A compact thermal neutron detector based on $Gd_3Ga_3Al_2O_{12}$:Ce,B single crystal scintillator and silicon photo-sensors

Kalyani[1,2], S. Rawat[1,2,3], A. K. Singh[1], P.S. Sarkar[1,4], Tarun Patel[1], G. Anil Kumar[2], Mohit Tyagi[1,4]*
[1]Technical Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA
[2]Department of Physics, IIT Roorkee, Roorkee - 247667, INDIA
[3]Pandit Deendayal Petroleum University, Gandhinagar – 382007, INDIA
[4]Homi Bhabha National Institute, Mumbai-400094
. * Email: tyagimt@gmail.com

Introduction

The global shortage of ^{3}He supply has increased the significance and the urgency to further develop alternate neutron detection materials. Gadolinium gallium aluminum garnet doped with Cerium (GGAG:Ce,B) is a recently discovered single crystal scintillator having light output of 54,000 photons/MeV, high density of 6.7 g/cm^3, fast decay time of 55 ns along with the high thermal neutron capture cross section of ~ 61,000 b and ~ 2,55,000 b for ^{155}Gd and ^{157}Gd respectively. In addition to compact detector geometry, it offers an advantage of high detection efficiency as well [1,2].

Photo multiplier tubes (PMT) are the most conventionally used photo-detectors. Due to certain limitations of PMTs such as their incapability to operate in magnetic fields, the requirement of high stable operating voltage (thousands of volts), the electromechanical complexity of their installation and the availability in large sizes have compelled us to test an alternate technology for these kinds of applications. The avalanche photo-diode (APD) and the silicon photomultipliers (SiPM), also known as Geiger mode avalanche photodiodes could be a replacement to the PMTs due to their striking features. The APDs are immune to the external magnetic fields, have high quantum efficiency, are cost effective and are compact in size, while SiPMs have lower operating voltage (20-70 V), fast response, low cost and are also compact in size.

In this paper we report the performance characteristics of GGAG:Ce,B coupled with the APD and the SiPM for thermal neutron detection.

Experimental details

In the present work, GGAG single crystals doped with 0.2 at% Ce and co-doped with 0.2 at% B were grown using Czochralski technique. A seed crystal was used to pull single crystal at a growth rate of 1 mm/h. The crystal was grown in argon ambient and annealed in air after the crystal growth [3]. A 5 × 5 × 2 mm^3 crystal was cut from an ingot crystal, polished and then coupled using optical grease to the APD and the SiPM individually. A teflon tape as a reflector for the best performance of the detector was wrapped around all the surfaces of the crystal except the one to be coupled. The crystal is coupled to an APD manufactured by Hamamatsu (S8664-55) having effective photosensitive area of 5 × 5 mm^2 and spectral response range of 320 to 1000 nm. Studies were also carried out by coupling the crystal to a SiPM (manufactured by SensL) mounted on PCB board with a fast output having a rise time of 300 ps and a spectral range of 300 to 950 nm. It has total active area 6 × 6 mm^2, breakdown voltage of 27.5 V and overvoltage of 4 V. A CAEN digitizer was used to supply voltage to SiPM and a Tukan MCA recorded the spectra. Detector calibration is done with 32 keV peak from ^{137}Cs, 41 keV and 78 keV peaks from ^{152}Eu, 59 keV peak from ^{241}Am and 122 keV peak from ^{57}Co. A thermalizing assembly with 500 mCi Am-Be source having graphite and HDPE as a moderator was used as the thermal neutron source. Detector was exposed to neutron flux of 250 n/cm^2/s from Am-Be source and spectra were recorded. Background spectra were taken with a 2 mm borated rubber and a 1 mm cadmium sheet. Detector was covered with a lead sheet for the whole time to avoid gamma background.

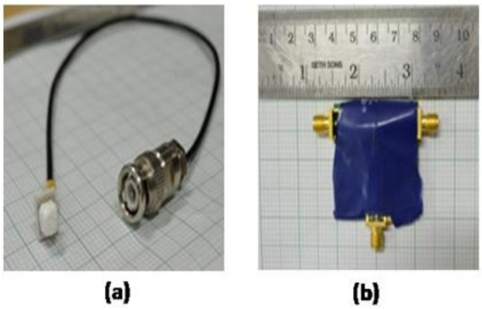

Figure 1. GGAG:Ce (5 × 5 × 5 mm^3) crystal coupled with **(a)** APD **(b)** SiPM.

Results and discussion

Fig 1(a) and 1(b) shows the APD and the SiPM modules used in this experiment and fig 2 shows the obtained pulse height spectra of GGAG:Ce,B from the irradiation of thermal neutrons from Am-Be source. The spectra recorded, using both SiPM and APD, are found almost identical. The irradiation of thermal neutrons on Gd produces low energy characteristic X-ray, conversion electrons and high energy gamma radiations. Low energy X-rays and conversion electrons produced by the thermal neutron capture by Gd lies in the range of 29 -182 keV in about 87% events. The red curve shows the scintillation spectrum measured by shielding the detector with Cadmium and borated rubber. The spectrum with black colour shows characteristic peaks at around 34 and 77 keV corresponding to thermal neutron capture as reported in Gd based scintillators [4]. Thus, the existence of distinctive peaks due to low energy X-ray and conversion electrons clearly indicate the efficient detection of thermal neutrons in a compact manner.

Summary

Thin GGAG:Ce,B has a very low gamma sensitivity which is extremely useful for good neutron sensors. The GGAG:Ce,B coupled with APD and SiPM as a photodetector is able to detect thermal neutrons and can be used as a compact, and simple portable thermal neutron detector for handheld applications.

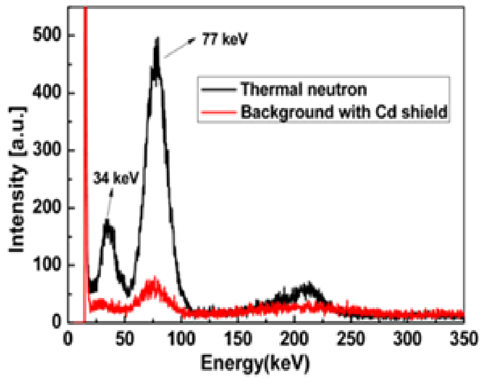

Figure 2. The pulse height spectra of thermal neutrons from Am-Be in GGAG:Ce,B scintillator.

References

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