Hybrid Pixel Detector for XRD and EDXRF

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Project objective:

To combine in one and the same detector concept, application for both X-ray Diffraction (XRD) and Energy-Dispersive X-ray Fluorescence (EDXRF), with superior performance in both cases. In particular for (respectively):

- XRD: Full-spectroscopy* superior spectral resolution (not photon-counting** style spectroscopy). Superior speed capability, comparable to photon-counting style.
- EDXRF: Superior speed capability compared with Silicon Drift Detectors (SDD). Spectral resolution comparable to SDD.

** Defined herein as single photon energy measurements by means of high resolution ADC.*
*** Defined herein as photon-counting by means of discriminator(s) and counter(s).*

Background:

Both strip- and pixel- geometry are used in XRD detectors today. The strip-type (Fig 1) has an inherent unexploited potential in the spectral resolution possible to obtain, because of the relatively large single-segment detection area adding to the capacitance and dark-current. For same reason, the full potential of detection speed is neither fully exploited.

The hybrid-pixel type used for XRD (Fig 2), however, does not have the limitation mentioned above regarding the strip-type, because of its ability to implement very small single-segment detection area. However, the current method for reading out these pixels is by means of the quite simplistic photon-counting style, which does not allow for full-spectroscopy, limiting the spectral information and resolution.

The most commonly used EDXRF detector today is based on the SDD principle. The spectral performance of the SDD is near 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 surface-area 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.

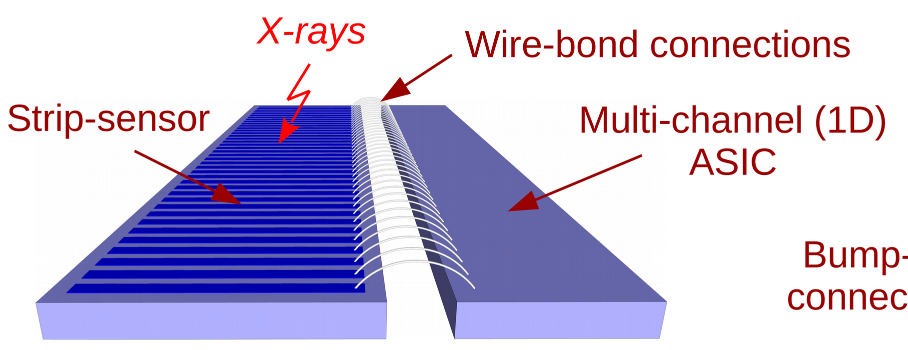


Fig 1: Classic strip detector arrangement (1D only)

