doi:10.1017/S1431927616008138

Microsc. Microanal. 22 (Suppl 3), 2016

Quantitative Phase Imaging of $Ba_2NaNb_5O_{15}$

Emrah Yücelen[1], Ivan Lazić[1], Eric Bosch[1]

[1.] FEI Electron Optics B.V. , Achtseweg Noord 5, 5651 GG, Eindhoven, The Netherlands

High-Resolution Transmission Electron Microscope (HRTEM) is one of the most powerful imaging tools to study the structure of materials at atomic resolution. However, HRTEM images, generally speaking, are not directly interpretable and also suffer from aberrations introduced by the objective lens. Last decade the resolution of HRTEM images is greatly improved by utilization of spherical aberration correctors [1]. Direct interpretation of HRTEM images can be achieved by restoring the amplitude and phase of the specimen exit-wave function using electron holographic met such as Through Focus Series Reconstruction (TFSR) and off-axis electron holography [2, 3]. Such reconstruction methods provide an aberration free complex exit-wave function and reconstructed exit waves also benefits from improved signal to noise ratio compared to a single electron micrograph, making direct imaging of atom columns with high precision and accuracy [4]. The phase and amplitude of the reconstructed exit wave can also be used to quantitatively analyze the atomic column composition and positions, respectively [4].

Recently a new way of direct imaging of the phase of the transmission function of thin samples was introduced [5]. This technique, called Integrated Differential Phase Contrast (iDPC) STEM, is able to directly image the phase of the transmission function by applying a 2D integration on a DPC vector image (two images obtained by subtracting two images acquired from opposite quadrants of the 4 quadrant (4Q) detector) obtaining an iDPC scalar image. Because the DPC vector image linearly represents the gradient of the phase of the transmission function, it follows that the iDPC scalar image then reveals the phase of the transmission function itself.

As the exit wave emanating from a sample is practically just a transmission function of the sample if the sample is thin and illuminated with a plane electron wave, it is interesting to compare this technique to the more commonly used technique of TFSR to reveal the phase of the exit wave.

The qualitative similarity, shown in Fig. 1, is of course already interesting by itself as it allows imaging the structure directly instead of having to take a focus series followed by a time-consuming reconstruction step. It is also interesting to do a quantitative comparison of the two images (Fig. 2).

The phase range of the exit wave TFSR image is -0.38 … +0.55 rad whereas it is -0.14 … +0.23 rad in the iDPC image. These ranges are very comparable, especially given the fact that we are not dealing with the same area and experiments were done several years apart.

This shows promise that iDPC can be used for quantitative phase mapping on thin samples next to offline electron holographic reconstruction methods.

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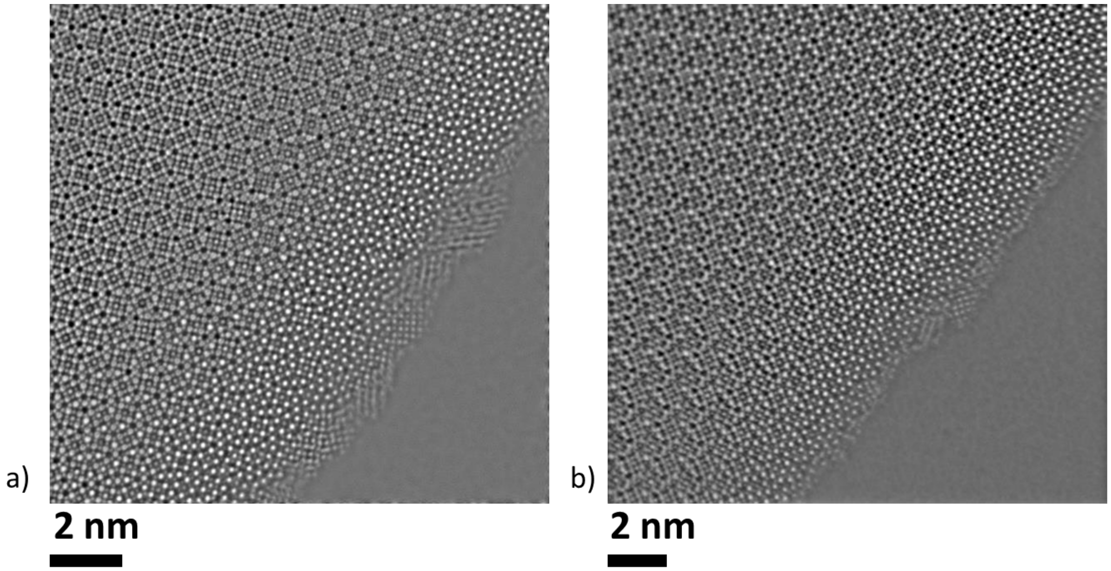

