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Active control of the gain of a 3 mm × 3 mm Silicon PhotoMultiplier

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ABSTRACT

Solid-state photodetectors working in the Geiger mode—known as Silicon PhotoMultipliers (SiPM) or MultiPixel Photon Counters (MPPC)—are currently being developed with increasingly large active areas. Potential applications for low-light-level detection were investigated with a 9 mm^2 MPPC, recently made available by Hamamatsu. The device was optically coupled with a scintillator and its performances, in terms of single photoelectron discrimination, were studied in a series of measurements under different operating conditions. An active control of the gain was implemented by a linear feedback on the operating voltage. The results of the tests are discussed.

1. Introduction

The Silicon PhotoMultiplier (SiPM) [1,2] is a novel solid-state photon counting device. It consists of a matrix of Avalanche PhotoDiodes operating in the Geiger regime with resistive quenching and connected in parallel into a single readout element. Along with a number of appealing features (insensitivity to magnetic fields, low-voltage bias, ruggedness, small material budget), this device suffers from a high dark-count rate and a dependence of the gain on the main operating conditions (bias voltage and temperature). Nevertheless, its excellent single-photon detection capabilities [3,4] makes the SiPM a natural candidate to replace conventional photomultipliers (PMTs) in many applications including high energy physics and nuclear physics instrumentation as well as in other disciplines.

In this paper, we describe the measurements carried out in our laboratory with a Hamamatsu [5] MultiPixel Photon Counter MPPC-S10362-33-050C. This new photosensor has a 3 mm × 3 mm active area covered by 3600 square pixels of 50 μm side. It provides approximately a 9 times larger detection area with respect to the 1 mm^2 SiPM devices that we have used in our previous measurements [6].

2. Test setup

The spectral sensitivity of the device (Fig. 1) allows for a direct optical coupling with plastic scintillators and Cherenkov radiators with a wavelength shifted emission peak in the blue. As the sensitive surface of the SiPM is protected by a transparent film, an optical grease was used to ensure a good coupling between the SiPM window and a 6 mm diameter cylindrical scintillator (T2) of 30 mm length. One side of the scintillator was optically connected to the SiPM, while the opposite end was coupled to the photocathode of a conventional PMT via a 3 mm diameter clear optical fiber.

The signal from the photosensor was matched via a 50 Ω impedance to a 3 stage Gali-5 wideband monolithic amplifier. The output signal was digitized by a CAEN V792 12-bit ADC with a gate width of 120 ns and a gain of 104 fC per ADC count. The readout of the module was carried out by a VME controller interfaced to a PC via an optical-fiber link.

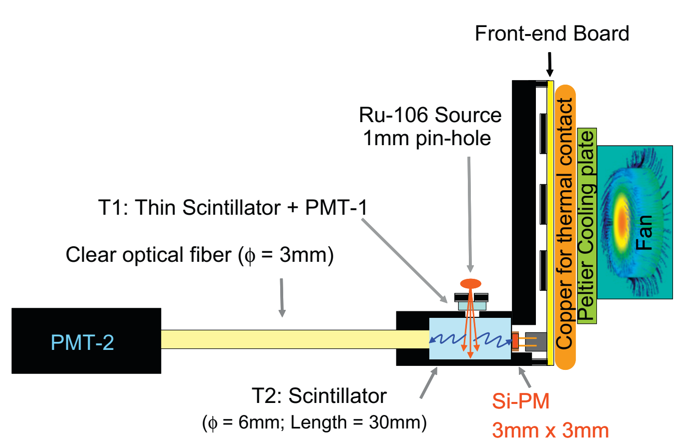

Fig. 1. Laboratory tests with a radioactive source: experimental layout.

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The scintillator was illuminated, from a direction orthogonal to the cylinder axis, either with UV light from an LED or with a radioactive β-source. In this way, we could monitor the intensity of the scintillating light, using the PMT as a reference, and measure the relative response and efficiency of the SiPM. The experimental layout is shown in Fig. 1.

A thin (1.5 mm thick) scintillator T1, readout by a conventional PMT, was placed between the source collimator and the scintillator under test. The coincidence between the T1 signal and the signal of the reference PMT connected to T2 was used as a trigger for the measurements performed with the electron source. The latter was a ^{106}Ru β-emitter with an energy spectrum end-point at approximately 3.5 MeV.

Both the SiPM and the Gali-5 amplifier were in good thermal contact with a copper cold mass connected to a Peltier cooler. The temperature was constantly monitored using a thermistor. During all tests, the bias voltage and the SiPM dark current were constantly monitored using a Keithley 487 picoammeter. Temperature and current were readout via a GPIB interface and then recorded and displayed using LabView. The SiPM digitized data were readout and displayed by custom data acquisition and monitoring programs, running under Linux and using the CERN ROOT package (Fig. 2).

