

Imaging Radiation Detectors for Synchrotron X-Ray Sources and Electron Microscopes

CNF Project Number: 306523

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Primary Source(s) of Research Funding: United States Department of Energy

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Primary CNF Tools Used: Cadence Virtuoso

Abstract:

Advances in the brilliance of synchrotron x-ray sources and electron microscopes have outpaced the ability of radiation detectors to efficiently capture high-resolution diffraction data. This is especially true for ptychography, a promising method that allows detailed atomic structural determination of samples even for non-periodic samples. Ptychographic diffraction data are characterized by an enormous dynamic range, with low-angle scatter often millions of times more intense than high angle data; both low- and high-angle data are required for ptychographical reconstructions. In consequence, there is need for radiation detectors that can simultaneously capture quantitative images containing very intense low-angle scatter and quantum limited single x-ray or electron data at high angles. Ptychography requires the sequential acquisition of many diffraction patterns to make a full data set; hence, a very fast image frame rate is also required. The goal of our research is to explore detector integrated circuit structures that would allow the fabrication of imaging radiation detectors to meet these challenges.

Summary of Research:

The imaging detectors being explored are Pixel Array Detectors (PADs). PADs consist of a silicon diode sensor array bump-bonded pixel-by-pixel to a pixelated Application Specific Integrated Circuit (ASIC). Each pixel in sensor layer detects incident radiation and produces an electrical signal whose charge is proportional to the integrated x-ray energy. This is conveyed by microlithographic solder connection “bump” to electronics in the corresponding ASIC pixel for processing (Figure 1).

The approach being explored is to advance the charge-pump amplifier arrangement pioneered in our laboratory [1] to provide both sensitivity and dynamic range at higher frame rates than existing detectors. The integrating amplifier that receives the sensor signal

must balance two conflicting requirements: It must have a high signal-to-noise ratio for unambiguous detection of single x-ray or electron quanta, thereby requiring a small feedback capacitor to provide high gain. At the same time a large dynamic range dictates use of a large feedback capacitor to integrate the signal from many quanta during an image exposure. The charge-pump circumvents these constraints by preventing the amplifier from reaching saturation. It does this via circuitry that constantly monitors the output of the amplifier. When the amplifier signal approaches saturation, corresponding to integration of many tens or hundreds of radiation quanta, a charge removal circuit is engaged that removes a fixed quantity of charge from the feedback amplifier capacitor and adds a bit to a digital counter. This process occurs without interrupting continued incident charge integration. At the end of the radiation exposure, the digital sum is scaled and added to the digitized value of any signal remaining on the feedback capacitor to provide the total integrated signal.

Research for the current project involved a cycle of redesign, simulation, fabrication, and testing to produce ASIC circuit structures with extended dynamic range, frame rate, and radiation hardness relative to prior designs.

Conclusions and Future Steps:

The next step is to combine the advanced circuits that were studied to produce a miniature detector to test actual radiation imaging performance. This will involve layout and fabrication of a 16x16 pixel test ASIC that will be bump-bonded to a sensor. It will also require the construction of accompanying external readout circuitry, cooling and vacuum housing and development of firmware to coordinate the many signals required to read out an image. This small prototype detector will then be tested for image acquisition performance with x-rays and in an electron microscope.

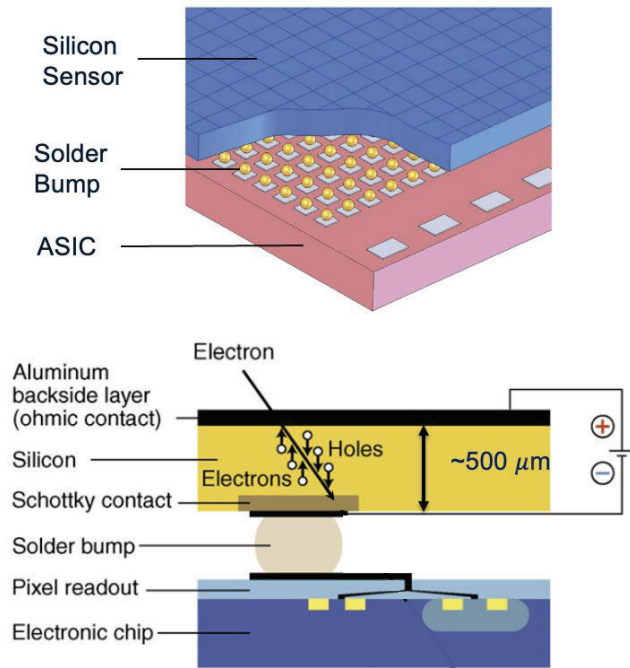


Figure 1: Simplified block diagram of a Pixel Array Detector

References:

- [1] D. Schuette (2008). A mixed analog and digital pixel array detector for synchrotron x-ray imaging. PhD thesis, Dept. of Physics, Cornell University, Ithaca, NY 14853