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Proton-induced Radiation Damage Effects on Silicon Photomultipliers for HEP and space experiments

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. SiPMs are also replacing photomultiplier tubes (PMTs), hybrid photodiodes (HPDs), or other in high-energy physics (HEP) experiments, and for the readout of scintillators in gamma-ray detectors for space. In such applications they receive a significant dose of particles (e.g. protons and neutrons) and X and gamma rays.
While the effects of radiation in silicon detectors are well-studied [6], the literature is not as much concerning Avalanche Photodiodes (APDs) and photon-counting detector, working in Geiger-mode (like SPADs and SiPMs). Indeed, there has been recently an increasing interest in assessing such effects on both SPAD-arrays and SiPMs for HEP and space-experiments.
During the last years, at FBK (Trento, Italy) we have been developing many different technologies for SiPMs and SPADs, optimized for different applications. Such technologies are based on different silicon starting-materials (with different doping species), made with different internal structures and cell pitch (i.e. SPAD pitch).
Given the big interest in SiPM for harsh radiation environment application, we irradiated several SiPM chips, each one containing few 1x1mm2 SiPMs, with protons at the Trento Proton Therapy Centre (TPTC), in 3 different irradiation campaigns, in 2020, 2021 and 2023. During these sessions the SiPMs were irradiated as a bare chips, on a custom support, or irradiated mounted on custom PCBs, and connected to measurements systems placed inside the experimental room. We used the "dual-ring"setup, to have uniform fluence on a large area area, thus to irradiate all the SiPM chips with the same dose and be able to compare the effects of irradiation on several technologies. This is typically working with protons at 148 MeV, but the energy in our case has been lowered with 10 foils of RW3 wafer equivalent material down to 74 MeV. We verified the beam profile to be uniform on a spot of 8 cm in diameter. We placed the PCB containing the SiPMs in a 3D printed box, with a motorized shutter, which was open during proton irradiation (to avoid plastic in the proton path) and closed during online measurements, to have the measurement in dark condition. In the box we also placed a 4-LED illuminator board (470 nm). After each irradiation step we measured the current-voltage (IV) curves of all SiPMs (in dark and with illumination). We compared the radiation damage effects on the detectors after each irradiation step to identify the main behaviors and the most radiation tolerant technological splits and layouts

Primary author: Dr ACERBI, Fabio (FBK)

Co-authors: Dr MERZI, Stefano (FBK); GOLA, Alberto Giacomo

Presenter: Dr ACERBI, Fabio (FBK)