Ultra fast direct electron detection for use in ptychography with (S)TEM

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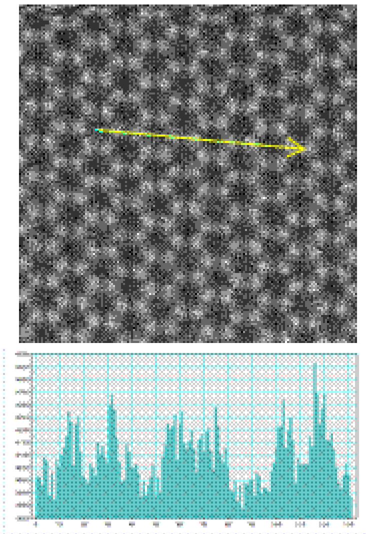
Ptychographic techniques require detection systems with good imaging capability, amplitude and spatial resolution and most importantly a high frame rate and a real-time display of the recorded data. Ptychographic measurements are usually performed with photons and with electrons. With both types of radiation, we have performed phase retrieving measurements. With X-rays those measurements were performed in X-rays microscopes (XRM) while scanning transmission electron microscopes (STEM) were used in the case of electrons. Up to now these measurements are executed with high speed, using 450 m fully sensitive Silicon pnCCDs with 264 x 264 pixels and with 48 x 48 m^2 pixel size, read out with up to 10.000 frames a second in dedicated operation modes. For the time being the pnCCD instrument represents the state-of-the-art direct electron detector system in the energy range from 5 keV up to 300 keV.

To further expand the experimental parameter space, we have investigated the feasibility of a detection system which operates at frame rates up to 100.000 frames per second. This system exhibits a logarithmic signal compression, leading to an almost unlimited dynamic range. Up to 100 pA from the TEM electron gun can be digested by every single pixel in this integrating mode. On the low flux side, it can also distinguish between 0, 1, 2, " electrons per pixel with energies between 10 keV and 500 keV from the STEM. The detector is based on the concept of fully depleted monolithic active pixel sensors: Depleted p-channel Field Effect Transistors, the DePFETs [1]. As the TEM electrons can never reach the sensitive area of the sensor where the amplifiers are located it does not suffer from radiation damage. Because of the extremely high frame rate and dynamic range the number of impinging (S)TEM electrons is no longer limiting the dynamic range of the measurement from the detector side: the electron gun and the radiation damage in the sample are now the limiting factors. In addition to those outstanding properties it allows a selective readout and a fast gating in the nano-second range. Due to the excellent noise performance of the detectors the position resolution can be improved at least by a factor of 5 per dimension compared to the pixel size by centroiding the signal electron charge cloud in a wide energy range. The high-speed operation of the DePFET detector of 100 kHz frame rate and a format of 100 x 100 pixel allows to perform single electron counting and centroiding up to a total flux of 10 pA in the focal plane and thus get the improved spatial resolution. Ptychographic TEM measurements will be shown. We will present results from a measurement campaign with a ARM200-CF analyzing double walled Carbon nanotubes and Graphene monolayers with atomic resolution [2, 3]. The potential and prospects of the two sensor types as direct electron detectors in electron microscopy will be highlighted.

[1] First results on DEPFET Active Pixel Sensors fabricated in a CMOS foundry - a promising approach for new detector development and scientific instrumentation, S. Aschauer et al., Journal of Instrumentation, Volume 12, Issue 11, pp. P11013 (2017)

[2] Simultaneous atomic-resolution electron ptychography and Z-contrast imaging of light and heavy elements in complex nanostructures, H. Yang et al. Nature Communications 7, Article number: 12532 (2016) doi:10.1038/ncomms12532

[3] A pnCCD-based, fast direct single electron imaging camera for TEM and STEM, H. Ryll et. al., Journal of Instrumentation, Volume 11, pp. P04006 (2016)



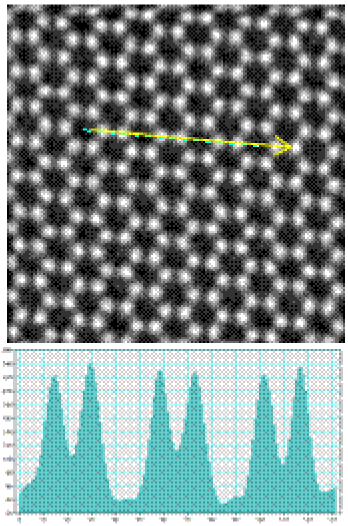


Figure (left): simultaneously obtained annular dark field measurement of a Graphene monolayer, recorded with a pnCCD camera, 256 × 256 probe positions in < 35 sec at 2.000 frames per second at a JEOL ARM 200F @ 80keV Emission 10.3μA, Spot 10C, Mag x80M.

Figure (right): simultaneously obtained phase image (contrast inverted) with the same instruments settings.
Line profiles in the (left) and (right) image show the intensity line cuts along the yellow arrows in the respective image.