Nanoscale imaging using a compact laser plasma EUV source

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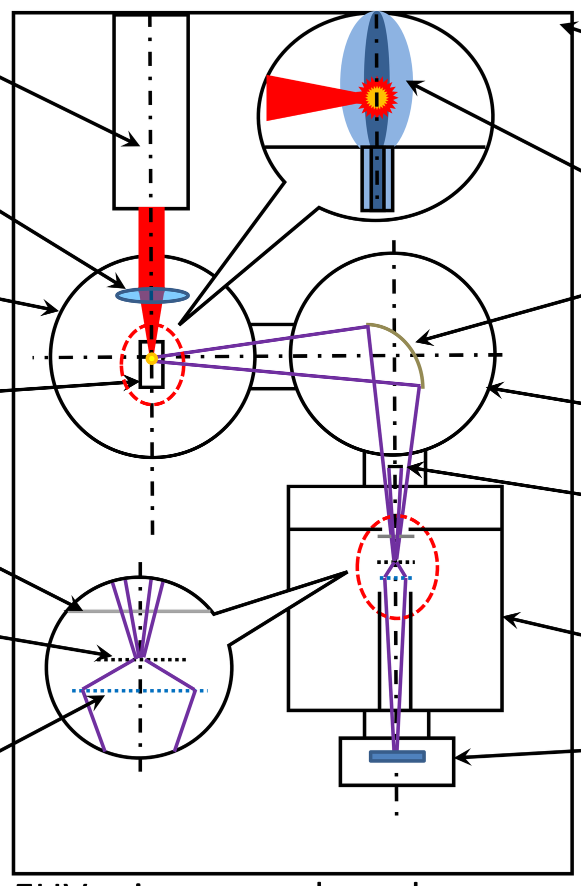
Abstract

We report a desk-top microscopy reaching 50nm spatial resolution in very compact setup using a gas-puff laser plasma EUV source. The thickness of an object and the bandwidth of illuminating radiation were studied in order to estimate their quantitative influence on the EUV microscope spatial resolution. EUV images of various thickness objects obtained by illumination with variable bandwidth EUV radiation were compared in terms of knife-edge spatial resolution to study the bandwidth/object thickness parasitic influence on spatial resolution of the EUV microscope.

EUV microscope based on laser plasma EUV source



Scheme of the EUV microscope based on a laser plasma EUV source.

H. Fiedorowicz et al., Appl. Phys. B 70, 305–308 (2000)

Microscope details:
CCD camera: iKon-M (Andor) 1k x 1k pix, 13x13 μm²
Condenser NA: H= 0.11, V=0.15
Objective NA: 0.137
Magnification: 470-1100x
Acquisition time: 5-100s/2Hz
Microscope size: fits inside vacuum chamber 24cm diameter, 35cm long.

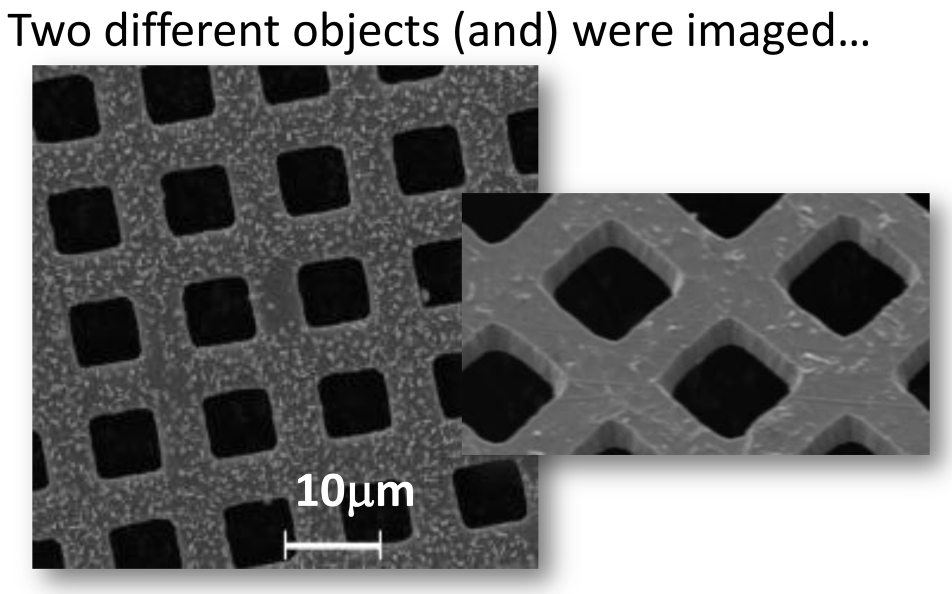
Photograph of the EUV source, microscope chamber and pumping laser.

