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Radiation damage on FBK Silicon Photomultipliers

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Silicon Photomultipliers are array of many single-photon avalanche diodes (SPAD) connected in parallel to common anode and cathode, each with an integrated quenching resistor. Each pixel is sensitive to a single photon, working in Geiger-mode, with high internal electric fields to trigger self-sustaining avalanche multiplication processes. They are emerging as detector of choice in many applications ranging from quantum physics, nuclear medicine and high-energy physics experiments, because of their versatility and their high dynamic range. In particular, when used for space applications or in high energy physics experiments, like the CMS-HCAL, SiPMs are often exposed to a significant dose of radiations. Typical values are in the order of 109 - 1010 neq/cm2 for space applications, or up 1014 neq/cm2 for calorimetry applications in experiments of HEP.

To be able to properly work up to the end of the experiment, a good radiation tolerance (or radiation hardness) is required and the SiPMs have to be properly optimized to be able to survive such radiation doses or to minimize the effects of the damage as much as possible, thus reducing their performance worsening.

In FBK (Trento, Italy) we have been developing different SiPM technologies over last years, optimized for different applications in terms of detection efficiency (for example with peak sensitivity in the blue-wavelength region, or in the green-wavelength region) and performance characteristics in specific application conditions (e.g. working in liquid nitrogen). It is therefore also interesting to be able to characterize and compare the main performance-parameters degradation, of these different technologies.

Generally, as for the majority of silicon-based photodetectors, the radiation damage can affect both the surface region and the bulk through ionizing energy loss (IEL) and non-ionizing energy loss (NIEL) respectively, introducing defects and recombination centers. Depending on the energy and the particle type, either one type of damage or the other one is more relevant and likely to happen. However, differently from other type of radiation sensors, SiPMs work in Geiger mode, with high electric field in the active volume, being possibly more sensitive to even small defects, particularly in the bulk. As a consequence of the damage the SiPMs show an increase of both leakage current (i.e. not multiplied one) and dark current (i.e. the multiplied current, generating the dark count rate, DCR, of the SiPM) resulting in an increase of the noise and possibly also a decrease of the signal amplitude, leading to a dominance of the noise events (i.e. dark counts) over the signal (photon counts). This is reflected in a decrease of the signal-to-noise ratio which is an important parameter for the performance of a SiPM.

In our investigation, protons have been chosen for their property of being heavy charged particles doing both ionizing and non-ionizing interactions. Their damage effect has been converted into 1 MeV neutron equivalent damage. We present and compare the characterization results of several SiPMs from different technologies. We irradiated the SiPMs with protons, with energy of 62MeV at INFN-LNS facility (Catania, Italy). The SiPM have been properly characterized after irradiation shown an important increase of the primary noise with some saturation effects. However, the main electrical characteristic, like breakdown voltage are not affected, as well as the correlated noise. We investigated also the activation energy of dark counts, showing a reduction as well as the sensitivity. Furthermore, we performed Emission Microscopy (EMMI) tests identifying the main failure position inside the micro-cell active area.

Author: ALTAMURA, Anna Rita (FBK - Università degli studi di Udine)

Co-authors: ACERBI, Fabio; MAZZI, Alberto (Center for Materials and Microsystems, Fondazione Bruno Kessler, Trento, Italy); ZORZI, Nicola (Fondazione Bruno Kessler - FBK); GOLA, Alberto (Fondazione Bruno Kessler)

Presenter: ALTAMURA, Anna Rita (FBK - Università degli studi di Udine)

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