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IT-1-P-2263 Maximising Phase Contrast in Aberration-corrected STEM using Pixelated Detectors

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For imaging weak phase biological specimens, phase contrast imaging using elastically scattered electrons provides the most information for a given amount of radiation damage as compared to electron inelastic scattering as well as X-ray and neutron scattering [1]. In scanning transmission electron microscopy (STEM), most phase information from weak scattering objects lies inside the bright field disc of the convergent beam electron diffraction pattern, which can be reconstructed using the method described by Rodenburg et al [2]. In this work we show that, compared to alternative modes including annular bright field (ABF) and differential phase contrast (DPC), phase contrast using a pixelated detector generates higher contrast in reconstructing the phase and therefore enjoys a higher dose efficiency in imaging weak phase objects.

With zero aberrations, any centrally symmetric detector will give no contrast for a weak phase object, as the two sides of disc overlapping regions in the convergence beam electron diffraction pattern are pi out of phase under weak phase approximation, and cancel each other when integrated using a central symmetrical detector geometry. Therefore, asymmetric detector geometries like DPC are expected to have higher phase contrast than ABF. In DPC, the quadrant detector can be divided into more segments with different collection angles, and the contrast transfer function is found to depend on the collection angles used, therefore the detector geometry of DPC can be further optimized to collect the maximum phase information per detected electrons. A pixelated detector provides even greater flexibility over where the information in the bright-field disc is retrieved from for each spatial frequency in the image.

Simulations have been done using an arbitrary weak phase specimen whose maximum atomic potential equals to that of a carbon atom, and has a Gaussian shape with a full width half maximum (FWHM) of 1nm. The artificially high width of the object is designed to test the lower spatial frequency transfer. The reconstructed phase with a dose as low as 50 electrons/Å^2 and Nyquist resolution of 4.6Å still shows an interpretable feature (Figure 1). This dose is close to the critical dose of 5-50 electrons/Å^2 for imaging biological specimen. In contrast to using a pixelated detector, neither ADF, ABF (Figure 2) nor DPC (Figure 3) show any recognizable structure feature under the same dose of 50 electrons/Å^2. The formation of image contrast in ABF relies the presence of aberrations for a weak phase object, and here we are assuming an aberration-corrected microscope with zero residual aberrations.

[1] Henderson, R. Quarterly Reviews of Biophysics 28, 171-193 (1995).

[2] Rodenburg, J. M. et al. Ultramicroscopy 48, 304-314 (1993).

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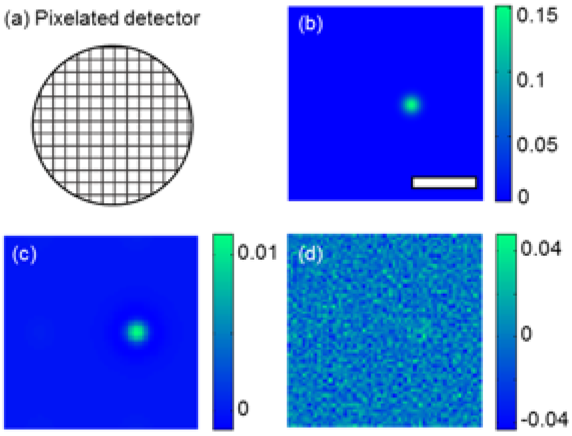

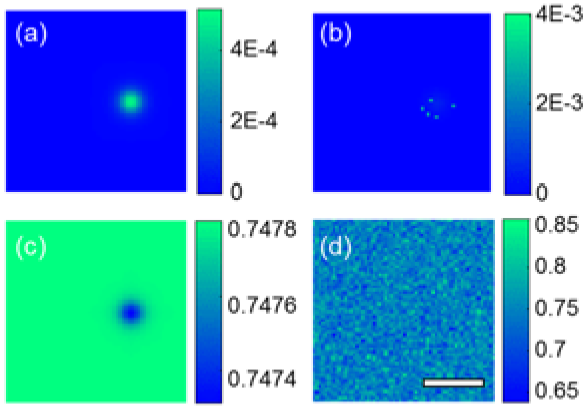

Fig. 1: Figure 1: Phase retrieval using a pixelated detector. (a) Schematic of a high speed pixelated detector. (b) A weak phase object with a maximum phase change of 0.15 radian. Reconstructed phase (c) assuming no noise, (d) with shot noise and a dose of 50 electrons/Å². The scale bar is 5nm.

Fig. 2: Figure 2: Simulated (a,b) ADF and (c,d) ABF images of the weak phase object. The intensity is normalized to the number of incident electrons. (a)(c) assume no noise in image, and (b)(d) consider shot noise with the electron dose being 50 electrons/Å². The scale bar is 5nm.

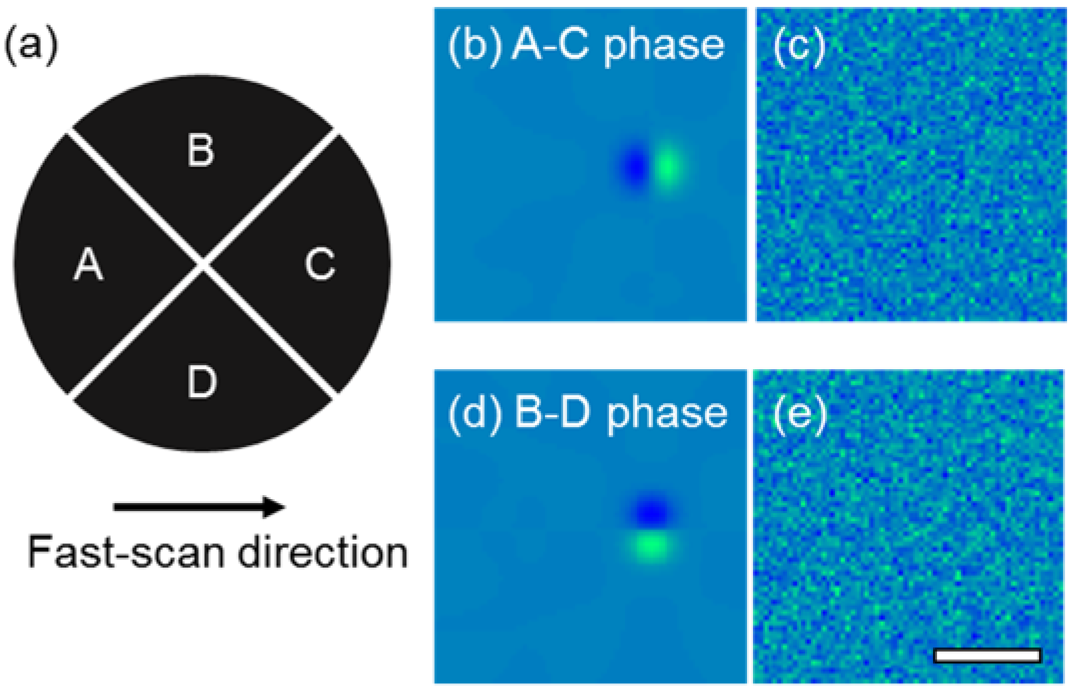

Fig. 3: Figure 3: Differential Phase Contrast (DPC) imaging using a 4-quadrants detector in (a). The simulated STEM DPC images using both (b,c) A-C quadrants, and (d,e) B-D quadrants, where (b)(d) assume noise free, and (c) (e) considers shot noise with the electron dose being 50 electrons/Å². The scale bar is 5nm.