X-Ray Photon Counting Chip with Backside Detector

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CSEM has developed an integrated circuit for single X-ray photon counting. The circuit is coupled with 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.

X-ray photon counting with energy discrimination opens the door to X-ray color imaging, offering advantages in term of tissue or material discrimination. Furthermore, the use of direct X-ray detection provides for sharper images, as well as reduced X-ray dose, compared to indirect detection based on a scintillator coupled to an image sensor. The state-of-the-art direct detectors exploit silicon (Si) or cadmium telleuride (CdTe) absorbers bump bonded to a readout circuit. Here we present an alternative approach that relies on a germanium (Ge) as the absorber material on the backside of a readout chip. The absorber is formed from germanium pillars grown on a p-type wafer. The absorber is subsequently covalently bonded by a low-temperature process to the backside of a readout chip (n-type wafer) thinned down to a thickness of 15 µm. This forms a heterojunction at the interface between the readout and absorber wafers. A schematic cross section of the detector is shown in Figure 1. When an X-ray photon is absorbed, electron-hole pairs are created and the holes are then collected at the common cathode and the electrons are collected by the 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.

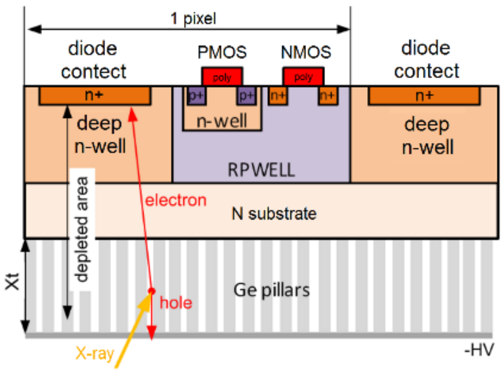

Figure 1: Lateral view of the pixel.

As germanium has a higher absorption coefficient than Silicon, an absorber made of germanium has the great advantage of a wider energy range of applications (e.g., 20-80 keV) whereas traditional silicon absorbers have comparatively low efficiency. The higher efficiency of a germanium absorber 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) in these germanium absorbers result in a higher leakage current (expected in the mA/cm^2 range) that needs to be compensated for by the analog front end.

A photon counting chip with an array of 16×16 pixel has been realized in a 150 nm process[1]. Figure 2 shows a microphotograph of the chip.

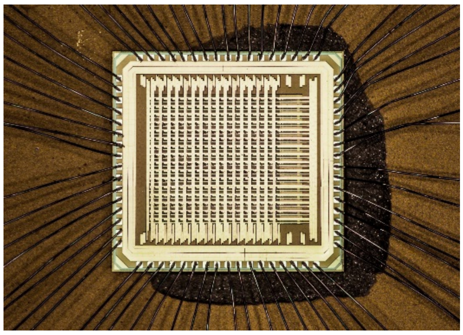

Figure 2: Microphotograph of the chip.

First trials have been done with a silicon absorber instead of a germanium absorber, with an X-ray source of 50 keV. As the active area of the chip is very small (1.6×1.6 mm), and in order to acquire large images, we mounted the target sample on an x-y-z micromanipulator acquiring images in different positions along the x and z axis combining the single acquisitions. A reconstructed image is shown in Figure 3. The number of photons counted per pixel during the exposure time is color encoded.

The next step will be to use a detector with a germanium absorber.

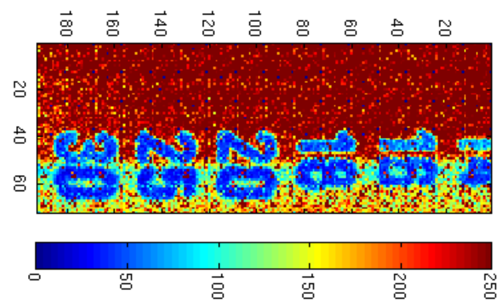

Figure 3: Reconstructed image of X-ray detection using silicon as an absorber material in the place of germanium.

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[1] R. Quaglia, *et al.*, "An integrated circuit for future X-ray imaging detectors based on a Ge pillars absorption layer", CSEM Scientific & Technical Report (2016), 109.