator has been described as a promising detector for gamma and charged particle spectroscopy.

Results and discussion

A comparison of PSD abilities of GGAG:Ce,B and CsI:Tl scintillator having dimensions of 18×18×10 mm^3 each, grown by Czochralski and Bridgman techniques respectively, is studied by coupling to a PMT and a SiPM. The studies made employing digital charge integration and analog zero-crossing technique have shown that GGAG:Ce,B coupled to a PMT and CsI:Tl coupled to SiPM have shown better PSD abilities. Interestingly, we have observed, for the first time, that the behavior of scintillation decay times of GGAG:Ce,B scintillator is opposite to that of CsI:Tl single crystal as seen in figure 1 [5]. The average scintillation decay times for GGAG:Ce,B crystals have been found to be fast for alpha excitations compared to that for gamma rays.

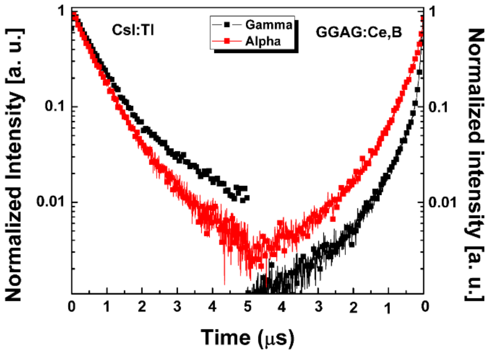

Fig. 1 Decay curves of CsI:Tl and GGAG:Ce,B single crystals coupled to a PMT.

In order to understand this opposite decay behavior, a novel approach is proposed to understand PSD and scintillation kinetics of boron and Calcium co-doped GGAG:Ce scintillators using optically stimulated luminescence (OSL), for the first time. The co-doping was found to have substantial effects on the PSD ability of these scintillators. A significant difference in the pulse-shapes for alpha and gamma radiations was observed in B co-doped GGAG:Ce scintillators while the difference observed in Ca co-doped crystals was quite insignificant. Consequently, B co-doped crystals exhibited the highest PSD while those with Ca co-doping showed no discrimination in spite of having strong quenching of the light yield by alpha radiations that resulted in a minimum α/γ ratio.

The exploration for a scintillator having better PSD ability is answered by proposing a novel design of phoswich detector, which can discriminate various types of nuclear radiation such as protons, heavy ions, neutrons and gamma rays. Its novelty lies in the use of two non-hygroscopic scintillators having similar light yield, peak emission wavelength and refractive index. Due to their different scintillation decay times and opposite behavior for alpha and gamma radiations, an increment of 100% in FOM is found compared (shown in figure 2) to that observed for any other individual crystal [6].

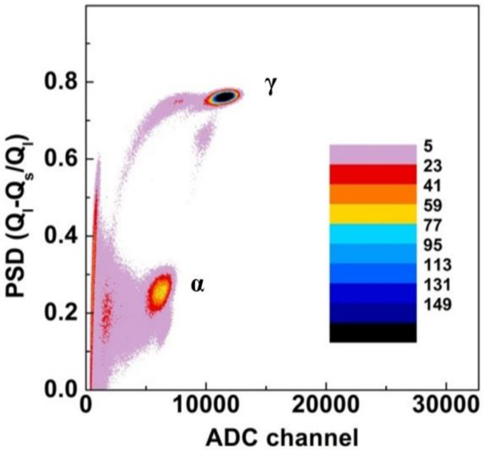

Fig. 2 PSD parameters measured for alpha and gamma irradiations on phoswich combination using the PSD ratio method.

Further, owing to its high effective Z (55) and high density (6.7 g/cm^3), we have carried out detailed realistic GEANT4 Monte Carlo simulations of absolute efficiencies (both total detection and photo-peak) of GGAG:Ce scintillator for gamma rays up to energy of 5 MeV and for different values of source-to-detector separation. The obtained results were compared with those obtained using $LaBr_3$:Ce, NaI:Tl, CsI:Tl, BaF_2 and SrI_2:Eu scintillators and it has been found that GGAG:Ce is a strong contender for gamma spectroscopy where detection efficiency is of paramount importance. The simulations were validated by making experimental measurements using ^{137}Cs source. Simulated and measured efficiency values of GGAG:Ce scintillator having dimensions 18 mm × 18 mm × 10 mm and 25.4 mm ×10 mm for different values of source-to-detector separation were found to be in good agreement [7].

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