High-Speed, High Dynamic Range Diffractive Imaging Camera for Scanning Transmission Electron Microscopy

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In scanning transmission electron microscopy (STEM) imaging a highly focused electron beam is rastered across a thin specimen. At each position of the scan, a diffraction pattern is generated that encompasses information from the specimen, i.e., crystal structure, defects, local fields, etc. The ability to record the entire diffraction pattern at each scan position provides rich, quantitative information about the specimen. Two major challenges are (1) detecting the diffraction pattern with enough sensitivity and dynamic range to interpret information such as local fields and strain intrinsic to the specimen and (2) having a sufficiently fast diffraction image acquisition time to minimize the impact of specimen drift. To meet these challenges we have successfully adapted and installed a mixed-mode pixel array detector (MMPAD) [1, 2] on a STEM.

Traditionally this recording is done with charge-coupled devices (CCD) [3, 4]. Although the large array of pixels in a CCD permits extraction of the angle and position sensitive information, CCDs suffer from limited dynamic range, slow frame rate, and pixels that are generally too small, given typical STEM beam voltages [5]. The MMPAD [1,2] overcomes these limitations. The MMPAD (Fig. 1) is made by coupling a CMOS application specific integrated circuit (ASIC) with a high quality pixelated silicon diode sensor 500 µm thick. Each 150 µm x 150 µm pixel in the sensor is coupled to a readout pixel in the ASIC via solder bump-bonds (Fig. 1). The MMPAD consists of a square array of 128 x 128 pixels, images continuously at 1 kHz (Fig 2(a)), has a dynamic range of >10⁶ STEM electrons/pixel/image while maintaining single STEM electron sensitivity (Fig 2(b)). Recently, the MMPAD has been successfully tested on FEI Tecnai F20 STEM for different electron energies, ranging from 60 kV to 200 kV. This highly pixelated design enables post-acquisition reconstruction of BF, ADF, HAADF, DPC images by integrating angle/position sensitive signals as well as information from crystal structure and local dipole fields (Fig. 3) [6].

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Figure 1. (a) Sketch of a hybrid pixel array detector. (b) Pixel level schematic of MMPAD. (c) MMPAD board, with sensor at left.

Figure 2. (a) Diffraction pattern recorded in 1ms extracted from a full dataset on a polycrystalline Co film. (b) Histogram of detector intensities showing single electron quantization.

Figure 3. Magnetic field from Center of Mass (a) X-deflection, and (b) Y-deflection from a Co film.