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Characterization of a 6×6-mm^2 75-μm cell MPPC suitable for the Cherenkov Telescope Array project

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ABSTRACT

This paper presents the latest characterization results of a novel Low Cross-Talk (LCT) large-area (6×6-mm^2) Multi-Pixel Photon Counter (MPPC) detector manufactured by Hamamatsu, belonging to the recent LCT5 family and achieving a fill-factor enhancement and cross-talk reduction. In addition, the newly adopted resin coating is demonstrated to yield improved photon detection capabilities in the 290–350 nm spectral range, making the new LCT MPPC particularly suitable for emerging applications like Cherenkov Telescopes. For a 3×3-mm^2 version of the new MPPC under test, a comparative analysis of the large pixel pitch (75-μm) detector versus the smaller pixel pitch (50-μm) detector is also undertaken. Furthermore, measurements of the 6×6-mm^2 MPPC response versus the angle of incidence are provided for the characterized device.

1. Introduction

Silicon photomultipliers (SiPMs) are a relatively new class of solid-state photodetectors suitable for an increasing number of perspective applications in many scientific fields. Thanks to their outstanding characteristics in terms of photon number resolution, low operating voltage, fast dynamic response and insensitivity to magnetic fields, SiPM applications have been continuously growing over time, especially in the fields of high-energy astrophysics [1–14], nuclear medicine [15–17] and cosmic-ray muon detection [18–20].

The unique features presented by most commercially available detectors from the world's leading manufacturers are the result of modern semiconductor fabrication technologies. Considerable effort is presently being invested by the producers of SiPMs to further improve the global performance achieved by this class of devices [21–25]. In addition, the large popularity of SiPMs in the sensors community has led to a remarkable number of characterization studies and methodologies for evaluating the detector performance [26–37]. The rising demand for optimal speed and single photon time resolution on one side, and for suitable integrated front-ends on the other, has also triggered research efforts for reliable analytical investigations on the dynamic response of SiPMs, allowing a detailed analytical description of the sensor behavior [38–44].

This paper presents the characterization of a newly available large-area (6×6-mm^2) Multi-Pixel Photon Counter (MPPC) detector from Hamamatsu Photonics, addressing the challenge of high sensitivity and low cross-talk, especially requested in the new generation of Cherenkov telescopes as the ones adopted in the ASTRI Mini-Array Project [4] within the Cherenkov Telescope Array (CTA) Observatory [5,6].

We also present a comparative analysis of the large pixel pitch (75-μm) detector versus the smaller pixel pitch (50-μm) device with the same active area (3×3-mm^2), to compare the detector performance when increasing the pixel dimension for the same device size. Furthermore, to investigate the 6×6-mm^2 detector response with respect to the incident photons, measurement at several angles of incidence are provided as well.

The measurements presented here are carried out at the Catania astrophysical Observatory Laboratory for Detectors (COLD) within INAF – Osservatorio Astrofisico di Catania.

2. Large-area low cross-talk MPPC device

In the last few years, the advances in LCT technology have produced new generation MPPCs with improved characteristics and performance. New materials and processes have been adopted,

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Table 1
Main physical features of the characterized large-area MPPC detector.

Device series	S13360-6075CS
Cell pitch	75 μm
Device size	6×6 mm^2
Microcells	6400
Surface coating	silicone resin
Fill-factor	82%
Breakdown voltage*	52.01 V

* At 25 °C.

achieving higher sensitivity and geometrical fill-factors. The optical trench improvement of the LCT detectors compared to the prior MPPC series of the same family is a result of new types of trenches which enables cross-talk reduction. On the other hand, the fill-factor improvement of the new MPPC series results from a functional optimization of the physical structure of the device (maximization of the active area).

The characterized large-area MPPC described in this paper belongs to the latest device series manufactured by Hamamatsu Photonics, denominated Low Cross-Talk (LCT) family and reported as the MPPC S13360 series in the manufacturer datasheet[1]. It is a prototype device provided by the vendor to the COLD laboratory for testing and evaluation purposes. Table 1 reports the main features of the characterized detector.

Moreover, silicone resin coating has been used for this device to achieve higher quantum efficiency in the near ultraviolet (NUV) spectral region. Since this kind of device is very fast and sensitive to the light in the 290–700 nm wavelength range, it is particularly suitable for the detection of Cherenkov flashes.

