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High resolution ptychography using off-axis illuminated zone plates

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The recent development and increased availability of third-generation synchrotron radiation sources together with the rapid progress of novel experimental techniques have made X-ray microscopy well-known in the scientific community. Amongst its most prominent merits are high resolution and penetration depth combined with elemental or magnetic sensitivity without the need of invasive sample preparation. The development of phase contrast imaging methods have extended the use of X-ray microscopy to allow the study of even weakly absorbing biological specimens. While the coherence properties of modern synchrotron light sources increased the possible resolution considerably, accessible traditional X-ray optics were unable to confront with the demand. However, with the rapid increase of available computational power, it has become feasible to circumvent limitations of X-ray optics using lensless X-ray microscopy schemes. Lensless imaging techniques measure the diffraction pattern of the sample object and attempt to numerically solve the relationship between the sample and its measured diffraction pattern. For this, they aim at recovering the phase that was lost during the measurement using a set of constraints and boundary conditions.

Ptychography is a scanning-based high resolution coherent diffractive imaging technique. It was first proposed in 1970s for transmission electron microscopy [2,3] and has been recently demonstrated in the X-ray and optical range [3,4]. It measures multiple diffraction patterns from partially overlapping sample regions to use the overlap as a constraint to recover both the sample object and the illumination function (probe) with much higher resolution than the scanning step size. For hard X-rays, ptychography can be realized with the experimental setup shown in Figure 1 using a Fresnel zone plate as focusing optic. It is basically a form of super-resolution scanning transmission X-ray microscopy utilizing mainly coherent illumination and a two-dimensional pixel detector. The sample is scanned by a well-defined, localized, but not strongly focused illuminating probe. The step size must provide a significant overlap between subsequently illuminated regions. For each scan point, a far-field diffraction pattern is recorded which requires sufficient oversampling for the phase problem to be completely resolved.

Afterwards, the measured dataset is loaded into iterative algorithms [5-7] to reconstruct the complex object transmission function and the illuminating wave front. In ptychography there is no restriction imposed on the type or shape of the illumination, yet, rough a priori knowledge of the probe may be needed at the beginning of the reconstruction. On the contrary, the phase retrieval can start from a completely random object guess. During the refinement process, the algorithms alternate between real and reciprocal space, substituting the calculated intensity in a detector plane with the measured intensities without further artificial boundary conditions. Most modern algorithms involve the simultaneous reconstruction of both the probe and the object, yielding therefore information not only about the specimen but also about the illuminating wave front. The resolution of ptychographic reconstruction is limited by neither the size of a focal spot nor the numerical aperture of a lens any more. It is restrained only by the dose and the finite amount of measured photons in high scattering vector q values allowing sub-10-nanometer resolution in the hard X-ray regime.

The talk will provide all necessary information about ptychography as a scanning high resolution imaging technique utilizing coherent synchrotron radiation. This will be followed by its demonstration at beamline P11 at PETRA III light source [8], DESY, Hamburg. The experimental setup (see Figure 1) was designed to investigate an influence of finite spatial coherence length on the quality of ptychographic reconstruction by providing different spatial coherence conditions as reported in [9].

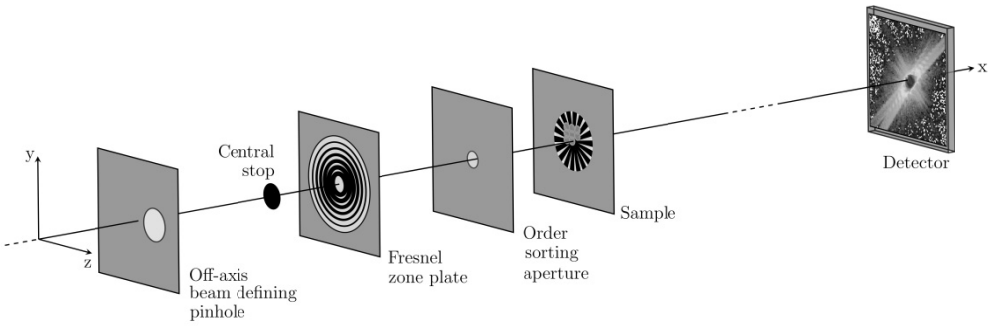

Figure 1. Schematic of the ptychography experiment using an off-axis illuminated zone plate.

