Ultra-broadband ptychography with self-consistent coherence estimation from a high harmonic source

Michal Odstrcil[1,2], P. Baksh[1], H. Kim[1,2], S.Boden[1], W.S.Brocklesby[1], J.G. Frey[3]

[1]Optoelectronics Reaseach Center, University of Southampton

[2]Experimental Physics of EUV, JARA-FIT, RWTH Aachen University

[3]Chemistry, Faculty of Natural and Environmental Sciences, University of Southampton

Abstract

With the aim of improving imaging using table-top extreme ultraviolet (EUV) sources, we demonstrate coherent diffraction imaging (CDI) with relative bandwidth of ≈20%. The coherence properties of the illumination probe are identified using the same imaging setup. The presented methods allow us to use fewer monochromating optics, obtaining higher flux at the sample and thus reaching higher resolution or shorter exposure time.

Setup of our EUV CDI microscope

- High harmonic generation in argon gas
- 800 nm driving laser with 50 fs pulse length and 2 mJ energy
- Driving laser focused on gascell by a 70 cm focal length lens
- Coherent EUV light around 29 nm, 2.5mrad diveregnce
- IR/EUV separation by a single 200nm Al filter
- Broadband light filtered by a single B_4C/Si multilayer mirror

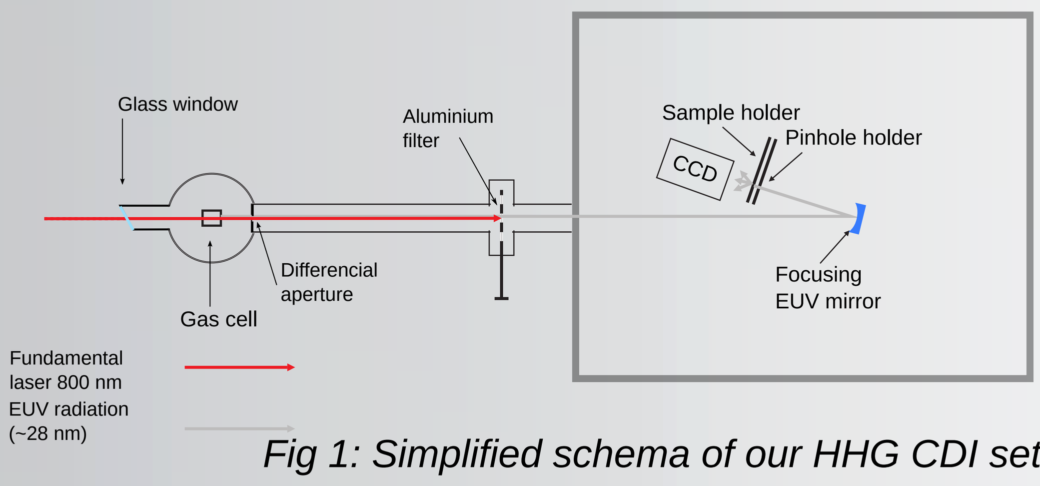


Fig 1: Simplified schema of our HHG CDI setup

- Sample was moved by 3D nanoprecision piezo stage
- Diffracted light was collected by EUV camera Andor DX440

Imaging relevant properties

+ Tabletop setup
+ High spatial coherence
+ Good coherent flux around 30nm wavelength
+ Low divergence and small generation region
– Limited pointing stability
– Intensity fluctuations
– Poor penetration depth of EUV at 30nm for most of materials

Laser stabilization system

- Pointing stability is one of the main issues for HHG CDI microscopes
- Standard stabilization systems are not overwhelming for 1kHz repetition rate pulse lasers
- We have developed our own system based on Raspberry Pi 2
- 20Hz rate, ~0.2 µrad precision

