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Advances in Multi-Pixel Photon Counter technology: First characterization results

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ABSTRACT

Due to the recent advances in silicon photomultiplier technology, new types of Silicon Photomultiplier (SiPM), also named Multi-Pixel Photon Counter (MPPC) detectors have become recently available, demonstrating superior performance in terms of their most important electrical and optical parameters. This paper presents the latest characterization results of the novel Low Cross-Talk (LCT) MPPC families from Hamamatsu, where a noticeable fill-factor enhancement and cross-talk reduction is achieved. In addition, the newly adopted resin coating has been proven to yield improved photon detection capabilities in the 280–320 nm spectral range, making the new LCT MPPCs particularly suitable for emerging applications like Cherenkov Telescope Array, and Astroparticle Physics.

1. Introduction

Silicon photomultipliers (SiPMs) are a contemporary highly-competitive class of solid-state photodetectors particularly suitable for a growing number of applications in many fields of high-energy physics, nuclear medicine, and astrophysics. Due to their unique features in terms of photon counting capabilities, low operating voltages, fast dynamic response, structural compactness, and insensitivity to magnetic fields, SiPMs have found widespread popularity in high-energy astrophysics [1–14], positron emission tomography systems for nuclear medicine [15–17], and cosmic-ray muon detection [18, 19].

The exceptional characteristics offered by most commercially available devices from the world's leading manufacturers result from new integration approaches and modern semiconductor fabrication technologies. Remarkable effort is presently being devoted by the SiPM producers to further improve the overall performance achieved by this class of devices [20–22]. Moreover, the growing popularity of SiPMs in the sensors community has led to a significant number of characterization studies and methodologies for investigating and quantifying the detector performance [23–34]. The rising number of perspective applications requiring optimal speed and single photon time resolution, along with the consequent demand for suitable integrated front-ends, have also provided research motivation for accurate analytical studies on the SiPM time response, exploring the physical processes contributing to the signal formation in the individual pixels, and allowing a detailed analytical description of the sensor [35–38].

This paper presents and discusses the characterization of a new class of recently available multi-pixel photon counter (MPPC) detectors from Hamamatsu Photonics, demonstrating the latest advances in the fabrication technology used by the manufacturer. Measurements are carried out at the INAF – Catania astrophysical Observatory Laboratory for Detectors (COLD).

2. New-generation Low Cross-Talk MPPCs

SiPM photon-counting ability may be seriously limited by the optical cross-talk effect, originated by correlated coincidences of two (or multiple) induced avalanches, affecting the linearity of the detector response and causing a significant excess noise contribution. Because it is impossible to determine the number of pixels that were fired by external photons, cross-talk may limit the photon-counting resolution of a SiPM device. The probability of optical cross-talk could be considered as one of the crucial performance parameters of a SiPM detector for ground-based gamma-ray astrophysics. Operating a SiPM at low overvoltages would significantly diminish cross-talk effects, but at the expense of degrading the photon-detection efficiency. Isolation trenches

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Table 1
Main physical features of the characterized MPPC detectors.

Device series	LCT1	LCT4			LCT5
Serial number	LCT-B/25	LCT4/2	LCT4/9	LCT4/20	LCT5/1
Cell pitch	50 μm	50 μm	75 μm	100 μm	50 μm
Device size	3×3 mm^2	3×3 mm^2	3×3 mm^2	3×3 mm^2	3×3 mm^2
Microcells	3600	3600	1600	900	3600
Surface coating	Epoxy resin	Silicone resin	Silicone resin	Silicone resin	Silicone resin
Fill-factor	61%	61%	73%	79%	74%
Breakdown[a]	55.00 V	50.92 V	51.10 V	52.31 V	52.5 V

[a] At room temperature (25 °C).

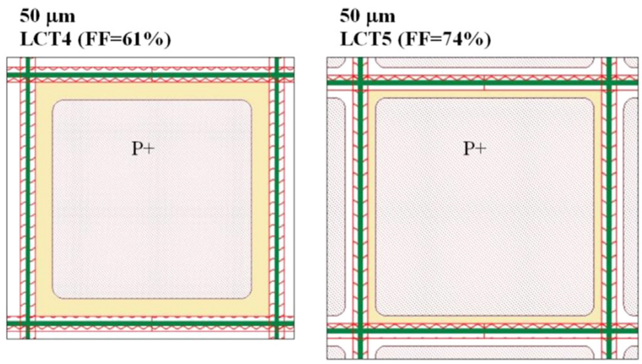

Fig. 1. Geometrical fill-factor enhancement from LCT4 to LCT5 50-μm MPPC devices: in this case, an improvement of 13% has been achieved (courtesy of Hamamatsu Photonics).

