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Inelastic Phase Contrast Using Electrostatic Zach Phase Plates

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Physical phase plates (PP) for transmission electron microscopy (TEM) are intensively studied since the first carbon film-based and electrostatic PPs have been experimentally realized [1,2]. By inducing a phase shift on a part of the electrons in the back focal plane of the objective lens, contrast enhancement can be achieved. Several groups have already demonstrated proof-of-principle experiments using different PP designs. Our approach is based on the electrostatic Zach PP [3] shown in Fig. 1. The Zach PP has a central electrode positioned on a single rod and surrounded by insulating ceramic and shielding metal layers. This design offers reduced obstruction in the back focal plane compared to Boersch PPs [2] and a controllable phase shift induced on the unscattered electrons by the inhomogeneous electrostatic potential created at the tip. To minimize contamination and electrostatic charging, a heating device is implemented and a thin amorphous carbon layer is deposited on the PP.

In this work, the effect of inelastic scattering processes on the generation of phase contrast by PP TEM is studied. The study is motivated by the fact, that substantial inelastic scattering cannot be avoided even in thin sections of low-density materials. It was shown by electron holography that coherence of plasmon-scattered electrons is partially maintained [4 and references therein]. Here, we examined phase contrast of Au nanoparticles (NPs) deposited either on the upper or lower surface of amorphous (a-)carbon films with different thickness. The experiments were performed in a 120kV Zeiss 912 microscope equipped with a LaB_6-cathode, an Ω in-column filter and a Zach PP in the back focal plane of the objective lens. PP TEM images were acquired at different voltages U without filtering and with filtering in the characteristic energy-loss range of carbon plasmon losses between 22 and 27 eV.

Fig. 2 depicts unfiltered PP TEM images of NPs on the lower surface of an a-carbon film and one corresponding power spectrum. Phase contrast inversion can be recognized for U = 5 V in Fig. 2b. Artifacts caused by the obstruction or the inhomogeneous potential are only visible in the large particle in Fig. 2b. It exhibits dark and bright contrast in direction of the PP rod on opposite sides of the NP.

Plasmon-filtered PP TEM images of the same region (Fig. 3) show weak but distinguishable NP contrast and phase-contrast inversion is obtained for U = 5 V (Fig. 3c). Electrons, which experience a plasmon scattering loss in the a-carbon film, are not coherent with respect to unscattered or elastically scattered electrons. However, the wave is self-coherent after inelastic scattering and can create phase contrast by a succeeding elastic scattering process. The influence of the a-carbon film thickness and NP size on the achievable phase contrast for both, unfiltered and plasmon filtered images, was analyzed. Differences in contrast are especially observed for NPs on the upper or lower surface of the a-carbon film [5].

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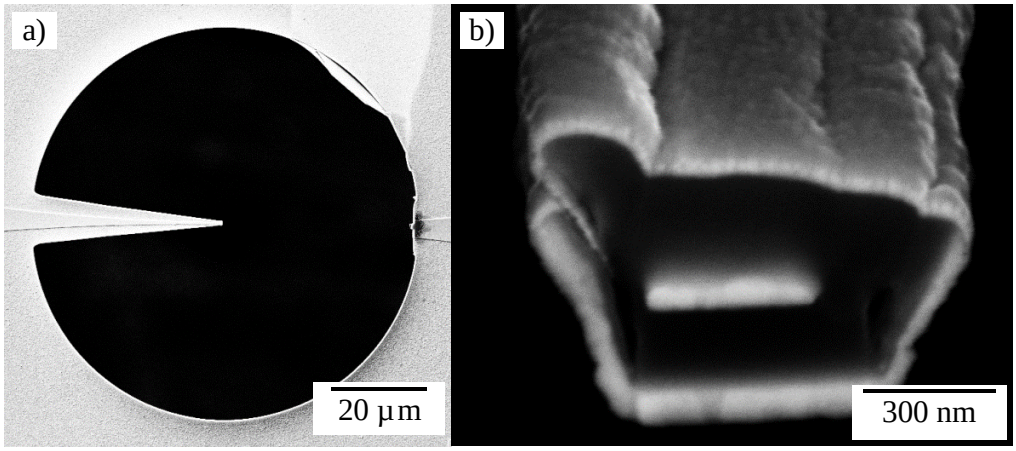

Figure 1. Scanning electron microscopy images of (a) a Zach PP and (b) the layer system at the PP tip consisting of electrode, insulating ceramic and shielding metal layers.

