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Integrated Differential Phase Contrast (iDPC) – Direct Phase Imaging in STEM for Thin Samples

Ivan Lazić[1], Eric G.T. Bosch[1], Sorin Lazar[1], Maarten Wirix[1] and Emrah Yücelen[1]

[1.] FEI Electron Optics, Achtseweg Noord 5, 5651 GG Eindhoven, the Netherlands

Imaging the phase of the transmission function has always been the ultimate goal of any (S)TEM imaging technique as it is, for thin samples, directly proportional to the projected potential in the sample. Customarily this information is obtained using Holography [1] or by performing focus series reconstruction in TEM (FSR-TEM) [2], recently also in combination with Phase Plates (PP) [3] and/or image Cs correction. Ptychographic reconstruction has also been considered as an alternative [4].

We present, a new direct phase imaging technique, called Integrated Differential Phase Contrast (iDPC) STEM, which enables live imaging of the phase of the transmission function of thin samples and was recently introduced in [5]. Unlike the mentioned techniques this new technique uses a normal STEM scanning procedure and gives the result directly (even live on the screen) as it does not require an elaborate reconstruction scheme. It is therefore just as simple as doing (A)BF-STEM or (HA)ADF-STEM. Another important feature of this new imaging modality is that it is a linear imaging technique, contrary to (A)BF-STEM [6].

In practice iDPC-STEM is performed using a 4 quadrant (4Q) segmented detector. It enables an elegant solution for the thin sample transmission function phase problem, because it is a very good approximation of an ideal center of mass (COM) or "first moment" detector [7]. Such a COM detector produces two images proportional to two perpendicular components of the gradient of the phase of the transmission function of the sample. By 2D integration the obtained integrated COM or iCOM image is then directly proportional to the phase itself [5]. Using the 4Q detector by forming the differences between two opposite quadrants we produce two DPC images which are an excellent approximation of the COM component images. By then 2D integrating the DPC vector image we obtain an integrated DPC or iDPC scalar image which is a very good approximation of the iCOM image, thus representing the phase directly.

Fig. 1 shows an iDPC-STEM image of a BaNaNbO sample compared with an FSR-TEM image. The iDPC image is available live on the screen and can be used for focusing and alignment of the microscope, while the TEM image is obtained after post processing. The CTF of iDPC shows full transfer of the low spatial frequencies and, therefore, the iDPC image shows low frequency information of the sample. None of the TEM images in the TFS are able to transfer the low frequencies, thus the final FSR is also lacking it. Both heavy and light elements including oxygen are clearly visible in both cases.

Figure 2 shows the iDPC-STEM image of a commercially available Zeolite alongside a standard ADF-STEM image under the same conditions, with a beam current of 2 pA. As Zeolites are beam-sensitive this image demonstrates the low-dose imaging potential of iDPC compared to ADF. The structure of the zeolite as determined in [8] is completely revealed (including the oxygen atoms). At the same dose the ADF image does not show this structure and attempting to increase the dose damages the sample before it can be imaged.

These two examples show the potential of iDPC-STEM for the imaging of light elements and as low dose imaging technique for beam-sensitive materials.

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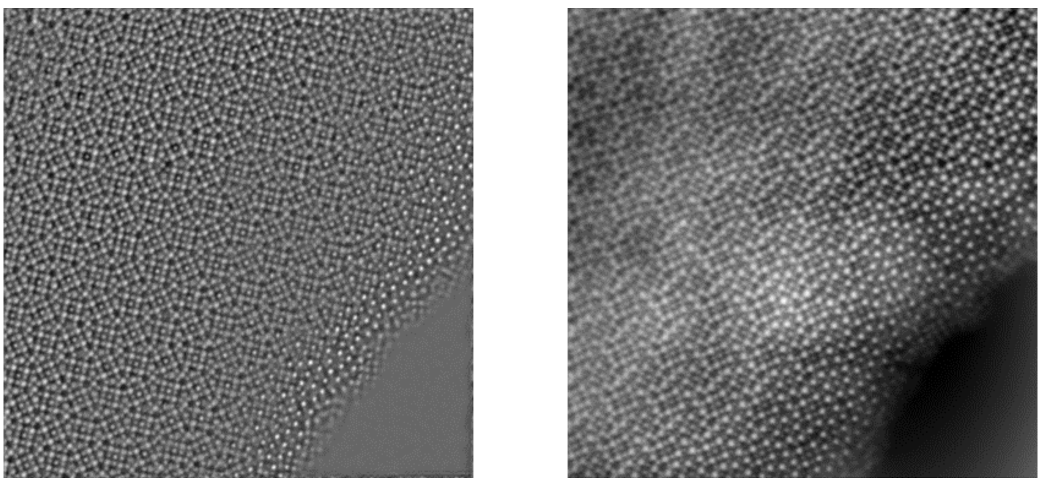

Figure 1. Left: TEM focus series reconstruction of the phase of the transmission function of BaNaNbO; right: iDPC-STEM image as shown live on the screen during acquisition on probe corrected FEI Titan Themis system at 300kV. Field of view: 12.5 nm.

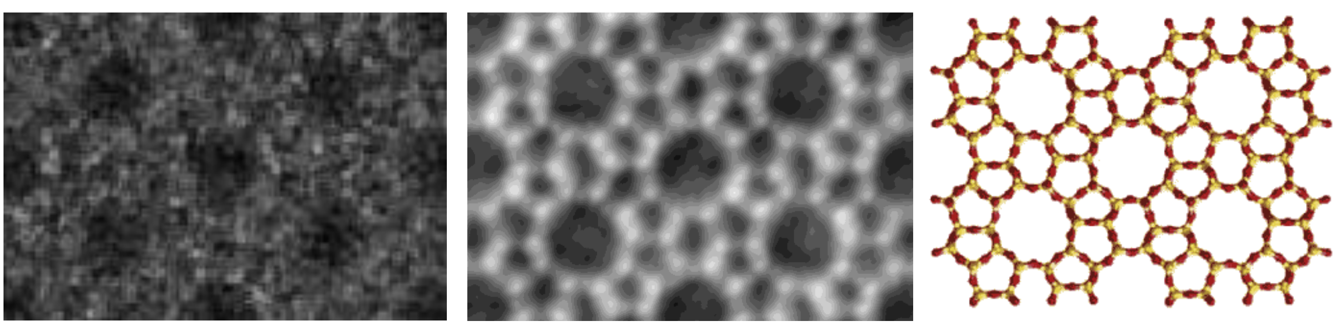

Figure 2. ADF-STEM image (left) and iDPC-STEM image (middle) of a Zeolite as shown live on the screen during acquisition on a probe corrected FEI Titan Themis system at 300 kV. The Zeolite structure taken from [8] is shown on the right. Note that even oxygen (red dots in the right image) is visible in the iDPC-STEM image. The images were acquired with a beam current of 2 pA.

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