ANAMORPHIC IMAGING: EMULATING FUTURE NODES OF EUV LITHOGRAPHY ON THE SHARP MICROSCOPE

SHARP High-NA actinic Reticle Review Project

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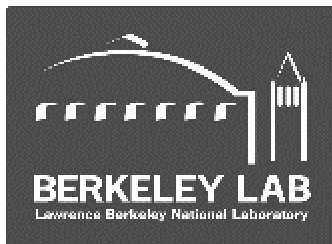
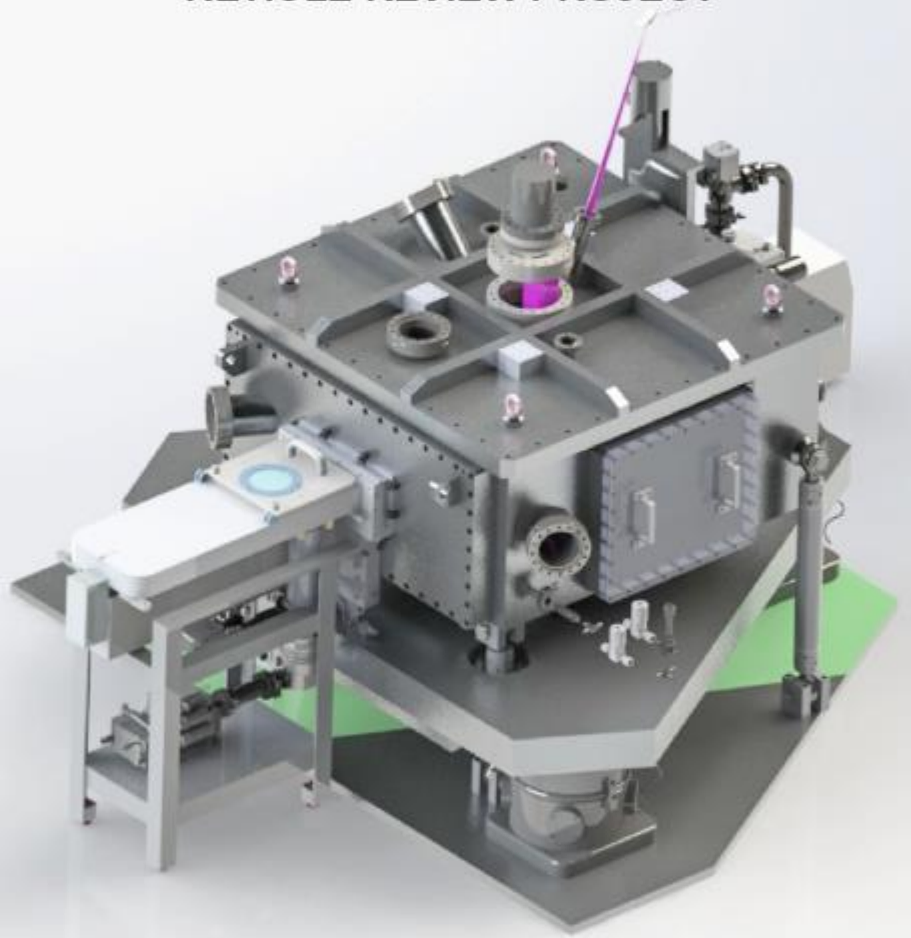
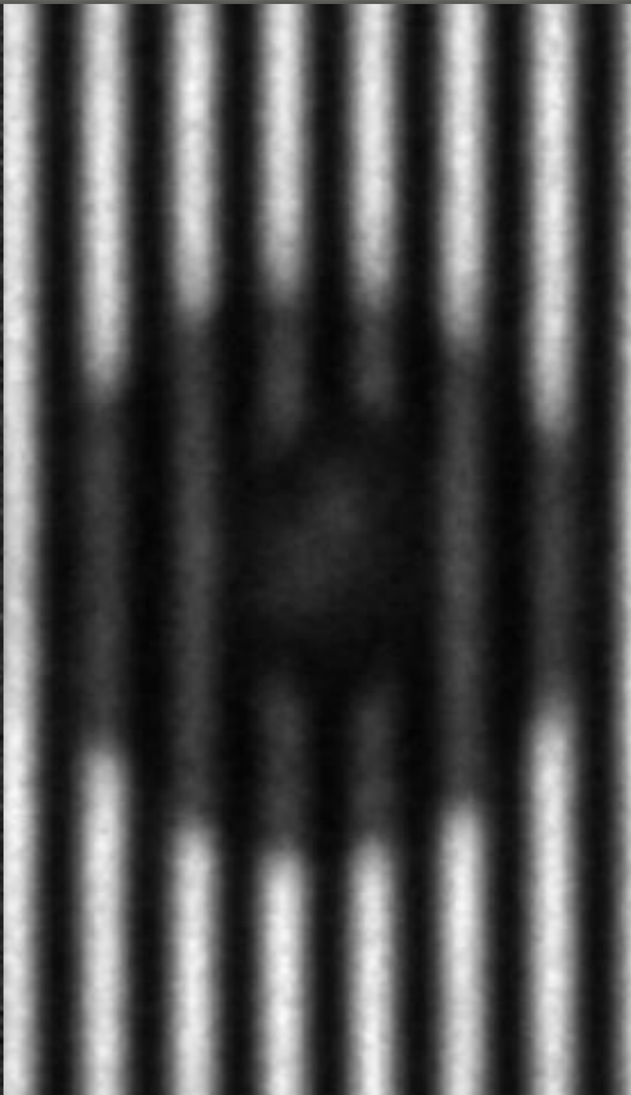
2017 International Workshop on EUV Lithography
Lawrence Berkeley National Laboratory, Berkeley, June 14



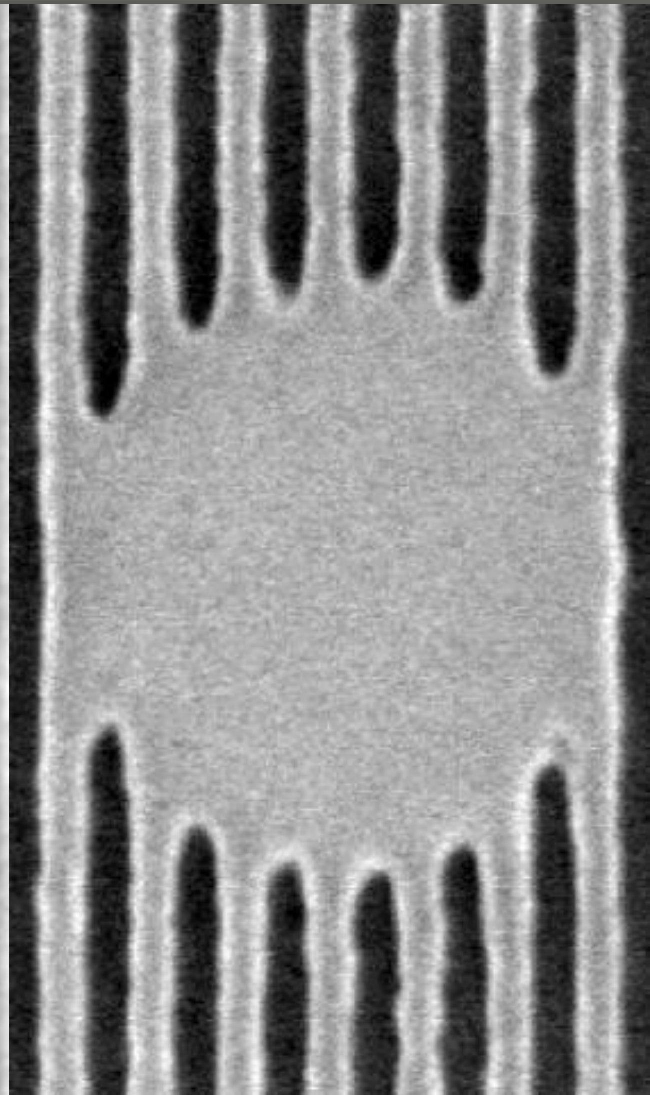


Source:	Synchrotron
Optics:	Zoneplate lenses
4×NA:	0.25–0.625
Sigma:	Programmable
Navigation:	Full-mask XY
Throughput:	up to 24 sites/hour

