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Structured Illumination Electron Ptychography at the Atomic Scale

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With the advent of fast direct electron detectors, electron ptychography is becoming increasingly popular as a high-resolution, high-sensitivity phase-contrast method in electron microscopy. Electron ptychography is a computational phase-contrast imaging method that reconstructs phase-contrast images from scanning diffraction measurements, acquired by raster-scanning a spatially confined beam over the field of view.

It is well known from X-ray and visible-light ptychography, that the illumination amplitude and phase profile can significantly influence the transfer of spatial frequencies in the reconstructed image [2,3,4]. First demonstrations in the electron microscope have shown that this statement also holds for near-field electron ptychography with nm-scale resolution [1].

Several experimental and theoretical works found that introducing phase-structure and vortices into the beam profile improves the overall reconstruction and the transfer of low spatial frequencies and that the Fourier-space roughness of the illumination plays an important role in designing optimized illumination [2,3,4,5].

Here we experimentally investigate two different, readily achievable modes of structured illumination creation in the scanning transmission electron microscope and their use for electron ptychography at the atomic scale: the use of amplitude modulating condenser apertures and the use of strong higher-order aberrations.

Figure 1 a) & d) show the two studied structured probes in the detector plane of the microscope, and Fig 1 b) & e) show the reconstructed probe functions in real space. The first probe is generated by inserting a bullseye-patterned amplitude grating [6] in the C2 aperture plane, while the second probe is generated by judiciously introducing strong higher-order aberrations after correction of lower-order aberrations.

Figure 2 shows a comparison of mixed-state electron ptychography reconstructions of a Au NP with the bullseye probe in Fig 1b) and a standard probe with defocus of 8nm. A low-pass filter of the reconstruction, shown in Fig. 2b) clearly reveals the transfer of low spatial frequencies of the nanoparticle. In comparison, the reconstruction with the defocused probe does not reveal contrast at the length scale of the nanoparticle. The experiment was performed at 300kV with the 4Dcamera [7].

In this talk, we will study reconstruction performance and experimental considerations when performing electron ptychography experiments with structured illumination at atomic resolution.

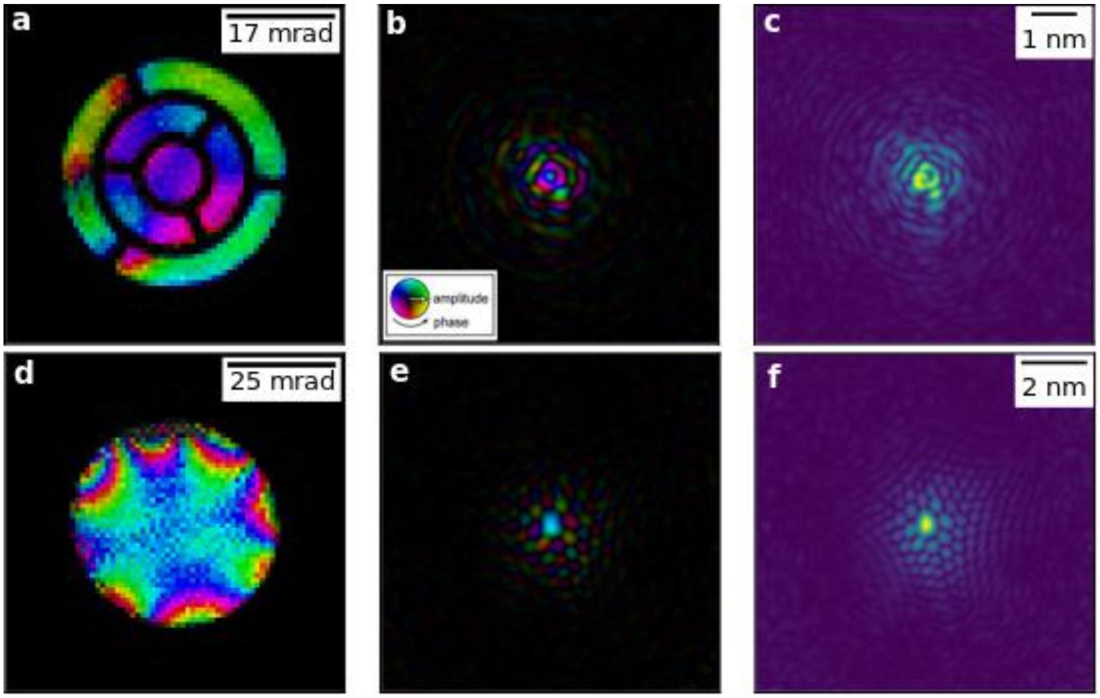

Figure 1. Two different structured illumination schemes studied. a)-c) Bullseye amplitude grating in the condenser aperture. d)-f) Strong 4-fold aberration, producing a 'flower petal beam'. First column: condenser-plane reconstructed phase and amplitude of the first probe mode. Second column: object-plane reconstructed phase and amplitude of the first probe mode. Third Column: Object-plane reconstructed amplitude of the first probe mode.

