Non-destructive readout in CMOS technology.

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Skipper-CCDs have an output readout stage with a floating gate that allows multiple non-destructive sampling of the charge packet for each pixel. After averaging the multiple samples, it is possible to achieve an extremely low readout noise of $0.068\, e^-_{rms}/pix$, reaching the absolute theoretical limit of silicon of 1.1 eV in energy threshold. This technology has been recently proved in [2], and its development has been motivated to provide the technology needed to build the next generation of Dark Matter (DM) and neutrino experiments that will be at the forefront of exploring physics beyond the Standard Model. The *Sub-Electron Noise Skipper-CCD Experimental Instrument* (SENSEI), has produced world-leading constraints on low mass dark matter searches [3]. The extremely low readout noise of Skipper-CCD allows the detection of single photons in the optical and near-infrared range. Unlike other silicon detectors with an avalanche gain, with Skipper-CCDs it is possible to count the exact number of electrons per pixel and therefore the number of photons that interacted on each pixel, being only limited by the Fano noise [4] [5]. Skipper-CCDs has been identified as a powerful tool for quantum information science, giving access to entangled measurements in momentum and spatial variables for single photons, with the initial demonstration recently completed at Fermilab.

Skipper-CCDs are fabricated in a dedicated facility using a customized process for scientific CCDs [6]. This process is required to produce the overlapping of the gates structures needed to achieve high charge transfer efficiency between pixels. Due to the very low demand of scientific CCDs, compared to commercial CMOS imagers, the number of facilities dedicated to scientific CCDs has been reduced to only a few in the world today, and this number is expected to continue dropping [7]. On the other hand, imagers fabricated in CMOS process have dominated the market of high-demand consumer cameras, and therefore several fabrication facilities with many processing options are available. Moreover, previous works have successfully implemented CCDs in different single-poly CMOS fabrication technologies achieving high charge transfer efficiencies [8][9][10][11], and the possibility to implement Skipper-CCDs in CMOS have been recently analyzed in [12]. The scaling of CMOS technology of at least 100 nm has allowed the implementation of pixels with a very low capacity, and therefore, high sensitivity and low noise (1-2 e^-) at room temperature and high frame rates (50-100 fps) [13][14].

The aim of this effort is to demonstrate the non-destructive charge readout of Skipper-CCD technology in CMOS technology and benefits from the mainstream commercial integrated circuits developments. This will bring the possibility to achieve an imager composed of pixels with extremely low readout noise, that allows single-photon detection. Also, this effort address directly the current challenge in the fabrication of scientific skipper-CCDs. It will have the additional advantage of allowing in-chip integration of a video processing stage (on-chip ADC), with the potential of converting the Skipper-CCD into a fully digital device. This development will provide the necessary detectors for future dark-matter and neutrino experiments, astronomy and quantum imaging that require increase the readout speed of the actual available Skipper-CCDs.

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