Zone plate objective parameters:
Diameter: 200 μm
Outer zone width: 50 nm
Focal length: 0.724 mm
Number of zones: 1000
Numerical aperture: 0.137
Theoretical resolution (Rayleigh criterion): 61 nm
Depth of focus: +/- 385 nm

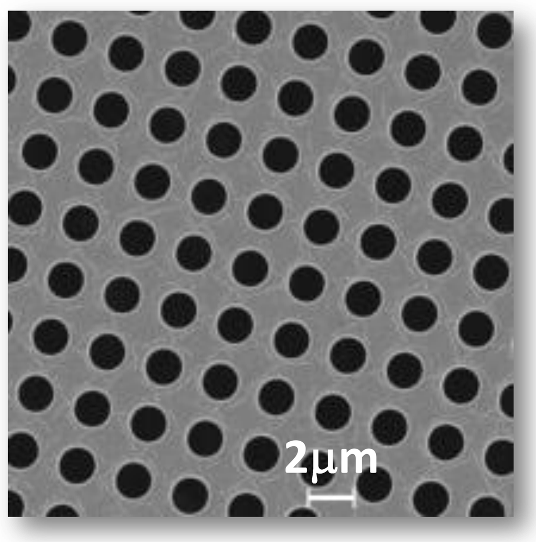
P. W. Wachulak et al., Optics Letters 35, 14, 2337-2339 (2010)

Experimental goals

Two different objects (and) were imaged…

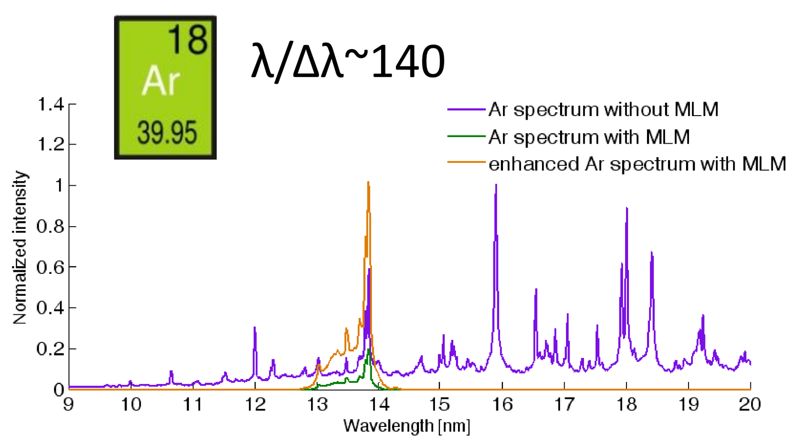


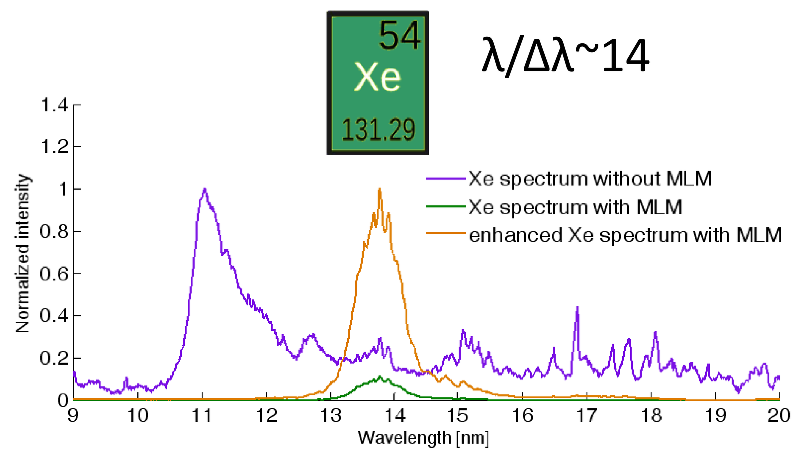
Mesh ~4μm thick, ~11xDOF



Hole pattern 70nm thick 10nm carbon foil + 60nm Au for optical contrast, ~0.2xDOF

