Contribution ID: **44** Type: **Oral**

Back-side-illuminated Silicon photomultipliers for improved radiation hardness

Thursday 6 February 2025 10:00 (15 minutes)

Silicon Photomultipliers (SiPMs) are single-photon sensitive detectors that continue to attract increasing interest in several industrial and scientific applications that require fast detection speed, high sensitivity, compactness, insensitivity to magnetic fields and low bias voltages. In particular, the SiPMs are used in high-energy physics (HEP) experiments, and for the readout of scintillators in gamma-ray detectors for space experiments. In such applications they receive a significant dose of radiation (e.g. protons, electrons, neutrons, ⋯) which degrades their performance.
During the last years, at FBK (Trento, Italy) we have been developing many different technologies for SiPMs and SPADs, optimized for different applications. We also studied extensively the effect of ionizing energy loss effects and non-ionizing energy loss effects (i.e. bulk displacement damage) on many different SPAD and SiPM technologies, highlighting the most interesting effects on noise and detection efficiency.
Based on such results, we started specific technological improvements aimed to improve the radiation hardness of novel SiPMs technologies. We are currently working on several directions. Among the most promising: i) we are exploiting the reduction of the high-field active area, with a novel SiPM structure based on charge-focusing mechanisms and back-side illumination, to mitigate the noise increment due to back damage, and ii) we are working on active control and draining of radiation-induced charge in the dielectrics, to mitigate the electric field modification effects of ionizing-energy loss. We performed TCAD simulations of the micro-cell (i.e. SPAD) structure, and we estimated the noise generation (including field-enhancement effects), to verify and quantify the beneficial effects of charge-focusing on the mitigation of the irradiation-induced bulk-damage effects, showing a reduction of the primary dark count rate (also after irradiation) and a reduction of the activation-energy lowering after irradiation.

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Session Classification: Technology

Track Classification: Technology