High-speed and fully spectroscopic X-ray Photon Counting Pixel Detector for XRD and EDXRF

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I. Background

In XRD applications today, silicon detectors are frequently used. In some cased these are strip-detectors using relatively long strips resulting in high-capacitance and high dark-current, both limiting factors for the spectral resolution. Or, they might be pixel detectors based on photon-counting electronics which significantly degrades the spectral analysis possibility. For EDXRF applications today, the SDD detector is dominating the market. The spectral performance of the SDD is close to perfection and cannot be improved much more. The detection-rate capability, however, is quite limited. This is because its one single output channel is limiting the total throughput capability, hence causing the rate-capability per mm^2 to drop in inverse proportion to the detector surface area. A tiny area detector can consequently be relatively fast whereas a very large area detector will be very much slower when comparing their rate-capability per mm^2.

II. Our solution

A hybrid pixel detector consisting of a 2D matrix pixel-ASIC in a bump-bonded sandwich with a matched pixel Silicon-sensor has been developed. This detector concept is offering significant improvements to the abovementioned limitations through combining the advantages of small pixels and yet large area sensitivity through the general features of modern-style pixel detectors, often also found in photon-counting style detectors. As opposed to the latter, however, each pixel in our concept is equipped with full spectroscopy functionality which in combination with novel read-out architecture allows for a data-driven, high-speed transfer of full spectral data from each pixel to the computer.

III. Briefly about the principles

Figure 1 shows a physical illustration of our hybrid pixel detector in a naked form, as well as a flowchart of the electronics functionality in one of the pixels. All the other pixels also comprise the exact same functionality and they operate independently of each other in parallel. In reference to the flowchart; Upon an X-ray impact in any of the pixels, the sequence-of-events (or function when in square brackets) in that pixel is: 1. Impact of X-ray, 2. Convert to electric charge, 3. Integrate, amplify & shape signal, 4. Stretch signal to analog peak value, 5. Check if signal is above a preset threshold, 6. Create the Sample/Hold signal after a delay, 7. Sample/Hold the analog peak value, [8. Stored pixel address], 9. Check if data-bus is free, 10. Make claim of the data-bus, 11. Enable the analog output ports, [12. Analog Output Port], 13. Output of the data, [14. Preset Delay], 15. Reset all.

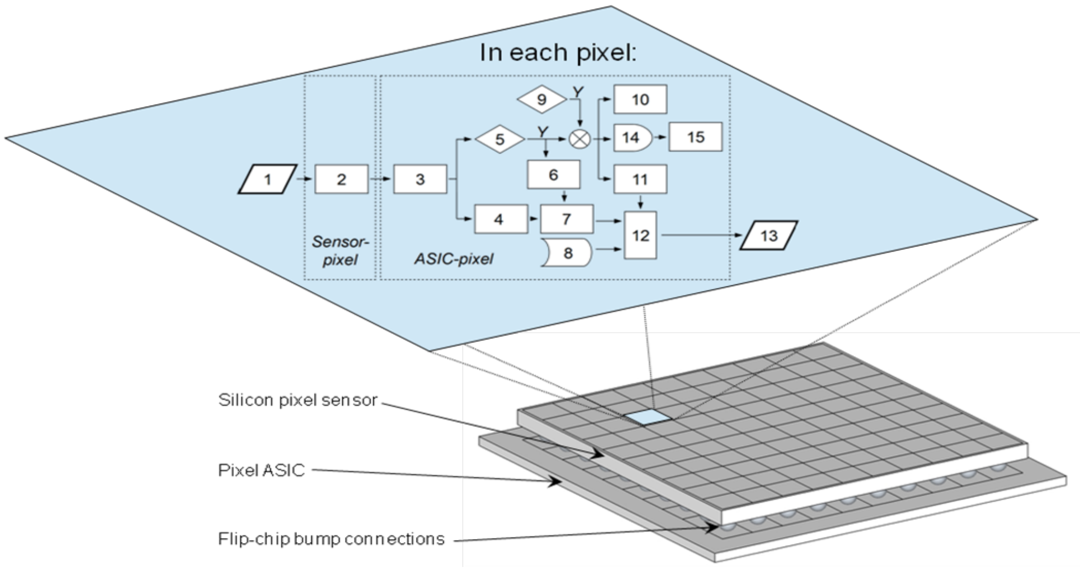

Figure 1. The functionality of a pixel

In the phase of outputting of the data, sequence 13 in the flowchart, an analog packet of data is automatically "pushed" from the pixel and to the Data-Acquisition-System (DAQ, Figure 2). The transfer of the data-packets can be significantly faster than the average time between pixel-events, and so the data-transfer bus can be shared between many pixels (by assistance of a "traffic-control" mechanism and local buffering). Depending on chosen configuration the system will typically also use parallel data-transfer buses. In the current prototype of 10x10 pixels, groups of 10 pixels share one bus and there are hence 10 parallel buses.

