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3D Digital SiPM with High Single Photon Timing Resolution for Radiation Instrumentation and Photon Science

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Medical imaging such as positron emission tomography (PET) and high energy physics experiments such as time imaging calorimetry are among examples that would benefit from better timing resolution and use time-of-flight (ToF) measurements to improve image contrast or mitigate pileup. The single photon timing resolution (SPTR) is the timing resolution of the photodetector and readout electronics when triggered by a single photon. This performance is an important feature for ToF PET in order to take advantage of the timing information of the first emitted scintillation photons. One of the biggest challenges in the development of photodetectors for these applications is combining high photodetection efficiency (PDE) with high SPTR. Current SiPMs have a high PDE, but are limited in SPTR by two factors. First, the photodetector has a high output capacitance which affects the rise time and thus the SPTR. Second, the SPAD position in the array has different timing skew generating a time jitter according to geographical light detection. The solution proposed to obtain ToF capabilities with high SPTR and high PDE is a 3D digital SiPM in which every SPAD are individually connected to a readout circuit and a Time-to-Digital Converter (TDC). This approach will minimize the aforementioned limitations of current SiPMs and will offer additional functionalities. While the 3D integration process with an industrial partner is underway, we realized a 2D version of the different components of the detector such as SPAD, readout circuit, TDC, array readout and on-chip post-processing. This presentation will be an overview of the implemented architecture and the different features that can be added for specific applications such as dark noise suppression, energy estimation, timing estimation and photon counting. Furthermore, prototypes'measurements demonstrating sub 10 ps timing resolution for a SPAD and its readout in TSMC CMOS 65 nm will be presented (current measurement 8 ps FWHM). This will change the paradigm and approach to many physics experiments.

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