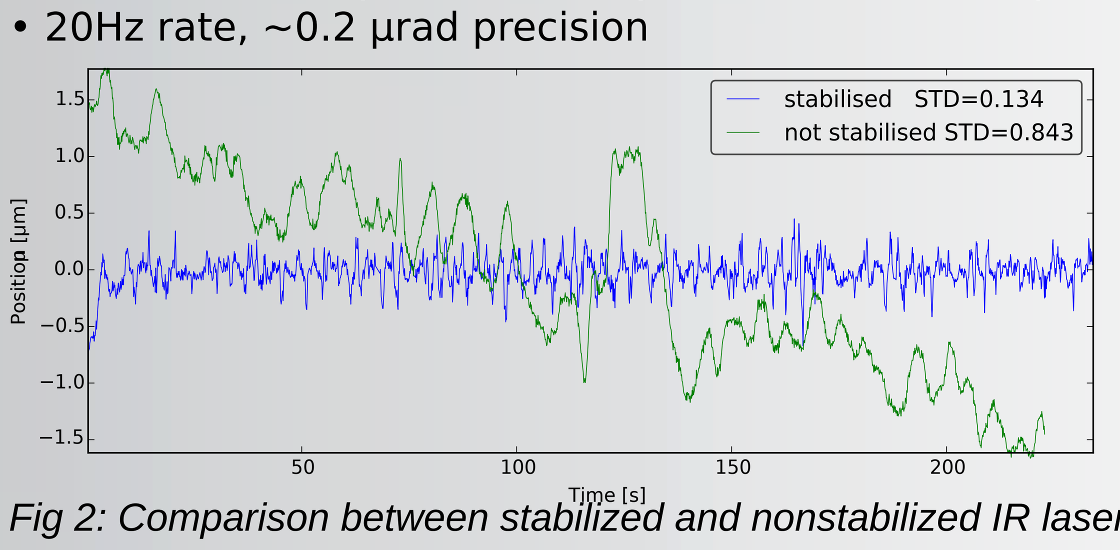


Fig 2: Comparison between stabilized and nonstabilized IR laser beam

Results from our HHG CDI microscope

- Our test sample is an asymmetrical grid covered by 100 nm gold layer
- Illumination pinhole size 7 µm
- FWHM of beam in circle of least confusion (CLC) ~7 µm

- 560 HDR diffraction patterns were collected with 2s exposure time
- Dynamic range ~10^6 counts without any beam block
- Reconstruction was done by ptychography method (ePIE) [1] with improved relaxation of different systematic errors: lateral coherence [2], temporal coherence [3],
- Achieved resolution diffraction limited resolution ~60 nm

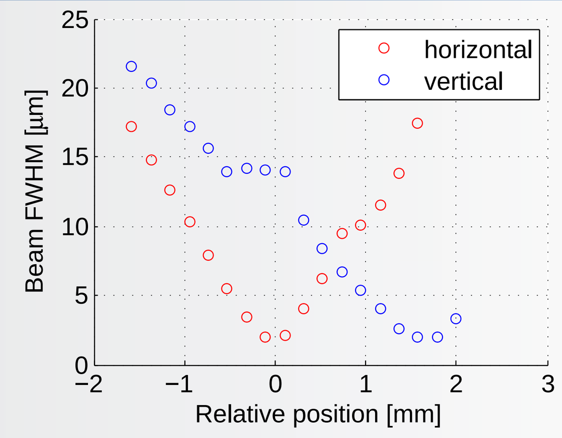


Fig 5 : Pinhole scan of the EUV beam to measure size (FWHM) is showing astigmatism of the EUV beam