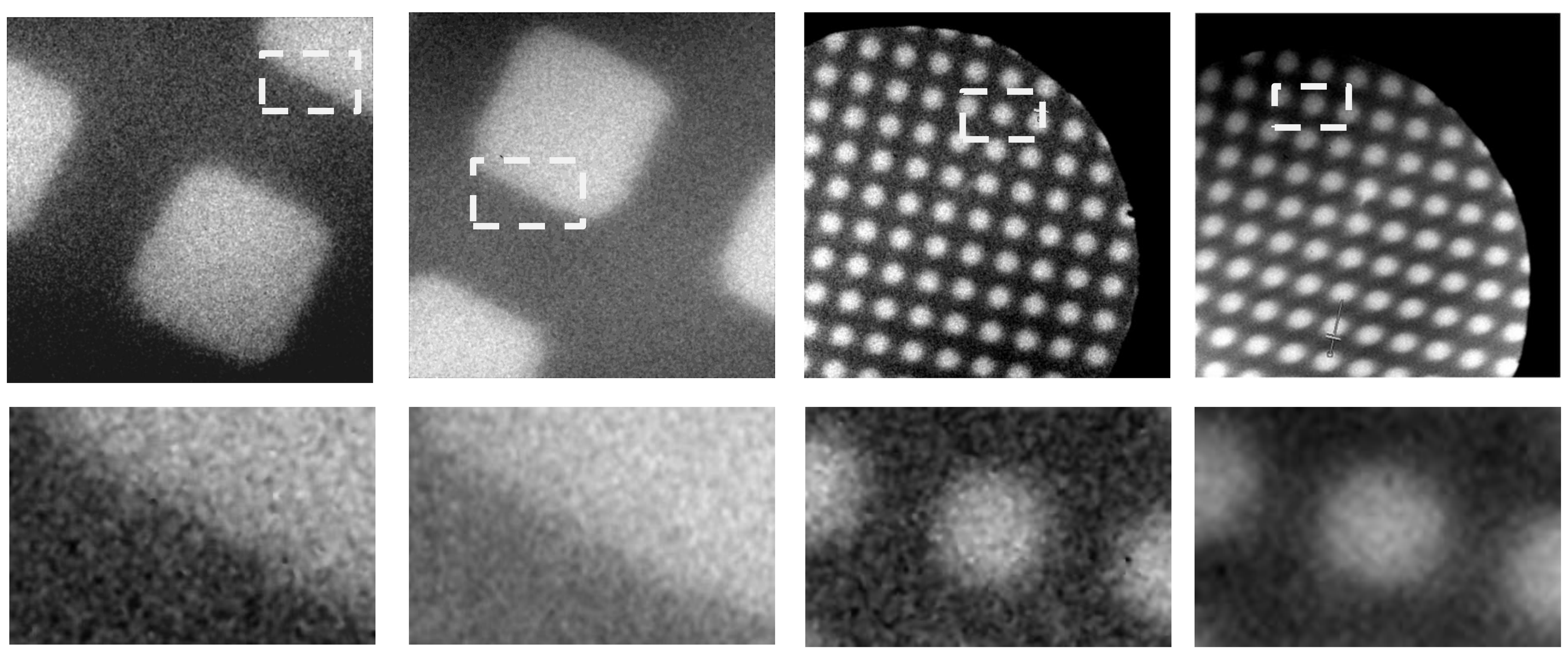
… with two spectrally different illuminations





P.W.Wachulak, et al., Appl Phys B, 100, 3, 461-469, (2010)