Mask SEM



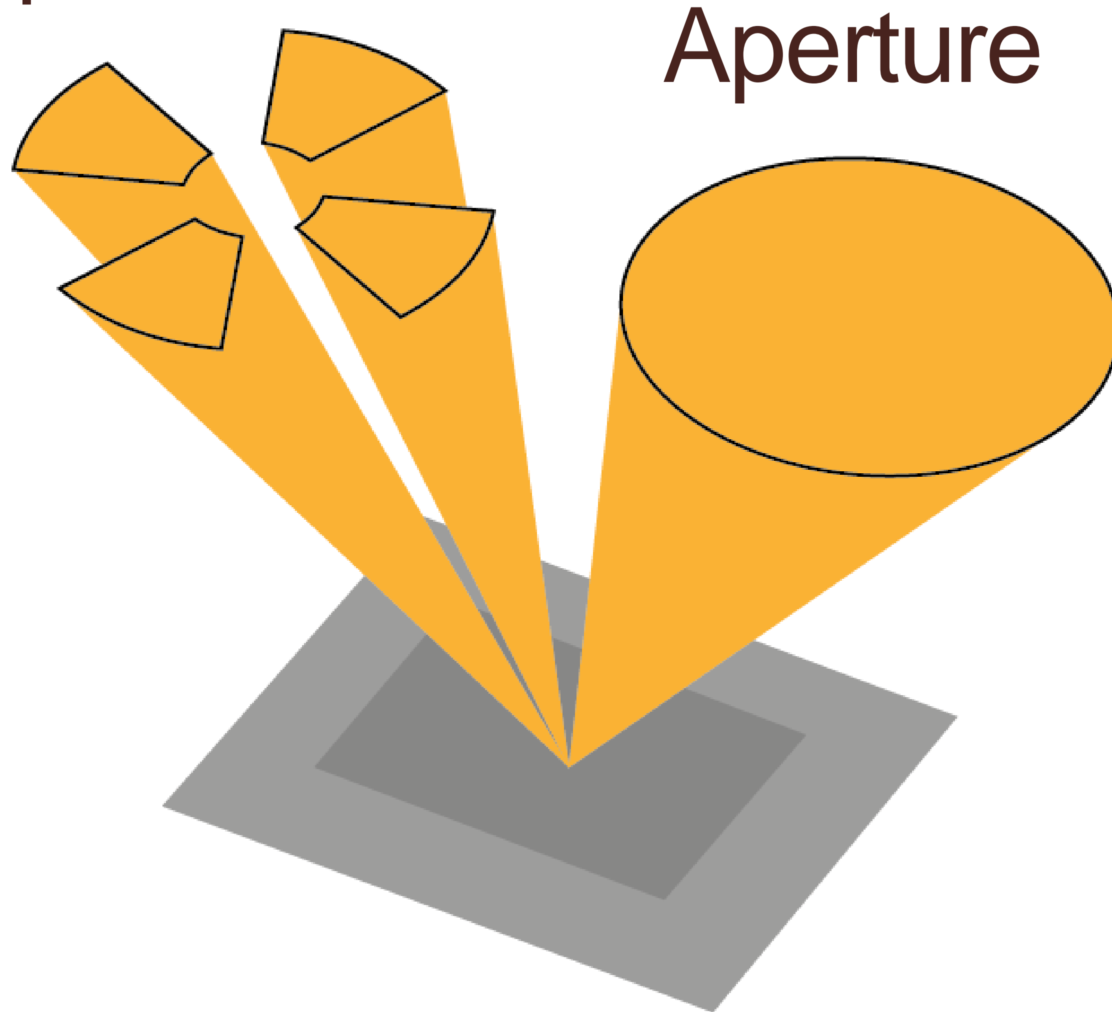
SHARP aerial image

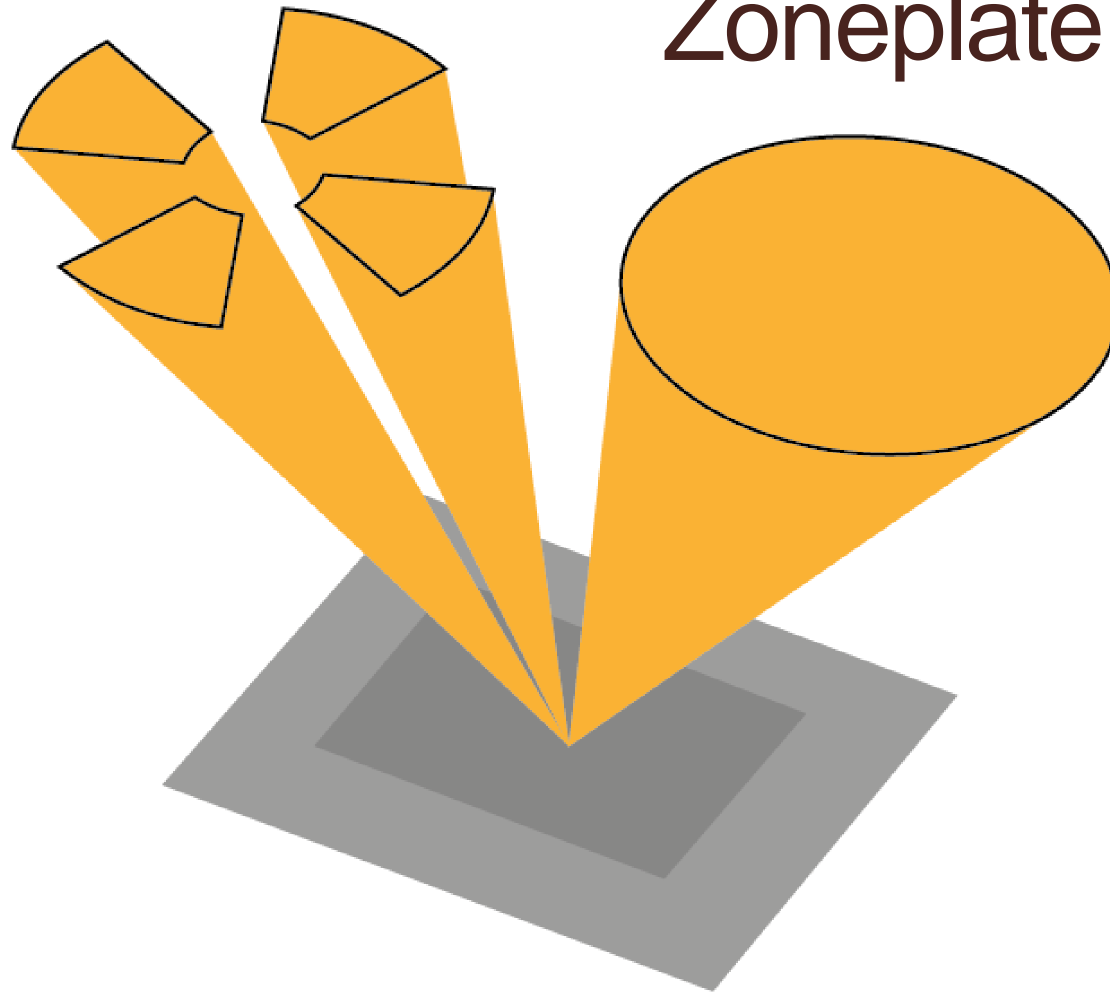


Wafer SEM

Mangat, PMJ 2015

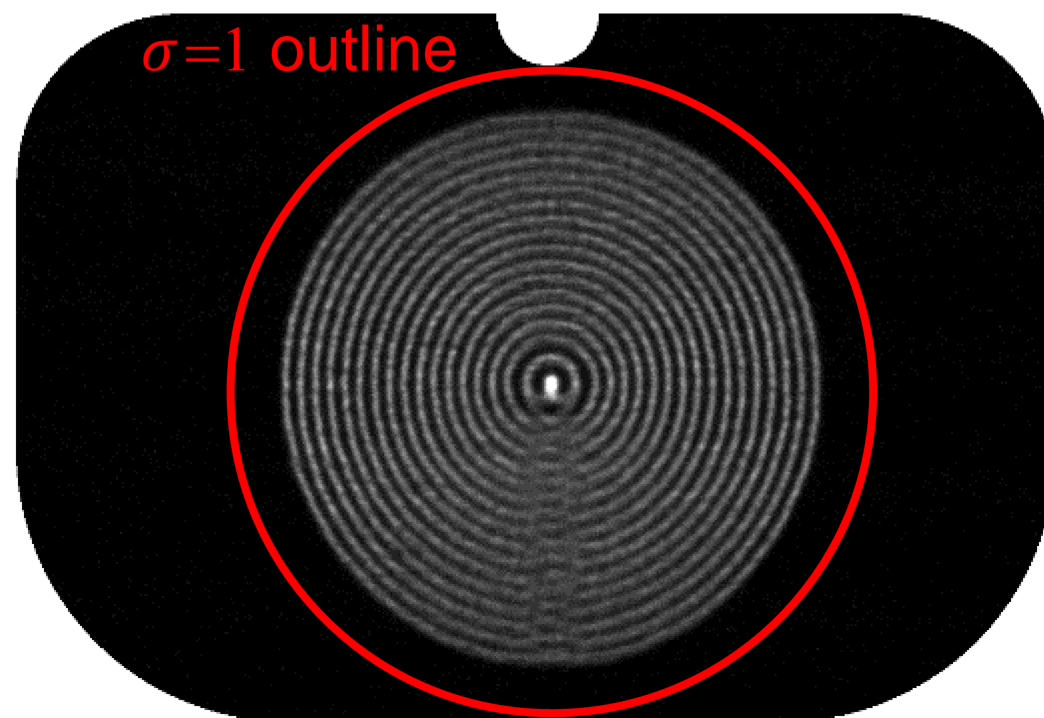
Source angular spectrum




Fourier Synthesis
Illuminator
Zoneplate lens

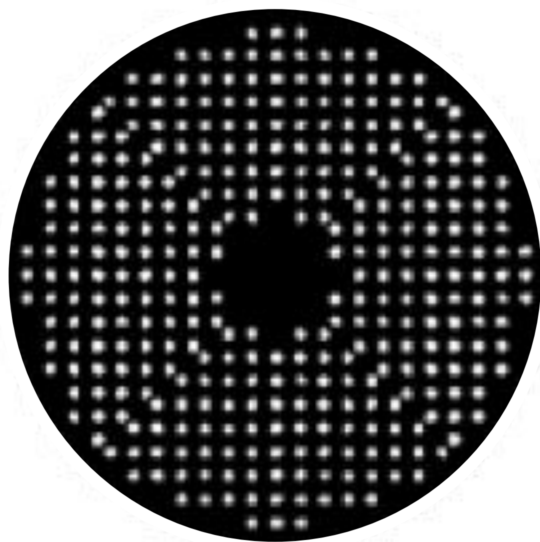
Illuminator angular range

- 0.625 4xNA
  10° CRA
  σ=0.8



Pupil fill

- Conventional
- 0.33 4xNA, 6° CRA



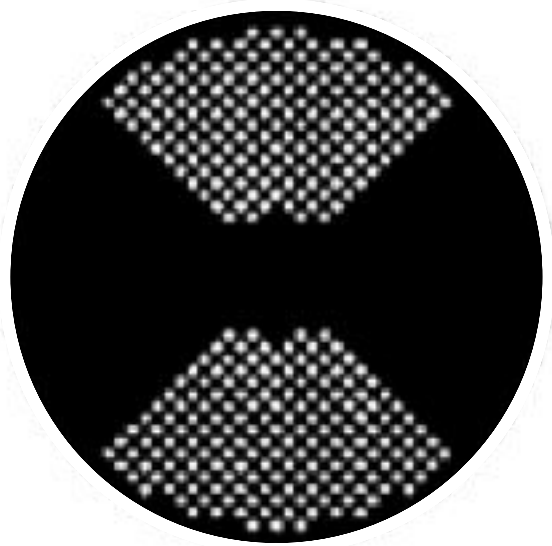
Pupil diagram

YAG image, 4mm below focus

Liu, SPIE 90480Q (2014)

Pupil fill

- Crosspole
- 0.33 4xNA, 6° CRA



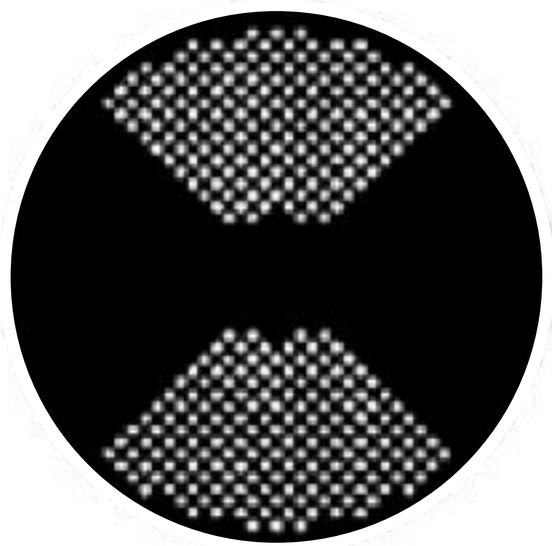
Pupil diagram

YAG image, 4mm below focus

Liu, SPIE 90480Q (2014)

Pupil fill

- Crosspole
- 0.33 4xNA, 6° CRA



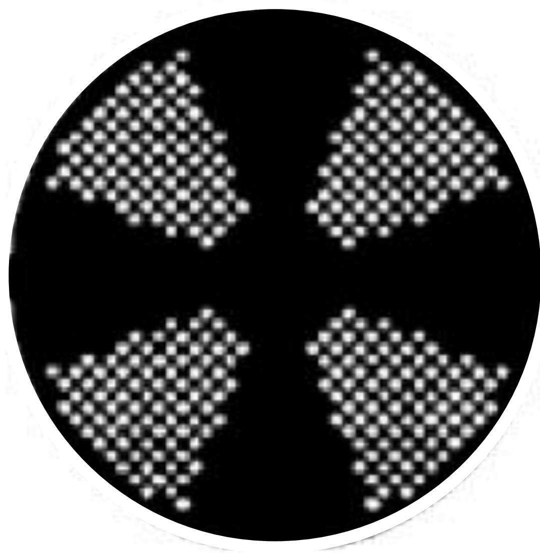
Pupil diagram

Modulation of flux in pupil channels

Liu, SPIE 90480Q (2014)

Pupil fill

- Quasar
- 0.33 4xNA, 6° CRA



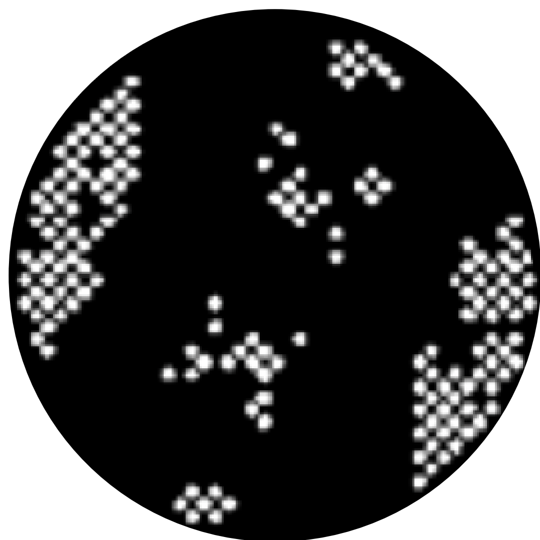
Pupil diagram

Modulation of flux in pupil channels

Liu, SPIE 90480Q (2014)

Pupil fill

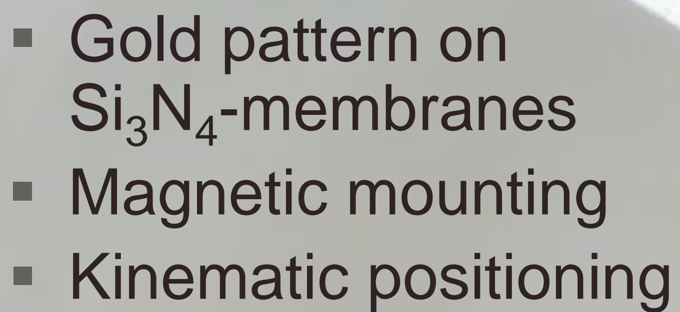
- Freeform Source
- 0.33 4xNA, 6° CRA



Pupil diagram

Freeform-source example

Liu, SPIE 90480Q (2014)

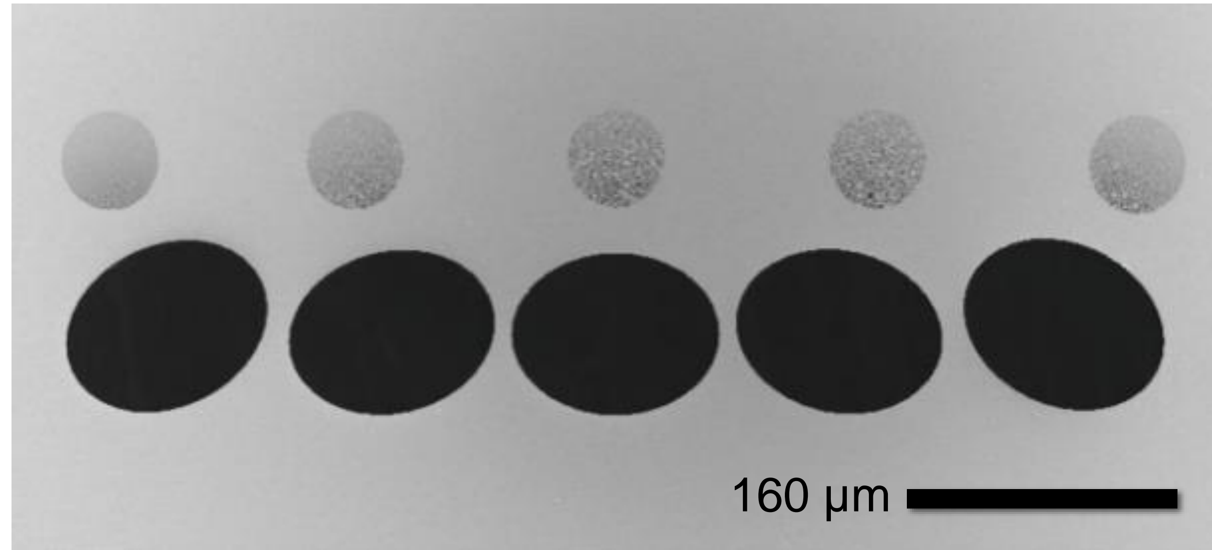

- Gold pattern on Si_3N_4-membranes
- Magnetic mounting
- Kinematic positioning
2 mm

Zoneplates

Chip A

Standard Zoneplates:

- 0.25 to 0.625 4xNA
- 6° to 10° CRA
- 5 azimuthal angles for 0.33 4xNA



Chip B

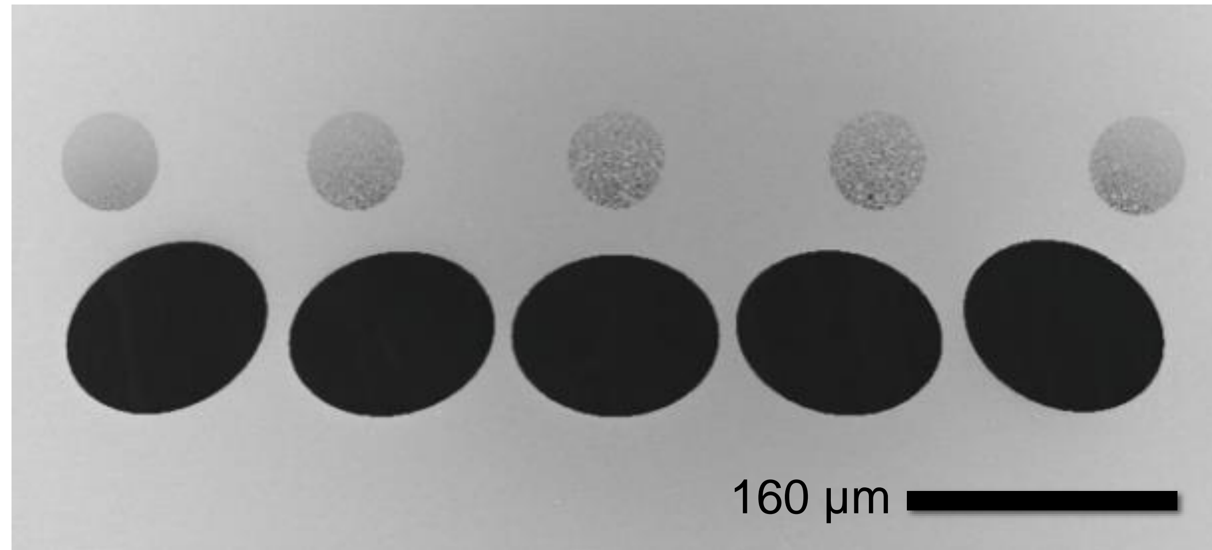
- Zernike Phase Contrast
- Differential Interference Contrast
- Stereoscopic imaging
- Cubic Phase Modulation

Zoneplates

Chip A

Standard Zoneplates:

- 0.25 to 0.625 4xNA
- 6° to 10° CRA
- 5 azimuthal angles

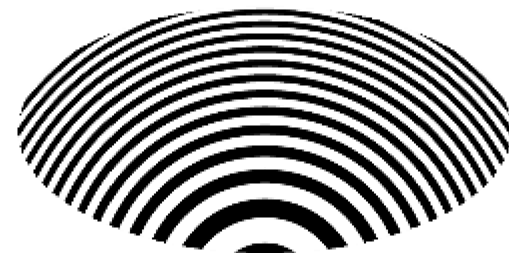


Chip B

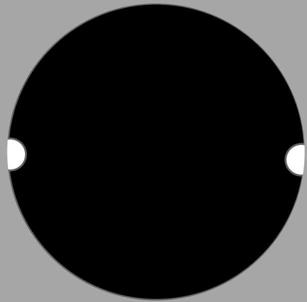
- Zernike Phase Contrast
- Differential Interference Contrast
- Stereoscopic imaging
- Cubic Phase Modulation