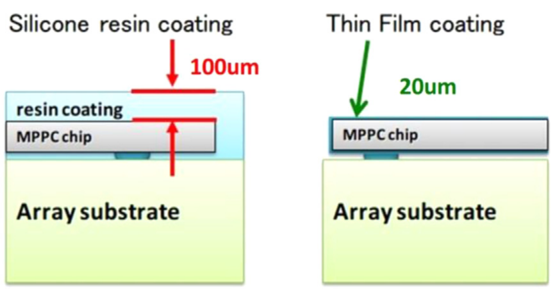

Fig. 2. Schematics of the silicone resin coating and thin film coating (courtesy of Hamamatsu Photonics).

around each pixel successfully reduce optical cross-talk. This technique has become a standard for this kind of photodetector; however, a non-negligible contribution to cross-talk can come from light reflected off the bottom surface of the silicon bulk, and thus, trenches would not be able to prevent this [21,39].

On the other hand, one of the main factors compromising the ability of a SiPM to generate an output signal from an incoming photon, i.e. its Photon Detection Efficiency (PDE), is its inherent geometrical inefficiency due to inactive regions between inner cells. The geometrical efficiency factor is defined as the ratio between the total active area of the SiPM cells and the overall device area, as a result of the gaps between the individual cells, and is solely determined by the detector topology. This parameter is commonly referred to as fill-factor.

To overcome such limitations, much effort has been put into technological progress and development of new types of detectors, and remarkable steps forward have been made in fill-factor enhancement and cross-talk reduction.

The characterized SiPM detectors presented in this paper are essentially the latest device series manufactured by Hamamatsu Photonics and identified by the definition of Low Cross-Talk (LCT) MPPCs. They are prototype devices provided by the manufacturer to our laboratory for testing and evaluation purposes. Table 1 reports the main features of the characterized detectors. As a result of the recent advances in LCT technology, new generation MPPCs have been produced with improved characteristics and performance. New materials and processes have been adopted, aiming at achieving higher sensitivity and geometrical fill-factors.

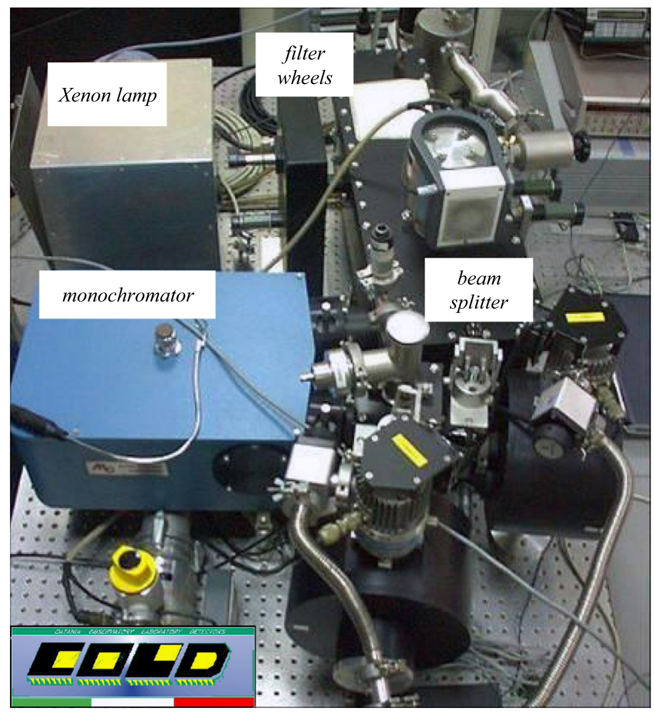

Fig. 3. COLD optical bench with the apparatus set-up used for SiPM tests and measurements.

The optical trench improvement of the LCT4 and LCT5 detectors compared to the prior MPPC series of the same family arises from new types of trenches enabling cross-talk reduction. On the other hand, the fill-factor improvement from the LCT4 to the LCT5 MPPC series results from a functional optimization of the physical structure and is pictorially sketched in Fig. 1 for the 50-μm devices. As shown, maximization of the active area (in gray) is accomplished for the LCT5 device.

In addition, epoxy resin coating, used for all previous MPPC devices tested in our labs [24–26], is adopted for the LCT1 series. However, compared to the epoxy resin coating, new thin film coating and silicone resin coating have been proven to show higher quantum efficiency in the near ultraviolet (NUV) spectral region. Both LCT4 and LCT5 series benefit from such technology development and address the challenge of high NUV sensitivity for applications like Imaging Atmospheric Cherenkov Telescopes [7].