Developmental status of SiPM coupled scintillator detector for the DEGAS array in FAIR

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Introduction

In nuclear spectroscopy experiments that use heavy ion fusion reactions to populate a nucleus of interest for looking into aspects of exotic nuclei, the emission gamma multiplicity is often very high. In such cases, modern detector systems that use high/hyper purity germanium (HPGe) crystals are employed to ensure proper identification and separation of different gamma radiations emitted by the nucleus of interest. Arrays that are comprised of multiple HPGe detectors form a critical part of these advanced experiments which can advance the general understanding about nucleon-nucleon interaction under extreme conditions [1].

Throughout, developmental activities needed to take into account the trade-off between achieving good position resolution and efficiency of detectors in the wide range from a few thousand electron-volts to tens of MeV (million electron-volts). The aforementioned HPGe crystals are able to achieve this compromise in the best possible manner and are widely used for experimental nuclear physics and astrophysics studies. HPGe crystals offer around 2 keV energy resolution for incident radiation of 1 MeV, and at the same time efficiently detects radiations from 100 keV to 20 MeV. When it comes to efficiency though, there is still some loss in terms of completely absorbing high energy radiations. For example, a large 8 cm long HPGe crystal of 7 cm diameter can only completely detect ~15% of incident 1 MeV gamma ray photons [2]. Most of the remaining are lost due to Compton scattered photons leaving the detector volume after partially depositing their incident energy. This gives rise to two separate problems individually hampering an arrays performance- in terms of loss in efficiency as well a large Compton background. The parameter of peak-to-total ratio (P/T) that is defined by the ratio of fully absorbed energy counts against the Compton scattered counts, is a good benchmark to improve spectrum quality obtained by gamma detector arrays. A higher and thus better P/T can be achieved when large volume HPGe detectors are accompanied by ancillary detectors that can detect the Compton scattered photons that carry partial energy information regarding the incident gamma rays. These ancillary detectors act as Compton shields for the primary HPGe array, in a way that photons detected by the secondary detectors in coincidence with the HPGe detectors are completely rejected from the spectra. This has helped improve the selectivity and using arrays with large number of such detectors to increase granularity, high gamma multiplicity studies to understand cascade decays can be carried out [3]–[5]. Presently, arrays use Bismuth Germanate (BGO) crystals as Compton suppressors which have very high density (7.13 g/cm^3) and can thus be used in lesser volume around the target area to enable the possibility of comparatively larger solid angle coverage for the HPGe detectors.

Nevertheless in the case of gamma spectroscopy done using large detector arrays [8] and high projectile velocity (>50 MeV.A), there is always a huge presence of background related to Compton scattered gamma rays, delta electrons and other relativistic particles. It is very important to either mask this background or to completely stop it from coming into interaction with the detector array. Towards this purpose, a new design feature has been proposed for setting up an array of photodiodes coupled with BGO to detect and remove the high energy noise. In order to simulate the experimental scenario of high energy relativistic particles impinging on the BGO-coupled-photodiode array which would generate high amplitude pulses with sharp rise times, a fast scintillator detector has been coupled to a single unit of photodiode and tested.

Silicon Photodiode

Photodiodes are very compact photon counters which have extremely high sensitivity and can be operated with very low bias voltages. Silicon Photomultiplier (SiPM) is an assembly of silicon photodiode sensors that addresses the challenge of sensing, timing and detecting signals as low as single-photon levels. SiPMs have performance characteristics comparable to conventional photomultiplier tubes, while being very light, compact and easy to use. A typical SiPM used here [6] is operated in Geiger-mode which enables high gain (~10^6) at moderate bias (~30V). This is achieved by creating a high field region in the diode that generates a self-sustaining charge avalanche when a photon is absorbed. During the avalanche process, all other microcells remain fully charged and ready to detect more photons. This method is thus capable of giving information on the magnitude of an instantaneous photon flux, as well. Thus, as an option to readout from BGO suppressors, SiPM arrays provide the best solution.

Test Details

In this report, we communicate the characterization, testing and results obtained from using SensL SiPM devices coupled to a fast plastic scintillator [7] with characteristics comparable to those of a BGO scintillator. The J-series SiPM was optically coupled to the NE-102 plastic scintillator using a light guide and optical grease. ^{90}Sr beta source was used to test the combination. Preliminary data was acquired using an advanced digital phosphor oscilloscope with 2.5GHz bandwidth and 40GS/s real time sampling rate (single channel). Fig 1 displays the three components of the setup: the SiPM board, light guide and the plastic scintillator.

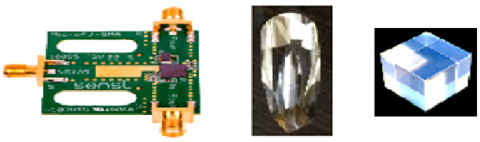

Fig 1: *(left to right) J-series SiPM board, light guide, NE 102 scintillator*

Results

As anticipated, the signal pulse from the SiPM-scintillator assemble is very fast. The signal has a rise time of a few nanoseconds and amplitude of ~100 mV. These characteristics are well suited for application in the intended domain of building arrays for BGO coupling in large HPGe arrays.

Further tests of the SiPM are being carried out for characterization with gamma detectors as well as with other scintillator materials to get a complete understanding. These results will be presented during the conference.

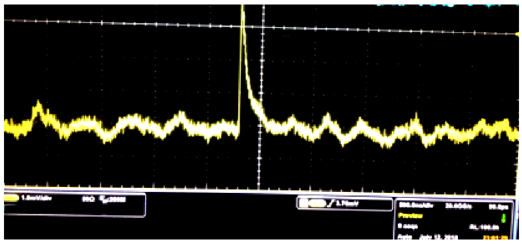

Fig 2: *sample signal obtained for the SiPM-scintillator combination*

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