Chip C

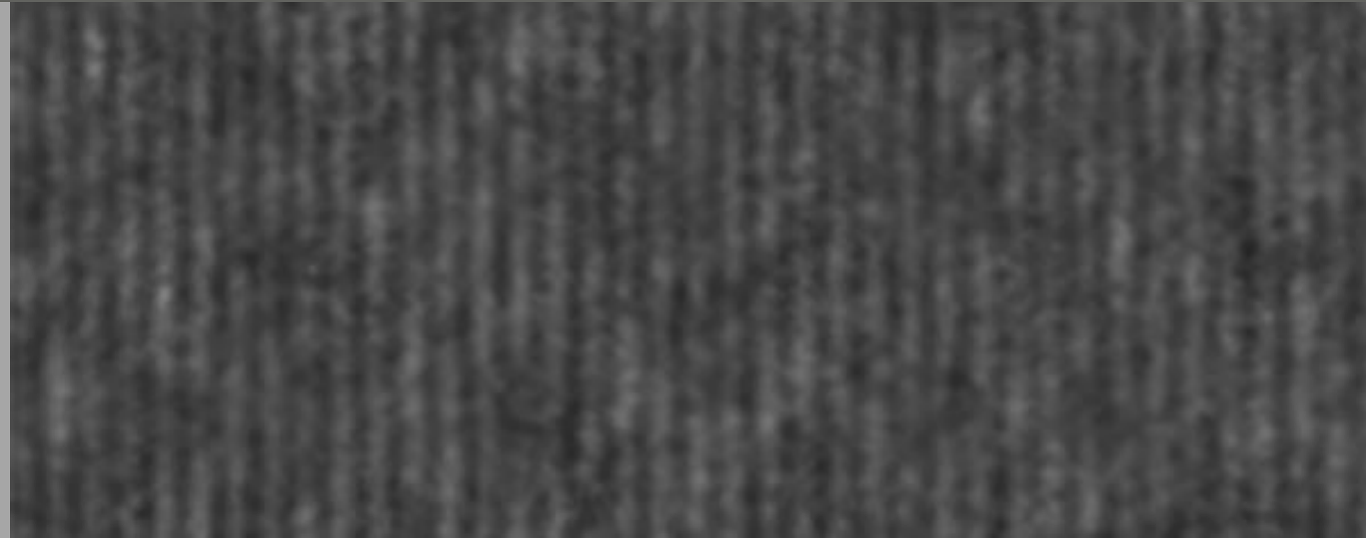
- Elliptical zoneplates



0.625 4xNA lens

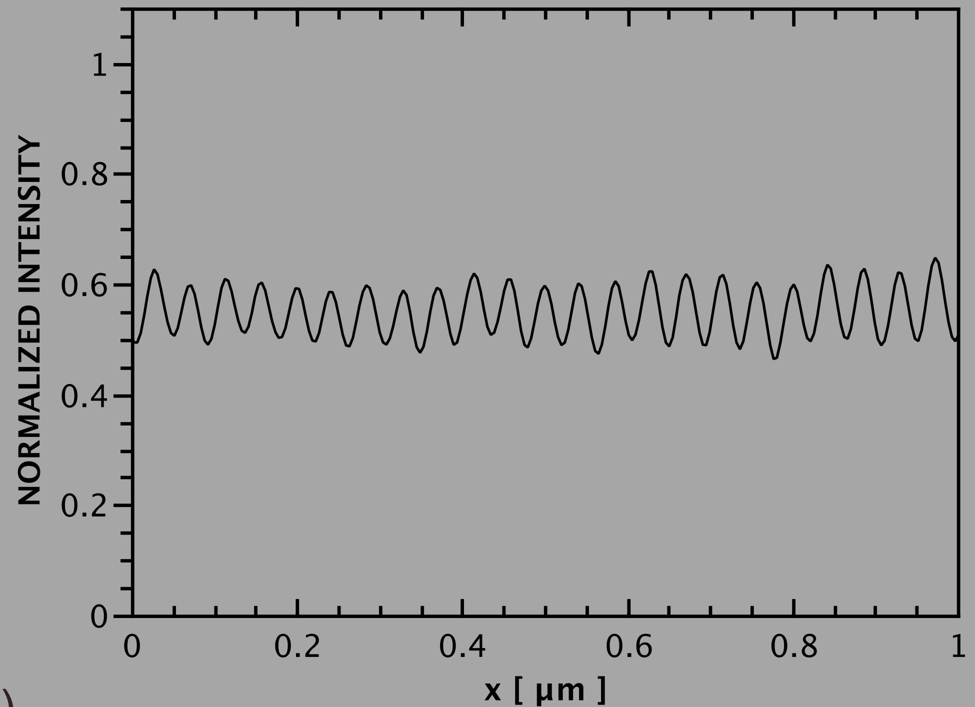


Extreme dipole



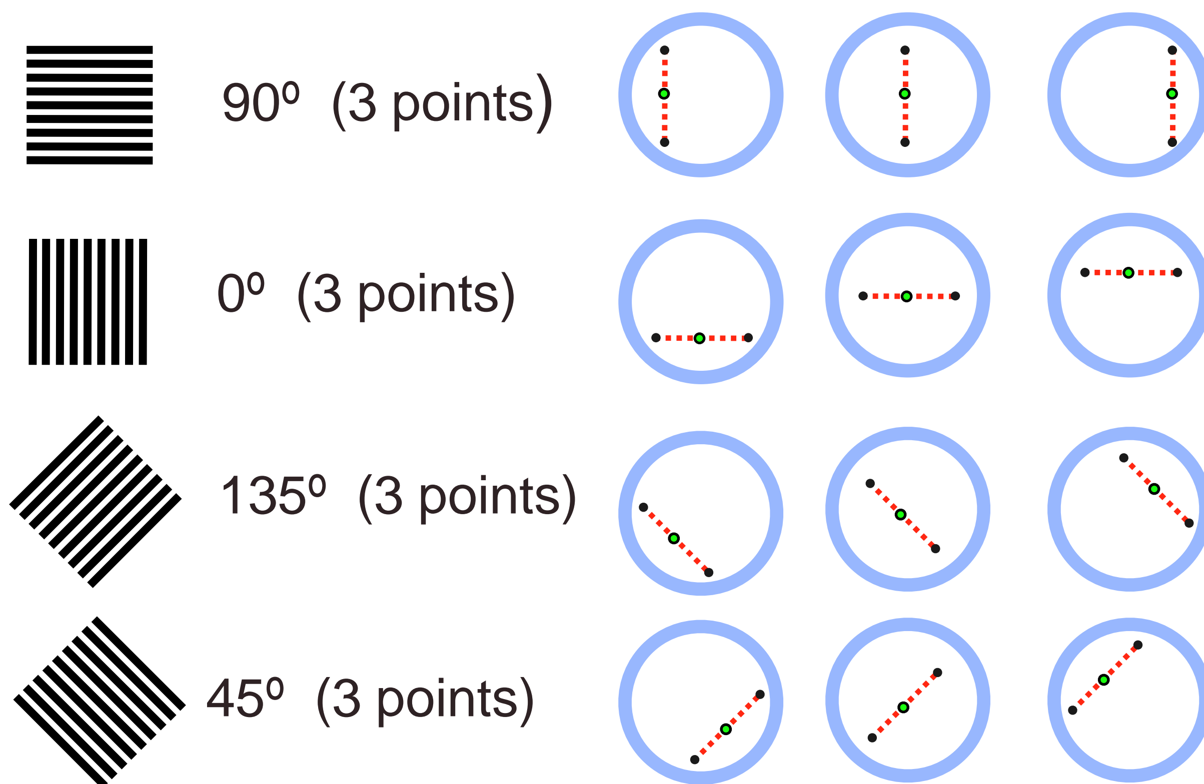
200 nm

- $r_L = \frac{0.25/}{\mathrm{NA}} =$ 22 nm hp (4x)
- 22-nm hp v lines
  10% modulation



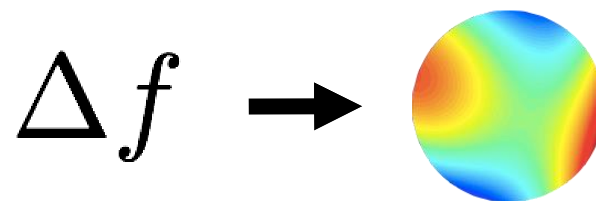
J. Vac. Sci. Technol. B 33, 06FE01 (2015)

AIS: Characterization of aberrations



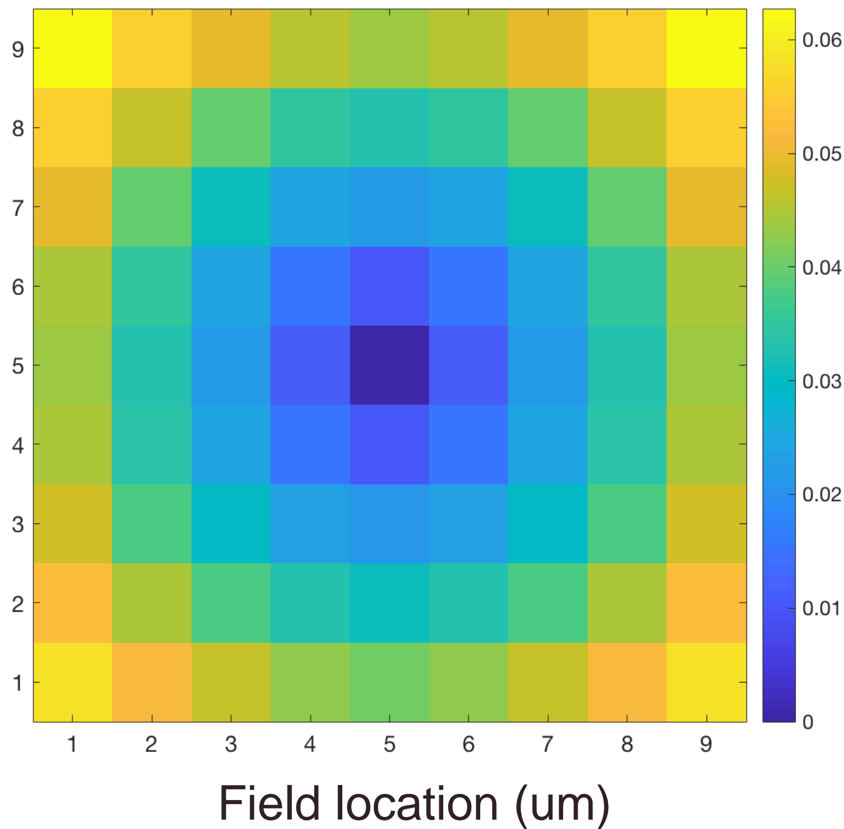
Through-focus image data of 4 grating orientations and 12 monopole illuminations

Aberrations solved from measured focus shifts using least-squares approach

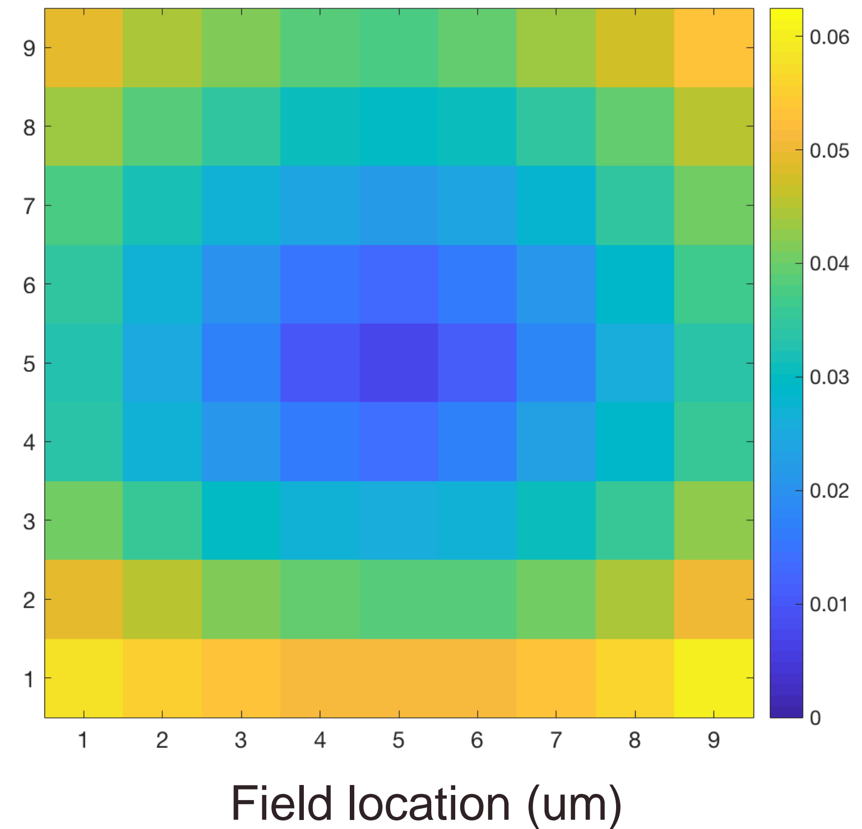


Field dependent aberrations

- Ideal 0.33 4xNA zoneplate

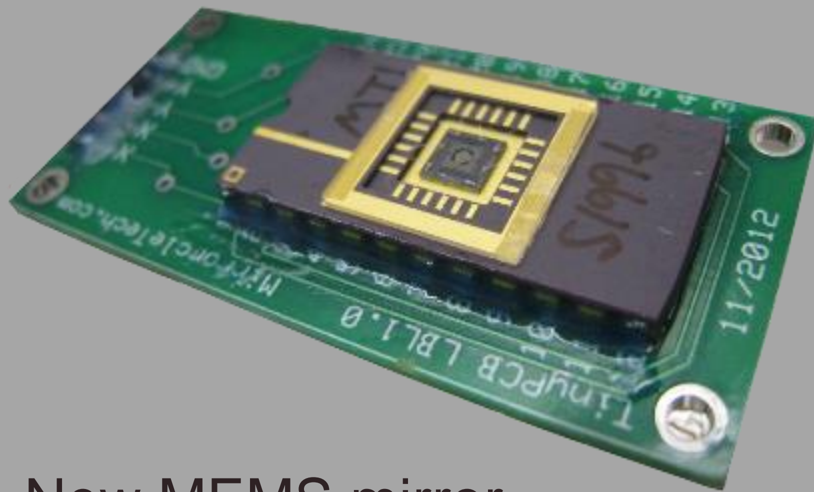


- AIS measurement



Sweet spot (Z_4 to Z_8) : **7.2 mλ** RMS (λ_{EUV}/139)

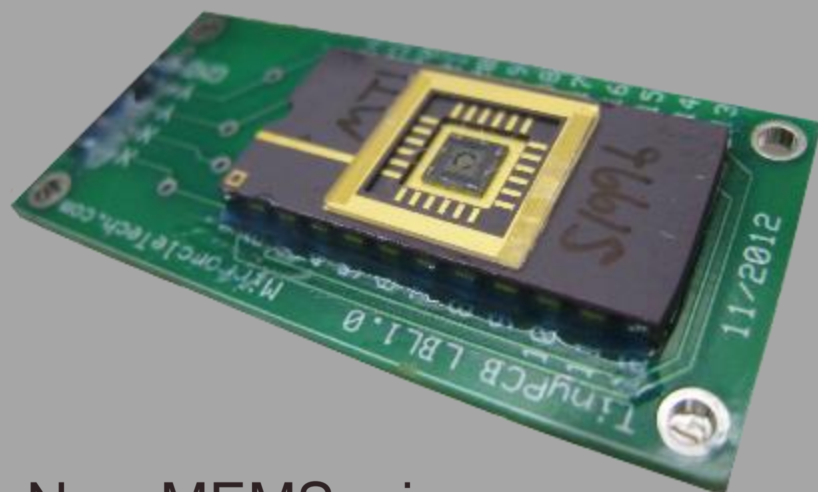
Flux



New MEMS mirror

- 3-s exposure time to full-well capacity on bright features
- Increased SNR, defect sensitivity and throughput
- Increased O2 partial pressure for extended mirror lifetime

Flux



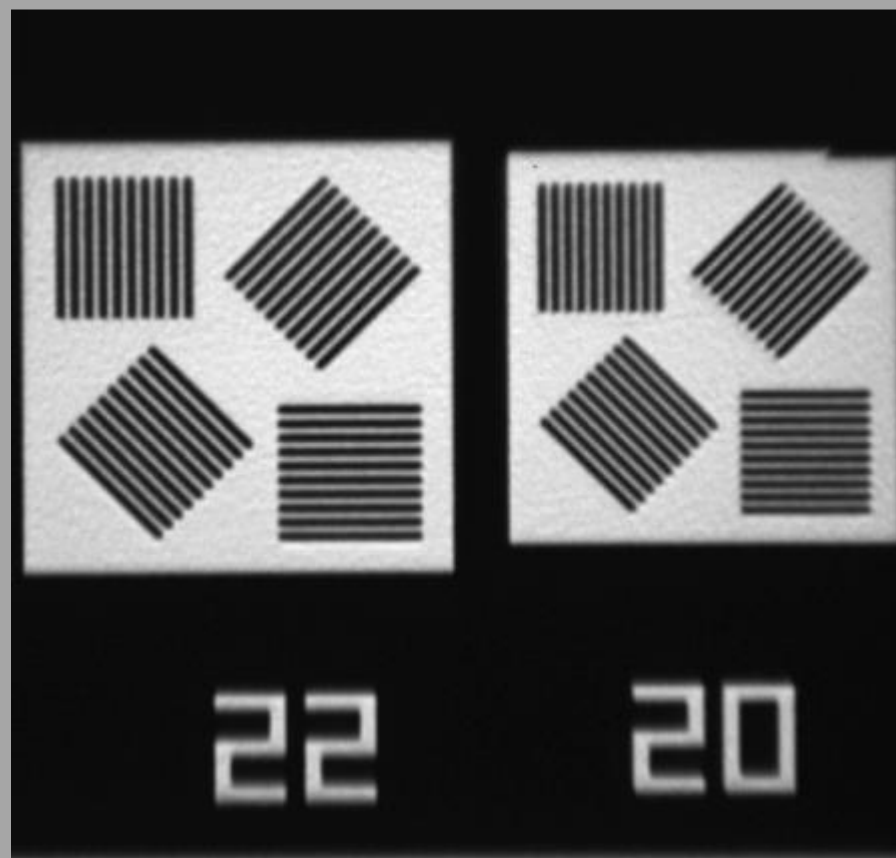
New MEMS mirror

- 3-s exposure time to full-well capacity on bright features
- Increased SNR, defect sensitivity and throughput
- Increased O2 partial pressure for extended mirror lifetime

