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Study of MPPC damage induced by neutrons

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ABSTRACT

This paper presents the results of neutron irradiation of two types of Multi-Pixel Photon Counter (MPPC). The measurements were taken at the National Centre for Nuclear Research (NCBJ), Poland and the Joint Institute for Nuclear Research (JINR), Russia. Two types of neutron source were used: PuBe with a continuous energy spectrum up to 11 MeV, and mono-energetic 4.8 MeV neutrons produced in a (d,d) reaction. For both sources, fluence in the range of 10^{10} n/mm^2 was achieved. A series of MPPC tests were performed after each irradiation. The changes in MPPC properties, such as current–voltage (I–V) characteristics, breakdown voltage and energy resolution of 662 keV from the ^{137}Cs gamma line for a $Gd_3Al_{2.6}Ga_{2.4}O_{12}$:Ce (1%) scintillator as a function of neutron fluence are presented.

1. Introduction

A Multi-Pixel Photon Counter (MPPC), also known as a Silicon Photomultiplier (SiPM), is a silicon photon counting device that uses multiple avalanche photodiode pixels operating in Geiger mode. MPPCs are widely used in science fields such as nuclear and high-energy physics [1], astrophysics, and medical imaging [2,3]. Due to their very good photon counting capability, they can also be used in various applications for detecting extremely weak light at the level of single photons. MPPC features include a high gain (10^5 to 10^7) comparable with standard photomultiplier tubes, fast response time, compact size, low bias voltage (below 100 V) and insensitivity to magnetic fields.

In our work we investigate the current–voltage (I–V) characteristics and breakdown voltage changes that occur with the increase of neutron fluence in two different types of MPPC. We determine the energy resolution of the irradiated photodetectors coupled to a non-irradiated $Gd_3Al_{2.6}Ga_{2.4}O_{12}$:Ce (1%) scintillator (later referred to as GAGG) and show that the degradation of energy resolution should be taken into account in gamma spectroscopy physics if a high neutron background is present. Finally, we calculate the noise contribution to energy resolution as a function of neutron fluence.

2. Experimental set-up

In our set-up (Fig. 1) we used two types of MPPC from Hamamatsu: S13360–3050CS and S13360–6050CS [4] (called: 3050CS and 6050CS, respectively), which each have a different active area size: 3 × 3 mm^2 and 6 × 6 mm^2, respectively, and a 50 μm pixel pitch size.

To minimize the gain — temperature dependence of the MPPCs, a Hamamatsu evaluation board C12332-01 [4] was used. This electronic circuit, equipped with a precision power supply and a temperature sensor, allows a temperature compensation factor to be set for each type of MPPC. Using this board and a 6 × 6 mm^2 MPPC coupled to a GAGG scintillator, a gain stability test was performed in a climate chamber. The temperature changes were programmed to be in the range of 14°C–26°C. In this controlled environment, the position of the 662 keV gamma line from ^{137}Cs was checked. The centroid of the full energy peak was determined by a Gaussian fit. Fig. 2 shows the obtained results. As can be seen, the 662 keV peak position mirrors the temperature trend (black line) and the calculated difference between the two opposite centroids stays below 1%. This illustrates good stability of our experimental set-up. It is worth mentioning that the temperature changes monitored during the two experiments described later in this paper were about two times lower than those tested in the climate chamber.

To determine the I–V characteristics of each MPPC, a Keithley 2400 Series SourceMeter was used. This instrument can register currents starting from single picoampers. For safety reasons, the upper current limit was set to 100 μA.

To observe energy resolution degradation caused by irradiation of the MPPCs, a GAGG scintillator was used. This 5 × 5 × 5 mm^3

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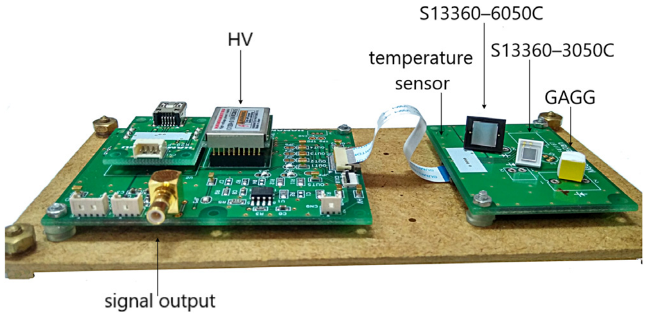

Fig. 1. MPPC photodetectors from Hamamatsu: S13360–3050CS and S13360–6050CS, GAGG scintillator and Hamamatsu evaluation board C12332-01.

crystal has a high light output (44600 ± 4400 photons/MeV) and, most importantly, a well determined intrinsic resolution component ((2.7 ± 0.3)% for 662 keV) [5] measured with an APD. This parameter was employed in our calculations. As a readout system, a CAEN digitizer DT5720 was used.

