Pulse shape discrimination properties of boron co-doped GGAG:Ce scintillator for charged particles and gamma rays

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Introduction

For the past fifty years, scintillators have been extensively used for the identification of charged particles, gamma rays and neutrons. Nuclear physics experiments which involve new element formation demand excellent detectors to identify the reaction products created in a nuclear reaction. Alpha particles, protons, heavy ions, gamma rays and neutrons form a bunch which every nuclear reaction comprises of. Scintillators which are mainly used for the identification of charged particles and gamma rays are NaI:Tl, CsI:Tl, BaF_2, LuAG:Ce, $LaBr_3$:Ce, $LaCl_3$:Ce,etc. Cerium doped gadolinium gallium aluminum garnet (GGAG:Ce,B) with co-doping of boron scintillator is a relatively new material having high figure of merit for alpha and gamma pulse shape discrimination [1]. In our previously published work [2], we reported that GGAG:Ce,B single crystal coupled with PMT and SiPM has a potential to discriminate gamma rays along with alpha particles. In this work, we have explored GGAG:Ce,B scintillator's pulse shape discrimination (PSD) ability for heavy ions in order to check its versatility for in-beam experiments.

Detector Setup

GGAG:Ce,B single crystal was grown using Czochralski technique. A 1 mm thick disk having 20 mm diameter was cut and polished from the grown single crystal. It was mounted on a 1″ Hamamatsu photomultiplier tube using optical grease. The detector was made light tight with the help of a reflector i.e. Teflon tape and a black tape. The PSD is carried out using analog technique of zero crossover time (ZCT) measurement. The standard setup of ZCT involving amplifier and TAC measures the difference in zero crossover time of different radiations falling on the detector. Subsequent to the calibration of TAC using different delays, ZCT is calculated. The value of ZCT determines how efficiently a crystal distinguishes the different types of incident radiation.

Alpha Gamma Discrimination

Fig. 1 illustrates the alpha and gamma separation of GGAG:Ce,B scintillator measured with Am-241 and Cs-137 sources using zero-crossover method. The ZCT time of alpha and gamma radiation is around 87 ns. From the figure, a clear separation of peaks corresponding to alpha and gamma can be seen. The gap between the peaks is due to the difference in pulse shapes of decay curves corresponding toboth alpha and gamma rays.

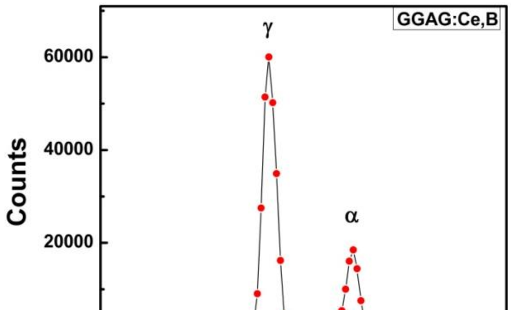

Fig. 1 PSD of GGAG:Ce,B crystal disk coupled to 1″ PMT for alpha and gamma radiation.

Different pulse shapes were a result of different de-excitation mechanisms inside the crystal depending on the ionization density. In contrast to CsI(Tl) crystals, alpha excitation slows down the decay in GGAG crystals. The figure of merit was found to be better in comparison with CsI(Tl) scintillators [2]. These results encourage us to observe the performance of these scintillators for heavy charged particle discrimination.

Charged Particle Discrimination

The detector was tested in-beam through ^{13}C (75 MeV) + ^{232}Th reaction. The in-beam experiment was performed at BARC-TIFR Pelletron facility, Mumbai. A self-supporting metallic foil of ^{232}Th (1.6 mg/cm^2) was used. A 5mm collimator was used in front of the detector. The PSD was achieved using ZCT technique. The TAC range was kept at 2 μs. The energy signal (from PMT anode) and timing signal (from PMT dynode) were processed through spectroscopic and timing filter amplifiers, respectively.

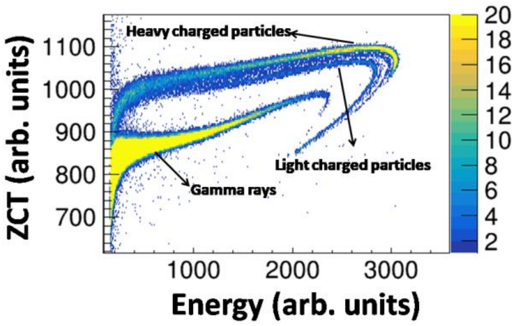

Fig. 2 Two dimensional plot of ZCT versus energy.

A typical two-dimensional plot of the ZCT versus energy is shown in fig. 2 for a detector angle of 81° with respect to the beam direction. Particle identification from this plot can be grouped into two bands corresponding to gamma rays and charged particles. Gamma rays appear with a long tail along energy axis due to the small thickness (1 mm) of the GGAG:Ce,B scintillator. As can be seen in the figure, two bands are merging each other at low energies. With increase in the energy of radiation, the separation between the bands becomes more prominent. The separation between lighter and heavier charged particle could be observed at higher energies only. Although GGAG crystals are reported to have better alpha gamma discrimination, the separation of charged particles was found to be weaker in comparison to that of measured with CsI(Tl) scintillators. A strange feature of ZCT turn around at high energies was observed. An interesting trend of the turn-around was also noted. The turn-around energy increases for gamma rays to lighter charged particles to heavier ^{13}C particles having energy of around 65 MeV. More experiments and simulations are in progress to understand the change in shape of bands after a particular value of energy of radiations.

References

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