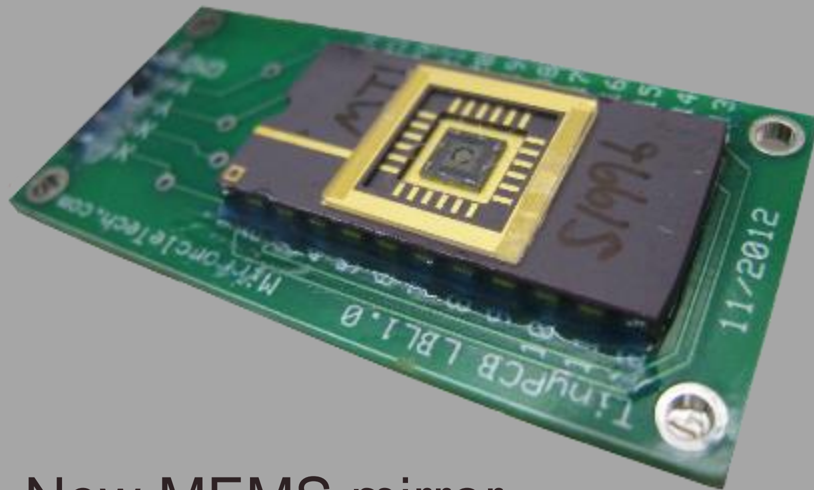
Clear multilayer

- 3-s exposure time
- 50,000 counts

2 µm



Flux



New MEMS mirror

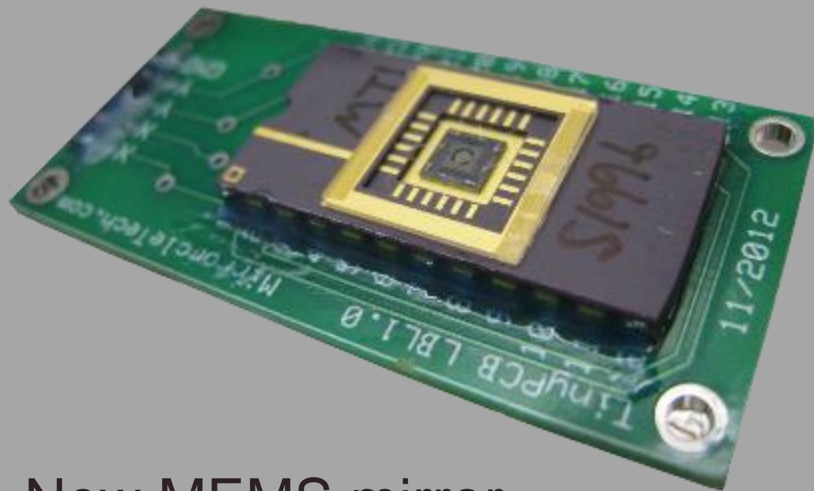
- 3-s exposure time to full-well capacity on bright features
- Increased SNR, defect sensitivity and throughput
- Increased O2 partial pressure for extended mirror lifetime

Absorber

- 40-s exposure time
- 2700 counts

1 µm

Flux



New MEMS mirror

- 3-s exposure time to full-well capacity on bright features
- Increased SNR, defect sensitivity and throughput
- Increased O2 partial pressure for extended mirror lifetime

Black border

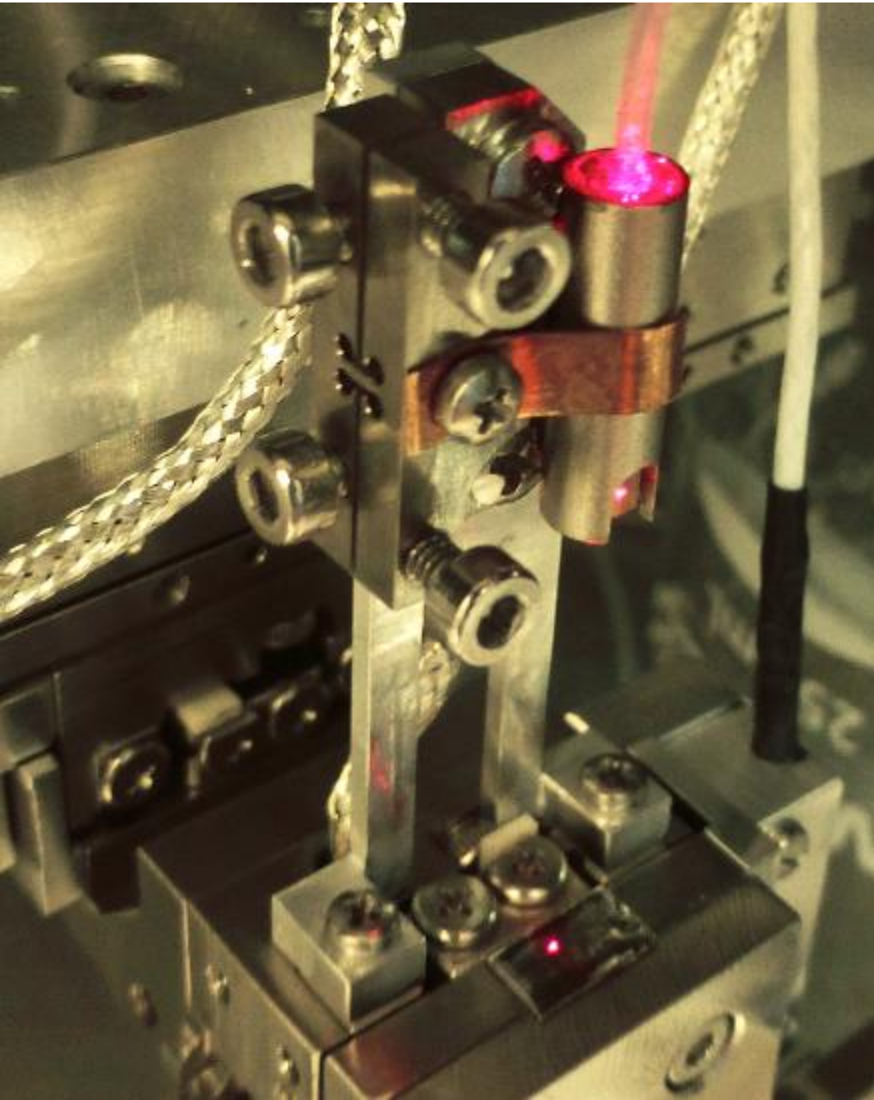
- 30-s exposure time
- 200 counts

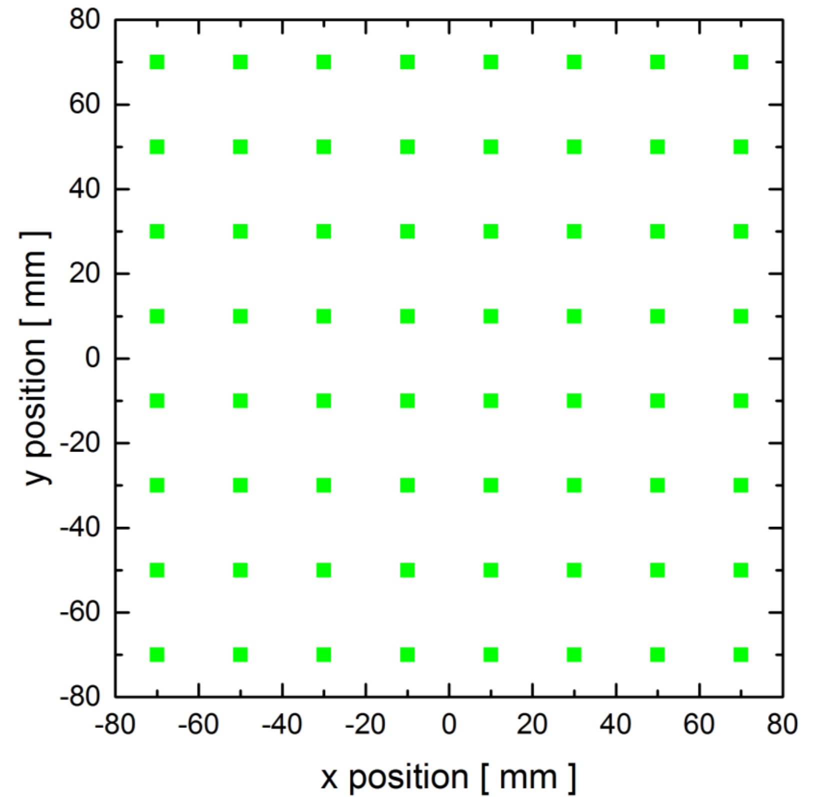
1 μm

Mask Handling and cleanliness

- RSP200 interface
- Robotic mask loader
- Clean mini environment
- Upgraded vacuum system
- Improved pump/vent cycle