EUV imaging results

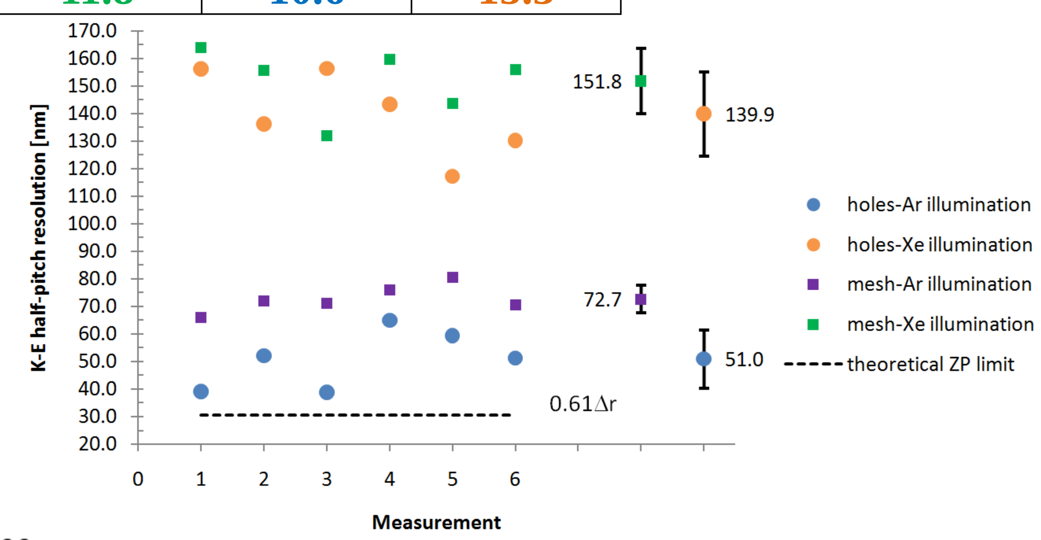


Mesh – Ar illumination ~11 x DOF λ/Δλ~140	Mesh – Xe illumination ~11 x DOF λ/Δλ~14	Holes – Ar illumination ~0.2 x DOF λ/Δλ~140	Holes – Xe illumination ~0.2 x DOF λ/Δλ~14

