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Towards High-Resolution Imaging at 13.5 nm Using a Fiber Laser Driven High-order Harmonic Source

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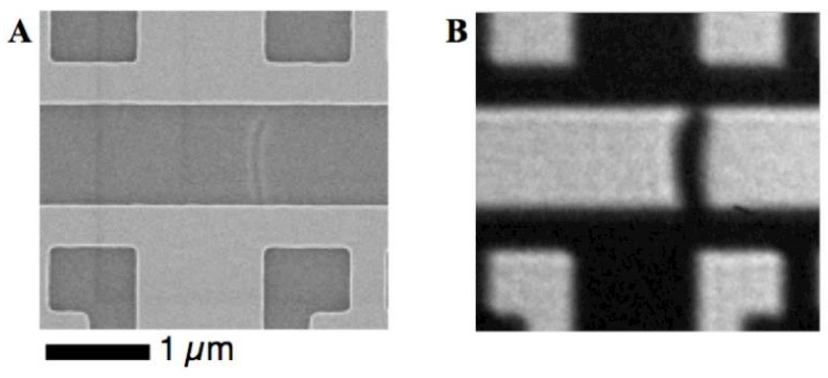
Motivation

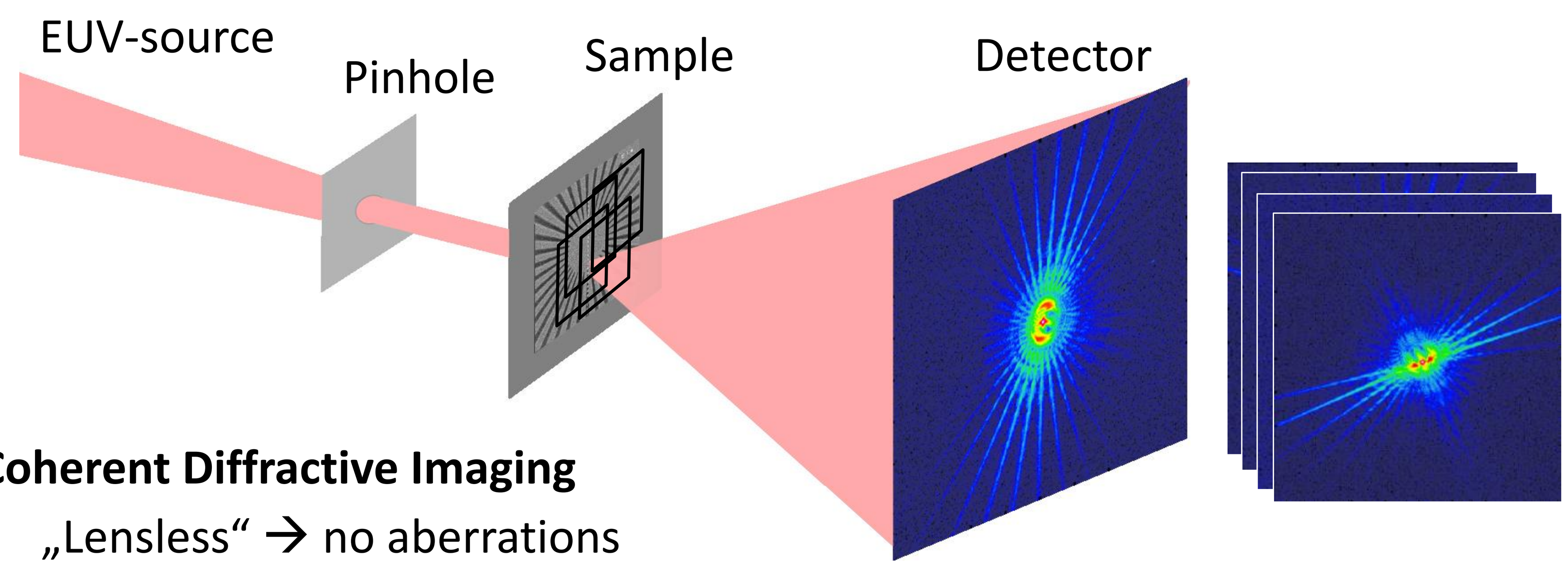
Actinic mask inspection

- Defects on the EUV masks have to be detected
- Electrons or photons at a different wavelength will show a different image and defects may be hidden or misinterpreted [1]
- Actinic mask inspection tool at 13.5 nm needed
- Lensless imaging is a promising cadidate for solving this problem



