High-density cell and high-efficiency Silicon Photomultipliers

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Silicon Photomultipliers (SiPM) are arrays of many (thousands or tens of thousands) Single-Photon Avalanche Diodes (SPADs), with integrated passive-quench per each pixel. Like SPAD, each SiPM cell works in Geiger mode and the output current is the sum of all the cells, giving a signal proportional to the number of photons detected. They are compact and insensitive to magnetic fields. These properties led to a big development of SiPM technology, especially for medical application, like positron emission tomography (PET), where also the good time resolution of this detector is important for time-of-flight information. However, SiPM can be a good solution for many other applications, like Light Detection and Ranging (LIDAR) [1], spectroscopy [2] and physics experiments [3], for its capability of combining single-photon sensitivity and high dynamic range (up to thousands of photons, in a 3x3mm² SiPM), for its good photon detection efficiency (PDE) and time resolution.

In FBK, we recently developed SiPM with high cell density, called SiPM-HD. The new devices feature very small cell size (CS) and considerably high fill factor (FF). In order to reach high area coverage, a new border structure to confine the high electric field region of each single-photon avalanche diode was developed. In particular, we implemented trenches between the cells, mainly to provide both electrical and optical isolation and to reduce the dead border region to 1 μm. In this way, we produced five different 1x1 mm² SiPM prototypes with cell size (CS) going from 30 × 30 μm² down to 12 × 12 μm². The fill factor is equal to 77% for the bigger cell and it is higher than 50% for the smaller one. The SiPM with the smallest cell has a density of more than 7000 cell/mm². The ability to reduce the CS preserving the FF leads to significant advantages in terms of correlated noise reduction, due to the proportional reduced gain leading to an effective reduction of the carriers trapped as well as the photons produced during the avalanche. The first one induces a proportional reduction of the afterpulsing probability, the second one lowers on the optical CT probability. Other relevant advantages of small cells are a higher dynamic range, because of higher cell density, and a shorter recovery time.

We will show and compare the performance of these devices, with different cell size, in terms of PDE, gain, noise, photon-number resolving capabilities and timing performances. The largest one has a considerably high PDE approaching 50% (including FF) in the green part of light spectrum and it is above 35% from 450nm to 650nm. For the devices with smallest CS (12 × 12 μm²) it is higher than 25% in the green spectrum portion.

In the smallest-cell device, thanks to the low gain, the direct cross-talk probability (DiCT) is ~ 10% even at 9 V of over voltage and the cell has a recharge time constant of only ~ 10ns, leading to a very high maximum photon rate on the SiPM. All these results are very promising for many applications that require good performance in terms of PDE, high linearity and dynamic range.

References