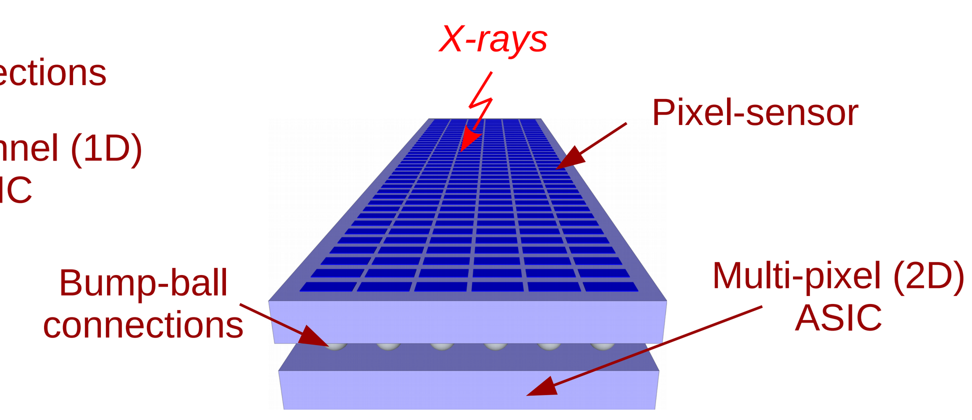


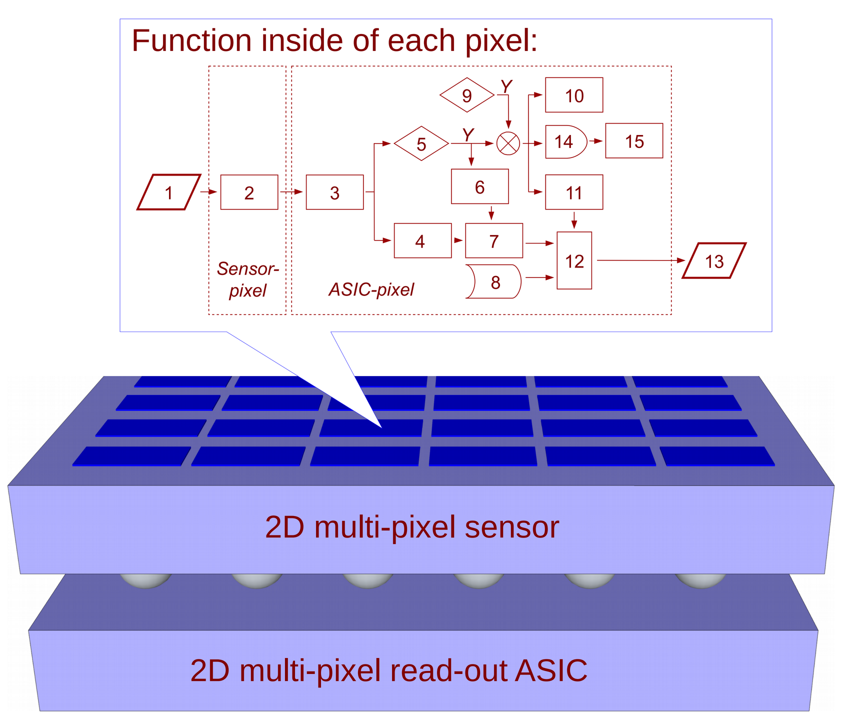
Fig 2: Classic pixel detector arrangement (1D and 2D)

Our solution:

We have developed a novel type of detector which also is based on the geometrical concept of hybrid-pixel detector (Fig 2), since this detector arrangement has no inherent limitations on what can be achieved with respect to spectral resolution and detection speed in these kind of detectors. These potentials just hasn't been fully exploited until now for XRD and EDXRF usage.

The key to unlock these potentials is in the front-end electronics, being the 2D multi-pixel read-out ASIC (bottom part in Fig 2), and mostly related to the electronics functionality inside of each pixel. The new functionality we have developed is explained in Fig. 3.

In the phase of outputting of the data, i.e. sequence 13 in Fig 3, an analog packet of data is automatically “pushed” from the pixel and to the Data-Acquisition-System (DAQ), Fig 4. 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.



1.X-ray impact (Input)
2.Convert to electric charge
3.Low-noise integrate, amplify & shape signal
4.Strech signal to analog peak value (= proportional to x-ray energy)
5.Check if signal is above a preset threshold
6.Create the Sample/Hold signal (after some delay)
7.Sample/Hold the analog peak value
8.Stored pixel address (as analog signal level)
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