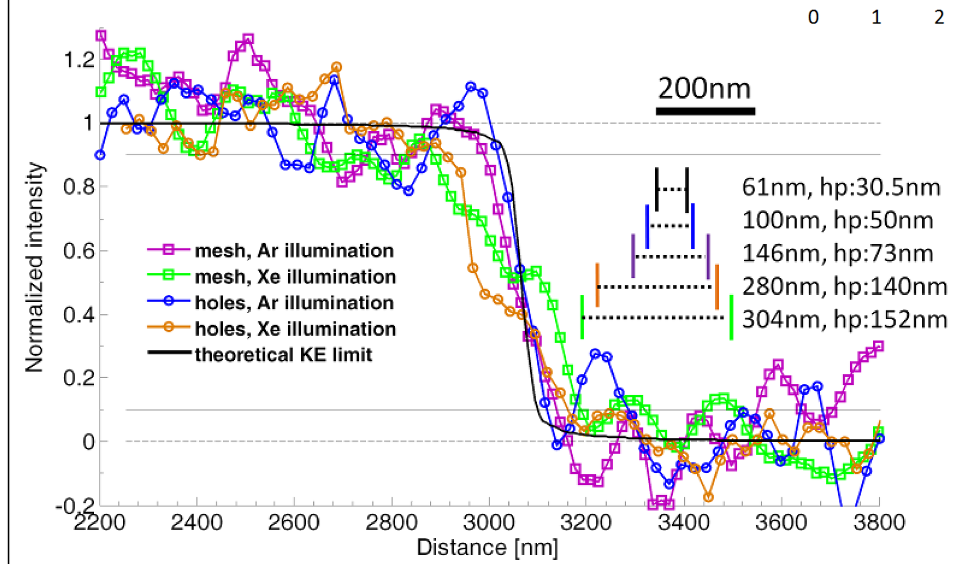
Knife-edge resolution measurements

Object	mesh		foil	
Thickness t	11 x DOF		0.2 x DOF	
Exposure for 2Hz repetition rate [s]	25	10	50	50
Illumination type	Ar	Xe	Ar	Xe
IRB λ/Δλ	140	14	140	14
Magnification [x]	840		523	
Image pixel size [nm²]	15.9x15.9nm²		25.9x25.9nm²	
Field of view [μm²]	16.3x16.3μm²		26.4x26.4μm²	
KE half-pitch resolution r_{KE}				
[nm]	72.7	151.8	51.0	139.9
[nm]	5.0	11.8	10.6	15.3

EUV imaging experimental details and resolution measurement results for different objects and illumination bandwidth.



Statistical KE resolution measurements for various objects and types of illumination with error bars corresponding to +/- standard deviation calculated from the measurements.

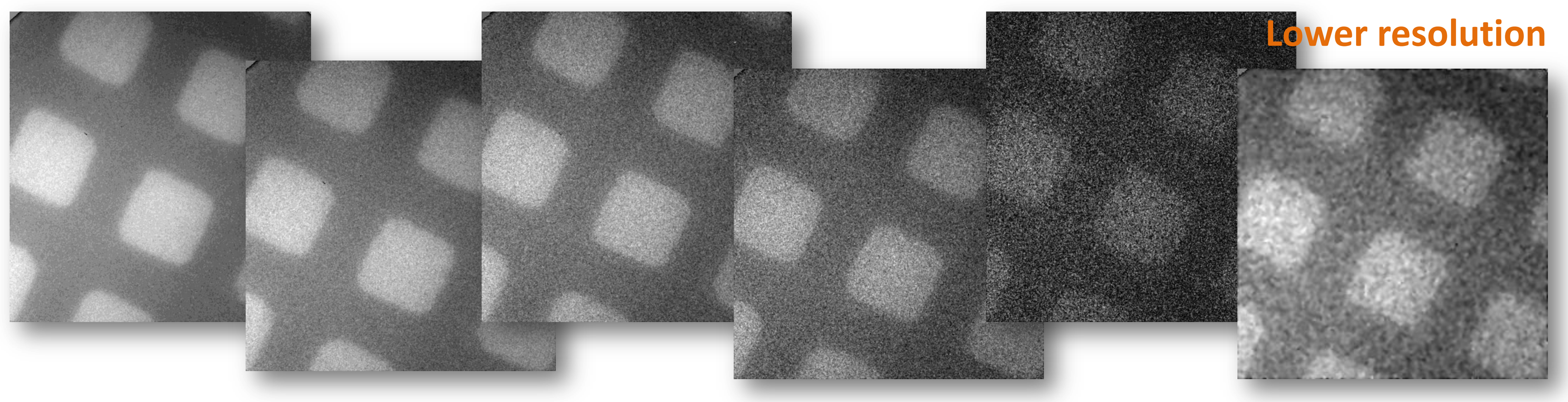


Typical KE lineouts indicating 10-90% intensity transition in the EUV image related to Rayleigh resolution criterion for both objects and different illumination bandwidths and the theoretical KE limit.

Przemyslaw W. Wachulak, et al., Optics Express 19, 10, 9541–9550 (2011)

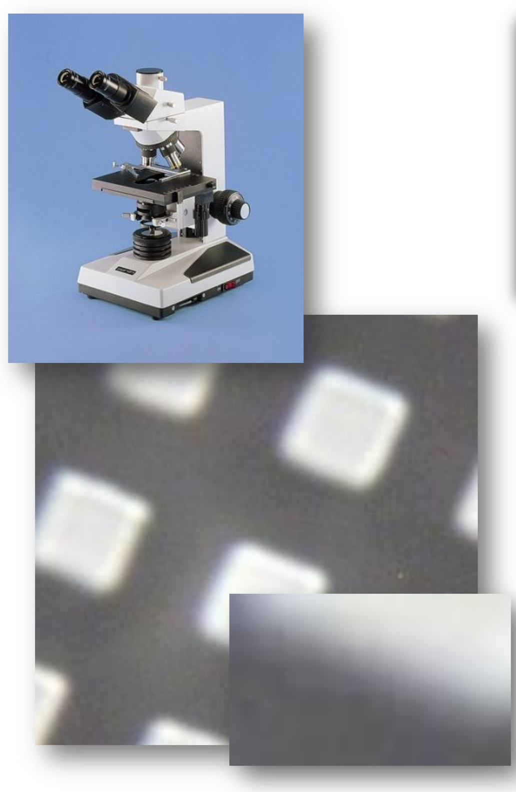
✓ object thickness influences the spatial resolution:
thicker object→ worse resolution
✓ illumination bandwidth affects the resolution:
broader the illumination bandwidth → worse resolution

