

Experimental investigation of the imaging capabilities of a DEPFET ladder of the DSSC X-ray camera at the European XFEL



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Introduction

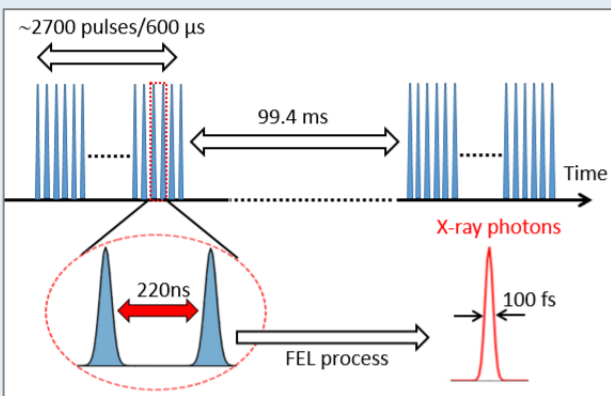


Fig. 1. X-ray bunch structure at the European XFEL. Adapted from [1].

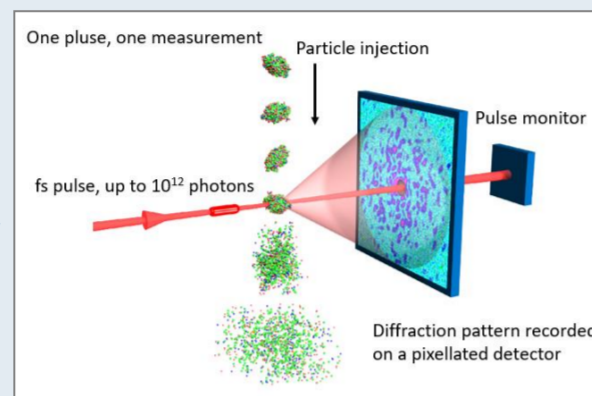


Fig. 2. Coherent diffractive imaging of single particles "diffraction before destruction" [2].

The unique bunch scheme of the European XFEL facility imposes rigorous restrictions on the development of X-ray imaging detectors intended for time-resolved experiments:

- High repetition rate and short pulses: delivery of up to 2700 pulses with 220 ns interspacing, resulting in an operation at a maximum frame rate of 4.5 MHz.
- From few photon to bright X-ray pulses: detection of photon flashes.

DSSC Project: Development of a novel X-ray imaging detector named **DSSC (DEPFET Sensor with Signal Compression)** to meet all of the above-mentioned requirements specified by the European XFEL [3].

Main features of DSSC detector

- Megapixel X-ray camera operating with a maximum frame rate of up to 4.5 MHz being developed by an international DSSC consortium and foreseen for fast imaging experiments using soft X-rays (250 eV to 6 keV) at EuXFEL (SCS and SQS instruments).
- Based on a silicon pixel sensor with a non-linear DEPFET as a central amplifier structure, providing thus the non-linear response of the detector.
- Non-linear DEPFET technology has the capability to handle the required dynamic range and achieve single photon resolution at Mega-frame rate due to the very low noise.
- DSSC detector is divided into four quadrants and each quadrant consists of four independent ladders.
- DSSC possesses 1024x1024 hexagonal pixels and the pixel size is in the order of 200 μm x 200 μm.
- DSSC has a detection efficiency closer to 100% for soft X-rays and a dynamic range of several thousand photons per pixel [4, 5].