Comparison of a defect inspected with a SEM (A) and a at wavelength mask inspection tool (B) [1].

Solution



Coherent Diffractive Imaging

- „Lensless" → no aberrations
- Object reconstructed by phase retrieval algorithm
- Scanning Coherent Diffractive Imaging → PTYCHOGRAPHY [2]
- Promising results shown at synchrotron [3]

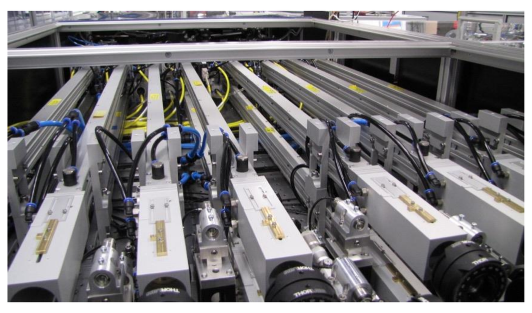
High Harmonic Generation

- HHG: Generation of spatially coherent EUV radiation
- Table-top setup

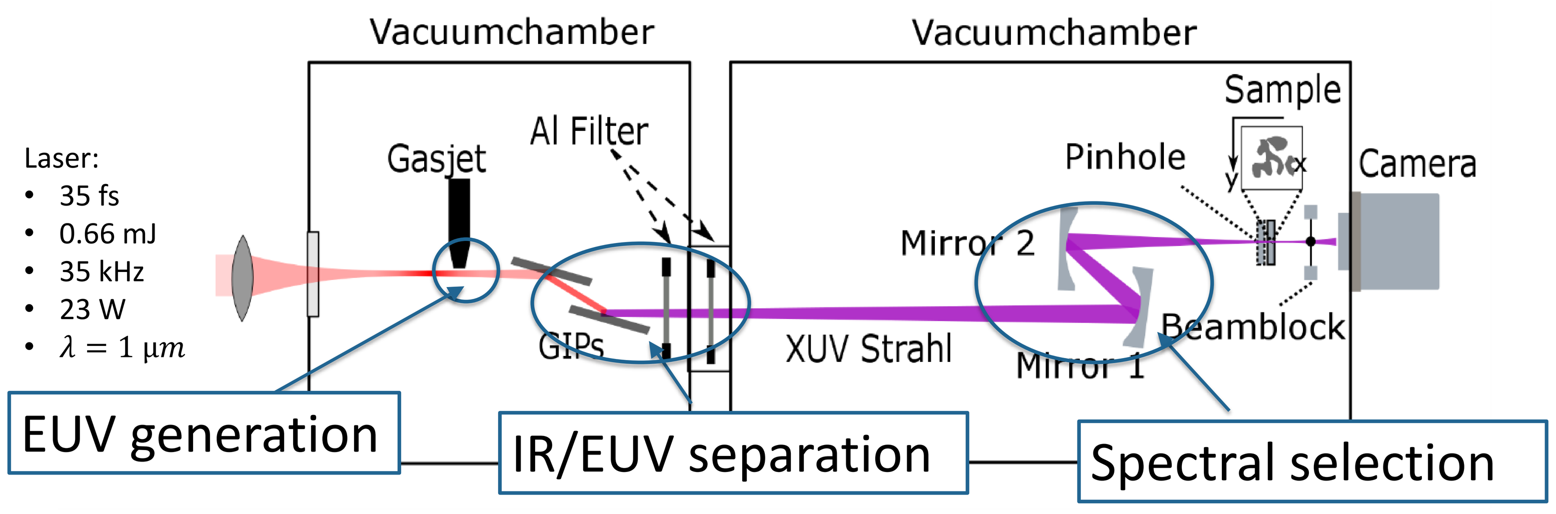
HHG and Imaging Setup

High photon flux HHG

- Fiber laser: kW average power combined with mJ pulse energy [4]
- ➢ EUV photon flux comparable with 3rd generation synchrotrons [5]
- IR beam focused in an Ar gas jet
- GIPs and Al-filters used for separation of IR/EUV
- ML-mirrors used for spectral selection

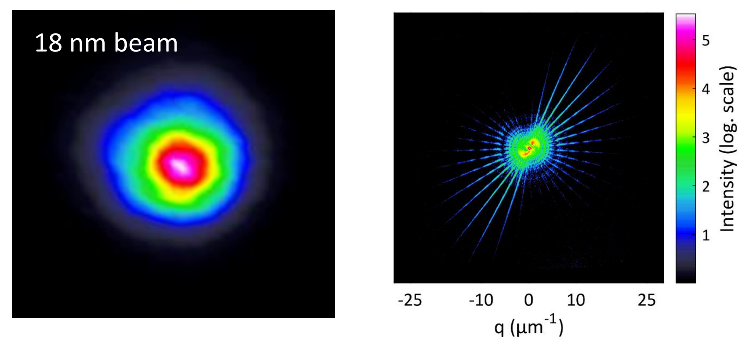


16 channel coherently combined fiber laser system.