Nanosecond time resolution capability

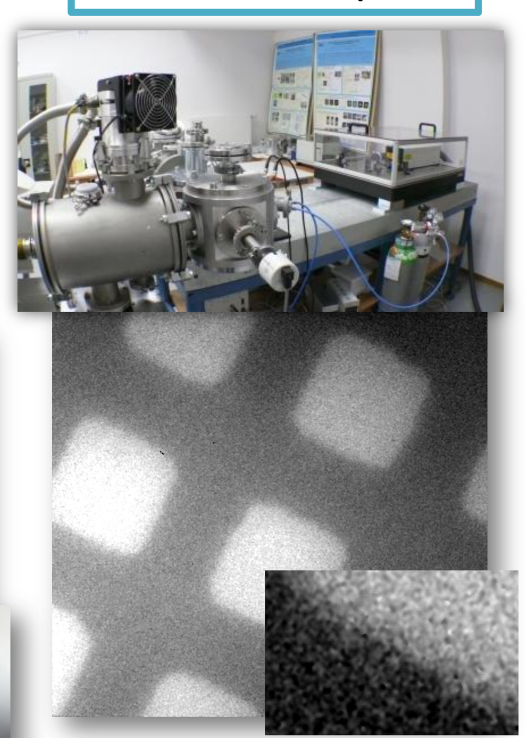


Size/performance comparison

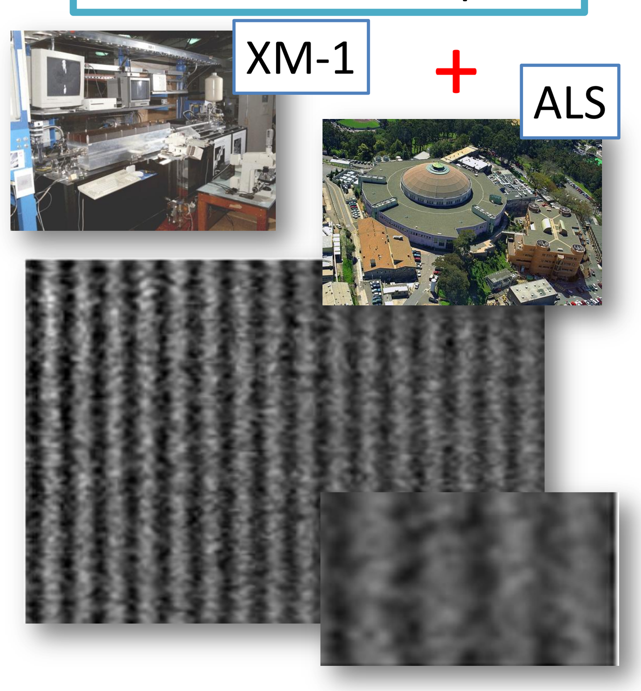
Optical microscopes	Compact EUV and SXR microscopes	large scale synchrotron EUV/SXR microscopes



λ=550nm, NA=1.3
δ_{HP}~130nm=0.24λ



λ=13.8nm, NA=0.14
δ_{HP}~50nm=3.6λ



λ=1.75nm, NA=0.073
δ_{HP}~12nm=6.9λ
Current world record SP resolution in SXR microscopy

*Weilun Chao, et al., Opt. Express **17**, 17669-17677 (2009)*

Acknowledgements

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