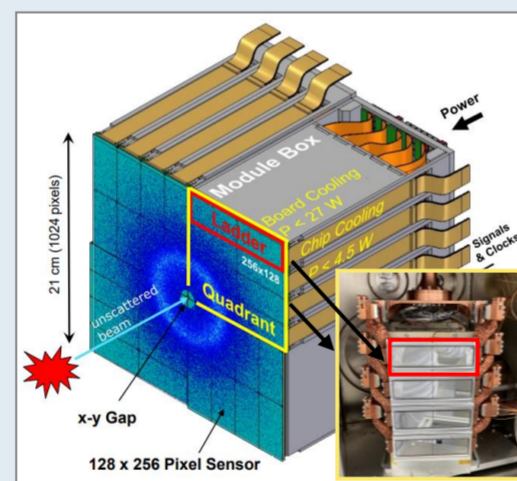
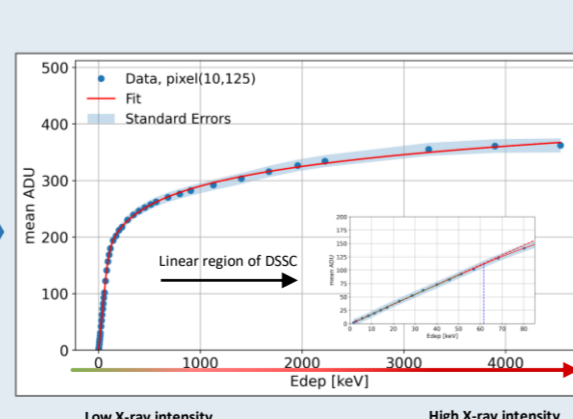
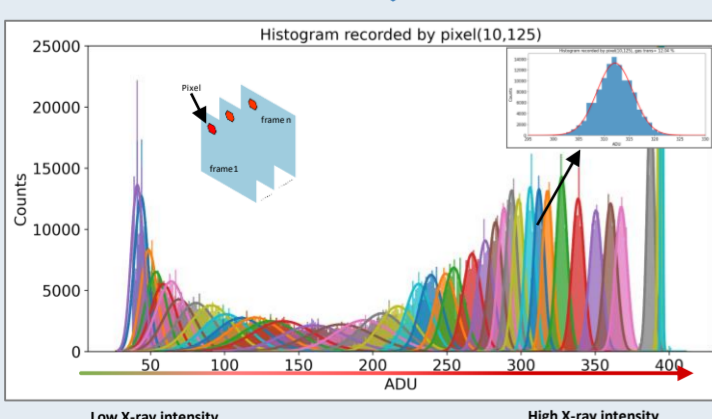
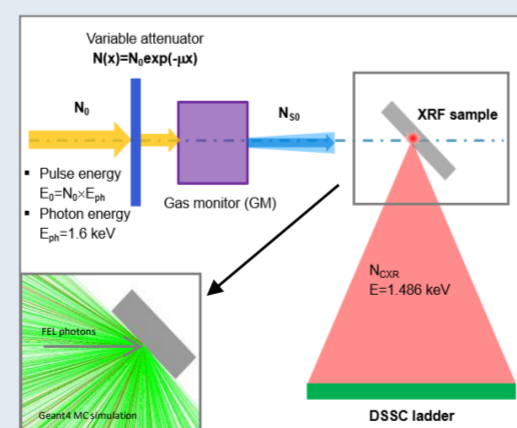
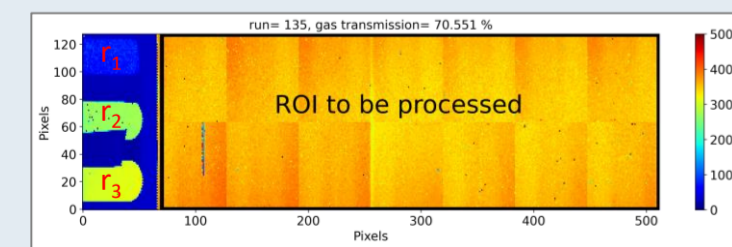


Fig. 3: 3-D view of the DSSC detector [6]. The inset figure shows a real DSSC quadrant consisting of four ladders.

Beam time at XFEL SQS beam line

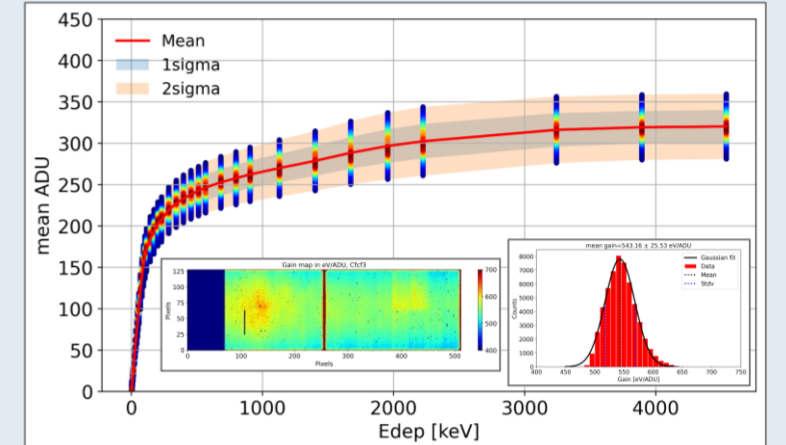
Investigation of the functionality and the key features of one DEPFET ladder (512 x 128 pixels) of the DSSC X-ray camera at XFEL SQS beam line (24-26.11. 2022)

- Assessing the Capability of DSSC pixels to detect single photons.
- Measuring the NL response curves of pixels.
- DSSC calibration and noise performance evaluation.
- r_1 : 50 μm, r_2 : 25 μm and r_3 : 15 μm Al filters.



