An Integrated Circuit for Future X-ray Imaging Detectors based on a Ge Pillars Absorption Layer

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We have developed an integrated circuit for single X-ray photon counting. The circuit will be coupled with a Ge layer which acts as an X-ray absorber material for a new generation of X-ray imaging detectors for applications in various fields from medical imaging to physics experiments. The proposed solution has potential advantages in terms of cost, reliability and modularity compared to the state of the art.

This work has been developed in the framework of the SNFS-NOVIPIX project. The goal of the project is the realization of a novel topology of X-ray imaging detector based on a germanium absorption layer intended to be readout by a single photon counting circuit. In the NOVIPIX concept, a hetero-junction diode (sensing element of the pixel) is formed between the wafer substrate (n-type) and a germanium layer (p-type) deposited on the backside of a thinned CMOS wafer. The germanium layer is deposited as structured pillars [1], taking also advantage of the CSEM MEMS capabilities. The diode formed in this way allows for the design of a monolithic detector with advantages in terms of cost, reliability and modularity compared to single photon detectors (e.g. HPD, Hybrid-Pixel Detectors) where a silicon detector has to be bump-bonded to the CMOS readout IC. Applying a sufficiently high negative voltage on this diode, a depletion region is formed between the Ge pillars and the wafer substrate. Figure 1 shows a lateral view of the pixel under development within this project. When an X-ray photon is absorbed, electron-hole pairs are created and, while holes are collected at the common cathode, electrons are collected by a pixel anode. Since the total charge collected at the anode is proportional to the energy released by the incident photon, a proper circuit can be placed inside each pixel in order to count (photon counting) the number of incoming photons exceeding one or more given thresholds.

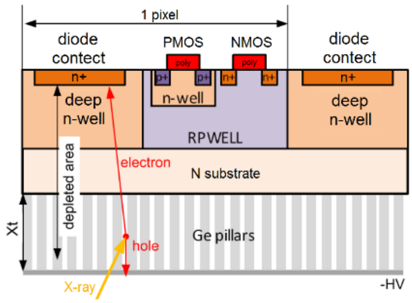

Figure 1: Lateral view of the NOVIPIX pixel.

As germanium has a higher absorption coefficient than silicon, a detector made of germanium has the great advantage of a wider energy range of applications (e.g. 20-80 keV) whereas traditional silicon detectors have very low efficiency. The higher efficiency of such a detector is also advantageous for low energy X-ray medical imaging (e.g. mammography) because a smaller total ionizing dose is required. However, the unconventional diode formation and smaller bandgap material (0.67 eV of Ge vs 1.12 eV of Si) result in a higher leakage current from the detector (expected in the mA/cm^2 range) that has to be compensated by the analog front end.

Recently, CSEM has developed a photon counting chip for a similar project [2]. Starting from that result, a new design has been carried out to reduce the pixel size (reducing the leakage current per pixel) while concurrently enhancing the functionalities by adding a second threshold discrimination capability (dual energy discrimination). The new circuit is implemented on a 16 × 16 pixels array (each pixel is 100 × 100 µm) and has been designed in a 0.15 µm CMOS technology. Figure 2 shows the structure of a single pixel.

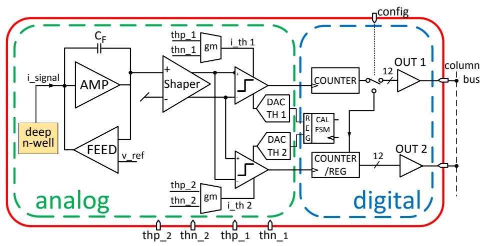

Figure 2. Building blocks of the single pixel.

The pixel architecture can be logically split in two parts: An analog front-end (green dashed box in Figure 2) and a digital back end (blue in Figure 2). The analog front-end is composed of a charge sensitive amplifier with a feedback circuit to compensate for the detector leakage current. This feedback block has been designed to guarantee stability with a leakage current up to 1 µA per pixel. After a shaping stage (bandpass CR-RC), the signal is converted into the digital domain by two continuous-time comparators designed to achieve good performances with a small area and low-power consumption. The thresholds are set by global references common to all pixels. Two 6-bits DACs (one per comparator) and a finite state machine are added to calibrate the thresholds mismatch. The outputs of the discriminators are then counted (each counter is incremented at every discriminator commutation) by two 12-bit ripple counters that store the number of photons exceeding each respective threshold during an acquisition. The output of the pixel is purely digital. An alternative configuration uses the second counter as a register and allows a simultaneous acquisition and reading (single threshold detection). The chip peripheral circuits include some bias generators and digital logic, providing row synchronization and serialization of the column outputs. The pixel power consumption is 18 µW.

The chip is currently under test and will be submitted soon for the final integration with the germanium layer.

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[1] C. V. Falub, *et al.*, "Scaling hetero-epitaxy from layers to three dimensional crystals", Science 335 (2012) 1330.

[2] Y. Zha, *et al.*, "Pulse counting energy-sensitive X-ray detector IC", CSEM Scientific and Technical Report (2013) 102.