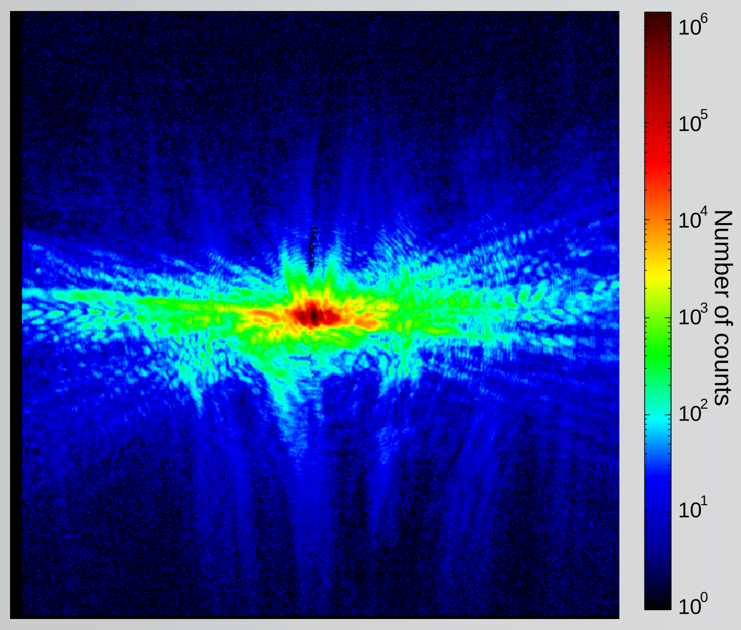


Fig 3: An example of diffraction pattern

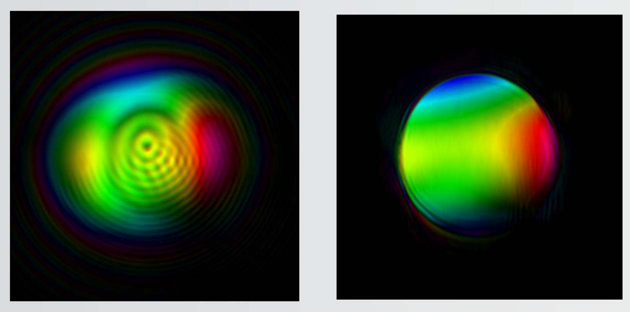


Fig 4: Reconstruction of illumination probe backpropagated 62µm on the pinhole plane

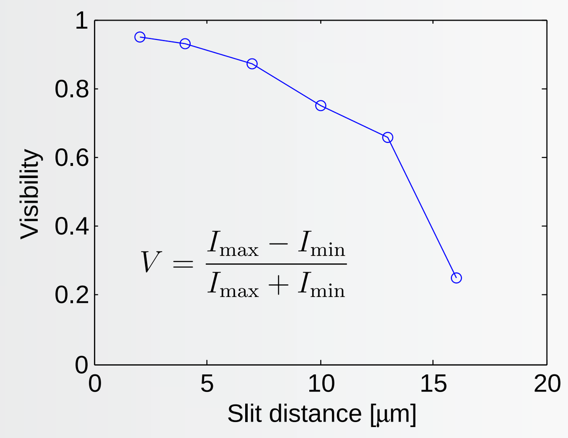


Fig 6 : Visibility of the Young's slits pattern for different slits distances in CLC of EUV beam

