Development of fast pixelated STEM detector and its applications for visualization of electromagnetic field and ptychographic reconstruction using 4D dataset

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In scanning transmission electron microscopy (STEM), one can obtain a variety of STEM images such as annular bright-field (ABF) and annular dark-field (ADF) images with variously shaped scintillators of the detectors [1]. However, the intensity distribution of the convergent beam electron diffraction (CBED) pattern, which is projected on the scintillator plane, is not fully utilized with conventional detectors, because they are single channel that cannot avoid integrating the intensity over the scintillator. Meanwhile, several direct electron detectors with fast frame rate and many pixels of several ten thousand or more, have recently been commercialized [2-4]. Such detectors, when used for recording CBED patterns for each STEM probe position, are called pixelated STEM detectors. With the obtained 4-dimensional (4D) dataset, any type of STEM images can be synthesized in a post or real time processing by a user-defined selection of the integration area. We have developed a pixelated STEM detector (JEOL, 4DCanvas™) using a fast direct electron CCD image sensor (PNDetector, pnCCD), whose maximum readout speed is 4,000 fps and works at 20-300 kV. The detector is integrated into JEM-ARM200F microscope with newly developed operational software and dedicated bottom mount housing that is compatible with an EELS detector and other cameras.

One of the applications using 4D dataset is a visualization of electromagnetic field in a sample. Figure 1 shows an electric field map of the junction between n-type (Si) and p-type (Zn) GaAs [5]. The map is created from the positional shift of the electron beam on the detector plane due to the electric field at the junction. The purple line that runs vertically in the middle of the image is the area where an electric field exists. From the color map of electric field in the inset, it is shown that the line is the electric field from N-type to P-type GaAs. Another application is a post processing technique called ptychography which has been shown to provide high efficiency for extracting a phase image from a 4D dataset [6,7]. Figure 2 shows a comparison between (a) an ADF STEM image and (b) a ptychographically reconstructed phase image of a single-walled carbon nanotube (SWCNT) recorded simultaneously. The phase image gives apparently higher image contrast and signal-to-noise ratio. From the FFT patterns in the insets, the higher frequency is observed in the phase image than in the ADF image. Using ptychography, we can correct residual aberration in the reconstructed image because once we have obtained the phase information we can access and manipulate the phase of the electron wave [8].

References

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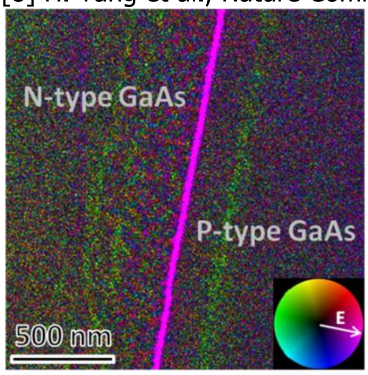

Figure 1. Electric field map of the PN junction in GaAs.

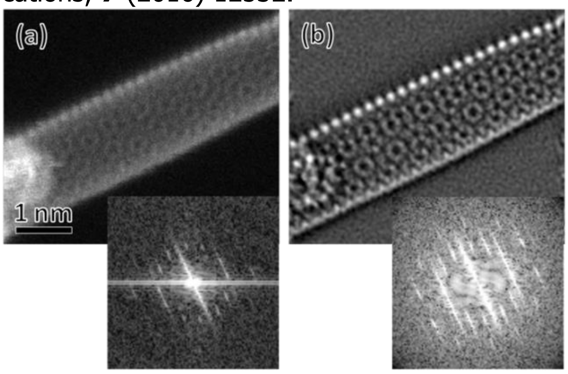

Figure 2. (a) ADF image and (b) ptychographically reconstructed phase image of SWCNT.