Fig 3: The functionality inside of each pixel in our concept

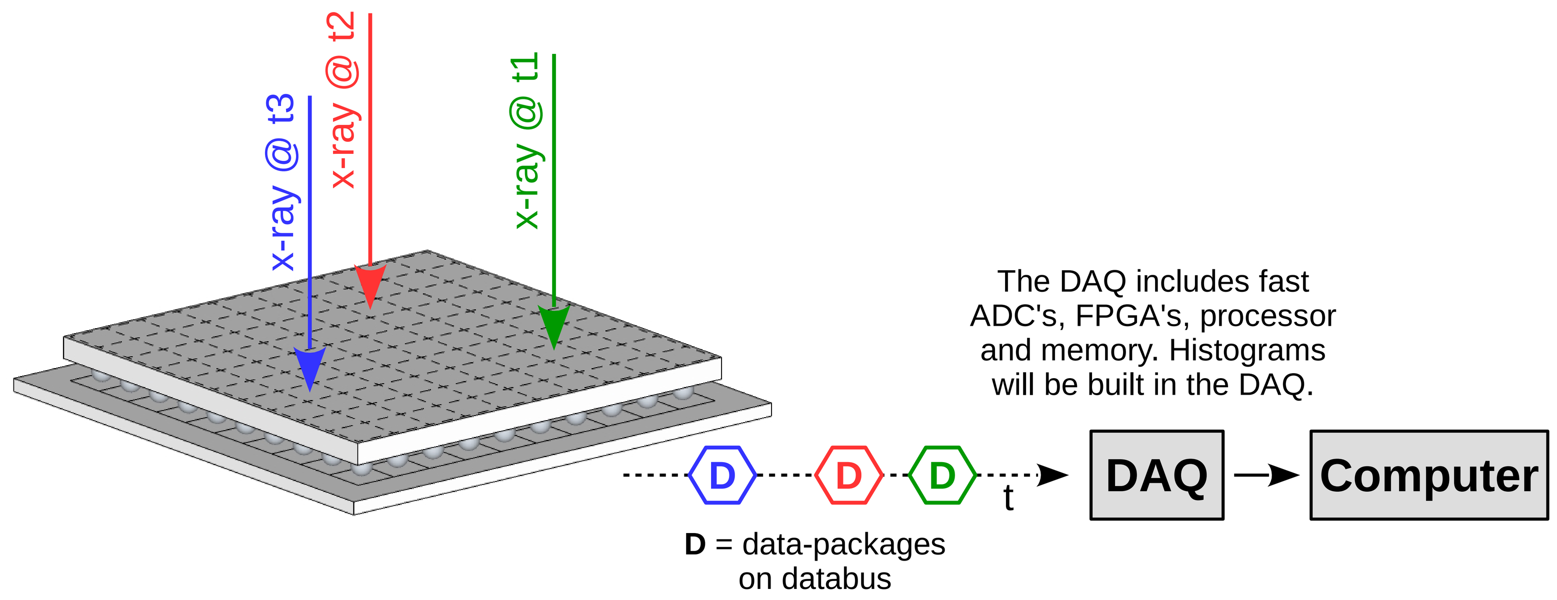


Fig 4: The transfer of data-packages

Results:

We have implemented this new concept in a 10×10 pixel matrix prototype using pixel-size of 250µm×250µm, yielding a total surface area of 6.25mm^2, Fig 5. The excellent Silicon sensor is about 0.5mm thick and is developed, and supplied in support of this project, by Hamamatsu Photonics.

We have demonstrated a spectral resolution of 250eV FWHM (@5.9keV), Fig 6, measured at a sensor temperature of -10℃. A detection speed per pixel of about 100.000 photons/second is observed. The pixel speed can be upheld for the entire detector, limited only by the designed capacity of the DAQ.