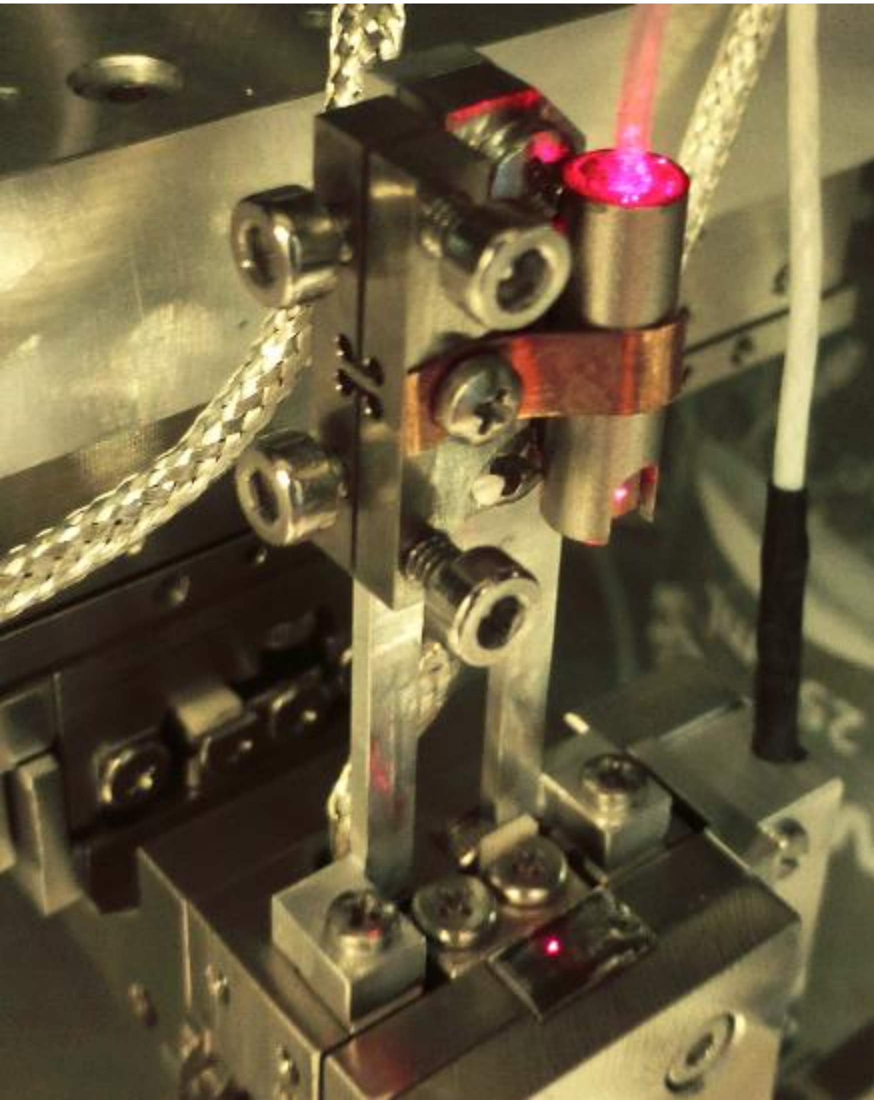
Position accuracy

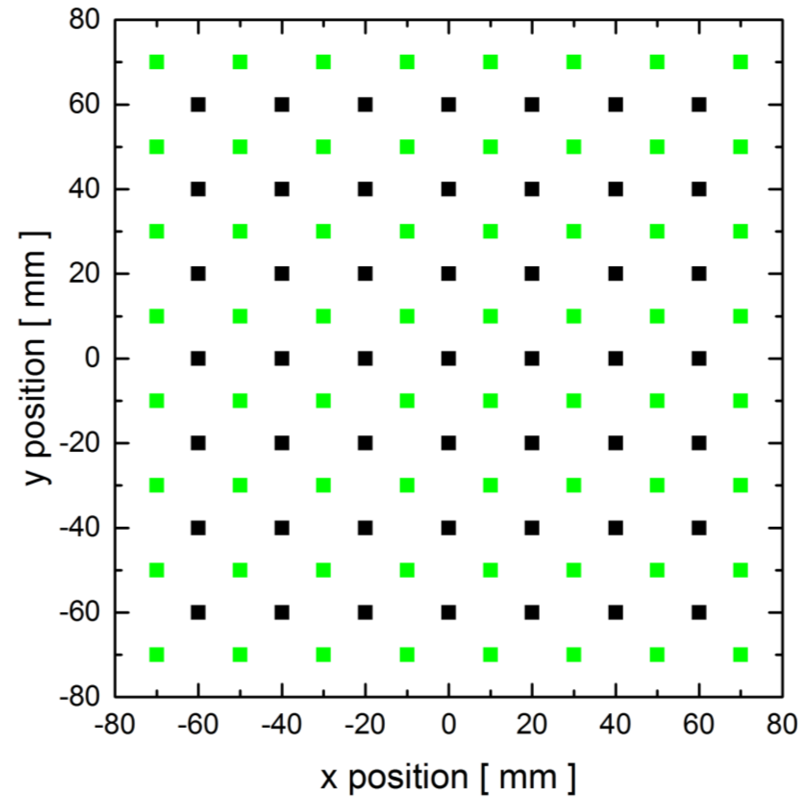




- Laser interferometer for mask positioning
- 1.4-µm wavelength

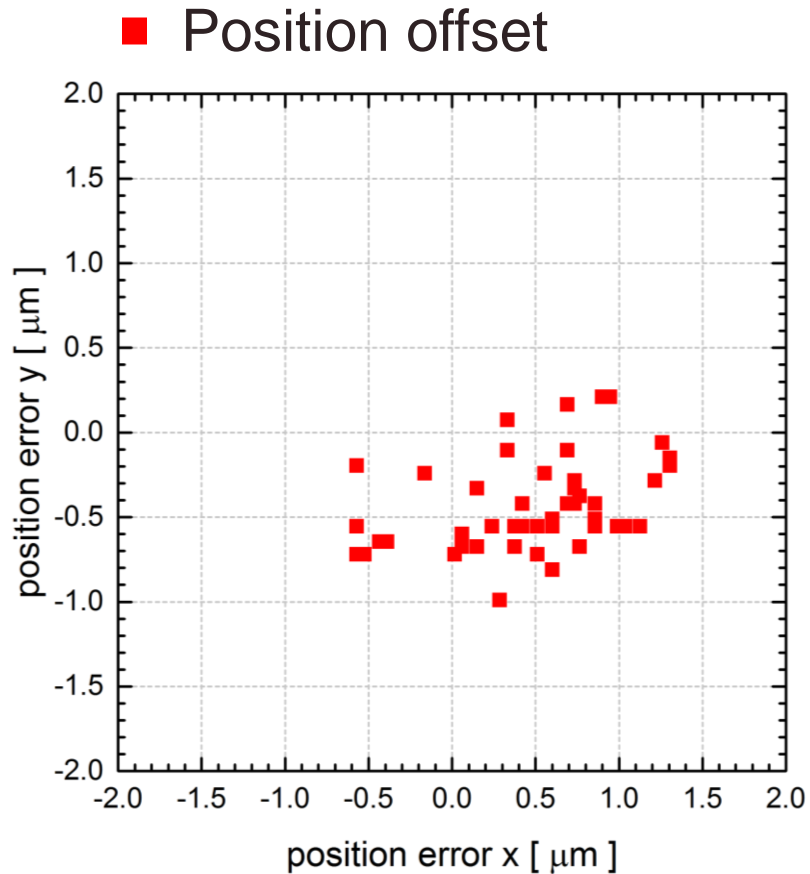
Position accuracy

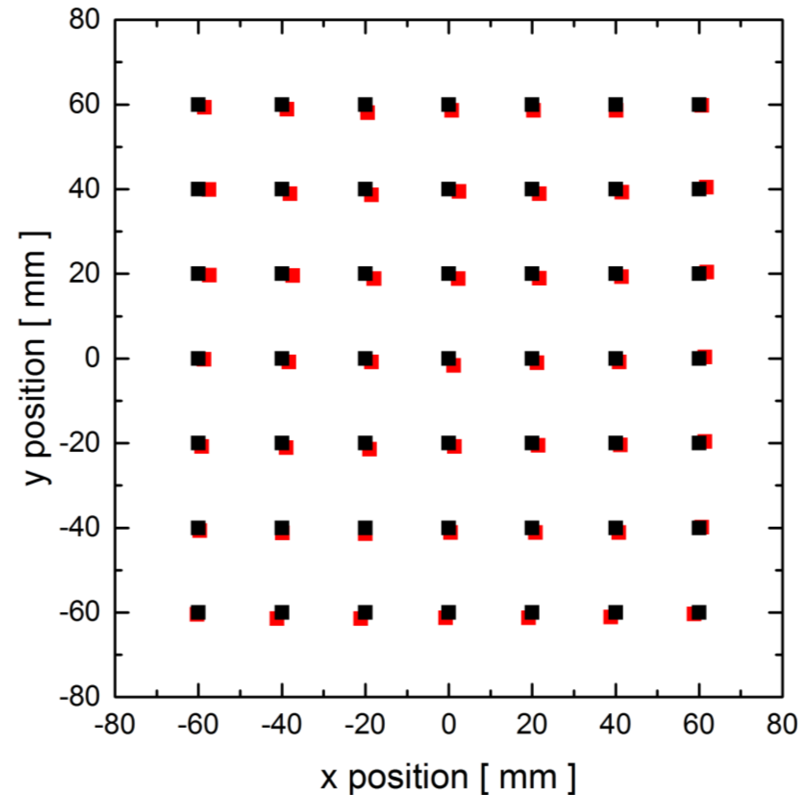




- Calibration sites
- Validation sites

Position accuracy

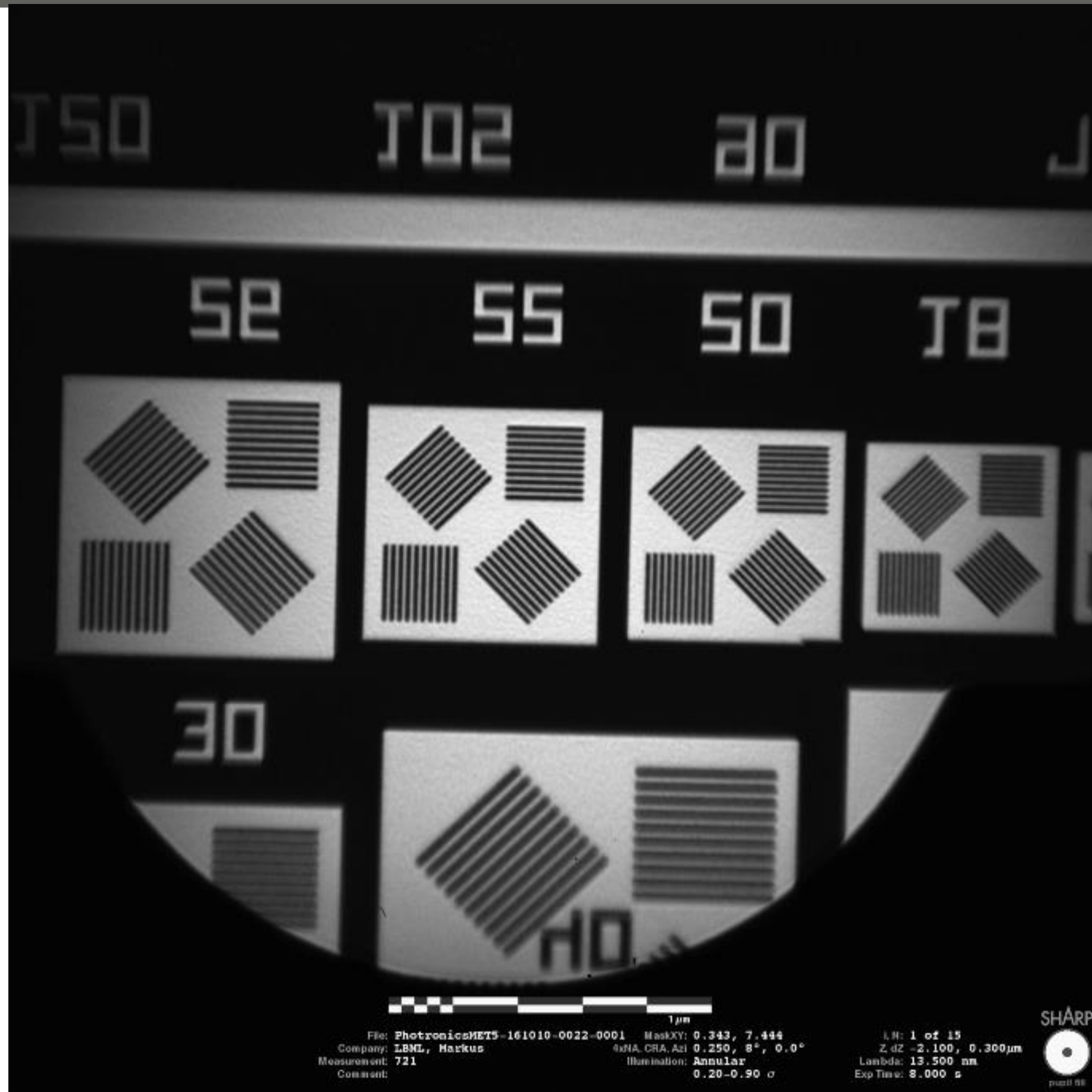




- Target position
- Stage position, offset scaled 2000x for visibility

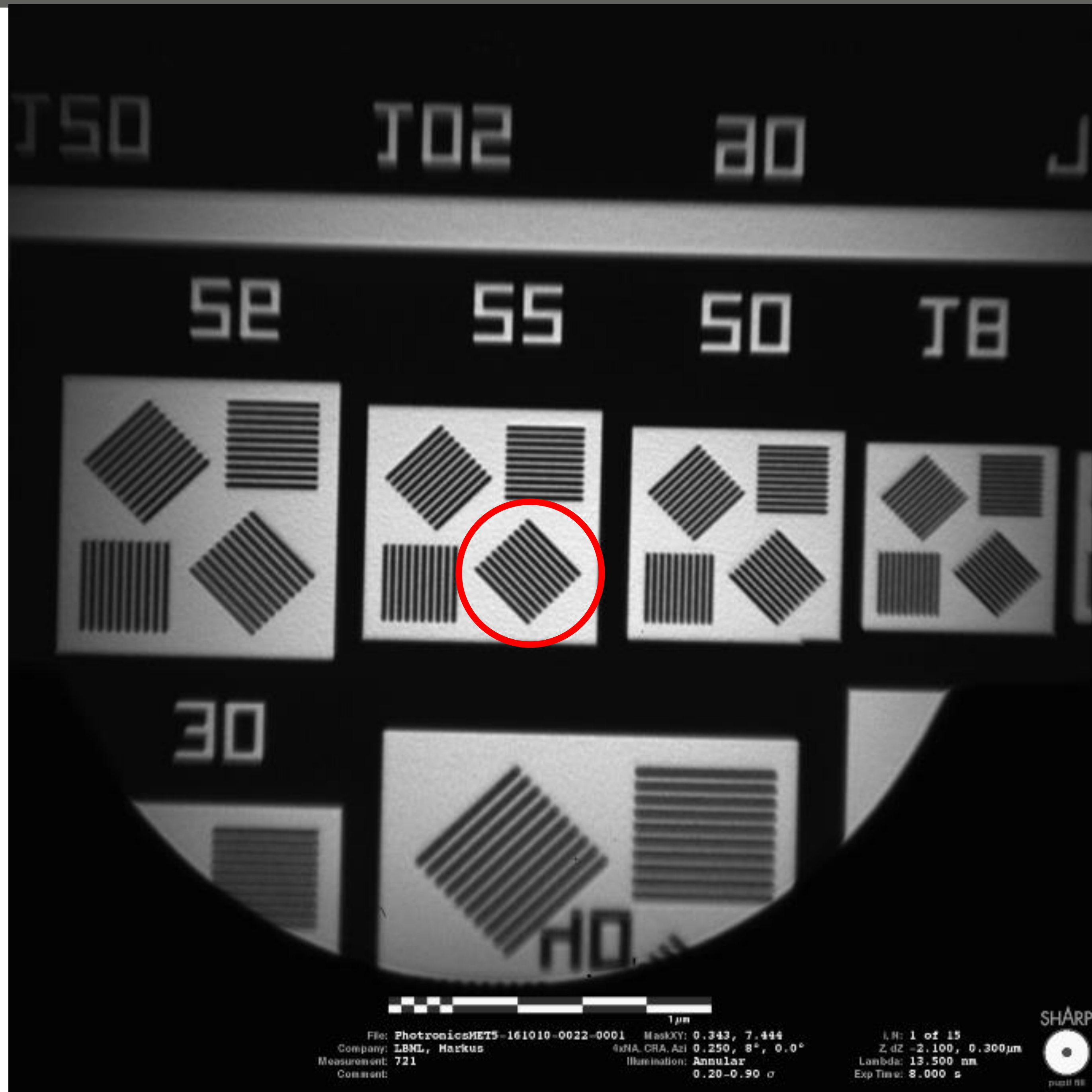
Position accuracy

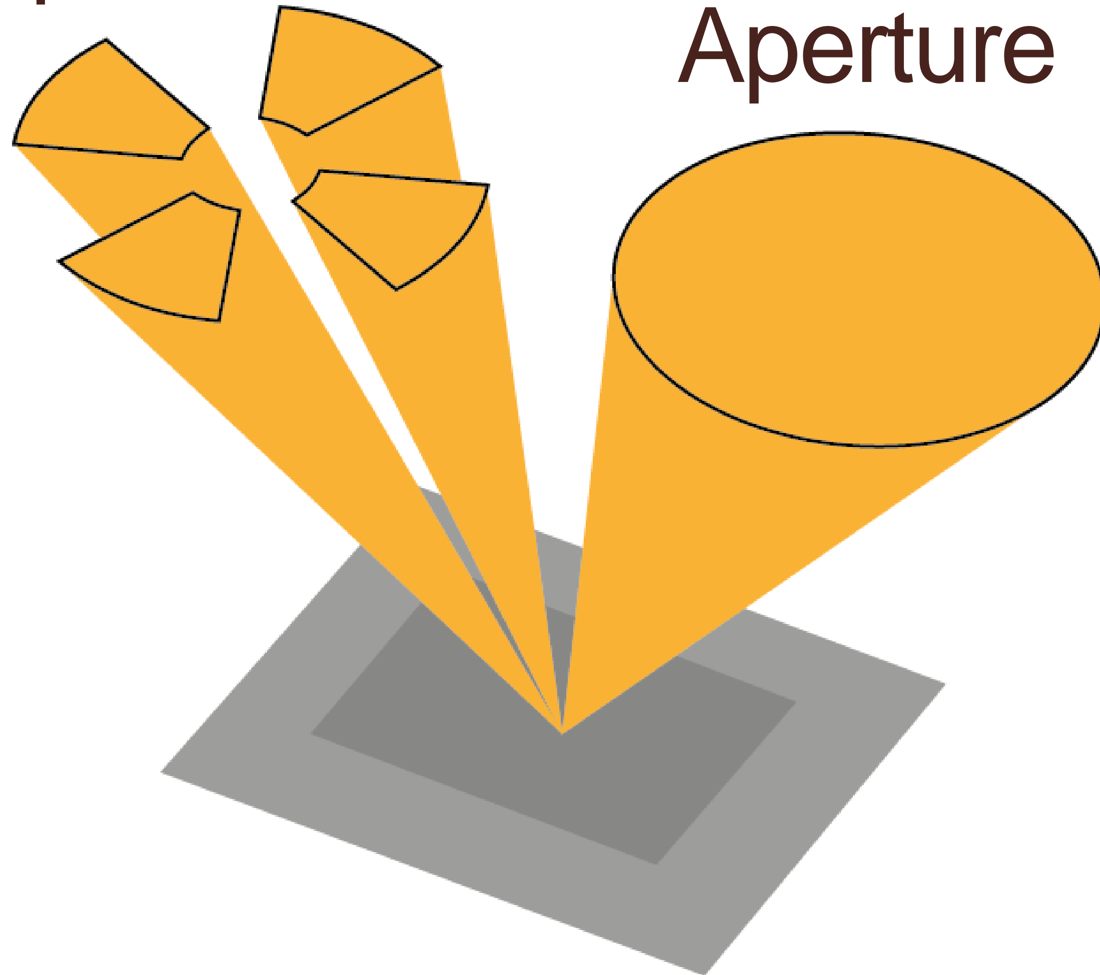
- $30 \times 30\,\mu m^2$ field of view



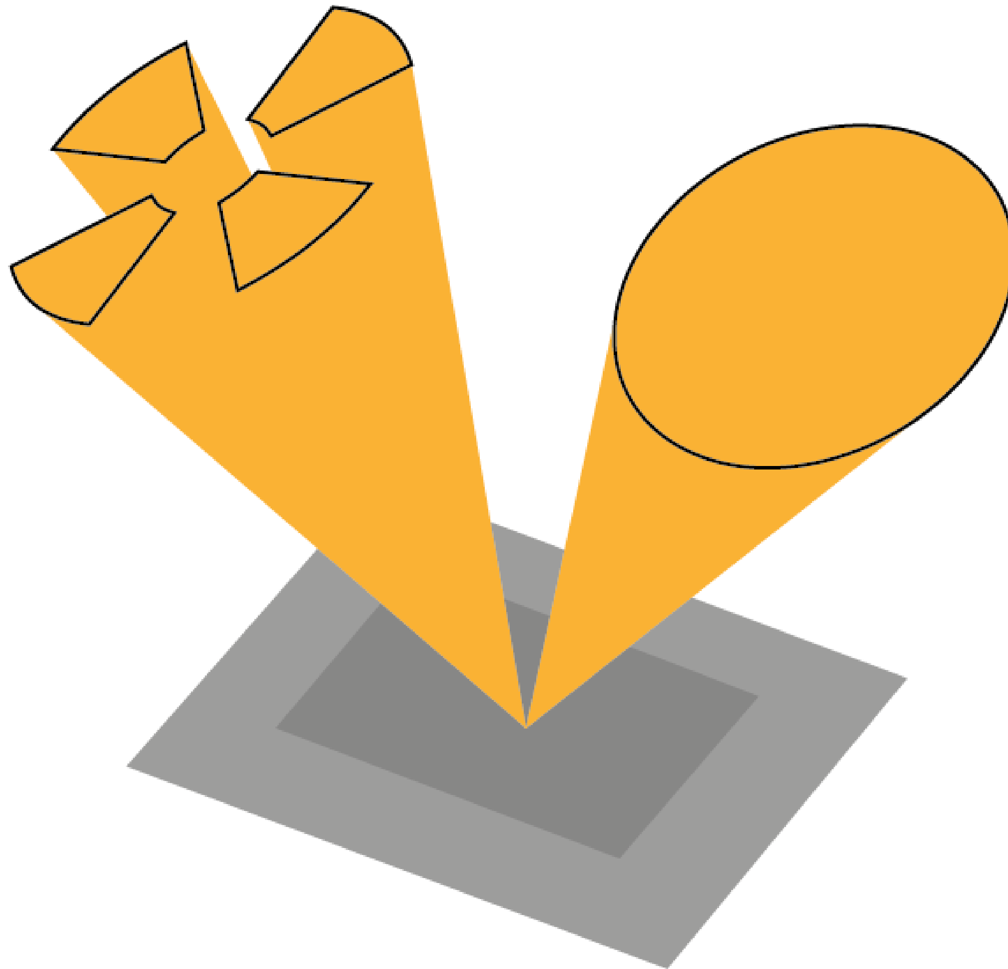
Position accuracy

- 30 x 30 μm^2 field of view
- 2-µm error radius

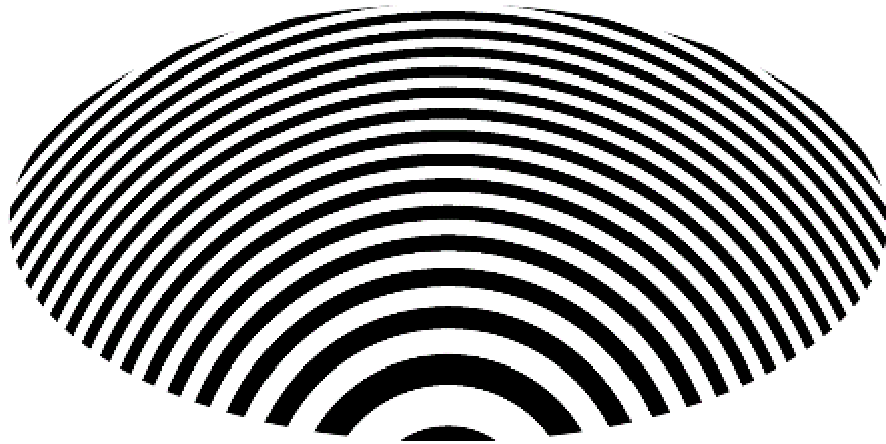



