ESRF	**Experiment title:** Imaging of nanocrystals in polymer films studied by x-ray waveguide beam	**Experiment number**: SI 1263
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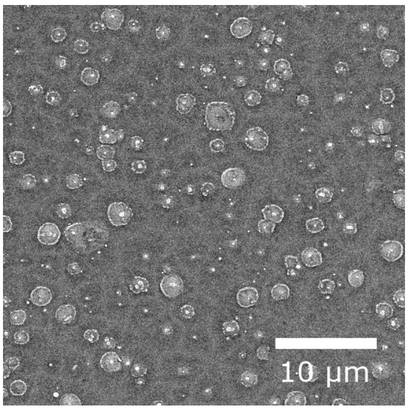
Report:

Based on the results of experiments MI 686 and MI 770, the experiment has aimed at lensless imaging of nanocrystals applying the coherent cone beam provided by an X-ray waveguide. An important experimental improvement compared to MI 770 was the application of a direct-illumination CCD camera, which provides higher detection efficiency and a smaller pixel size resulting in greatly improved quality of the recorded images.

We have imaged micron-sized Cu islands prepared by pulsed-laser-deposition on a thin Si foil with the waveguide beam and the individual islands can be directly recognized in the recorded image (Fig. 1). To resolve smaller features, the recorded image has to be considered an in-line hologram



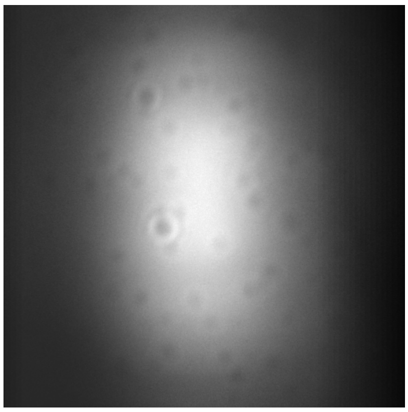


Fig. 1: *Scanning electron microscopy image of the investigated Cu islands (left) and image recorded with the waveguide beam (right). Individual islands are well resolved.*

and a holographic reconstruction is necessary [1]. We have recorded several in-line holograms of a lithographically-prepared test structure. A reconstructed phase image is shown in Fig. 2. The sample consists of gold structures with a thickness of 150 nm and we find a spatial resolution of below 400 nm. However, from the cross-sectional dimensions of the waveguide we had expected a resolution below 100 nm. Furthermore the image is significantly disturbed by artifacts. This is probably related to the inherent "twin image" problem of in-line holography.

This "twin image" problem can be overcome by two-beam holography techniques. Thus we have carried out a waveguide-based off-axis holography experiment (Fig. 3, left). Two coherently illuminated slightly curved waveguides provide two coherent cone beams. One waveguide illuminates the sample while the other one provides an additional reference wave. This enables the recording of a magnified off-axis hologram, from which much better phase images can be calculated. We have recorded multiple off-axis holograms of a small tungsten tip. Numerical reconstruction has yielded phase images of high quality and a spatial resolution of about 100 nm (Fig. 3).

In summary, the technique of waveguide-based hard-X-ray imaging was strongly improved during this experiment. In particular the feasibility of waveguide-based in-line holography and off-axis holography was demonstrated. Highest resolution of about 100 nm and best image quality is achieved by off-axis holography. Micron-sized Cu islands have been imaged and in principle one might decrease the distance between the waveguide and the sample to illuminate single islands, which can then be studied by X-ray diffraction or fluorescence. The investigation of smaller particles like nanocrystals will require smaller waveguide cross-sectional dimensions and higher flux than currently available. However, they will likely be available in near future.