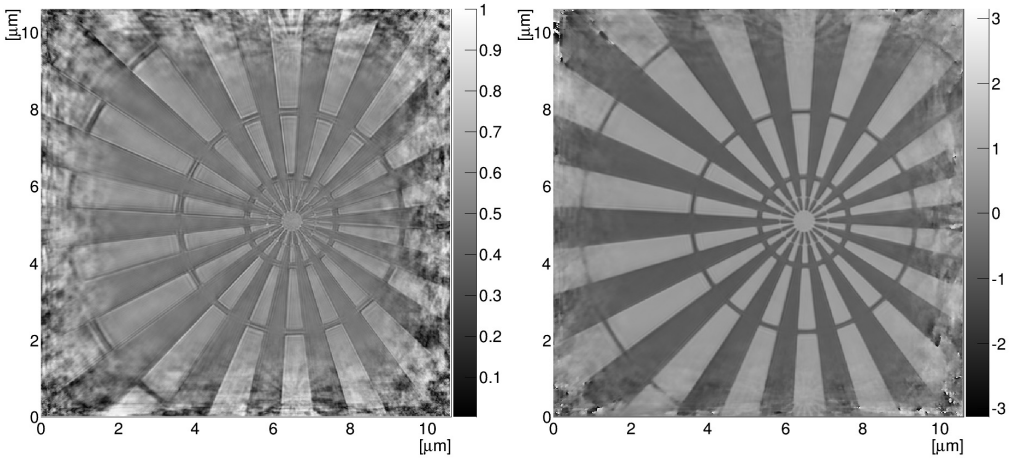

Figure 2. An example of reconstructed amplitude (left image) and phase (right image) of the Siemens star.

An evaluation of reconstructed images' resolution of a test object (Siemens star) will be discussed for those cases. Figure 2 presents reconstructed amplitude (left image) and phase (right image) of the Siemens star. Figure 3 shows a typical diffraction pattern recorded with a PILATUS 1M single photon counting detector [10] for the most coherent illumination. During the talk, ptychographic reconstructions of fossil diatoms and stained hepatoma cells will be presented as applications of the technique in biological imaging. The experimental results will be compared with simulated data. Both the simulation of the beamline and the reconstruction tools are software prepared in the C/C++ with support of the ROOT Data Analysis Framework [11].

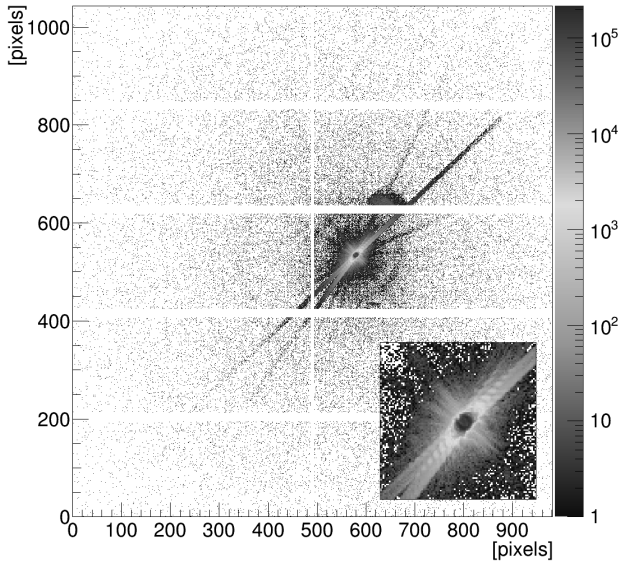

Figure 3. A typical far field diffraction pattern from the ptychographic dataset recorded with PILATUS 1M detector. Horizontal and vertical lines correspond to intermodule gaps with no readout. In the inset the central part of the diffraction pattern is presented.

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