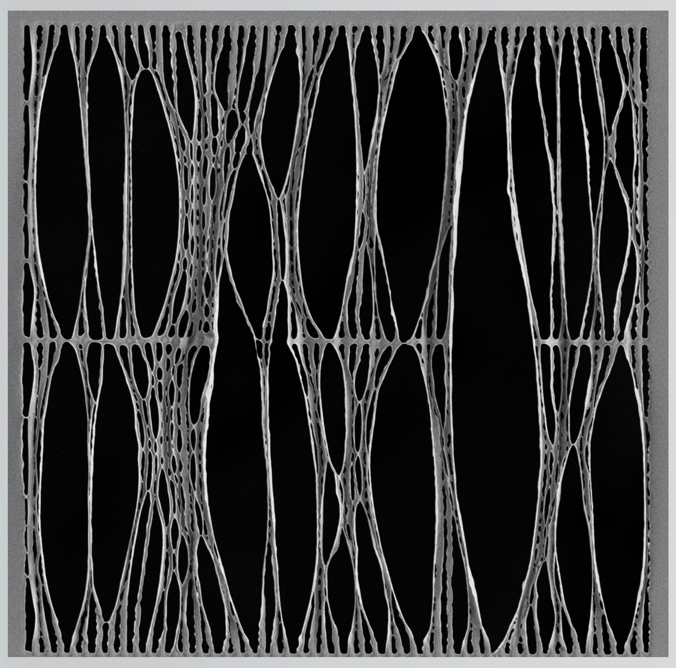


Fig 7 : SEM image of the images sample

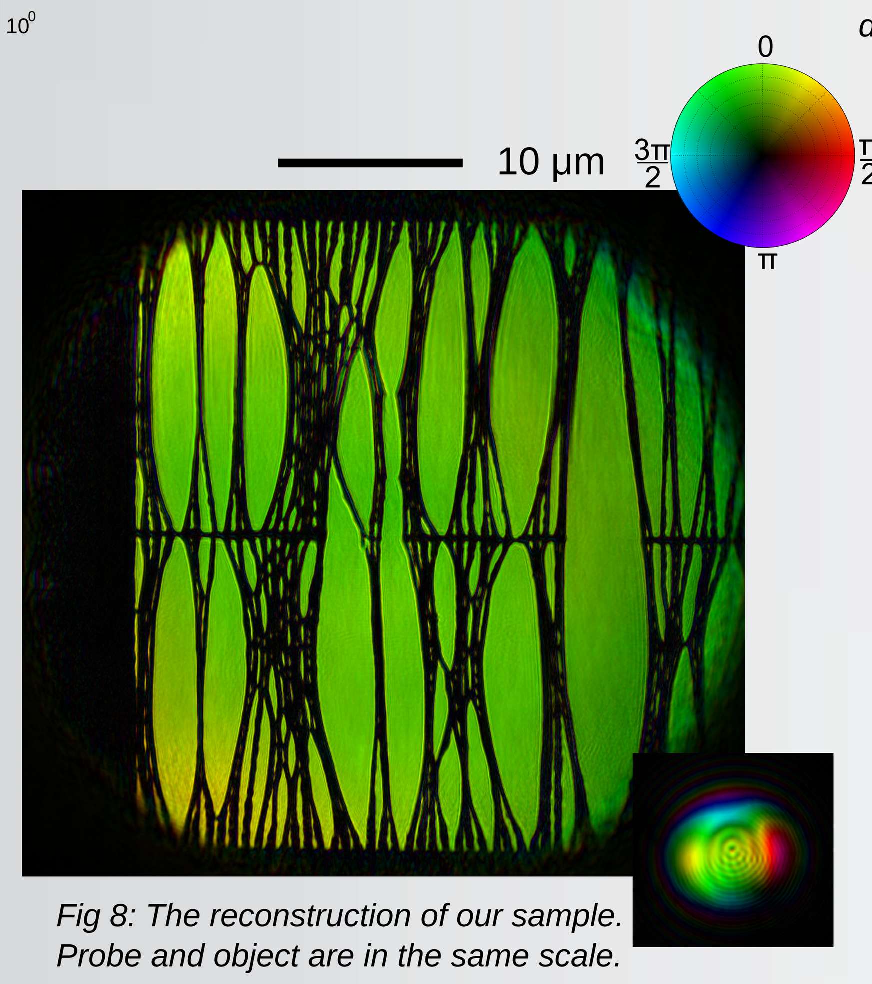
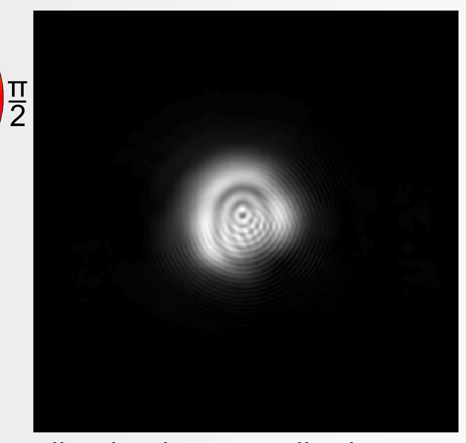
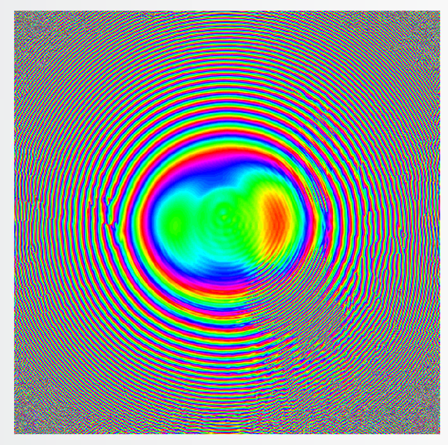


Fig 8: The reconstruction of our sample. Probe and object are in the same scale.



