Phase-Related Techniques and Holographic Beam Shaping (inc. phase plates, DPC, vortices, electric and magnetic field imaging...)

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Full-resolution high-contrast imaging of phase objects by gradient-flipping-assisted focal series reconstruction

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When considering elastic electron scattering by thin samples in the transmission electron microscope (TEM) (e.g., by applying zero-loss energy filtering), samples that consist of light elements (e.g., almost all thin samples investigated by cryo TEM) affect mostly the phase of the probing electron wave function and produce very little absorption contrast. However, the phase component of the image is lost during conventional imaging processes. Fresnel fringes visible in defocused images as a result of the interference of the wave scattered by the sample and the forward-transmitted wave can be used to reconstruct this phase information. Such Fresnel fringes are very efficient in retrieving high spatial frequency information. However, in order to reliably recover lower spatial frequencies (within the lateral coherence length of the illumination), highly defocused images are needed. There exist many iterative reconstruction algorithms that are based on approaches such as the transport of intensity equation (TIE)[1], the weak phase object approximation[2] and maximum likelihood optimization[3]. Although they each have their strengths, none of them is fully capable of reliably recovering very low spatial frequencies[4], especially in the case of limited spatial coherence. Here, we present results obtained by using a modified flux-preserving focal series reconstruction algorithm[5]. The modification consists of flipping the gradient of the recovered phase every few iterations where its absolute value is below a certain threshold. Such a procedure is known to favor solutions that are sparse in the domain where the flipping is applied[6]. In order to test this approach, both off-axis electron holograms and focal series of images of the same sample were acquired. The off-axis holography experiment was carried out using round illumination and a biprism voltage of 89.4 V in an FEI Titan 80-300 TEM equipped with two electron biprisms and a Gatan imaging filter with a 2048 × 2048 pixel charge-coupled device camera. For focal series acquisition, the conditions were kept the same, with the exception that the biprism was retracted. Iron-core/carbon-shell nanoparticles were used as a test sample. The reconstruction results show that the new in-line reconstruction approach is able to recover both high and also very low spatial frequency components of the phase, except for a few extremely low spatial frequencies (Fig. 1). This remaining discrepancy may be in part due to imperfect zero-loss filtering. While similar noise levels are determined for both approaches (0.063 for the improved reconstruction algorithm and 0.058 for the conventional algorithm), the signal to noise ratio is approximately 300 times higher for the conventional algorithm and 12 times higher than for the off-axis case. [7]

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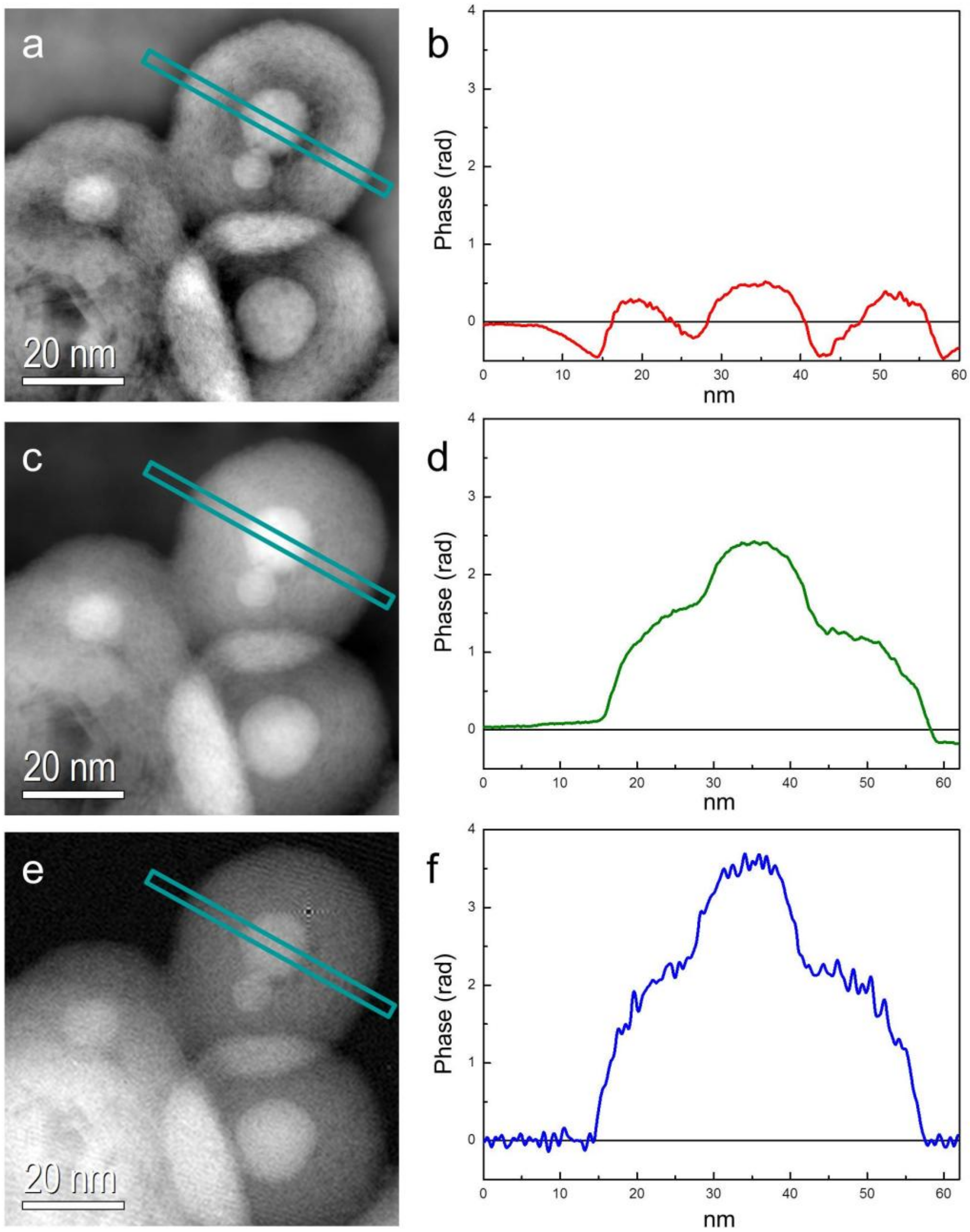

Figure 1. (a, c, e) Phase images and (b, d, f) corresponding line profiles across a feature within them. (a, b) Phase retrieved using conventional focal series reconstruction[5]. (c, d) Phase retrieved using gradient-flipping-assisted focal series reconstruction. (e, f) Phase retrieved using off-axis electron holography.