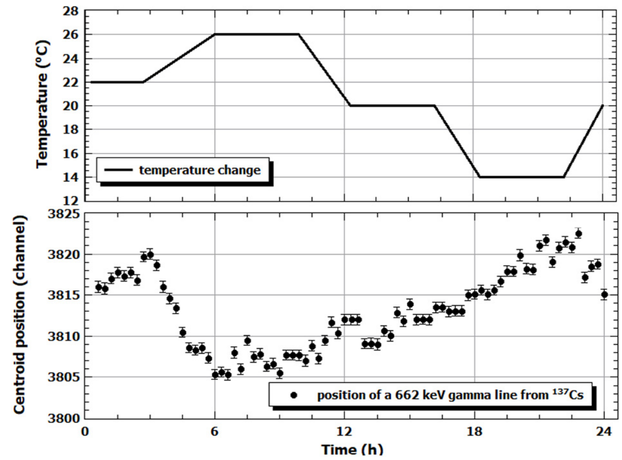

Fig. 2. Test of position stability of a 662 keV gamma line from ^{137}Cs for a temperature range of 14 °C–26 °C, performed in a climate chamber. Top — temperature change programmed in climate chamber. Bottom — position of the full energy peak of ^{137}Cs determined by a Gaussian fit. Each point corresponds to an 18 min measurement time.

2.1. Experiment timeline

Before irradiation of the MPPCs, initial parameters such as I–V characteristics, dark count spectra and energy resolution dependencies for different operating voltages were collected for each type of MPPC.

Next, two independent experiments with different neutron energy profiles were performed. In both experiments, during the irradiation process, the geometry between the MPPC and neutron source was chosen in order to keep the same neutron flux for each type of MPPC (3050CS or 6050CS). To obtain the neutron fluence, the flux was integrated over the irradiation time.

The first experiment was performed at the National Centre for Nuclear Research (NCBJ), Poland, with neutrons from a PuBe source. This source is characterized by a continuous neutron energy spectrum with average energy of about 4.6 MeV and internal activity of 8.0 × 10^5 n/s in a 4π angle. Neutron flux and the calculated fluence chosen for each measurement session were determined by MPPC — PuBe source

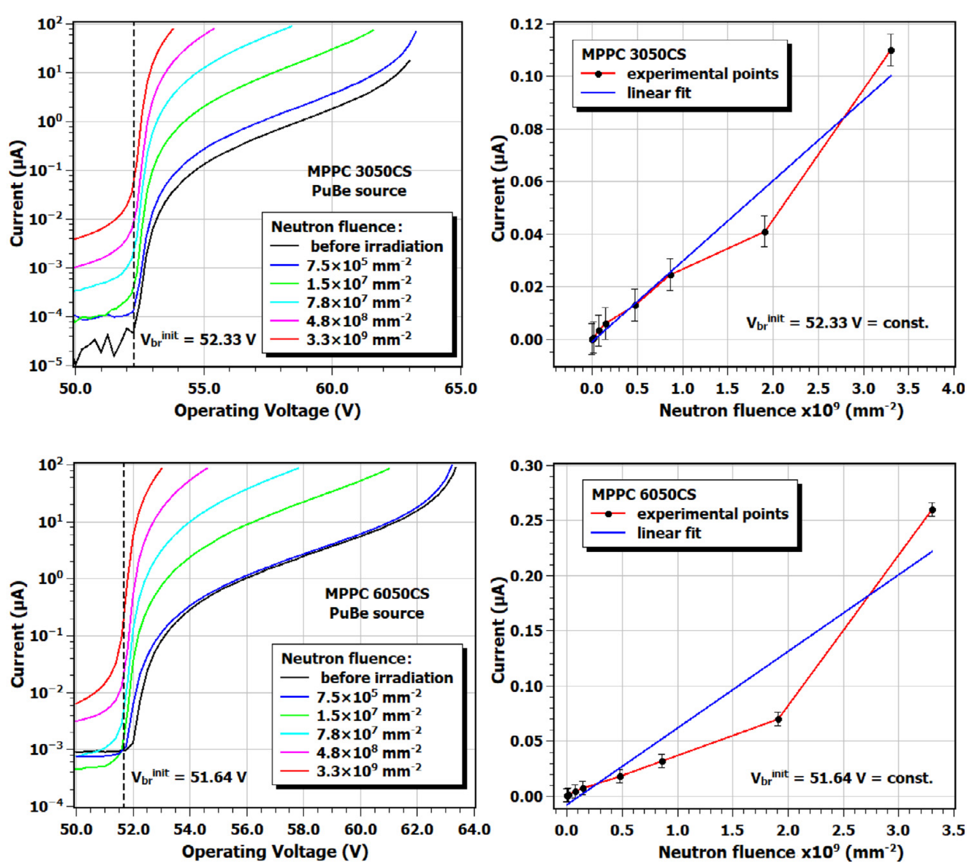

Fig. 3. Changes in I–V characteristics with the increase in neutron fluence from a PuBe source for a 3 × 3 mm^2 (upper part) and 6 × 6 mm^2 (lower part) type of MPPC. Dashed vertical lines show the calculated breakdown voltage parameter (V_{BR}^{init}) for the non-irradiated (initial) MPPC. Right hand graphs present the current increase for V_{BR}^{init} compared to linear fit. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)