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Wavelength-scale Coherent Diffractive Imaging using a High-order Harmonic Source

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Coherent diffractive imaging (CDI) and related techniques avoid the use of lossy optics after the sample and instead record the intensity of the diffracted field directly on a pixelated detector [1]. The sample is then reconstructed using iterative algorithms that retrieve the missing phase of the diffracted field. So far, these experiments are mainly conducted at synchrotrons and X-ray free electron lasers (XFELs) which have limited accessibility. In recent years, table-top XUV sources employing high-order harmonic generation (HHG) were shown to generate a photon flux up to 10^{14} photons/sec [2] and already demonstrated sub-wavelength resolution using CDI [3]. In this contribution, we report imaging of structures with sizes close to the illuminating wavelength of 18.1 nm using different coherent imaging techniques. The resulting high aspect ratio for such small feature sizes gives rise to waveguiding effects [4] which are found to play an important role in image formation and interpretation.

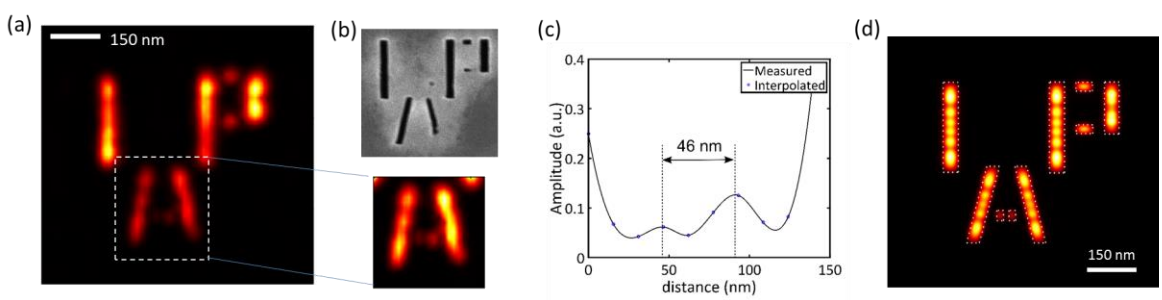

Figure 1. (a) Reconstructed exit wave from an FTH experiment. (b) Helium ion microscope (HIM) image of one side of the sample. Inset of letter ‘A’ from (a) is color rescaled and shows two horizontal dots not visible in the HIM image. (c) Cross-section along the two dots of the inset of (a). (d) Simulated exit wave from the sample surface.

Two imaging techniques are used to investigate these effects: Fourier transform holography (FTH) and ptychography. In FTH, a reference wave from a structure close to the sample is used to encode the phase information as an interference pattern on the detector [5]. We used an HHG-based XUV source at 68.6 eV to image a transmission sample (Fig. 1(b)) with features close to a wavelength. The reconstruction from

FTH and subsequent phase retrieval is shown in Fig. 1(a) and exhibits intensity fluctuations and modulations along the larger dimension of each feature. A finite difference time domain (FDTD) simulation of the structure (Fig. 1(d)) shows similar intensity modulation not existing in the actual sample. This is found out to be due to propagation of multiple waveguide modes in the structure with the exit wave being a superposition of these modes. In addition, embedded features with a half-distance of 23 nm are resolved which are the smallest features ever resolved in a table-top setup.

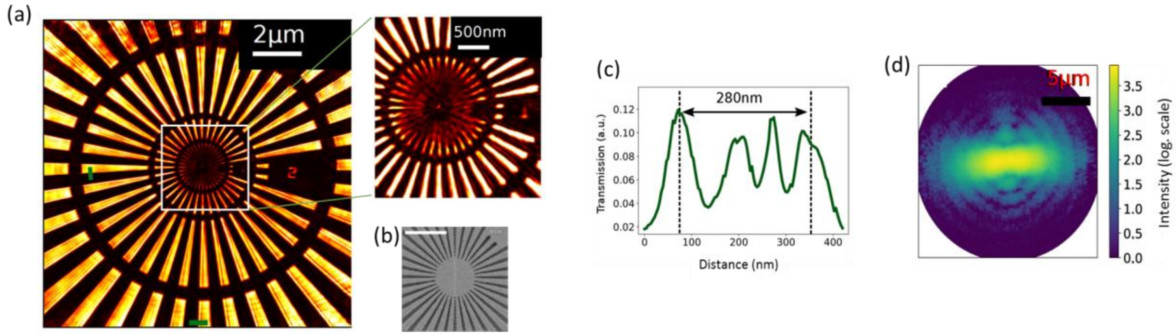

Figure 2. (a) Ptychographic CDI experimental result on a Siemens star sample. (b) Scanning electron microscope (SEM) image of central part of a typical Siemens star sample (scale bar is 500 nm). (c) cross-section along the innermost resolved lines of (a) demonstrating a half-pitch resolution of 47 nm. (d) reconstructed probe.

As a second method for wavelength-scale imaging, we used ptychography where a sample is raster scanned across a beam to image a larger field of view [6]. Previous table-top ptychography experiments have reported knife-edge (10%/90%) resolution values on the order of the illuminating wavelength although the feature sizes imaged were much larger [7]. In contrast, most high-resolution applications require resolving the smallest features possible and the classical Rayleigh criterion is found to be necessary for reliable resolution estimation in these cases [8]. The smallest features ever resolved using a table-top ptychographic setup are reported in this work with sizes of just few wavelengths as shown in Fig. 2. Variation in resolution estimates of a knife-edge test compared to Rayleigh criterion and differences in transmission between large and small features show that additional issues of reliability and waveguiding need to be considered in imaging wavelength-sized features. In addition, numerical simulations of periodic and non-periodic test samples for ptychography indicate that there are critical differences in convergence properties and reliability of the reconstruction. In future, imaging of wavelength-scale features using CDI techniques will enable studies from biological samples to investigations of integrated circuits especially for sources in the XUV and soft X-ray regime.

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