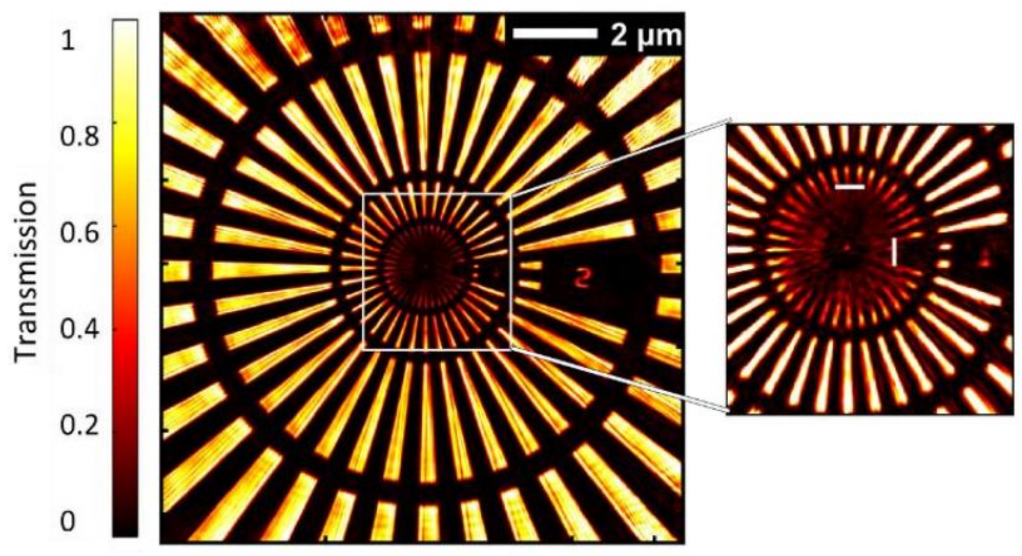


Proof of principle experiment at 18 nm

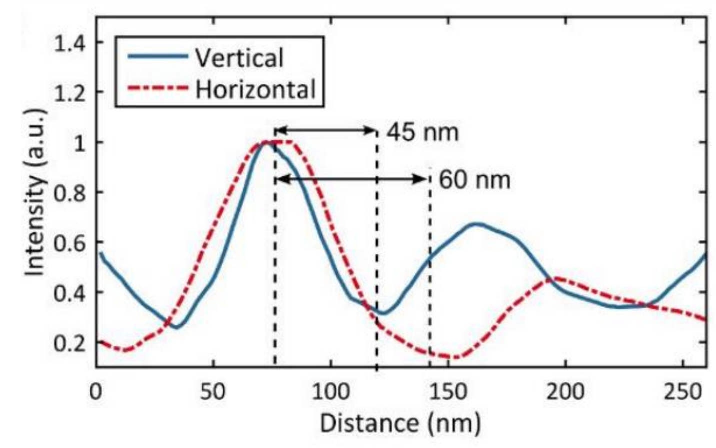
- 18 nm: 10^{11} phot/s
- Ptychography using a resolution test chart
- 45 nm features resolved [6]



18 nm beam and one of the measured diffraction patterns.



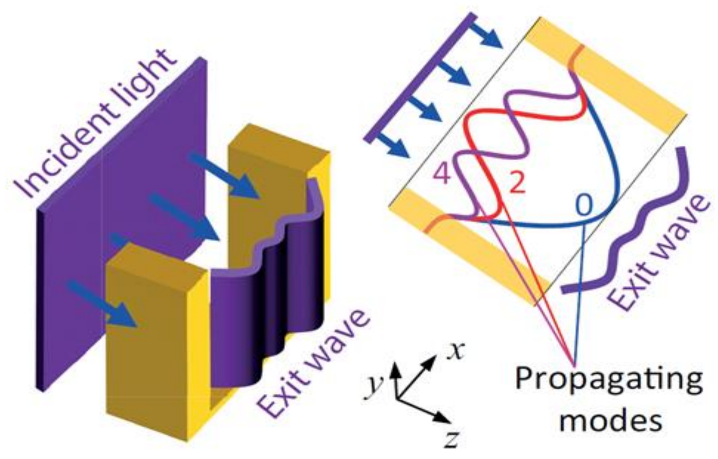
Reconstructed siemens star [6].