Illumination - amplitude



Illumination - phase

Spectrum measurement

- HHG spectrum depends on experimental settings
- Spectrum of sample illumination needs to be precisely known
- The spectrum is techically problematic to measure it by spectrometer

Young's slits spectrometer [4]

- Very simple measurement
- Ideal monochromatic pattern $I(x) \propto \left[1 + \gamma\cos^2\left(\frac{\pi\mu x}{Z\lambda}\right)\right] \operatorname{sinc}^2\left(\frac{\pi b x}{Z\lambda}\right)$
- Broadband pattern is incoherent sum of the monochromatic model
- Solved by nonlinear Tichonov regularization [5]

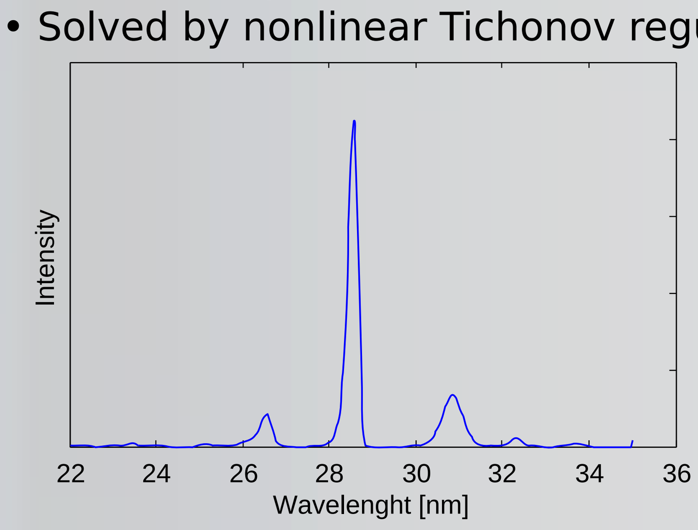


Fig 9: Reconstructed illumination spectrum at the sample position

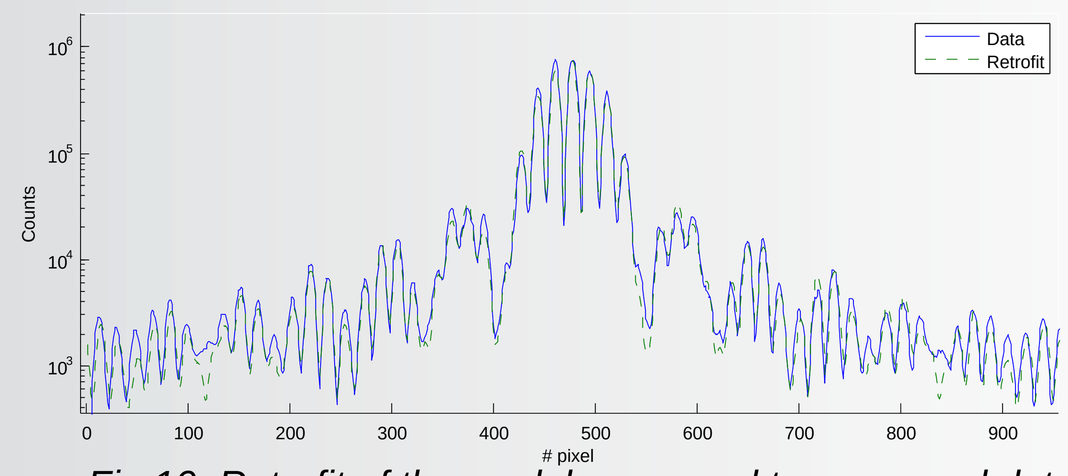


Fig 10: Retrofit of the model compared to measured data

Conclusion

+ High harmonic generation is a powerful source for CDI
+ Higher flux can be achieved for the price of broadbandness

– Maximal resolution is limited by achievable dynamic range
– Stability and coherence properties HHG source needs to be improved
– Low penetration depth of 30nm EUV light is limiting availible samples

References

[1] Maiden, A. M. and Rodenburg, J. M., Ultramicroscopy 109(10), (2009).
[2] Clark, J. N. and Peele, A. G., ," APL 99(15), 154103 (2011).
[3] Abbey, B., et al., Nature Photonics 5(7), 420-424 (2011).
[4] Dilanian, R. et al, Optics Letters 33, 2341 (2008).
[5] Tikhonov, A., in Soviet Math. Dokl.], 5, 1035–1038 (1963).

Acknowledgements

This work is associated with the EU FP7 Erasmus Mundus Joint Doctorate Programme EXTATIC under framework partnership agreement FPA-2012-0033