Phase retrieval using diffraction from straight edge apertures

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In a transmission electron microscope (TEM), electron diffraction patterns and images of specimens are recorded as an intensity distribution; so that the phase of the scattered electron wave function is not available - the so-called "phase problem". This limits the information that is available about the specimen. Several methods have been developed to retrieve the phase of the scattered electron wave function from experimental images and diffraction patterns in TEM, such as through focal-series reconstruction, electron holography and ptychography, but they require special instrumentation and/or complicated post-processing.

In this work, we develop a simple method to retrieve phase from far-field electron diffraction patterns. Unlike conventional diffractive-imaging techniques, a straight edge aperture is placed close to the object. This straight edge not only provides a scattered reference wave to interfere with the object wave, but also greatly simplifies the phase reconstruction due to the mathematical convenience afforded by its shape, as has been demonstrated for X-rays [1]. To reconstruct the object, the recorded electron diffraction intensity distribution $I(k_x, k_y)$ is first multiplied with the reciprocal coordinates k_x, k_y and then a Fourier transform operation is applied. As shown in equation 1, this gives a differential of the electron exit wave $\psi(x, y)$ in the object plane convoluted with the conjugate of $\psi(x, y)$. The differential of a straight edge (rectangle function) is a Delta function [2]. When the object is separated far enough from the straight edge, the conjugate of the object wave function will be convoluted with the Delta function and will be well separated from the self-interference pattern of the object wave. In this way, the full wave function of the object wave can be obtained.

$$\mathcal{F}\{4\pi^2 k_x k_y I(k_x, k_y)\} = \frac{\partial^2 \psi(x,y)}{\partial x \partial y} \otimes \psi^*(x, y) \quad (1)$$

In practise, the straight edge could be replaced by a square aperture. Figure 1a shows a simulated phase object located in a square aperture. The corresponding electron diffraction pattern is shown in Figure 1b. The phase object is then successfully reconstructed (Figure 1c) using the approach described in equation 1. In practise, a square aperture could be fabricated using focused ion beam (FIB) milling on a thick metal foil, as shown in figure 2.

This method opens the possibility of determining phases from just a single image, with potential applications in beam-sensitive materials and biological samples.

Reference:

1. S.G. Podorov, K.M. Pavlov, and D.M. Paganin, "A non-iterative reconstruction method for direct and unambiguous coherent diffractive imaging," Opt. Express 15, 9954-9962 (2007)

2. Joseph W. Goodman. "Introduction to Fourier optics", 3rd edition, ISBN: 0974707724 (2005).

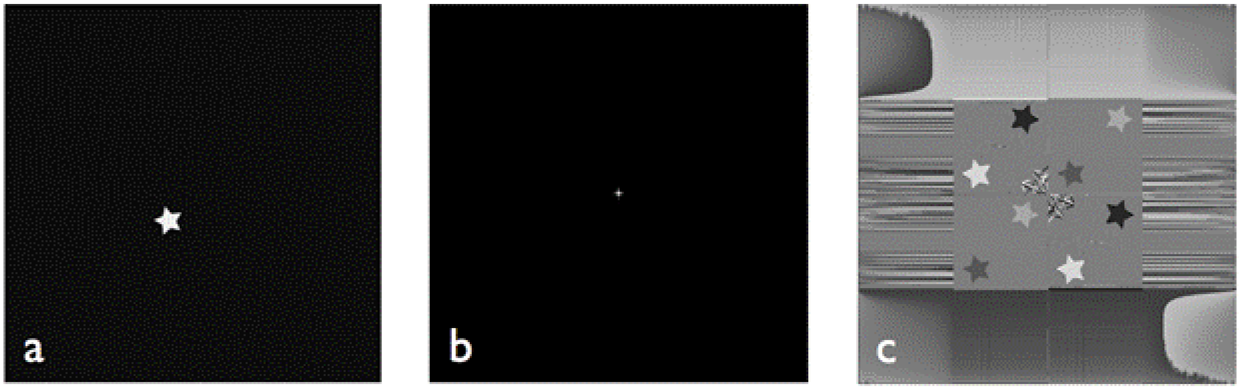

Figure 1: Simulation of phase retrieval of a shaped phase object with straight aperture. (a)Simulated phase object with shape of a star surrounded by straight apertures. (b)Corresponding diffraction pattern (c) The reconstructed phase image.

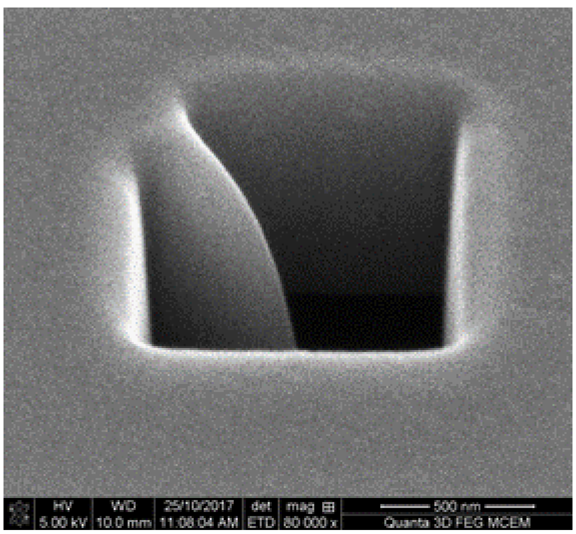

Figure 2: Experimental setup for a test object located in a square aperture made in Aluminium (made by FIB).

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