Characterization of aberrations of Fresnel Zone Plate optics by ptychographic diffraction imaging

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Ptychographic imaging has been shown to be a proper tool to characterize the optical performance of focusing x-ray optics [1]. Ptychography allows both, to reconstruct the complex transmission function of an object, as well as the complex wave field of the illuminating x-ray beam without prior knowledge about the object or illumination. Thus, ptychography can be used to verify whether a specimen is properly placed within the focal plane, to align the focusing optics, to retrieve information about aberrations of these optics, and last but not least for high-resolution microscopy. In [1] a nanofocusing lens (NFL) was used to focus the x rays, but we suppose, that ptychography is also qualified to characterize other x-ray optics like Fresnel zone plates (FZPs), compound parabolic lenses (CRLs), multilayer Laue lenses (MLLs), or adiabatically focusing lenses (AFLs).
The nanohutch of the PETRA III beamline P06 provides an x-ray microscope which is well-suited for ptychographic imaging [2]. It is possible to equip the optics unit of that nanoprobe instrument with different kinds of x-ray optics. In this report we describe an experiment at the P06 nanohutch, where we utilized ptychography to characterize the x-ray beam generated by a Fresnel zone plate. The FZP was provided by the Laboratory for Micro- and Nanotechnology and had been fabricated by a zone-doubling technique [3]. The FZP was made of iridium, had a diameter of $150\ \mu\mathrm{m}$, and the width of its outermost zone was $25\ \mathrm{nm}$. Its efficiency was between $7\,\%$ and $10\,\%$ in the hard x-ray regime around $10\ \mathrm{keV}$. With a distance of $98\ \mathrm{m}$ away from the undulator, the source was imaged only slightly behind the focal plane of the FZP which was about $30\ \mathrm{mm}$.
A test pattern from NTT-AT (Figure 1a), `http://ntt-at.com`) made of $500\ \mathrm{nm}$ thick tantalum was mounted near the focal plane and served as a test object in a ptychographic scan. The scanning area of $2 \times 2\ \mu\mathrm{m}^2$ was covered by 101×101 scan points. The resultant step size of $20\,\mathrm{nm}$ ensured a sufficient overlap of the illuminating wave field between neighboring scan points. At each scan point, the farfield diffraction pattern of the object was recorded by a PILATUS 300k pixel detector in a distance of $2\ \mathrm{m}$ behind the object, and the fluorescence signal was detected by an energy dispersive drift detector. The exposure time of $0.7\ \mathrm{s}$ was chosen such that the diffraction pattern was measured with large count rates but without saturating the detector.

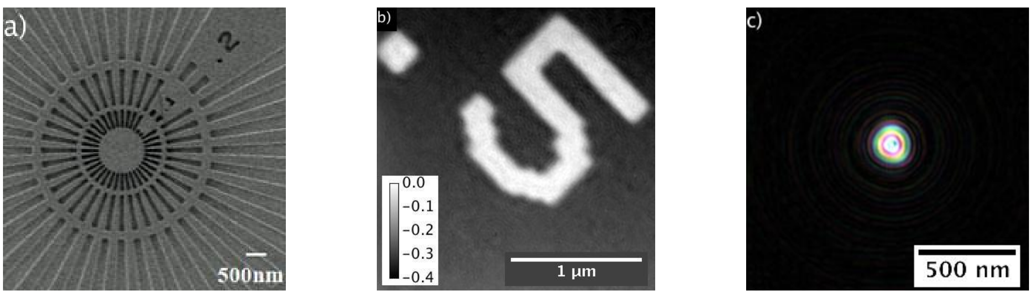

Figure 1: a) SEM image of the NTT-AT test pattern. b) Reconstructed phase of the transmission function of the scanned region. c) Reconstructed complex wave field of the illumination within the object plane.

Figures 1b) and c) show the reconstructed phase of the object's complex transmission function of the scanned region and the complex wave field of the illuminating x-ray beam within the object plane, respectively. The object phase is reconstructed with a spatial resolution of about 25 nm. In a microscopy experiment, the setup and the reconstruction would have been optimized to improve spatial resolution. Here, our intention was to measure the caustic of the complex wave field of the zone-doubled FZP, and the object serves rather as a test pattern.
The complex wave field within the object plane was numerically propagated along the optical axis. Figure 2 shows the wave field in the object plane 2a), propagated to the focal plane 2b), and 1 mm away from the object towards the zone plate 2d). The distance between 2a) and 2b) is 50 μm. In agreement with [4], the ptychographic reconstruction still succeeds, even though the object was off-focus by that amount. In Figure 2c) the horizontal and the vertical line profiles through the intensity distribution in the focal plane are shown. The FWHM size of the focus was 21×24 nm^2 (h$\times$v) and this conforms quite well with the expected size of the Airy pattern for the given photon energy of 10 keV (1.2 Å wave length) and a numerical aperture of about 2.5 mrad (30 mm focal distance, 150 μm geometric aperture). Figure 2d) shows the wave field 1 mm before it reaches the object. There is a large decrease of amplitude in the inner circle, which is caused by the central beam stop absorbing the first order zones of the FZP.
This experiment demonstrates that ptychography is an appropriate tool for optics characterization not only for NFLs, but also for FZPs. Publications related to this work are in preparation. Experiments applying ptychography to CRLs and MLLs at PETRA III beamline P06 are described in separate reports.
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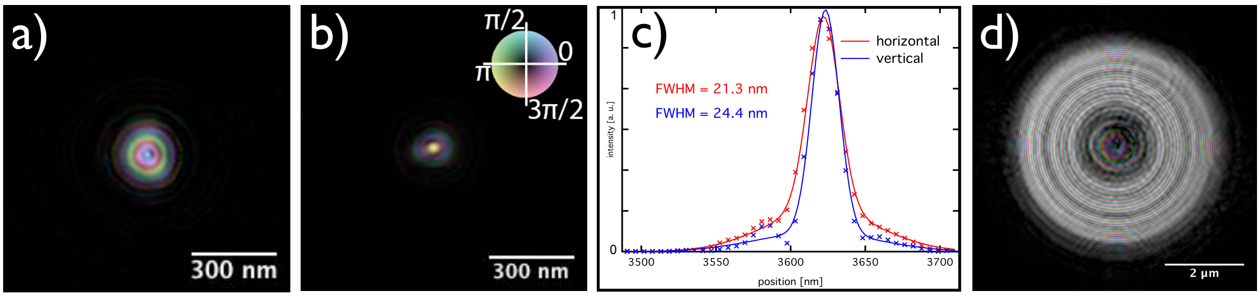

Figure 2: Complex wave field propagated along the optical axis (phase: color, amplitude: hue). a) Wave field in object plane, b) in focal plane, c) horizontal and vertical line profiles in focal plane, d) wave field 1 mm before reaching the sample.

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