Radiation damage and recovery studies of SiPMs

T. Tsang, et.al.

Instrumentation Division, Brookhaven National Laboratory, Upton, NY 11973

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Abstract

Silicon Photomultipliers (SiPMs) are attractive candidates for light detection in many nuclear and particle physics detectors. They outperform conventional photomultiplier tubes in many respects. They are insensitive to magnetic fields, operate with <100 volt bias, exceed 10^6 charge gain with a good signal-to-noise ratio, hold high (>50%) photodetection efficiency, reach noise levels below 1-photoelectron equivalent, and possess excellent photon number resolving capability at ambient temperature. However, in many applications, they are often exposed to high ionization radiation environments such as in the proposed sPHENIX and EIC detectors. Two undisputable effects of radiation on SiPMs are the marked, often orders of magnitude, increase of dark current and the lost of single photon number resolving (PNR) capability, leading to poor signal-to-noise ratio and indiscernible photoelectron spectrum We characterize the performance of SiPMs before and after exposure up to 10^{12} neutron/cm^2 dosage. Despite the typical orders of magnitude increase of dark current upon neutron irradiation we show that the elevated dark current can be suppressed and single-photoelectron detection can be restored by operating them at a lower temperature. The required operating temperature depends on the dosage received. Furthermore, after high temperature thermal annealing with a forward bias, there is compelling evidence that the eminent dark current is lowered by orders of magnitude and single-photon detection performance is revived at ambient temperature. The restoration of SiPM's unique PNR characteristics after high temperature annealing appears to be effective on all SiPMs tested and could be a universal behavior for all variant of SiPMs. These findings open up a possible scheme for extending the functionality and the useable lifetime of large scale SiPM detectors deployed in ionization radiation environment.