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PERCIVAL: Design and Characterisation of a CMOS Image Sensor for Direct Detection of Low-Energy X-Rays

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PERCIVAL (Pixelated, Energy Resolving CMOS Imager, Versatile And Large) is a wafer-scale, CMOS imager under development at Rutherford Appleton Laboratory (RAL; Didcot, UK) in collaboration with Deutsches Elektronen-Synchrotron (DESY; Hamburg, Germany), Elettra –Sincrotrone Trieste (Trieste, Italy), and Diamond Light Source (DLS; Didcot, UK).

PERCIVAL is designed for high-speed and low noise detection of soft X-rays to address the growing need for such sensors in the FEL and synchrotron research areas. It is based on a novel 27µm pitch, high dynamic range pixel, designed in a 0.18µm standard CMOS image sensor process. Specifications for the final sensor are noise below 15e-, 20 bits dynamic range, and a continuous frame rate of 120Hz with digital correlated double sampling. The sensor will be Back-Side Illuminated (BSI) in order to achieve quantum efficiency in excess of 90% in the primary energy range of 0.25 –1 keV.

The need for a high pixel resolution led to a stitched design, allowing the manufacture of large-area sensors with seamless boundaries. The final sensors will be made of repeated unity block that can be stitched to give a variety of sensor sizes. The first version of the Percival sensor will be comprised of a 1408 x 1484 array, with a second PERCIVAL sensor arriving later in a 3528 x 3717 configuration, using the full size of a 200mm CMOS wafer. With both versions a 2x2 cloverleaf module will be possible.

The pixel allows for in-pixel adaptive gain switching between the diode and three capacitors of increasing size. This gives single photon discrimination at low flux, while retaining the capability to measure higher flux when required at the cost of increased noise. Four sample readings are taken while only the result from the highest-required gain mode is then converted by the on-chip, column-parallel, 12-bit ADC. Both reset and signal frames are sampled, allowing for off-chip, or digital, Correlated Double Sampling (CDS). This is then passed through a high-speed serialiser, and read out over LVDS lines, giving a final data rate of over 50Gb/s.

The final sensor is currently being designed; we will present results from test structures undergoing optical and X-ray characterisation for both Front Side Illuminated (FSI) and BSI sensors. The method of optical characterisation to be discussed is based on the Photon Transfer Curve (PTC), derived from integration sweeps using a calibrated, uniform light source of known wavelength. The X-ray tests performed were using an Iron-55 source of known activity. This allows for corroboration of the gain results from the PTC, as well as a measure of the noise based on the spread of the Gaussian peaks from the primary emission K-alpha and K-beta X-rays.

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