doi:10.1017/S143192761400734X
Microsc. Microanal. 20 (Suppl 3), 2014

The pnCCD for Applications in Transmission Electron Microscopy: Further Development and New Operation Modes

Henning Ryll[1], Robert Hartmann[1], Martin Huth[1], Sebastian Ihle[1], Julia Schmidt[1], Martin Simson[2], Heike Soltau[2] and Lothar Strüder[1]

[1.] PNSensor GmbH, Otto-Hahn-Ring 6, 81739 Munich, Germany
[2.] PNDetector GmbH, Emil-Nolde-Str. 10, 81735 Munich, Germany

Direct electron imaging with the pnCCD in transmission electron microscopy has been demonstrated successfully recently [1,2]. The pnCCD under investigation has a physical pixel size of 48x48µm^2 with 264x264 pixels. Previous experiments proved that the sensitivity and low noise of the pnCCD enables single electron detection. This capability and further processing of the raw image data under low dose conditions allows for a subpixel resolution up to 1320x1320 pixels. More than 1000 full frames per second can be recorded continuously with the pnCCD's multi-parallel readout. Previously, time consuming measurements can thus be executed in a practical time frame, reducing the acquisition time by a factor of up to 200 [2]. Additionally, dynamic experiments can be resolved on the millisecond timescale. The back-illumination through a thin unstructured entrance window allows the imaging of TEM electrons in the energy range from 300keV down to 10 keV with single electron detection capability.

The previous results motivated further development and we have established new operation modes of the pnCCD that greatly improve imaging in TEMs. Almost all parameters that determine the response and readout signal of the pnCCD are configurable during operation. This capability was exploited to increase the number of TEM electrons that can be imaged in a single frame or pixel. Usually, there is a limit on the number of TEM electrons that can be collected in a single pixel. The energy of a TEM electron is deposited in the detector bulk and generates a number of electron-hole pairs, depending on the primary energy. These so called signal electrons are collected in potential minima under the pixels and make up the signal of the pixel. The pixel potentials can only hold a certain number of signal electrons, which is called the charge handling capacity (CHC). Any excess signal electron will spill over to neighboring pixels. The new operation modes shift this limit or remove it for practical purposes.

The first new mode is called High Charge Handling Capacity Mode (HCHC mode), the second one Anti Blooming Mode (AB mode) and the third mode is a combination of the previous two, called XPLUS mode. In the HCHC mode (Figure 2b), optimized voltages allow a 3-4 fold increase of the CHC to approximately 350,000 signal electrons. Translation to the number of detectable TEM electrons in a single pixel depends on the energy of the primary electron and the readout speed. For the case of 80 keV and 1000 fps, approximately 16,000 TEM electrons can be collected in one pixel during a one second acquisition. At the same time, it is still possible to distinguish one single primary electron from the background noise.

In the AB mode (Figure 2c), the voltages are adjusted such that any signal electrons that cannot be collected in one pixel, do not spill over to neighboring pixels. Instead, these signal electrons are extracted from the bulk of the detector and do not contribute to the readout signal. The main advantage is the possibility to image spots of very high intensity without degrading spatial information. At the same time, spots with very low intensity can be imaged down to single electrons, obtaining TEM images with large contrast of TEM electron intensities.

The XPLUS mode (Figure 2d) combines properties of the HCHC and AB modes. The CHC is increased compared to the AB mode, while overflowing signal electrons are drained off.

The different operation modes and their distinct properties will be explained. Measurement results under varying TEM conditions will be presented to illustrate the benefits of the pnCCD for TEM applications.

References:

[1] H. Ryll et al., Microscopy and Microanalysis **19** (2013), p.1160-1161.
[2] K. Müller et al, Appl. Phys. Lett. **101** (2012), p. 2121101-2121104.

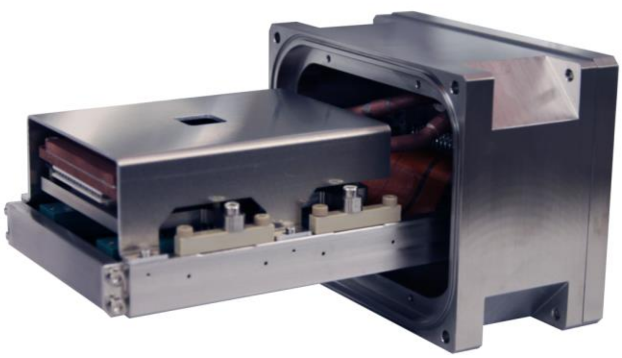

Figure 1. The pnCCD camera for TEM applications.

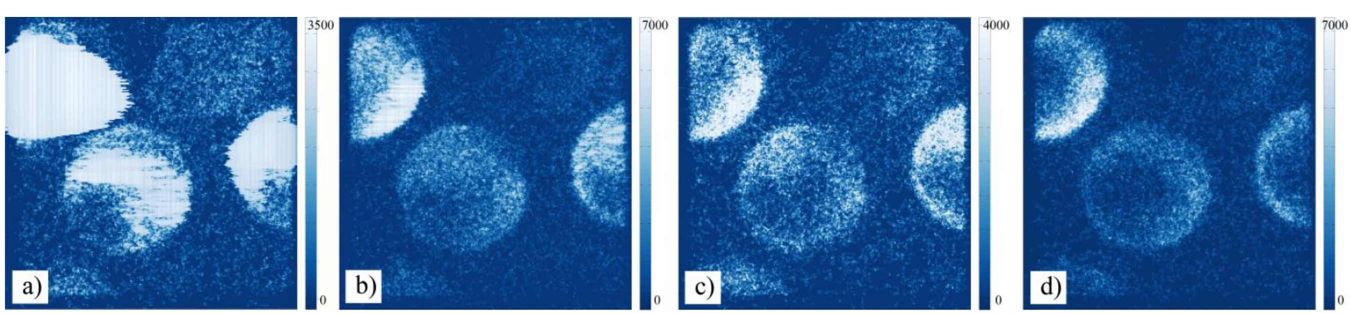

Figure 2. Comparison of images taken with 300keV and a readout out speed of 1000fps under constant TEM settings in the different pnCCD operation modes: a) The high electron dose causes overflowing pixels in the Normal mode. b) More TEM electrons can be collected in the pixels in the HCHC mode. c) The AB mode prevents overflowing pixels. d) The XPLUS mode prevents overflowing pixels while increasing the number of collectable TEM electrons.