Advances and Optimizations of CMOS sensors for Charged-Particle Imaging

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Direct-detection CMOS image sensors optimized for charged-particle imaging applications, such as particle physics and electron microscopy, have been designed, fabricated and characterized. These devices directly image charged particles without reliance on image-degrading hybrid technologies such as the use of scintillating phosphor screens. Based on standard CMOS Active Pixel Sensor (APS) technology, the sensor arrays uses an 8 to 20 µm epitaxial layer that acts as a thicker sensitive region in the generation and collection of ionization electrons resulting from impinging high-energy particles. A wide range of optimizations to this technology have been developed via simulation and experimental device design. This includes the measurement of charge collection efficiency vs. recombination, effect of diode size vs. signal gain and noise, effect of different epitaxial silicon depths, the impact of random telegraph noise in small-capacitance pixels, comparisons to Monte-Carlo simulations and the implementation of per-pixel correlated double sampling and other noise-reduction technologies. Details of several experimental devices and full-scale prototypes will be presented, including prototypes for vertex detection applications and two complete high-resolution cameras for Electron Microscopy. The two EM cameras have 550 by 512 pixels and 1k by 1k pixels, both with a 5 pixel micrometer pitch. Temporal noise was measured to be slightly 0.9 mV RMS, and the dynamic range was 60 dB. Power consumption at 70 frames/s is 20 mW. Approximating the single incident-electron point-spread distribution as a Gaussian, the full-width half-maximum (FWHM) of the collected ionization electron distribution was found to be 5.5 µm, giving a spatial resolution of approximately 2.3 µm for individual incident electrons, and the modulation transfer function at the Nyquist limit was estimated to be 32 %. Finally, sample images taken with the EM camera will be presented, along with plans for future developments for both vertex detection and microscopy.