X-ray ptychography using randomized zone plates

Elettra: TwinMic

A randomized GCZP (Grating Condenser Zone Plate) was developed to provide a µm-scale probe for use in soft x-ray ptychography. This novel x-ray optical element gives better x-ray throughput than probes defined by pinhole apertures, while providing a clearly-defined level of phase diversity to the sample illumination, and spreading the signal over the detector plane to reduce its dynamic range.

X-ray ptychography is a hybrid of coherent diffraction imaging and STXM (Scanning Transmission X-ray Microscopy), allowing images to be formed with significantly better resolution than the spatial extent of the illuminating probe. This allows a relatively large probe to be used to survey extended sample areas at high spatial resolution with only a modest number of probe positions. Using a focusing element, such as a zone plate, to define the probe (instead of a pinhole aperture) spreads the zero-order signal downstream of the sample plane over an extended area of the detector plane, better matching the dynamic range of signals to that which soft-x-ray detectors such as CCDs (Charge-Coupled Devices) can handle. The use of phase-randomized illumination has also been shown to have theoretical and practical benefits for the quality of ptychographic image reconstructions. Such randomization can be introduced by inserting a diffuser into the x-ray beam, but this reduces the overall x-ray signal throughput. Instead we have designed a randomized GCZP for use at soft x-ray energies: this single optical element produces a focused probe while at the same time introducing a well-defined level of phase randomization into the illumination. A conventional FZP (Fresnel Zone Plate) consists of a series of concentric annular zones whose spacing decreases with increasing radius, as shown in Fig. 1a. Each annular zone has the

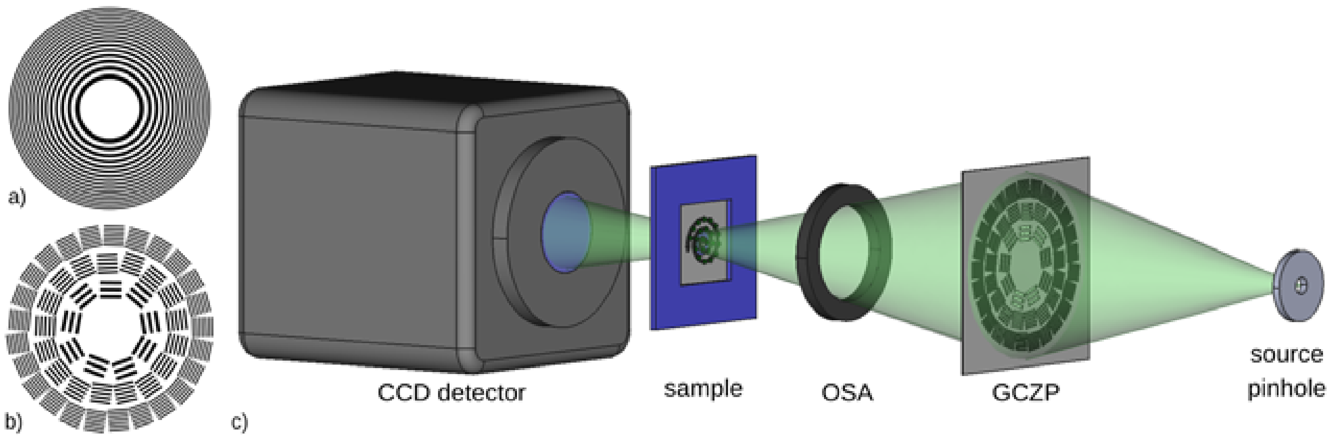

Figure 1: Schematic diagrams showing a) a conventional FZP with the two innermost zones blanked; b) a randomized GCZP with the same inner and outer radii as the Fresnel zone plate in (a); c) the setup used for ptychographic imaging on the TwinMic beamline at Elettra. The source pinhole was 50 µm in diameter and located about 2 m upstream of the GCZP, the CCD camera was about 685 mm downstream of the sample. The GCZP had a 60 µm-diameter central stop on its upstream side, and an order-selecting aperture (OSA) of 20 µm diameter was placed on the optical axis about 6 mm downstream of the GCZP to ensure that only the convergent first-order diffracted beams could reach the sample plane. Adapted with permission from DOI:10.1364/OE.26.014915. Copyright 2018 OSA Publishing.

