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Ultra-low noise SPADs in 350 nm CMOS technology for Cherenkov radiation detection in particle and astrophysics

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An optimized design and process flow in a specialized 350 nm CMOS technology yields Single-Photon Avalanche Diodes (SPADs) with extremely low Dark Count Rates (DCR). They show optimal properties for detecting visible and near infrared photons in low quantity with high timing resolution. These characteristics are crucial for building up Silicon Photomultipliers (SiPM) to detect Cherenkov radiation in particle detection and astrophysics. SPAD-based SiPM typically excel photomultiplier tubes (PMT) with regard to detection efficiency, integration possibilities and their tolerance of magnetic fields, struggle, however, with a higher noise level, introduced by the DCR [1]. The presented SPADs show extremely low DCR values of 2·10-4 cps/µm^2 at 260 K down to 4·10-8 cps/µm^2 (= 0.04 cps/mm2) at 160 K [3] and thus can outperform PMTs in demanding detection applications.

A novel technology for 3D integration using direct bonding of 8”wafers was developed to allow a highly compact and integrated combination of low-noise backside-illuminated SPADs with circuits fabricated in advanced CMOS nodes achieving high readout speed and timing resolution. Customized through-silicon vias (TSV) establish the electrical interconnection of sensor and readout wafers for each individual SPAD. Utilizing this technology, a versatile SPAD-based detector with photon timing as well as counting capabili-ties was developed and successfully applied in LiDAR (Light Detection and Ranging), quantum imaging and quantum number generation [2]. This technology enables integration of high-performance circuits to en-hance the digital SiPM and could make separate front-end-electronic ASICs in detection modules redun-dant. Additionally, multiple techniques in CMOS processing as well as post-processing are shown to en-hance the detection probability and efficiency in specific spectral regions to optimize the performance for various applications.

The combination of these technologies promises great potential for highly integrated, low-noise, efficient and high-resolution digital SiPM. High flexibility in design, improvements by CMOS- as well as post-processing and the availability of a reliable 3D integration technology enable a viable path towards small to medium volume fabrication of enhanced detectors for Cherenkov radiation.

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