Fourth generation accelerator-based light sources, such as VUV and X-ray Free Electron Lasers (FEL), deliver ultra-brilliant ($\sim 10^{12}$-$10^{13}$ photons per bunch) coherent radiation in femtosecond ($\sim 10$ fs to 100 fs) pulses and, thus, require novel focal plane instrumentation in order to fully exploit their unique capabilities. As an additional challenge for detection devices, existing FELs (FLASH, Hamburg, LCLS, Menlo Park; SACLA, Hyogo) cover a broad range of photon energies from the EUV to the X-ray regime with significantly different bandwidths, intensities and pulse structures.

In order to meet these challenges, a novel, large area, broadband (50 eV to 25 keV), high-dynamic-range, intensity and spectroscopic imaging X-ray detector based on the pnCCDs has been established [1]. The sensor covers an area of 60 cm$^2$ with 1024 x 1024 pixels and 10,000 x 10,000 spatial resolution points, including a hole in the center for the non-scattered X-rays. They have been operated up to 120 Hz in a full frame high resolution mode. The pnCCD detectors have been used in experiments from 30 eV (FLASH) up to 9.5 keV (LCLS, SACLA). The sensitive thickness of the fully depleted, fully sensitive CCDs is 450 µm. As the detectors are back-illuminated, an ultra-thin radiation entrance window has been developed to achieve clean energy spectra and high quantum efficiency for the lowest to the highest energies. Some of the detectors are equipped with integrated light blocking filters to avoid signal deterioration through visible light (see Fig. 1).

Different classes of experiments have been performed, each going towards the physical limits of measurement precision of the detectors: highest energy resolution (see Fig. 2) (atomic physics), the highest dynamic range (nano-crystallography), imaging of biological samples and X-ray scattering experiments (Bond orientational order of liquid and supercooled water) requiring a position resolution well below 10 µm. For all of the above experiments optimizations have been realized to fulfill the experimental requirements. The deep subpixel resolution and the controlled extraction mode of the detectors have already been demonstrated at the light sources [2]. Fig.3 shows the improvement of the charge handling capacity from $3 \times 10^6$ electrons per pixel to more than $1.5 \times 10^6$ measured at LCLS. The better understanding of the detector physics and data analysis leads to an optimization of operation modes for specific experiments, enabling for the development of new and more precise measurement methods. Detectors of this type will be used in X-ray microscopy this summer. Measurements from this application will be shown equally.

Fig. 1: Image of the pnCCD detectors on a 150 mm Si-wafer. The central chip has an area of 60 cm$^2$, a pixel size of 75x75 µm$^2$ and a format of 1024x1024. The sensitive thickness is 450 µm. It has a center hole for the passage of the non-scattered X-rays.

Fig. 2: X-ray emission of highly excited Xe –atoms (35+) at an LCLS experiment. The excitation energy was 1.5 keV, the energy resolution is approx. 100 eV (FWHM) at 1.5 keV, integrated over an area of 60 cm$^2$ with a frame rate of 120 Hz of a 1024 x 1024 format of the pnCCD spectroscopic X-ray imaging array.

Fig. 3: Left: charges over flooding neighboring pixels. The max. charge handling capacity (CHC) in approx. $3 \times 10^5$ electrons per pixel for this standard setting. Right: The same scattering process with a CHC of approx. $1.5 \times 10^6$ electrons per pixel due to different operating conditions of the same detector.