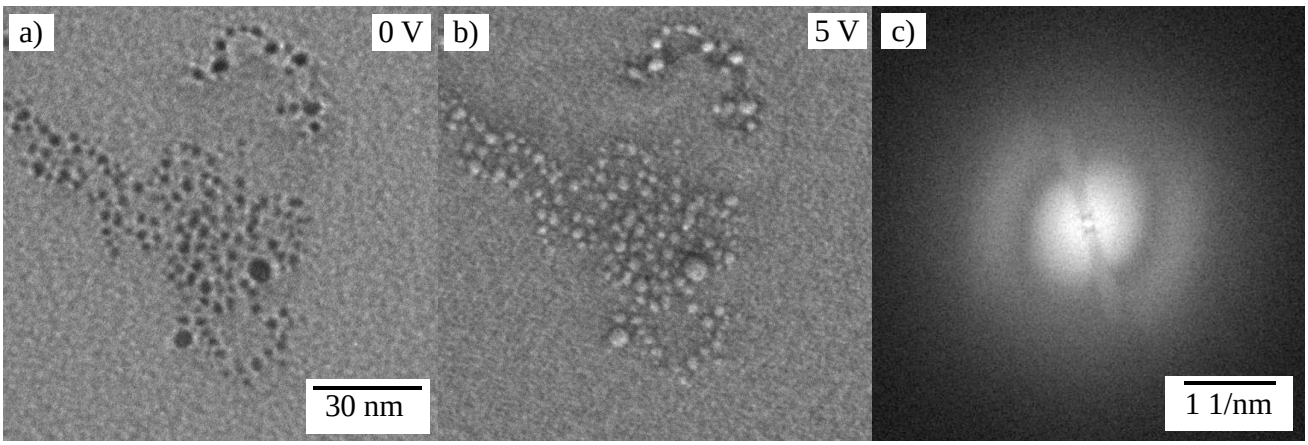

Figure 2. PP TEM images of Au NPs and one corresponding power spectrum. (a) NPs appear black for U = 0 V at a defocus value of -280 nm. (b) Contrast inversion is achieved for U = 5 V. (c) The corresponding power spectrum reveals the PP rod.

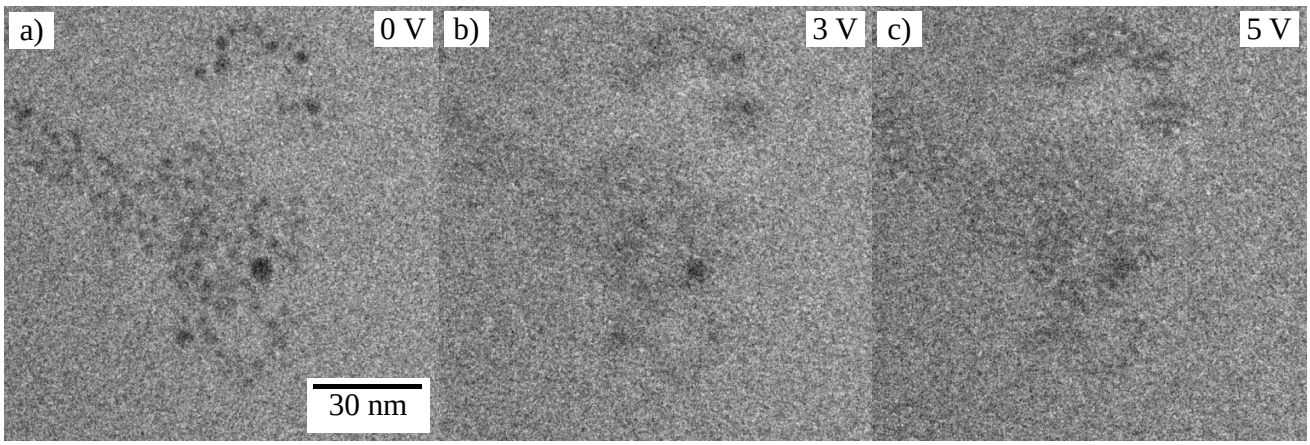

Figure 3. Plasmon-filtered PP TEM images of Au NPs. (a) NPs appear black without applied voltage. (b) A contrast reduction is observed for U = 3 V. (c) NP contrast is inverted for 5 V.

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