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Results of a pnCCD Based Ultrafast Direct Single Electron Imaging Camera for Transmission Electron Microscopy

Henning Ryll[1], Knut Müller[2], Sebastian Ihle[1], Heike Soltau[1], Ivan Ordavo[3], Andreas Liebel[1], Robert Hartmann[1], Andreas Rosenauer[2], and Lothar Strüder[1]

[1.] PNSensor GmbH, Otto-Hahn-Ring 6, 81739 Munich, Germany
[2.] Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee 1, 28359 Bremen, Germany
[3.] PNDetector GmbH, Emil-Nolde-Str. 10, 81735 Munich, Germany

Up to now in a typical transmission electron microscope (TEM) camera, the incident electrons are indirectly detected. They are converted into photons in a phosphorous layer, which are then guided via fiber optics to a CCD or CMOS imager for detection. This results in inherent disadvantages of conversion efficiency, scattering of photons, reflections at optical interfaces and absorption losses. Contrary, this can be avoided in a direct detector which directly converts the incident electrons into a spatially resolved signal. This brings an increase in resolution and sensitivity, minimizing specimen damage. Therefore, in past years various systems compromising direct detectors have been launched, however mostly CMOS imagers [1, 2]. In contrast, we present first results of a new ultrafast TEM camera based on a pnCCD detector [3].

A pnCCD is a radiation hard, back-illuminated device, which is fully depleted over the whole thickness of 450µm thick, high-purity n-type silicon, which is also the sensitive region. In this version it features a 48x48µm² pixel size with 264x264 pixels. The multiparallel readout of the pnCCD enables a frame rate of up to 1000 full frames per second offering increased temporal resolution. The sensitivity is such that each incident primary electron can be easily distinguished from noise, including primary electrons that are scattered out of the detector again. With an appropriate low-dose (100-1000 incident electrons per frame), single individual primary electrons can be separately detected, enabling further analysis and processing of these electron events.

The final image can be obtained by simply integrating multiple frames and their intensities, which results in a conventional intensity image (called intensity mode). Even more, by using the potential of electron event processing, the image can formed by taking the individual events with their reconstructed point of entry and count them in a subpixel grid. A simple method to determine the point of entry is to calculate the center of gravity of each event (called CoG method). Since this is done with a subpixel precision, the grid for the final image can be chosen much finer than the device pixel size of 48µm (see Figure 1). Additionally, the frames and events used for image formation can be chosen after the exposure to correct for specimen drift and selecting only those images which have been recorded before the specimen was damaged. Also temporary changes of the sample, e.g. oxidation processes, can be nicely observed with a time resolution of 1000 images per second.

The pnCCD TEM camera was installed at a TEM (Titan80/300) for evaluation of the imaging capabilities at electron energies of 80, 120, 200 and 300keV. The modulation transfer function was calculated with the slanted knife edge method for the intensity mode and with event processing with no subpixel and 5x5 subpixel grids (see Figure 2). Generally, the contrast increases with lower electron energy. Looking at the higher energies of 200 and 300keV in intensity mode, the contrast fell below 10% after 0.58 and 0.34 Nyquist respectively. For 80 and 120keV, the contrast increased from 24% and

11% respectively at full Nyquist in intensity mode to 72% and 39% with event processing and a 5x5 subpixel grid. This resolution improvement is also evident in the images (compare in Figure 1.b "CoG method" with Figure 1.c "5x5 subpixel").

The principles and the setup of the pnCCD camera will be explained. A first application is presented, where the TEM is operated in STEM mode and Bragg discs of diffraction patterns are imaged on a millisecond timescale [4].

References:

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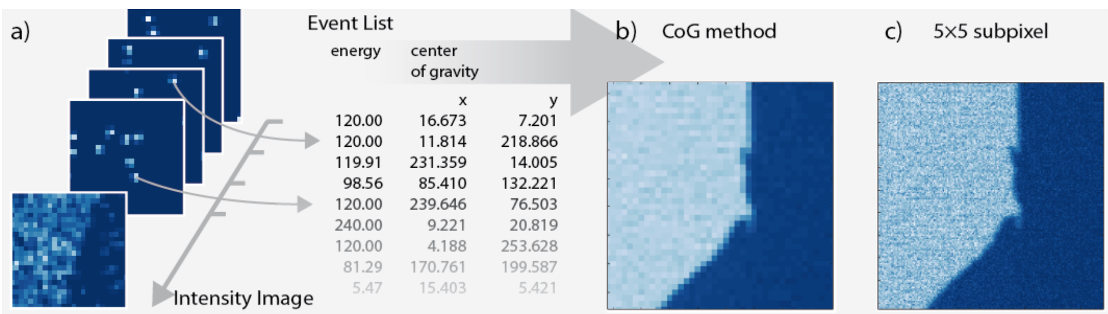

Figure 1. Illustration of the different image formation methods possible with the pnCCD camera.

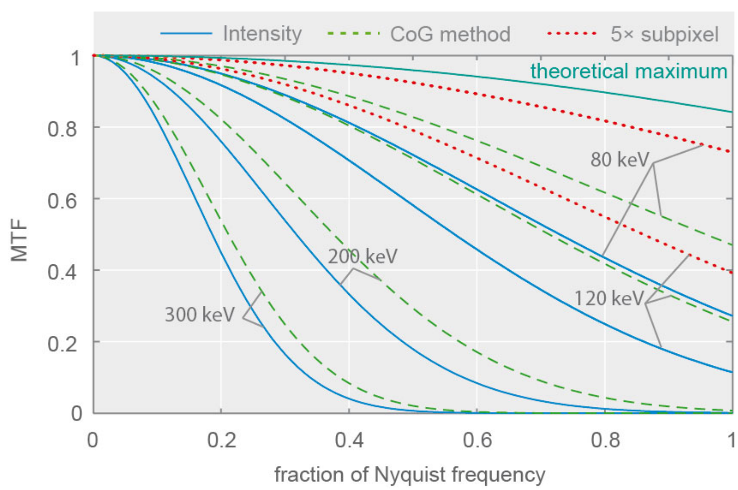

Figure 2. MTFs measured with the pnCCD camera at a Titan 80/300 and analyzed with the slanted knife edge method for different imaging modes at primary electron energies of 80, 120, 200 and 300 keV. The solid blue lines correspond to images which were formed with integrated intensity images (Intensity). The dashed green lines correspond to images formed by processing primary electron events and applying the center of gravity method (CoG method) with no subpixel resolution. The dotted red lines for 80 and 120 keV correspond to the CoG method with a 5x5 subpixel resolution. The uppermost curve is the theoretical maximum given by sin(x)/x.