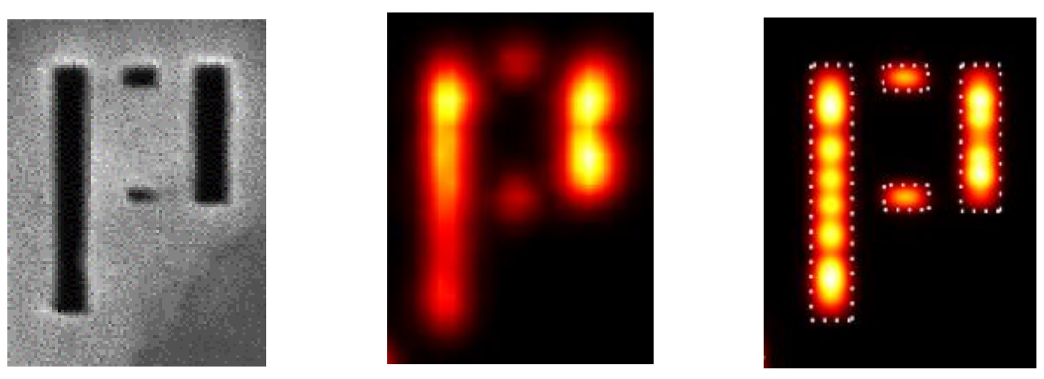
Waveguiding

For imaging of features with sizes close to the used wavelength waveguiding effects have to be considered [7, 8]

- Reconstruction algorithms commonly assume 2D objects
- Quality and resolution limited by propagation effects



Waveguiding in a three-dimensional sample [6].