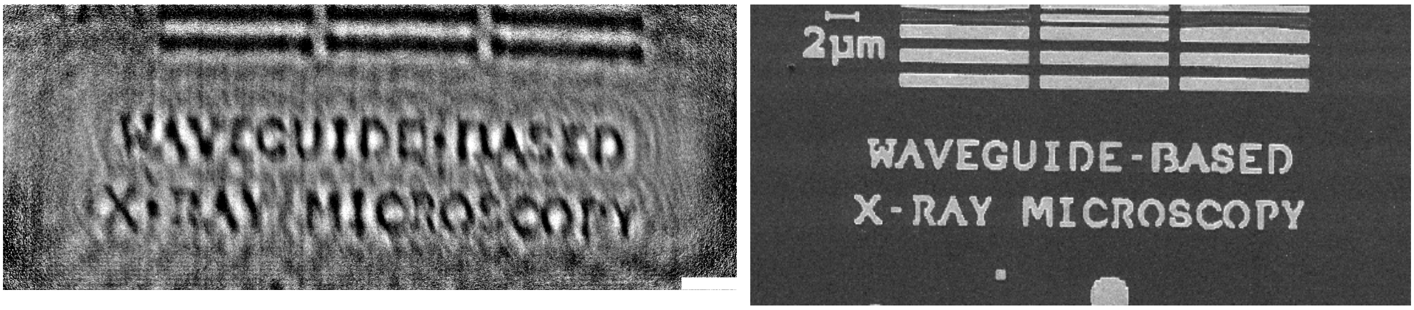


Fig. 2: *Reconstruction from in-line holograms recorded with a lithographically-prepared test structure (150 nm Au on a thin Si foil, left). Scanning electron microscopy image the sample (right).*

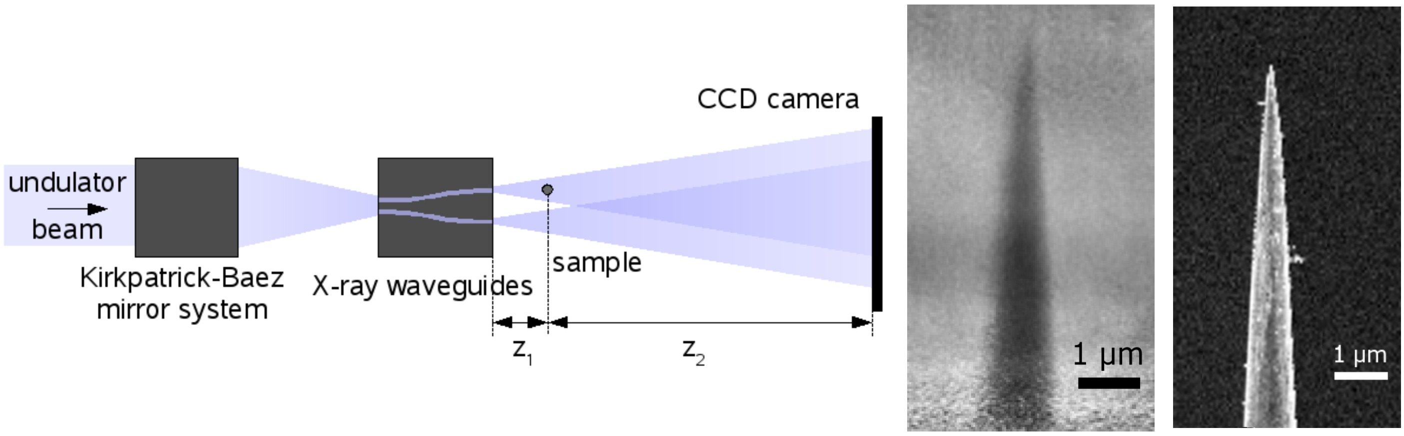


Fig. 3: *Experimental setup for waveguide-based off-axis holography (left). Phase images calculated from off-axis holograms (middle) yield the phase part of the optical transfer function with a spatial resolution of about 100 nm. A scanning electron microscopy image is shown for comparison (right).*

[1] C. Fuhse: *X-ray waveguides and waveguide-based lensless imaging,* PhD thesis, Georg-August-University of Göttingen (2006), http://resolver.sub.uni-goettingen.de/purl/?webdoc-742