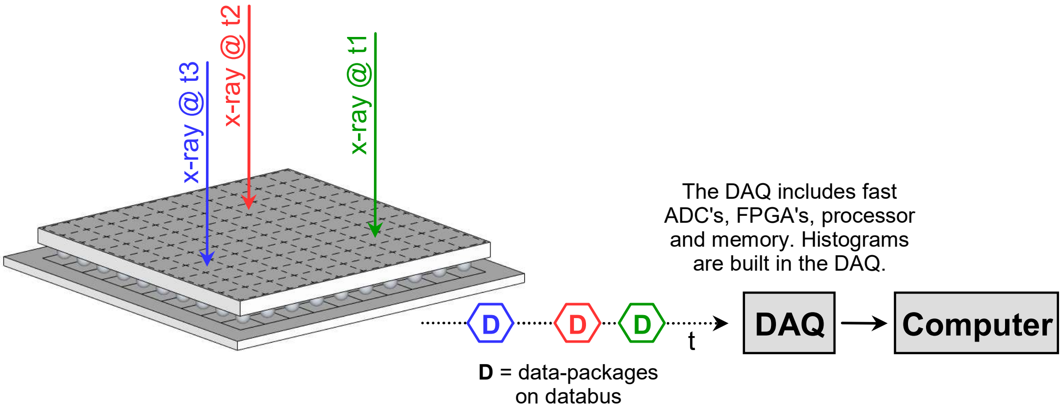

Figure 2. The transfer of data-packages

IV. RESULTS

A current prototype of the concept is implemented in a 10×10 pixel matrix with a pixel-size of 250µm×250µm yielding a total surface area of 6.25mm^2 (Figure 3). The Silicon sensor is about 0.5mm thick and is developed by Hamamatsu Photonics. We have demonstrated a spectral resolution of 250eV FWHM (@5.9keV), measured at a sensor temperature of -10°C (Figure 4), and a rate-capability of up to 500 kcps per pixel (Figure 5). With the current pixel-size of 250µm×250µm (yielding 16 pixels/mm^2) the latter corresponds to a rate-capability of 8 Mcps/mm^2.

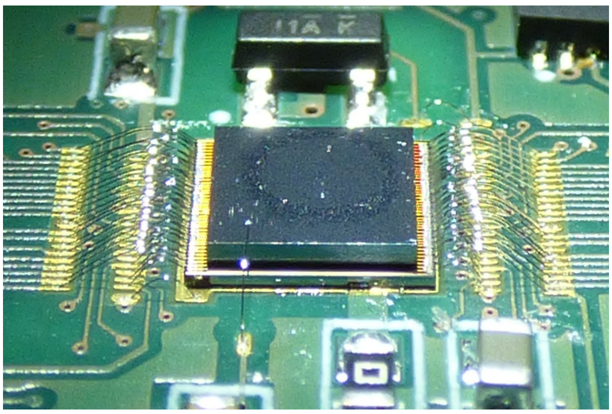

Figure 3. Our Hybrid Pixel Detector prototype

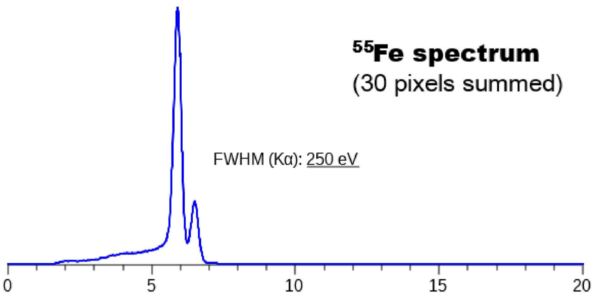

Figure 4. ^{55}Fe XRF spectrum

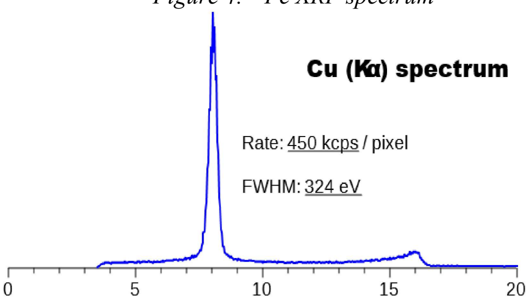

Figure 5. High speed performance

V. FUTURE DEVELOPMENT

In looking ahead for next versions to be made based on this concept, we are pursuing two paths. A first path, where we optimize for XRD with the goal to achieve fine pitch (< 100µm), large area and very high detection rate. And a second path, where we optimize for EDXRF with the goal to achieve very high detection rate and a spectral-resolution comparable to state-of-the-art SDD (~125eV).

Example: If using the same 16 pixels/mm2 as in the prototype, and the same amplifier, a 100mm^2 surface area detector which is in the ballpark of what we aim to develop next, will have the potential to achieve an overall rate-capability of up to 800 Mcps with full spectroscopy, nearly 3 orders of magnitude faster than a conventional SDD detector.

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