Source angular
spectrum
Aperture

Emulation of anamorphic imaging



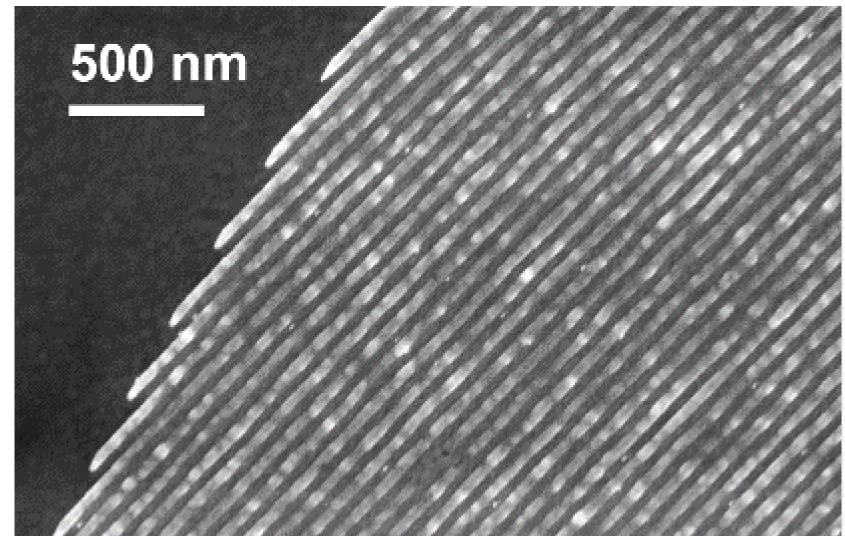
Emulation of anamorphic imaging



Elliptical zoneplates

- 4x/8xNA = 0.55
- 6° CRA
- Magnification from 1250 to 1636

SEM image



J. Micro/Nanolith. MEMS MOEMS 15(3),033501 (2016)

Anamorphic image

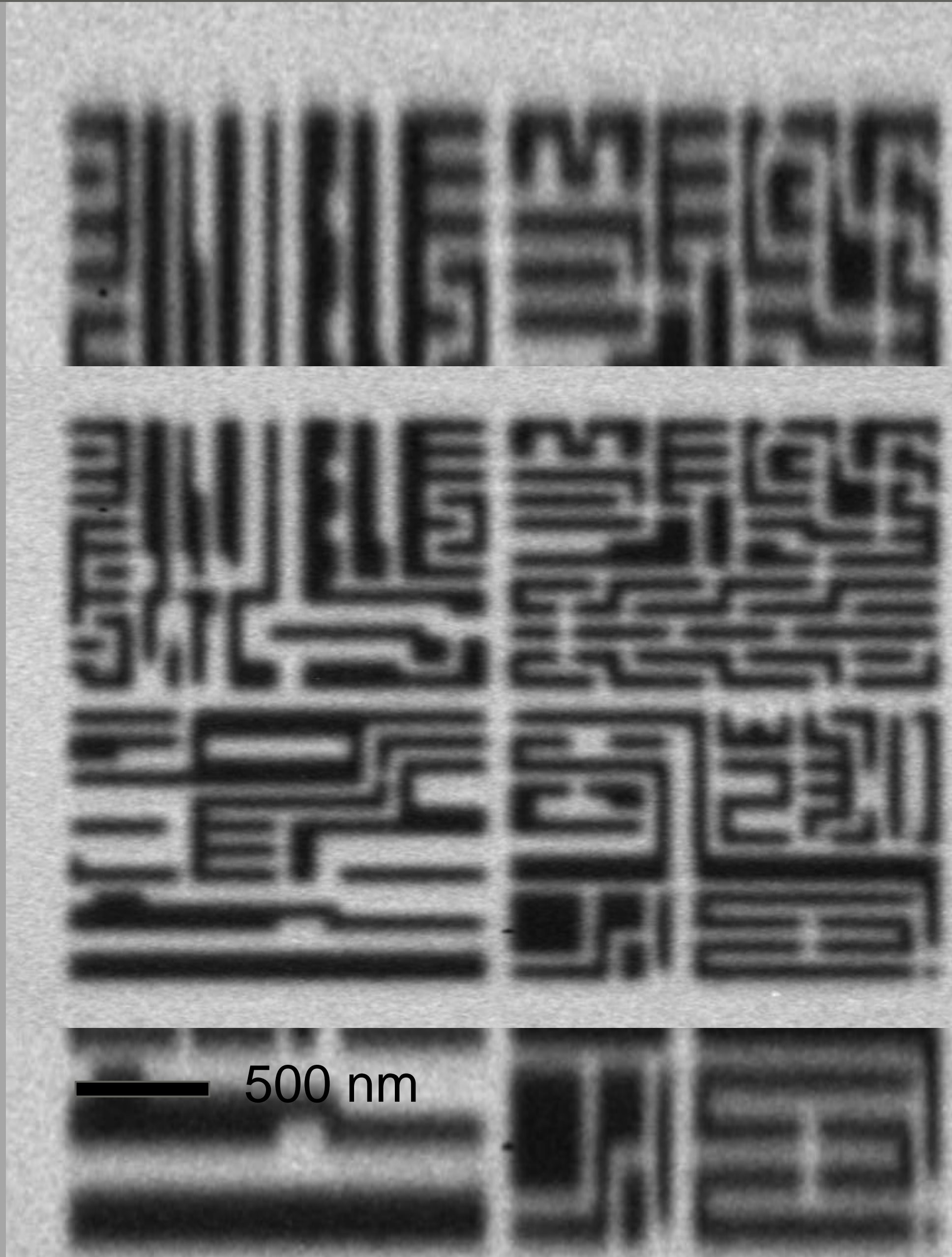
- 0.55 4x/8x NA
- 6° CRA
- Quasar 45°, σ=0.2 to 0.9

Raw image

Compressed image

- 50-nm CD
- 100-nm CD
- 12.5-nm CD (1x)

JM[3] 15(3),033501 (2016)



- 0.55 4x/8x NA
- 6° CRA, anamorphic

200 nm

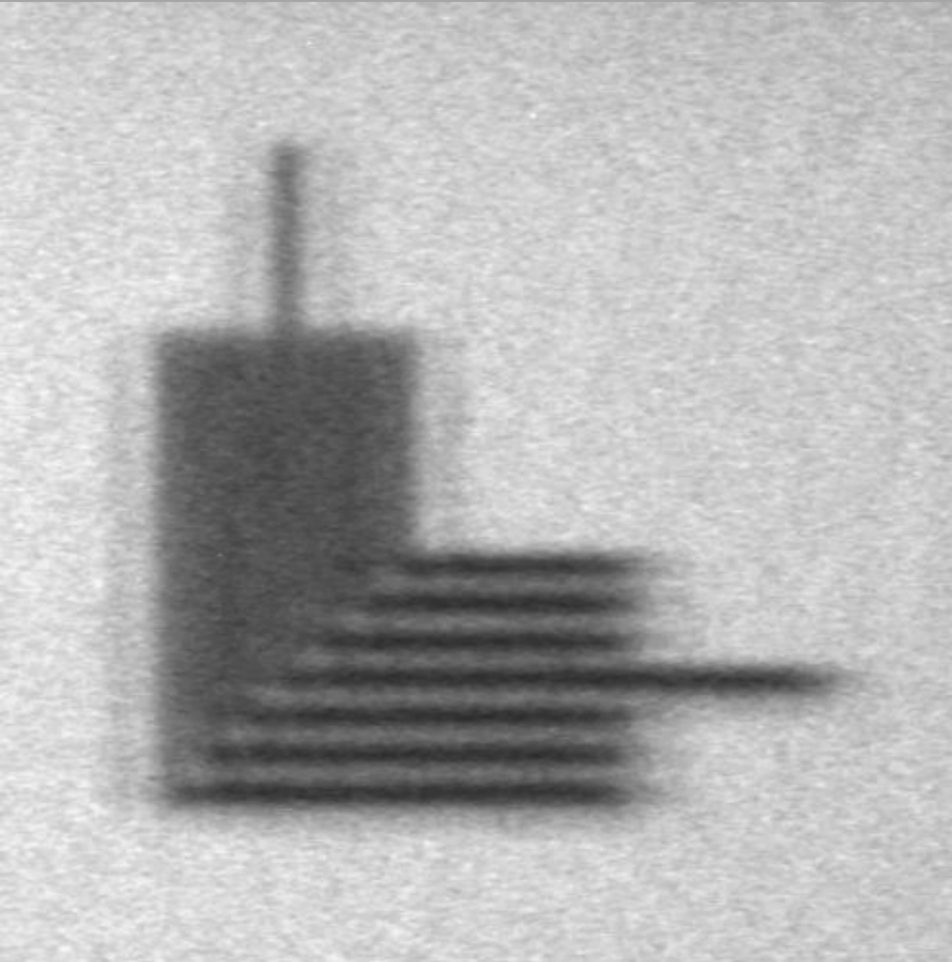
- 0.55 4x/8x NA
- 6° CRA, anamorphic

200 nm

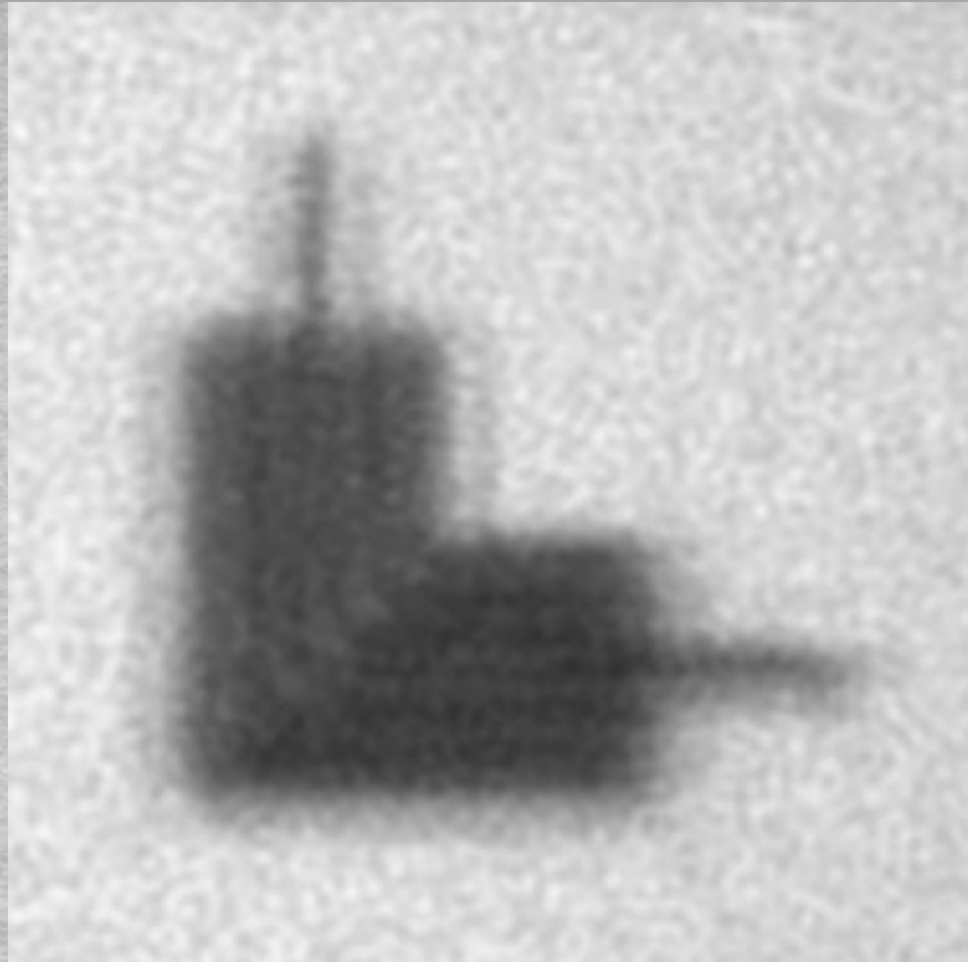
- 0.5 4x NA
- 8° CRA

50-nm elbows (4x)

JM³ 15(3),033501 (2016)