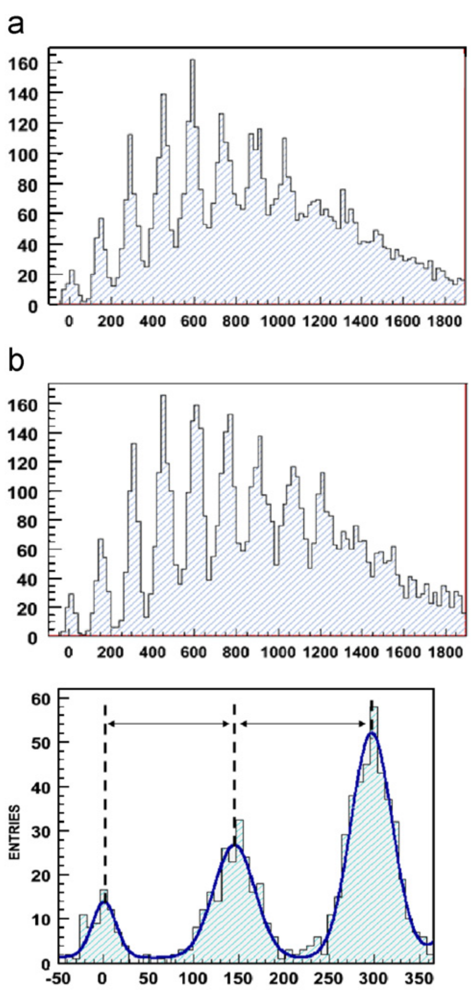

Fig. 2. Photopeaks observed with the scintillator: (a) at 10 °C and (b) at 3 °C. Lower panel: pedestal and first two photopeaks at 3 °C.

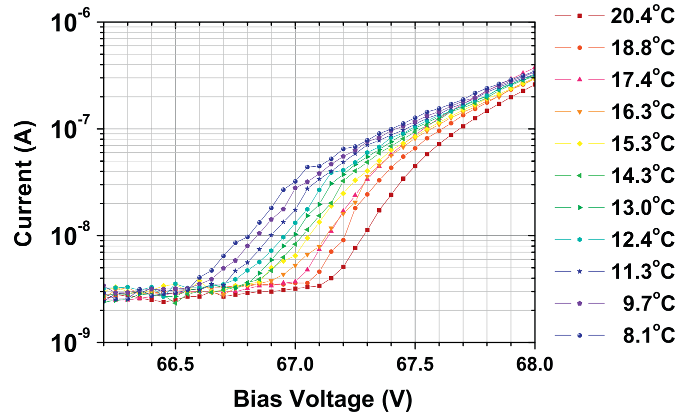

Fig. 3. Measured $I-V$ curves as a function of the temperature T.

3. Static measurements

The MPPC-S10362-33-050C was first characterized by measuring the $I-V$ curve. The measurements were carried out for different values of the temperature T. During each measurement the temperature was monitored and kept stable using the Peltier cooler. The family of curves, shown in Fig. 3, refer to a temperature range between 8.1 and 20.4 °C.

4. Measurements with a scintillator

In a first series of measurements with the radioactive source, we were able to observe photopeaks in the pulse height distribution of the SiPM signals (Fig. 2) as a result of the detection, by individual cells of the photodetector, of the light generated by the incident electrons in the cylindrical scintillator.

Data were collected with the source trigger for different values of the bias voltage V_{bias}, while the temperature was kept at a constant value. The pedestal distribution was measured with random triggers and its mean value was subtracted from the data.

4.1. Measurement of the gain

Using the data collected with the scintillator, the distance of the first photopeak from the pedestal and the relative distances among the first three consecutive photopeaks were fitted to Gaussians. By averaging these values, the gain G of the SiPM was determined and plotted as a function of the reverse bias voltage V_{bias} in Fig. 4, where each curve refers to a given value of the temperature.

By linear extrapolation of each curve of Fig. 4 to zero gain, the reverse bias breakdown voltage V_{bd} was determined and plotted in Fig. 5 as a function of the temperature T.

The linear increase of V_{bd} with the temperature was fitted as $V_{bd}(T) = a_0 T + V_0$ with a slope $a_0 = 50.2 \pm 0.1\,\text{mV}/^{\circ}\text{C}$ and a constant term $V_0 = 66.07 \pm 0.02\,\text{V}$.

For a given value of the reverse bias, the gain decreases approximately by a factor of 2 for an increase of 10 °C. The actual dependence was fitted from the data of Fig. 4 to the expression: $G(T) = G_0(V_{bias} - V_{bd}(T))$, where $G_0 = 4.57 \times 10^5$ is the photodetector gain corresponding to an overvoltage $\Delta V = V_{bias} - V_{bd}$ of 1 V.

4.2. Measurement of the dark count rate

Data taken with a random trigger showed a pedestal width $\sigma_0 \sim 20$ ADU. This translates into an rms noise of ~8 fC, for an