3. Experimental results

The electro-optical equipment used for SiPM measurements is described in [26]. The main element of the front-end electronics for SiPM characterization is the Cherenkov Imaging Telescope Integrated Read-Out Chip (CITIROC) [45–47], which is an advanced version of the Extended Analog SiPM Integrated Read-Out Chip (EASIROC) [48–51], both produced by WEEROC[2]. The modifications to CITIROC stem from INAF and originated from the design of the ASTRI SST-2M telescope camera [2,3]. To provide a versatile interface between the SiPM terminals and the CITIROC evaluation board, specific mechanical and electrical adapters have been fabricated, allowing several functional tests and measurements for SiPM characterizations to be performed. Temperature control and stabilization is obtained through a dedicated thermoelectric cooling system based on a Peltier cell; the entire cooling system is thermally calibrated and can achieve temperatures from 10 °C to 30 °C. The mechanical housing is able to host various types of detectors by simply using a dedicated electronic adapter board.

Based on the equipment mentioned above, experimental measurements on the large-area MPPC of the LCT series are presented here in terms of the main detector performance parameters, i.e. gain, dark count rate, cross-talk and Photon Detection Efficiency (*PDE*).

3.1. Gain

In order to evaluate the MPPC gain at a fixed temperature and in a specific range of operating voltages, charge amplitude histograms are produced while illuminating the SiPM detector with a LED laser source of adjustable intensity and duration. By computing the average spacing between subsequent charge peaks in terms of Analog-to-Digital Converter (ADC) channels, and scaling for the constant ADC rate (charge/channel) and amplification factor, the SiPM gain is obtained for a fixed bias condition. A detailed description of the apparatus and the adopted technique can be found in [28]. The resulting measured gain data points, as a function of the applied overvoltage (*OV*) at 25 °C are reported in Fig. 1 for the characterized detector.

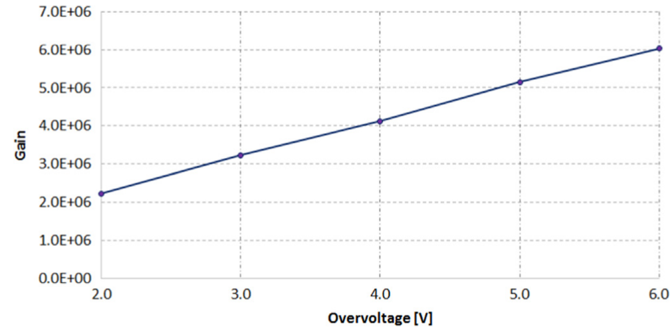

Fig. 1. Gain measurements of the characterized S13360-6075CS detector as a function of the applied overvoltage, at 25 °C.

The expected linear trend of the gain as a function of the overvoltage is observed. Gain values higher than 2×10^6 are obtained in the analyzed overvoltage range.

3.2. Dark Count Rate and cross-talk

The Dark Count Rate (*DCR*) is essentially defined as the count rate of avalanche pulses produced by primary (uncorrelated) carriers, resulting in events that are perfectly equivalent to the signal from real photons.

SiPM optical cross-talk, as reported in literature [25,27], is evaluated as the ratio of the *DCR* at 1.5 pe with respect to that at 0.5 pe. This approach is based on the assumption that the probability of triggering two uncorrelated avalanches at the same time is negligible.

Fig. 2 shows the *DCR* curves (also known as staircase functions) for the characterized LCT detector as a function of the discriminator threshold and for overvoltage values from 2.1 V up to 5.5 V, in steps of 200 mV. For a threshold above the electronics noise, all thermally generated avalanches are counted as a single pulse, as well as tunnel-assisted generated charge, afterpulsing and indirect optical cross-talk (extra-charge noise). Fig. 3 reports the measured *DCR* and cross-talk probability as a function of the overvoltage.

It can be observed that, in the analyzed overvoltage range, the *DCR* of the 6×6-mm^2 device remains lower than 700 kHz. On the other hand, for a typical 3-V overvoltage operation, the cross-talk probability is around 12%, due to the effects of the improved optical trenches adopted with respect to previous MPPC families [27].

3.3. Photon Detection Efficiency

SiPM absolute *PDE* measurements are carried out based on the photon counting method [27–29], by which the number of pulses per unit time in monochromatic light conditions are compared to the light level recorded by a reference NIST photodetector at the same time, and this process is then repeated for several wavelengths.

It is worth noting that the adopted photon counting technique for determining the detector *PDE* is insensitive to the optical cross-

[1] http://www.hamamatsu.com/jp/en/product/category/3100/4004/4113/S13360-6075CS/index.html.
[2] http://www.weeroc.com.