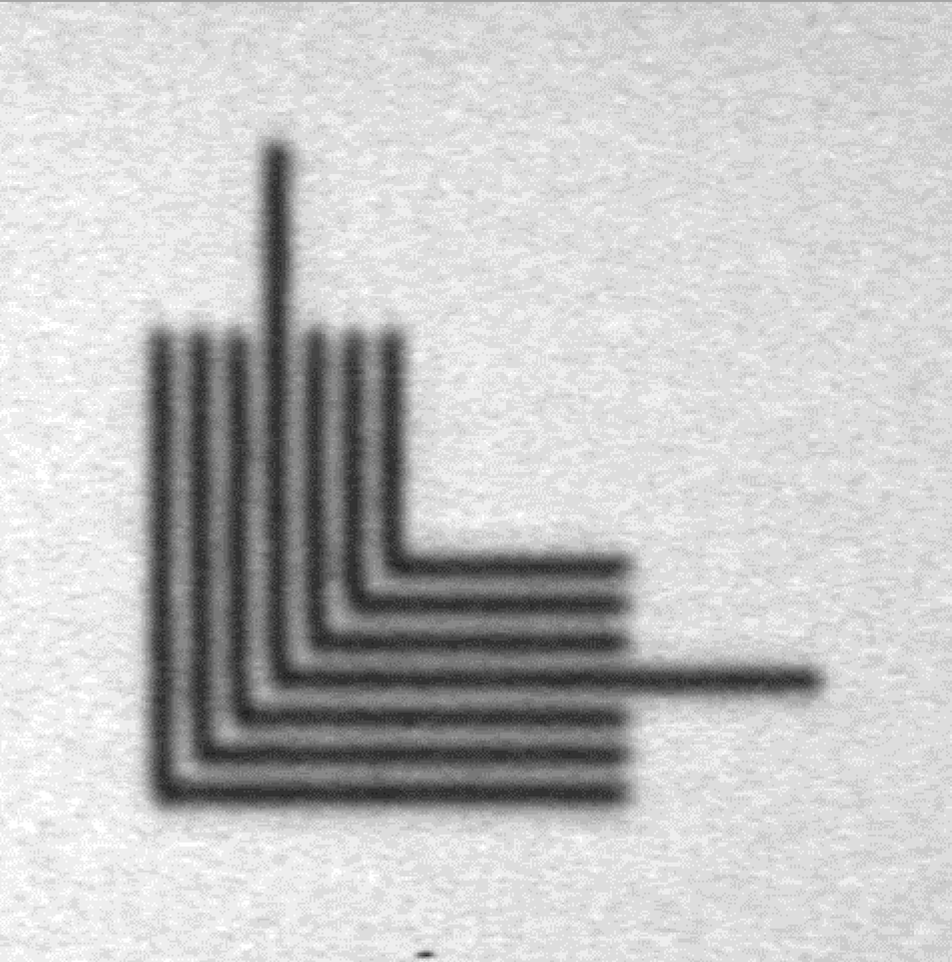
- 0.55 4x/8x NA
- 6° CRA, anamorphic



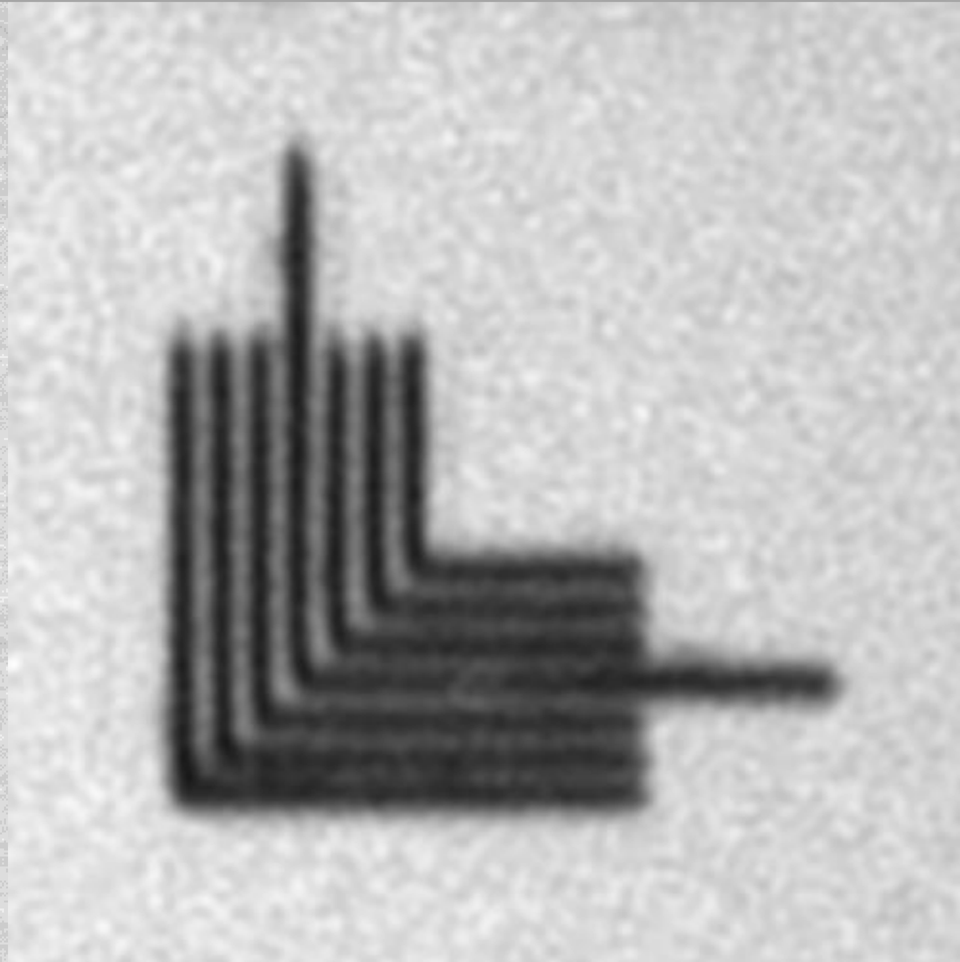
- 0.5 4x NA
- 8° CRA

50-nm elbows (4x)

JM³ 15(3),033501 (2016)



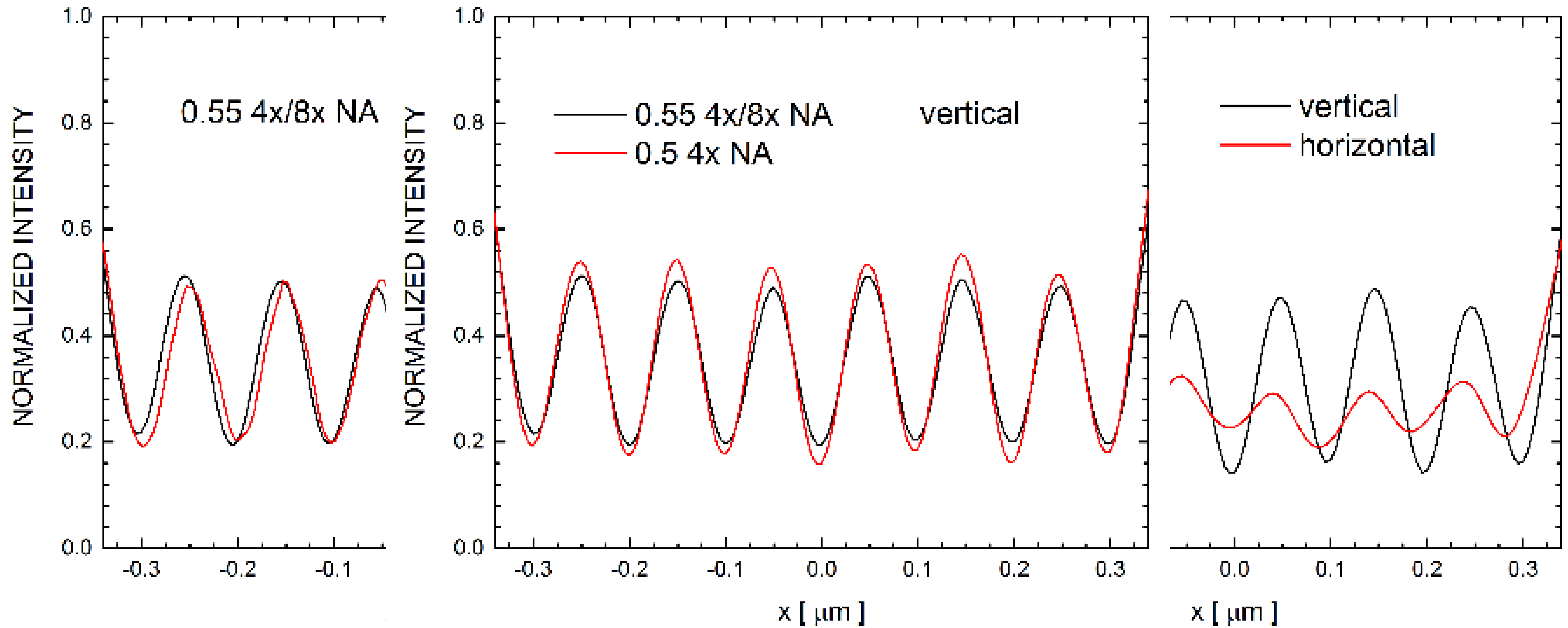
- 0.55 4x/8x NA
- 6° CRA, anamorphic



- 0.5 4x NA
- 8° CRA

50-nm elbows (4x)

Modulation

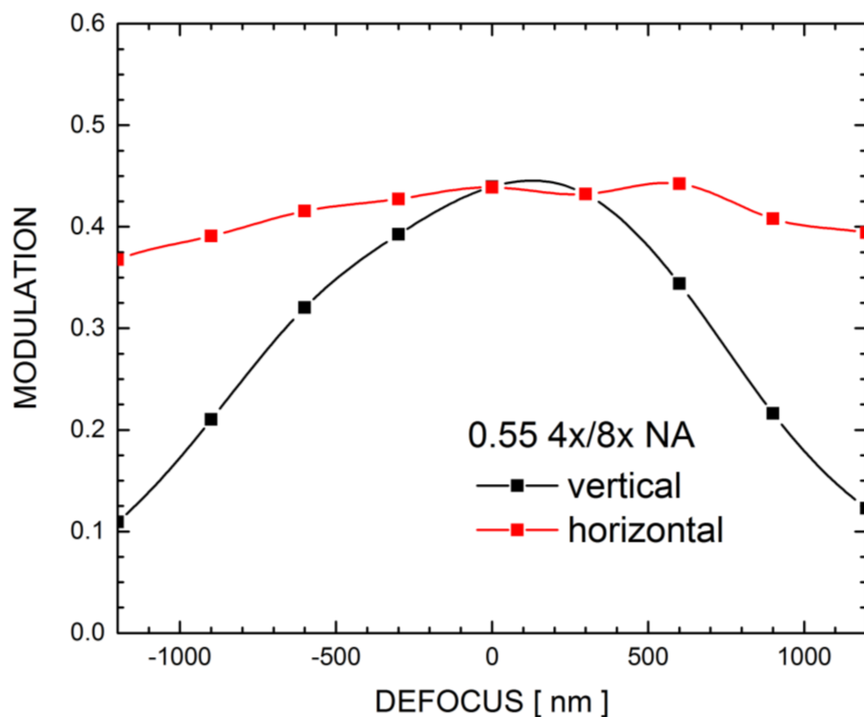


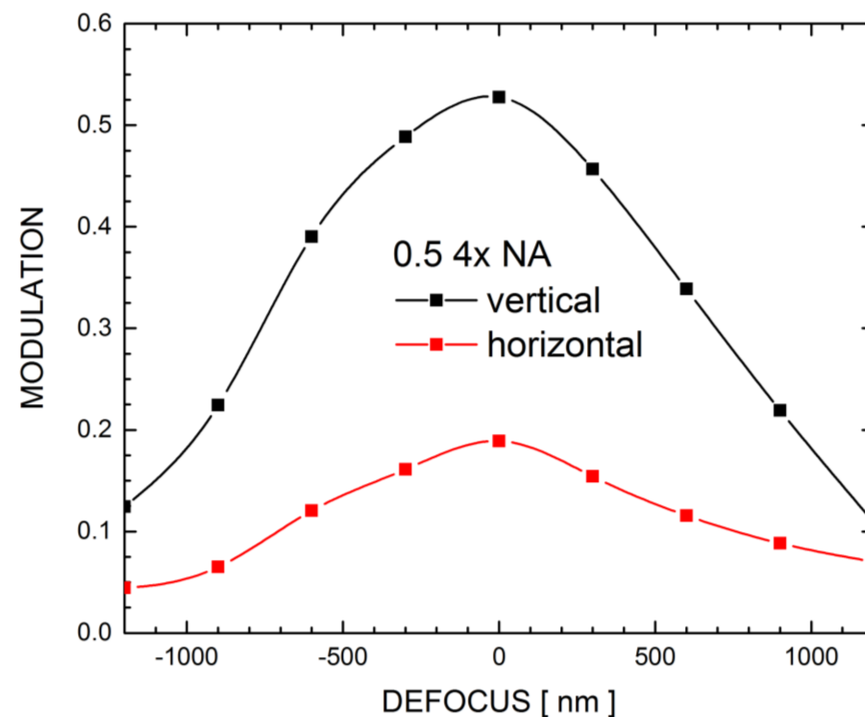
- 0.55 4x/8x NA
- 6° CRA, anamorphic

- 0.5 4x NA
- 8° CRA

50-nm elbows (4x)

Modulation through focus



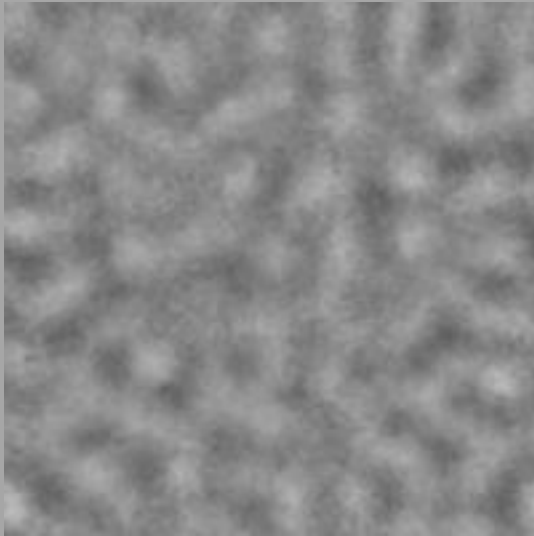


- 0.55 4x/8x NA
- 6° CRA, anamorphic

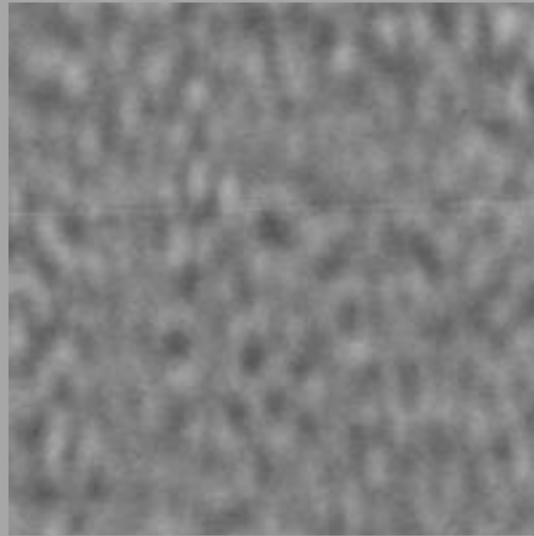
- 0.5 4x NA
- 8° CRA

Contrast enhanced.