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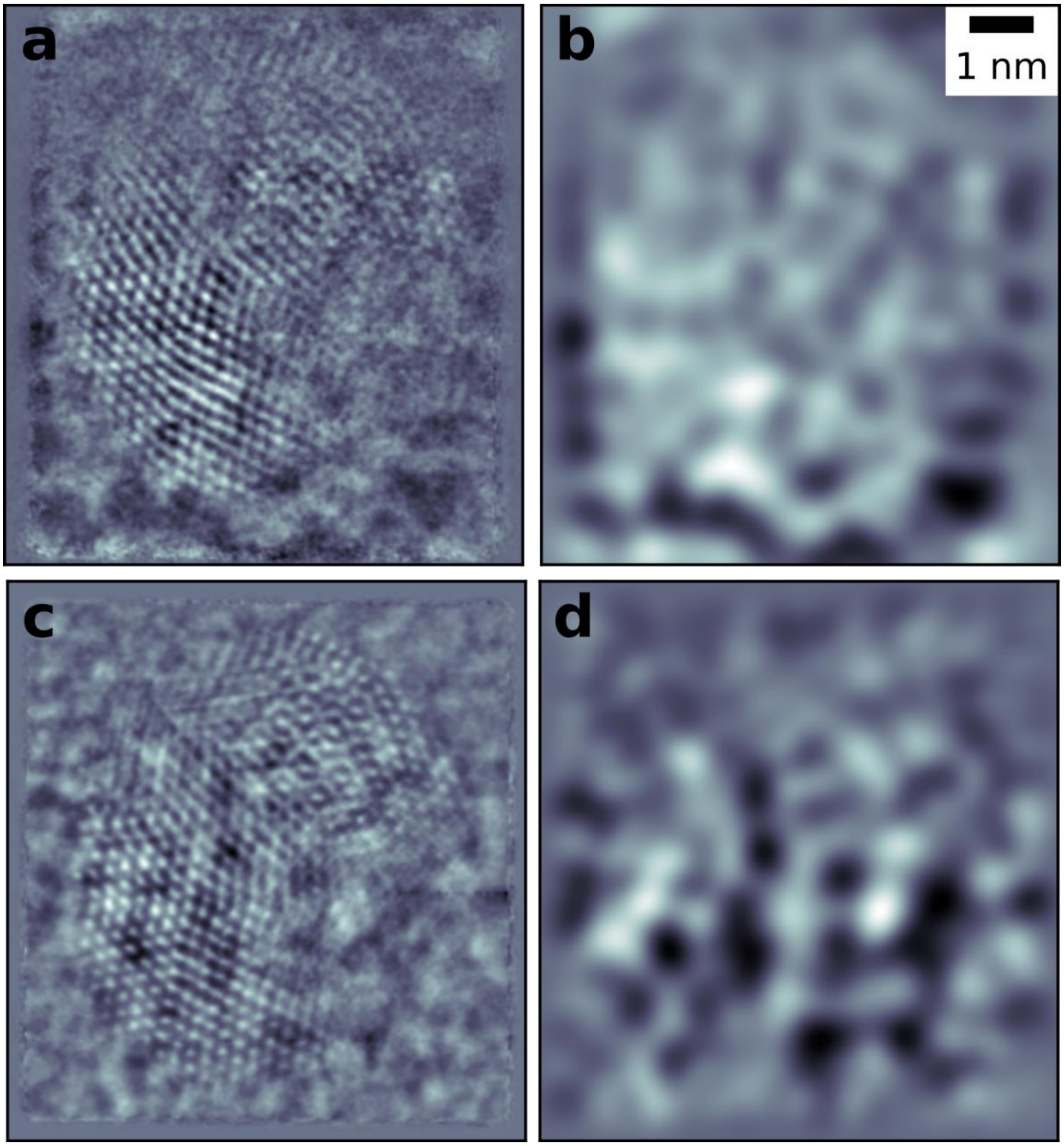

Figure 2. Au nanoparticle reconstructed with mixed-state electron ptychography. a) Reconstruction from a scan with the bullseye probe in Fig 1b). b) A low-pass filtered version of Fig. 2 a) with a Gaussian kernel (FWHM of 3.3Å) reveals the recovered low spatial frequency contrast of the nanoparticle. c) Reconstruction of the same particle in Fig 2 a) from a scan taken with a round aperture and 8nm defocus. d) Low-pass filtered version of Fig 2 c) with a Gaussian kernel of FWHM of 3.3Å

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