Phase accuracy and contrast transfer in electron ptychography methods

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The development of fast pixelated detectors (FPD) for the transmission electron microscope (TEM) and scanning TEM (STEM) has enabled significant developments in phase imaging of materials [1]. These direct electron detectors can record 2-D convergent beam electron diffraction (CBED) patterns for each 2-D probe position of the field of view. These 4-D datasets enable us to obtain phase images using ptychography. Upon reconstruction, one can retrieve structural and chemical information. Ptychography is a dose efficient technique, enabling effective phase reconstruction of radiation sensitive samples. There are several methods of STEM ptychography currently of interest. Focused-probe ptychography (FPP) methods require a CBED pattern to be recorded at each probe position [2]. Defocused-probe ptychography (DPP) methods require less data to cover the field of view, but an iterative algorithm is required to retrieve the phase [3]. In addition, TEM ptychography, or Fourier ptychography, retrieves electron phase information from a series of tilted images. The amount of information obtainable from each of these methods is determined by the contrast transfer and signal-to-noise ratios for each spatial frequency transferred into the image.

For this study, 4-D STEM datasets were obtained for amorphous carbon and a mono-layer of graphene using the probe-corrected JEOL ARM-200F at Oxford Materials and the double-corrected JEOL ARM-300F at ePSIC, Diamond Light Source. Each of these microscopes are equipped with FPDs: the JEOL 4D canvas and the Medipix3, respectively. A comparison of two FPP methods, single side-band (SSB) and Wigner distribution deconvolution (WDD) methods will show that avoiding the deconvolution step of the latter increases robustness to noise and residual aberrations. An experimental dose series of graphene reconstructed using FPP, a section of which is shown in Figure 1, demonstrates the dose limit at which such ptychography methods fail, and this is compared to alternative ptychography methods. The phase contrast transfer functions (PCTFs) that result from ptychography can be controlled during the reconstruction process. We compare the effects of different PCTFs, and more importantly examine the signal to noise ratios that arise when applying different ptychographic reconstruction methods at low dose for radiation sensitive materials. Figure 2 shows how modification of the effective PCTF alters the profile for single atom imaging. [4]

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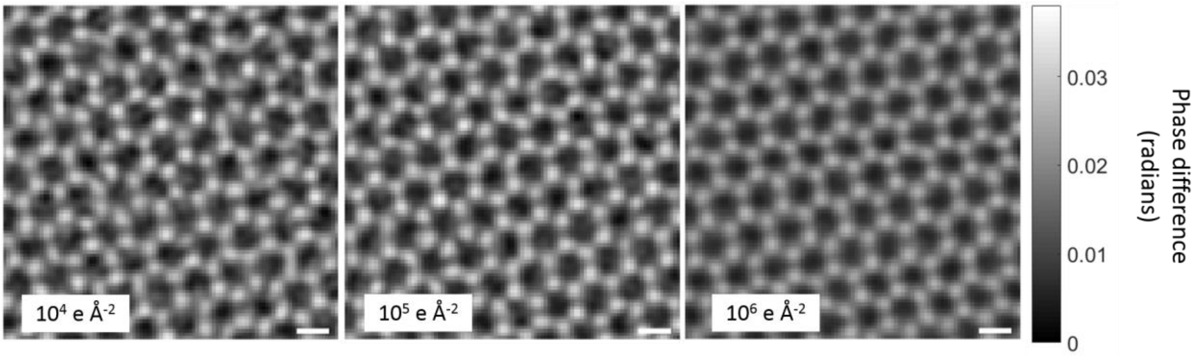

Figure 1. Section of a STEM experimental dose series acquired on the JEOL ARM-300F reconstructed using FPP (HT = 80 kV, convergence angle = 24.8 mrad). The electron dose refers to the total dose of the 4-D STEM dataset. Scale bar: 2Å.

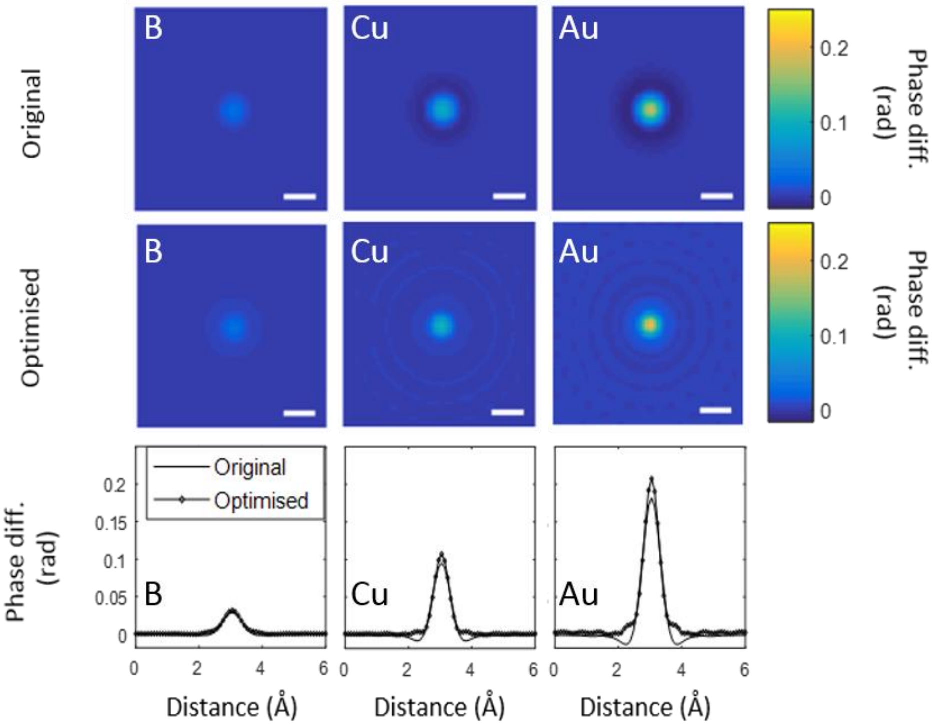

Figure 2. 3D and 2D atomic profiles for simulated single atoms using FPP with (optimised) and without (original) spatial frequency boosting (HT = 200 kV, convergence angle = 22.5 mrad). Boosting lower and higher spatial frequencies removes unexpected dips in the atomic profiles. Scale bar: 1Å.