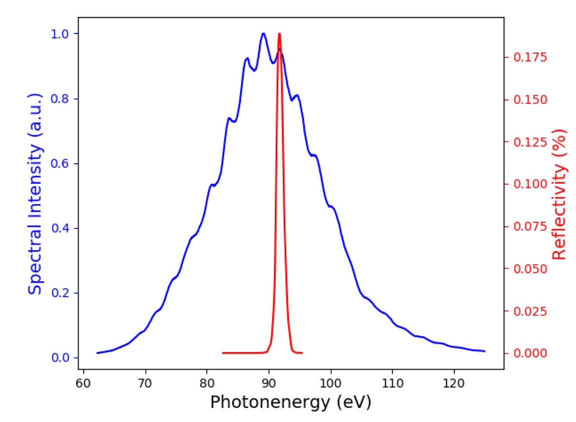


Helium ion microscope | Holographic CDI (18 nm) | FDTD simulation

Towards Imaging at 13.5 nm

Pushing HHG towards 13.5 nm

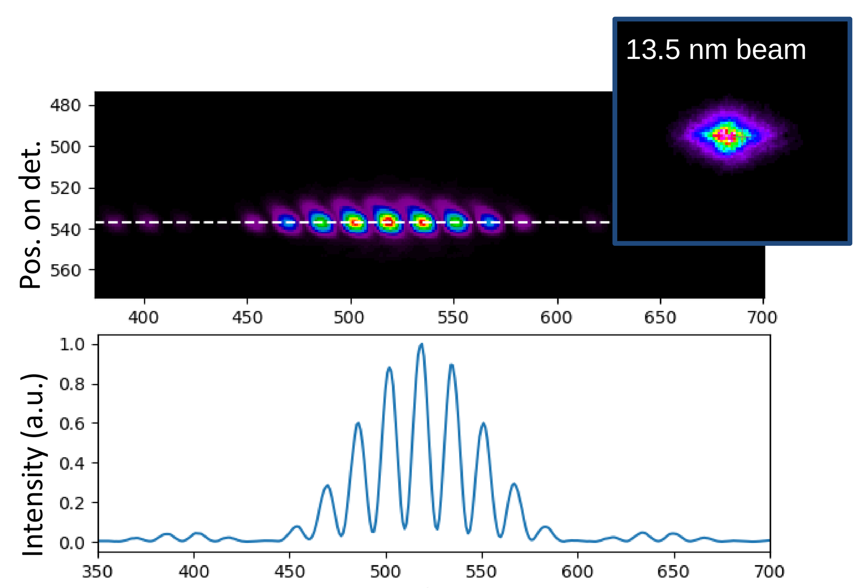
- Cut-off pushed to shorter wavelengths by using few-cycle pulses (7 fs)
- Generation of broadband XUV radiation
- Photon flux of $5 \cdot 10^9$ phot/s/eV at 13.5 nm



HHG spectrum and reflectivity of the multilayer mirrors in use.

Imaging at 13.5 nm: First results

- Three ML-mirros for spectral filtering at 13.5 nm
- Nearly Gaussian shaped 13.5 nm beam
- High degree of spatial coherence
- 10^7 phot/s on the sample



Measured diffraction of a double slit with a seperation of 3 µm.

→ **Ready for ptychography at 13.5 nm**

References

[1] I. Mochi et al. Proc. SPIE 7636, 76361A (2010)
[2] P. Thibault et al. *Science* 2008 321, 5887, pp. 379-382 (2008)
[3] Rajendran, Rajeev, et al. *Metrology, Inspection, and Process Control for Microlithography XXXI*. Vol. 10145 2017
[4] M. Kienel et al. Opt. Lett. 41, 3343-3346 (2016)
[5] R. Klas et al., Optica 3, 1167 (2016)
[6] *G. Tadesse et al., Scientific Reports* 9, 1735 (2019)
[7] S. Zayko, et al, Opt. Express 23, 19911-19921 (2015)
[8] G. Tadesse, *Scientific Reports* 8, 8677 (2018)

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