Figure 1. a) Phase of the experimental exit-wave b) high pass filtered iDPC image of a thin, wedge-shaped $Ba_2NaNb_5O_{15}$ crystal. Clearly the images look very similar and the crystal lattice, including the oxygen sites, is easily recognized

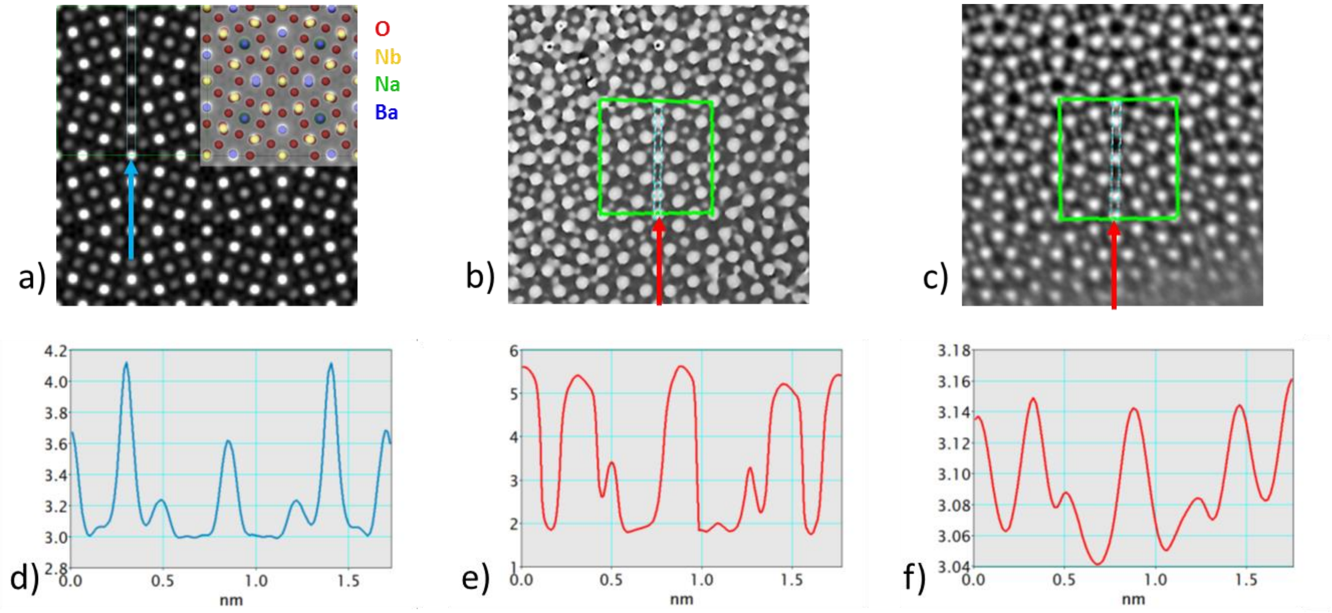

Figure 2. a) The phase of the exit wave of a 2 nm thick $Ba_2NaNb_5O_{15}$ crystal reconstructed from simulated HRTEM images; b) The phase of the experimental exit wave c) iDPC image. The experimental images were not taken on the same area d), e) and f) are the phase profiles taken along the indicated lines, respectively.