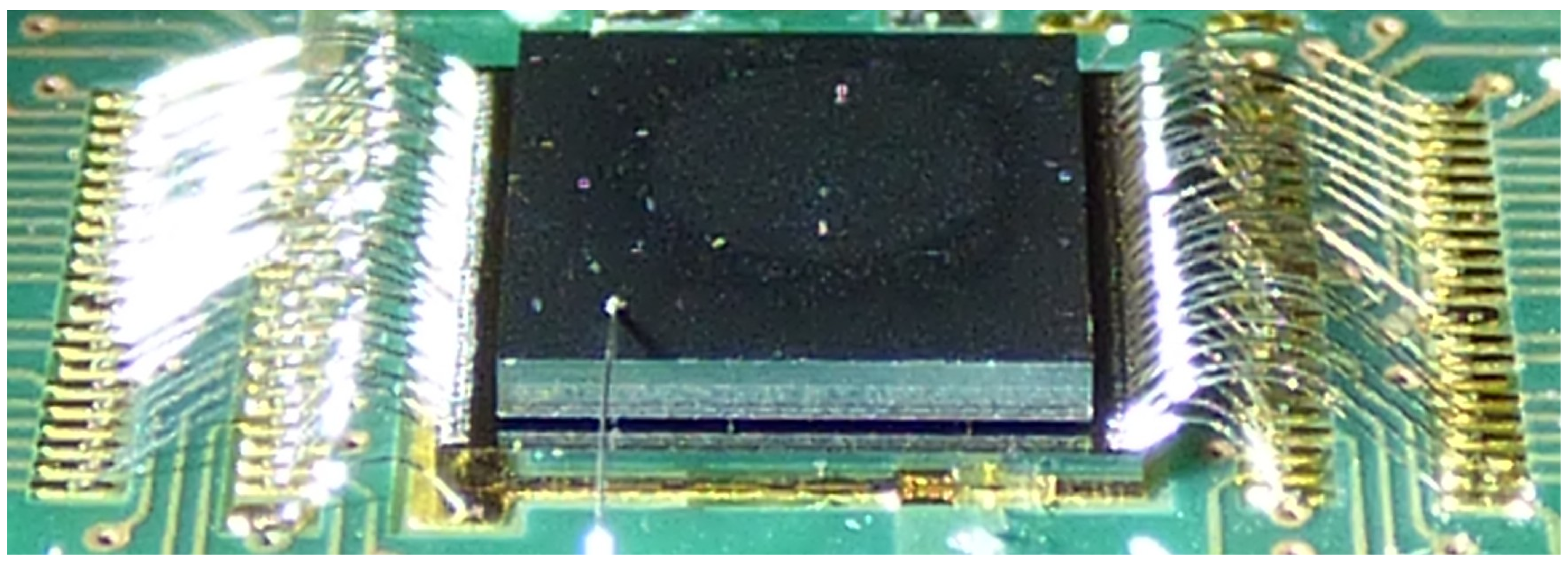


Fig 5: Photo of our hybrid pixel detector prototype

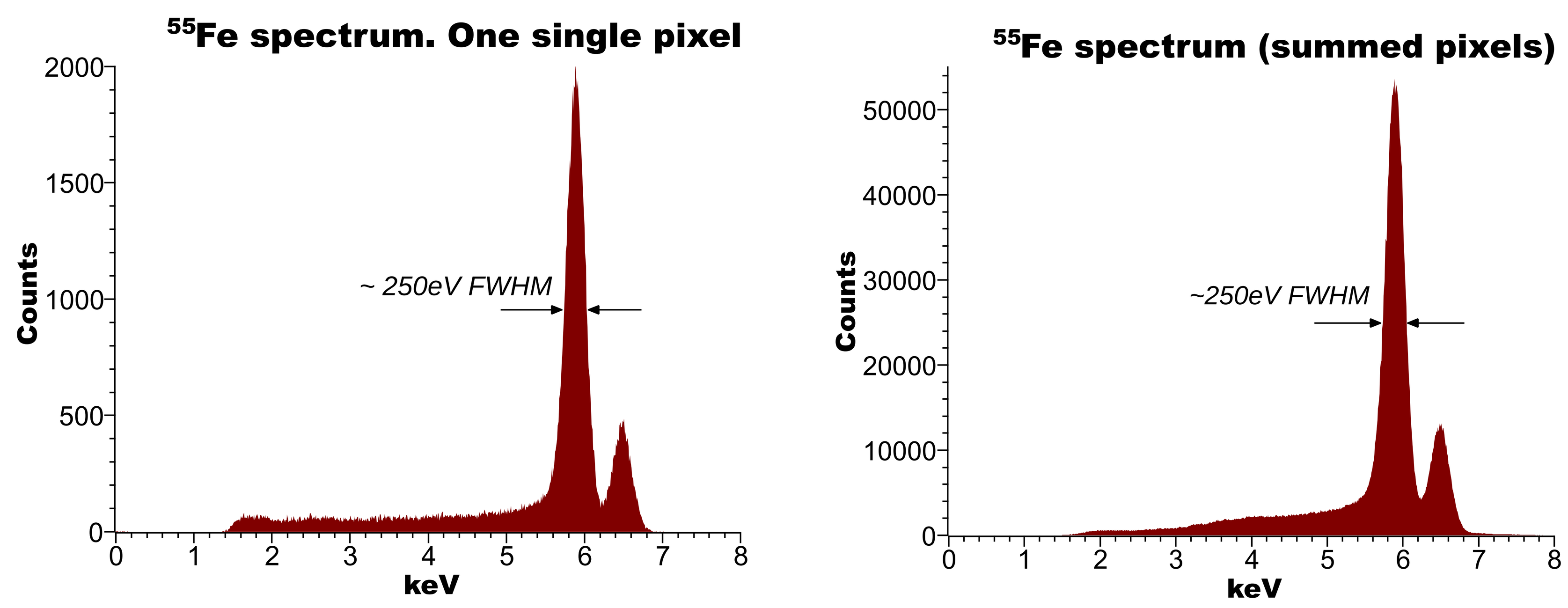


Fig 5: Spectra obtained using 55Fe source*

** Note: To obtain the full detection speed benefit for EDXRF usage, the single spectra of all the pixels needs to be summed in one cumulative spectrum. In the spectrum of the right hand side of the figure, this is done for 30 pixels, demonstrating negligible loss in spectral resolution in doing this.*

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).

XRD and EDXRF combined in one detector: One and the same version of our detector concept can be used both for XRD and EDXRF. In EDXRF, spatial information is not needed and the geometrical aspect ratio of the surface of the pixel is not decisively important. It will therefore perform in EDXRF also with elongated rectangular pixels (similar to the depiction of these in Fig 2&3). In XRD, however, the entire row of pixels, horizontal in these figures, will constitute one segmented line in a 1D XRD detector. This segmentation is what secures a significant improvement in detection speed and spectral resolution in comparison to the strip-type detector arrangement (Fig 1).

Acknowledgment:

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