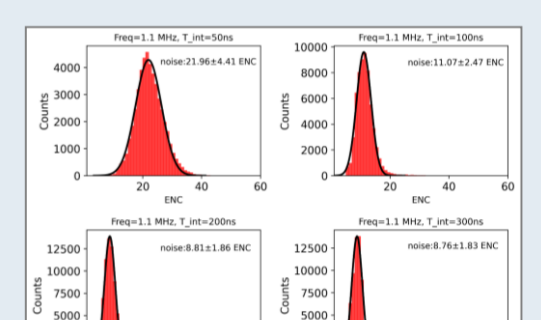
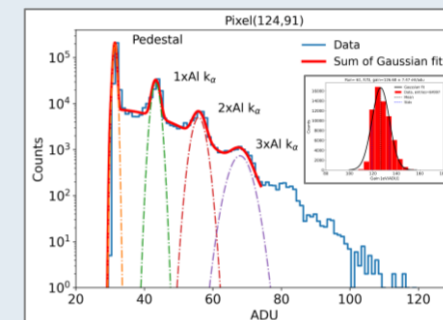
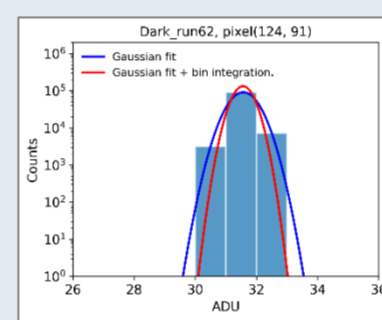
Non-linear response curves of DSSC pixels

- Linear region: single photons resolution.
- Non-linear region: high dynamic range.
- Gain of each pixel can be determined by the slope of the linear region of the NLR curve of the DSSC pixels.
- Mean gain at 2.2 MHz, integration time T_{intg} = 100 ns and T = 18 °C: μ_{gain} = 543.16 ± 25.53 eV/ADU

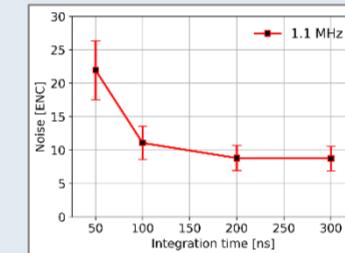


Noise performance

- Noise is calculated at +18°C and integration times spanning from 50 ns to 300 ns.

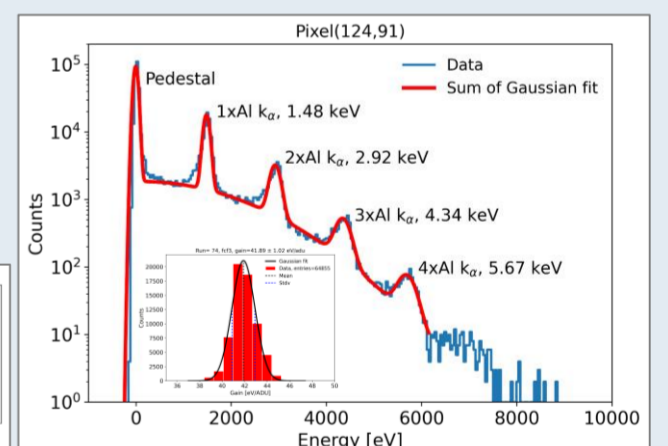
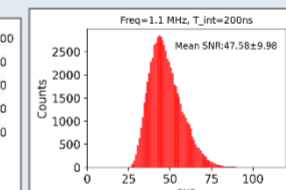
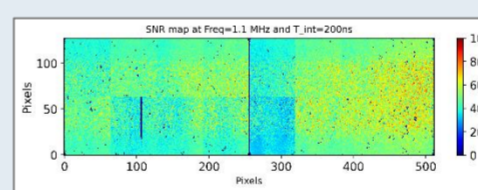


- F = 1.1 MHz, T_{intg} = 100 ns
- Gaussian: 31.57 ± 0.41
- Gaussian + bin intg.: 31.56 ± 0.3
- Pixel gain: 122 eV/adu
- Pixel noise: 10.1 ENC
- Pixel(124, 91) SNR = 40



Single photon resolution

- Single photon detection requires a high pixel gain, linear response and high quality data.
- Freq = 1.1 MHz, T_{intg} = 300 ns, T = 18 °C
- Mean noise in equivalent noise charge (ENC): μ_{noise} = 8.7 ± 1.8 ENC
- Very high gain was achieved: 42 eV/adu.
- Single photon detection capability with SNR = 44
- Mean SNR of all pixels: SNR = 47.58 ± 9.98



Summary

- DEPFET-DSSC ladder was successfully tested and instrumented at SQS beam line
- DSSC response curve has a linear region up to 82 keV, which enables single photon resolution, while the non-linear region provides a high dynamic range.
- DEPFET-DSSC has demonstrated very low noise and great spectroscopic performance.
- Dynamic range of approximately 3100 Al K_α photons of 1.48 keV was achieved at 2.2 MHz.
- Single photons were detected with an impressive noise of about 8 ENC and SNR=44.
- These results highlight the suitability of the DSSC project for fulfilling the needs of the soft X-ray instruments at the European XFEL.

Reference

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