Object wave reconstruction by phase plate transmission electron microscopy

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Recently several approaches involving physical phase plates in a transmission electron microscope have emerged to enhance contrast of weak-phase objects by applying an additional relative phase shift between undiffracted and diffracted electrons. Besides carbon-film-based Zernike- and Hilbert-phase plates [1,2] there are also electrostatic approaches like the Boersch-phase plate [3] which offers adjustable phase shifts by varying the applied electrostatic potential.

However any image in transmission electron microscopy (TEM) corresponds to the absolute square of the image wave function, while phase information is lost. Moreover the image wave function is aberrated compared to the object wave function due to imperfect lenses. Several techniques exist in TEM to recover the amplitude and phase information of the object wave function. Besides through-focal series and electron holography an additional method for object wave reconstruction by the use of a phase plate was proposed for weak-phase objects [4].

We present here a new technique for object wave reconstruction which is not restricted to weak-phase objects. It requires only three images to be taken at different arbitrary phase shifts induced by a phase plate. Other parameters like defocus, spherical aberration and exposure time have to be identical in all three images. Since the images are subtracted from each other during the reconstruction process all contributions due to non-linear image formation vanish as they are independent of the phase shift of the undiffracted electron beam. Hence this technique provides a fully analytical reconstruction of the object wave function irrespective of non-linear image formation. It is also applicable to crystalline objects where dynamical electron diffraction dominates.

The validity of the presented approach is demonstrated by an experimental object wave function of nanoscaled Pt-particles on an amorphous carbon film which was obtained by electron holography [Fig. 1]. Moreover non-linear image formation was simulated for a crystalline Si-specimen in a [100]-zone axis orientation with a thickness of 5.43 nm containing vacancies in the Si-atom column indicated by the arrow [Fig. 2]. For both objects the required images at three different phase shifts were calculated. Subsequent reconstruction yields amplitude and phase distributions which agree well with the original object wave function.

For the considered specimens, which are not weak-phase objects, it will be shown that noise does not inhibit the reconstruction of the object wave function at low electron doses. While ideal phase plate devices are assumed in the simulations, the effect of different phase plate geometries is discussed qualitatively.

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To summarize, the method allows an analytical reconstruction of arbitrary object wave functions on the basis of three bright-field phase contrast images acquired by the use of a physical phase plate.

1. R. Danev, K. Nagayama, Ultramicroscopy **88** (2001) 243.
2. R. Danev, K. Nagayama, J. Phys. Soc. Jpn. **73** (2004) 2718.
3. K. Schultheiß et al., Rev. Sci. Instrum. **77** (2006) 033701.
4. R. Danev, K. Nagayama, J. Phys. Soc. Jpn. **70** (2001) 696.

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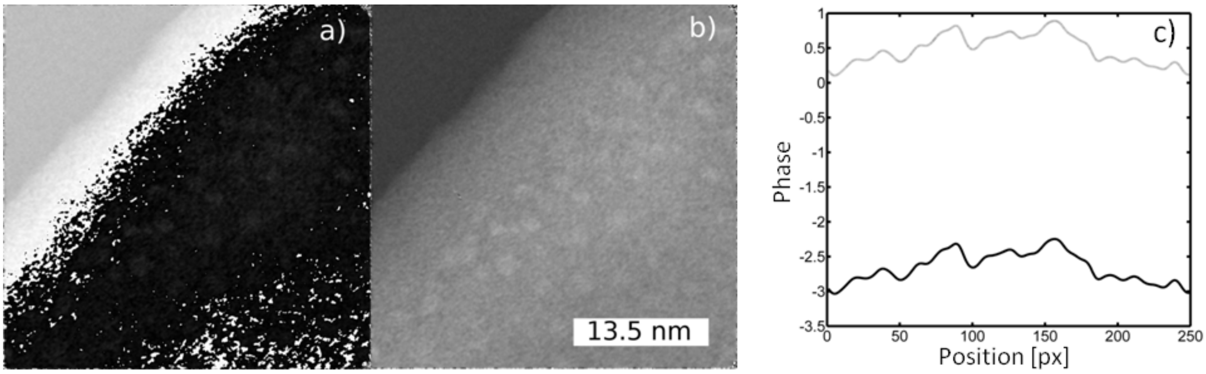

Figure 1: a) (left) Phase of the original object wave function acquired by off-axis electron holography scaled from -pi (white) to +pi (black). b) (right) Reconstructed phase on the basis of three simulated images at different phase shifts of the undiffracted electrons c) Line scans across a Pt-particle, taken from a) (black) and b) (gray). Apart from a constant offset, due to the fact that the phase of undiffracted electrons was set to zero, the phase distributions are in very good agreement.

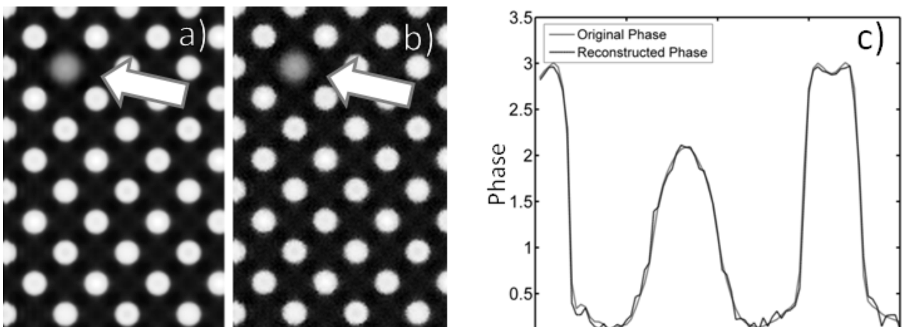

Figure 2: a) Phase of the original object wave function used to simulate images of a Si-specimen at three different phase shifts. b) Phase of the object wave function reconstructed on the basis of three noisy images. c) Line scans across the vacancy position and two adjacent atom positions, taken from a) (gray), and b) (black). Apart from the noise the distributions are in very good agreement and show that the reconstruction also works if non-linear contributions are present in the images.

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