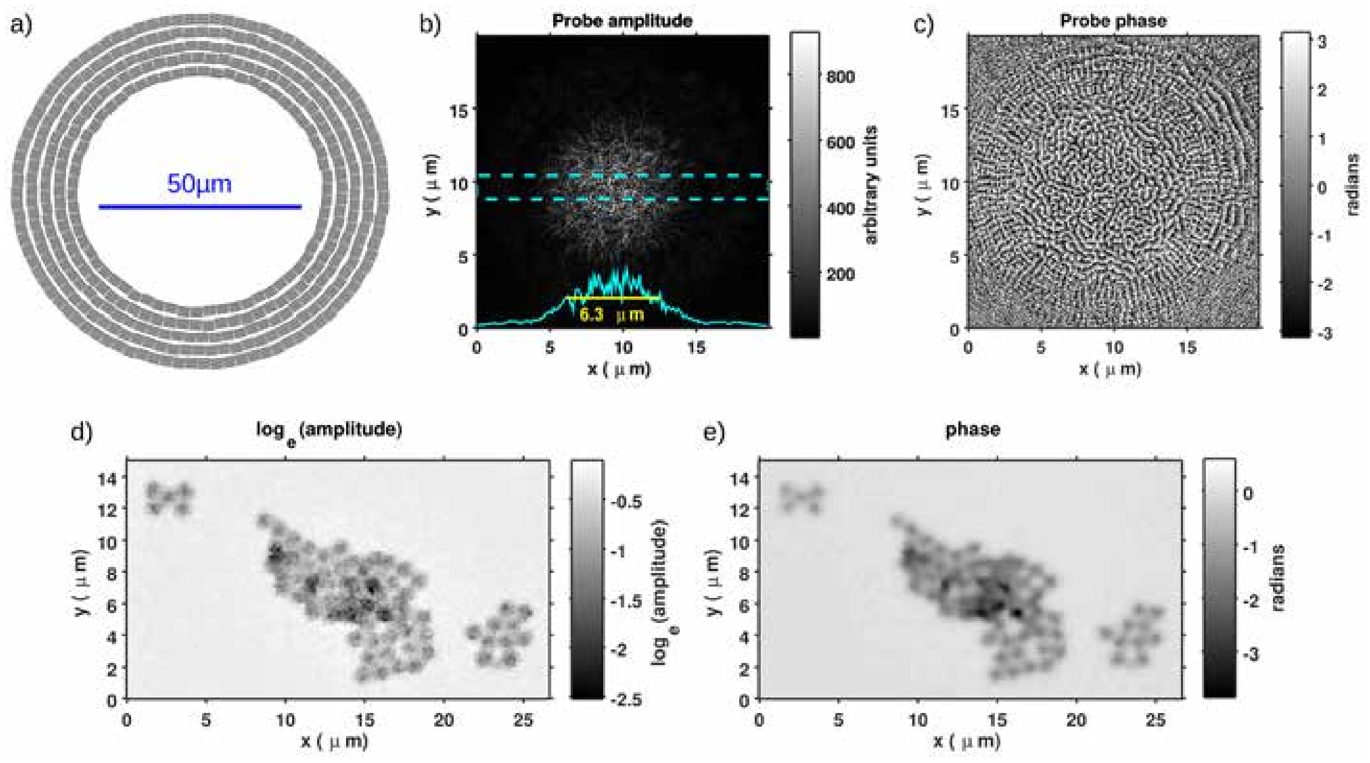

Figure 2: a) A schematic showing the design of the randomized GCZP used on TwinMic; b) ptychographic reconstruction of the probe amplitude distribution, overlayed with a plot showing the average profile across the probe for rows between the dashed lines; c) the probe phase distribution; ptychographic reconstructions of the amplitude (d) and phase (e) of the transmission function for an assembly of 1.09 µm-diameter polystyrene spheres. Adapted with permission from DOI:10.1364/OE.26.014915. Copyright 2018 OSA Publishing.

same area, and the zone boundaries are chosen to ensure that all positive first-order diffracted beams overlap at the same focal distance along the optical axis. A GCZP approximates an FZP by replacing the annular zones with concentric polygonal shells whose sides form the inner edges of a set of linear gratings. Within each shell the grating periods are chosen so that the first-order diffracted beams again overlap on the optical axis at the same focal distance. For the GCZP shown in Fig. 1b, the individual gratings are square and of equal area, and their positions have all been randomized: the angular start position of each shell of gratings has a random offset, and each grating has a random radial offset, up to a maximum of one period of that grating. The net effect is that the GCZP generates a focal spot whose diameter is determined by the size of the individual gratings, and there is a random phase associated with each of the diffracted beams contributing to the focal spot.

The setup used on the TwinMic beamline is shown in Fig. 1c. The GCZP replaces the conventional FZP used for STXM operation, and the transmitted x-rays are detected by a soft-x-ray sensitive CCD downstream from the sample. In practice, the GCZP consisted of 383 gratings, each 3 µm × 3 µm square, located in 5 annular shells between an inner diameter of 60 µm and an outer diameter of 94 µm, as shown in Fig. 2a, and had a focal length of 8 mm at 600 eV. Our design was fabricated in 236 nm-thick tungsten film on a 100 nm-thick silicon nitride support film by Zoneplates Ltd. Ptychographic image reconstructions of the sample allow the probe amplitude and phase to be recovered, and these are shown in Fig. 2b-c. The probe diameter at FWHM (Full Width Half Maximum) is seen to be 6.3 µm, significantly larger than the 1.09 µm spheres clearly resolved in the ptychographic image reconstructions shown in Fig. 2d-e. The half-period image resolution is estimated to be 140 nm. The randomized GCZP has been found to be an attractive and cost-effective option for ptychography measurements on the TwinMic beamline.

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Original paper

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