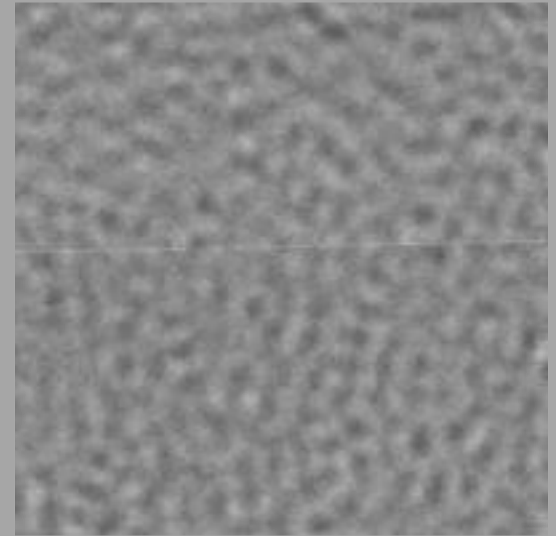
500 nm (4x)



- 0.25 4x NA



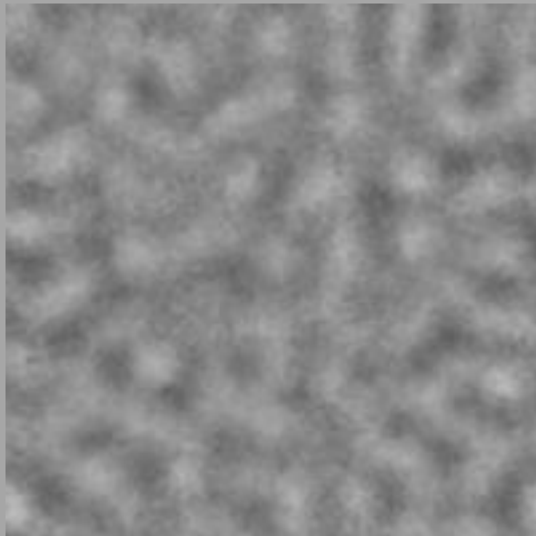
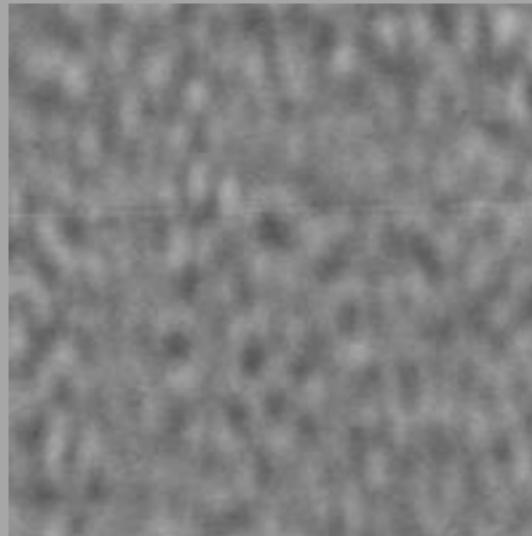
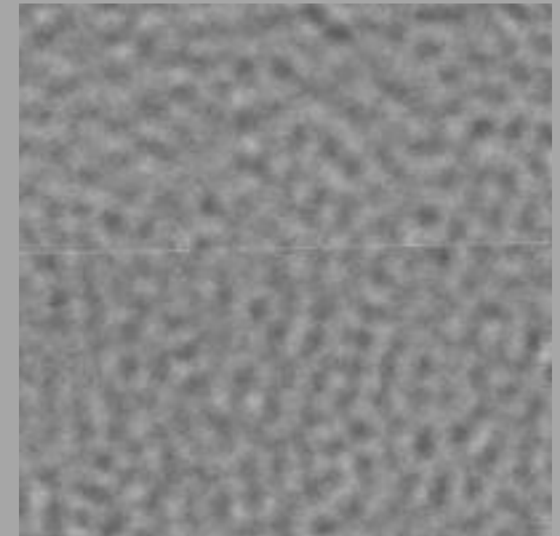
- 0.55 4x/8x NA



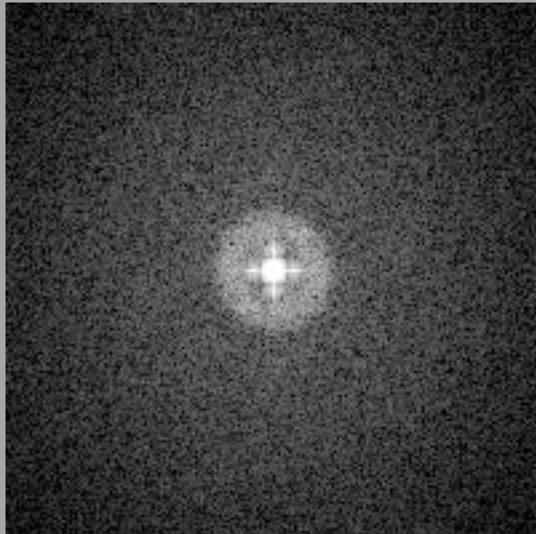
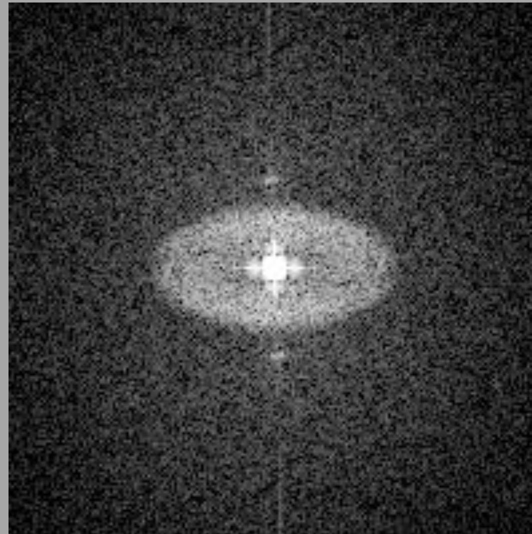
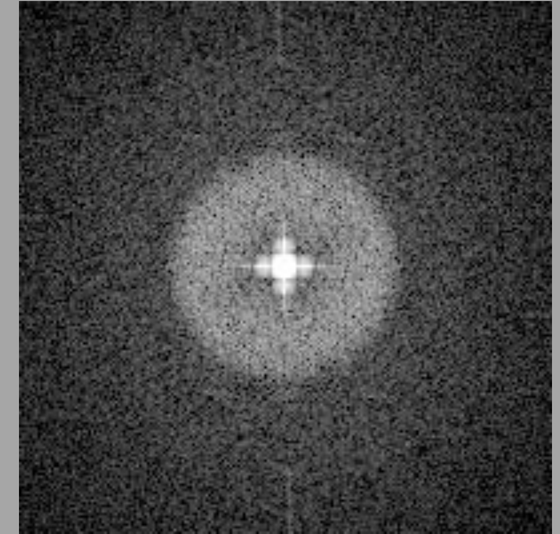
- 0.5 4x NA

Contrast enhanced.

500 nm (4x)

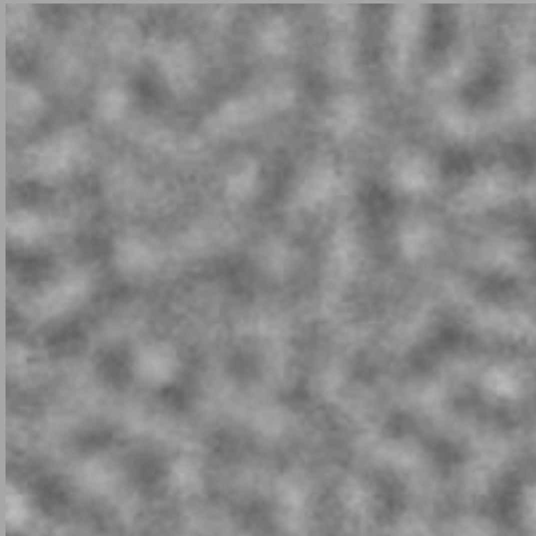




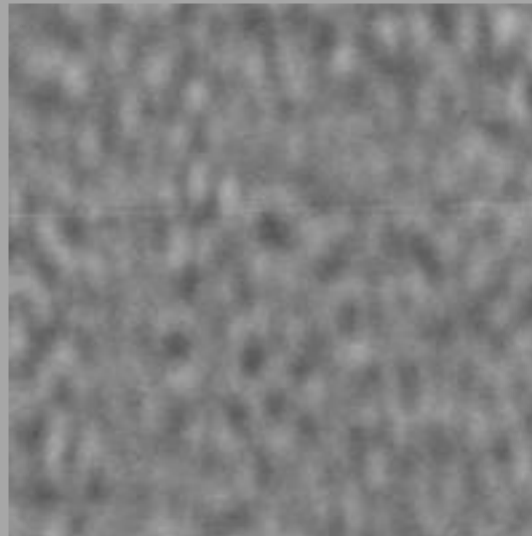
- 0.25 4x NA
- 0.55 4x/8x NA
- 0.5 4x NA

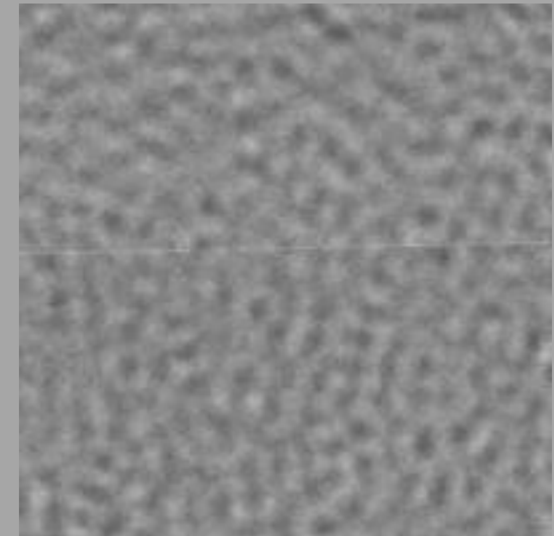




Log-scale power spectra

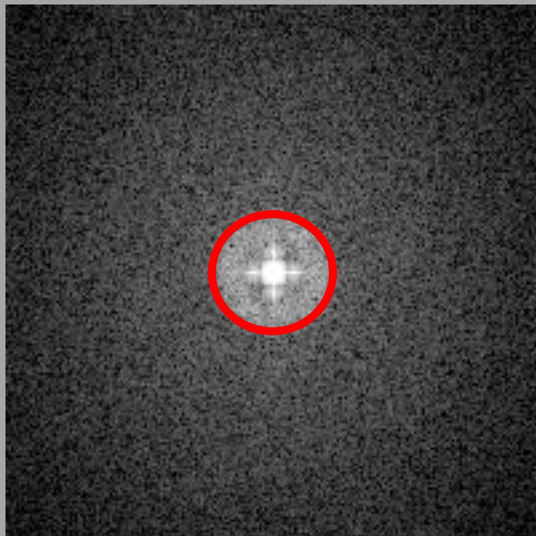
Contrast enhanced.

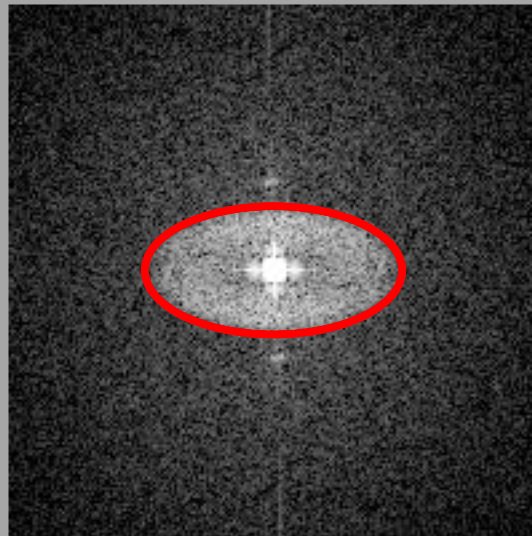


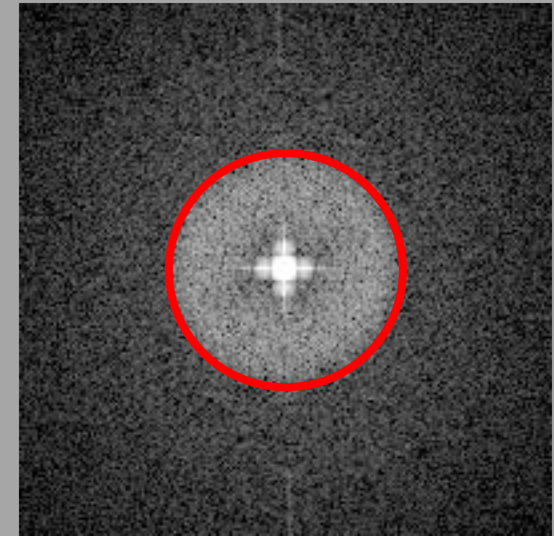




- 0.25 4x NA
- 0.55 4x/8x NA
- 0.5 4x NA



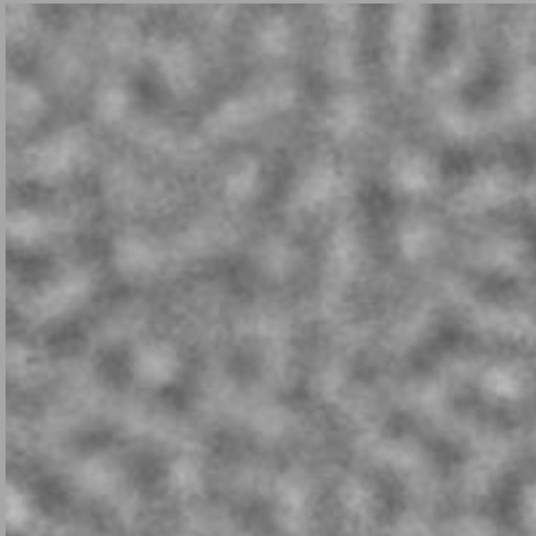


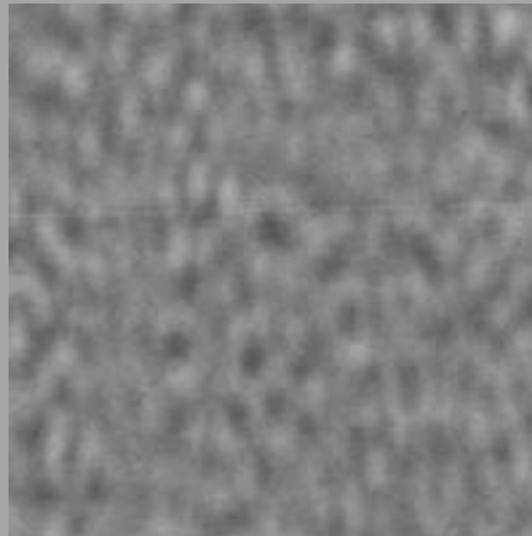


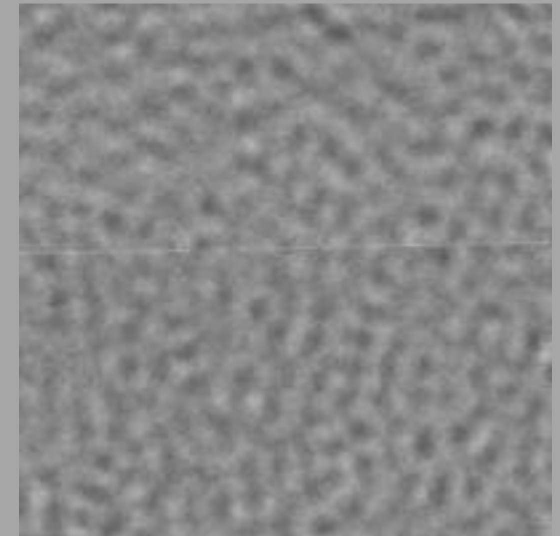
Log-scale power spectra

Contrast enhanced.

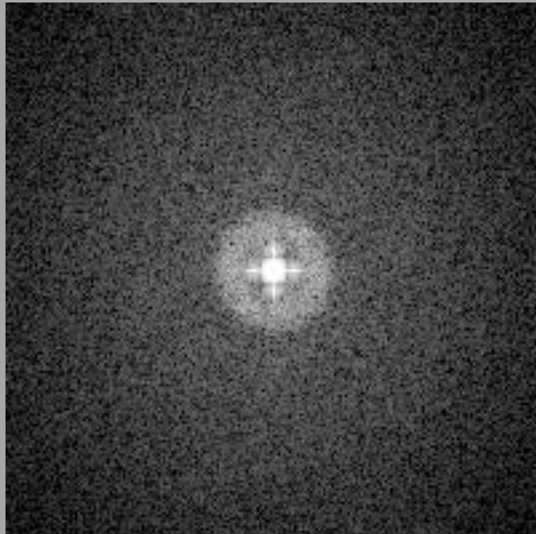
500 nm (4x)

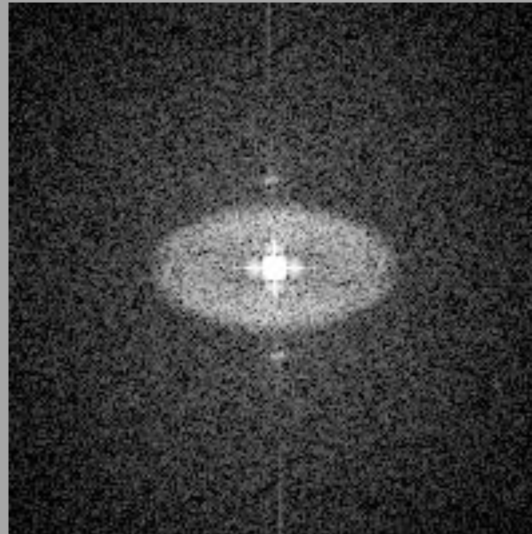


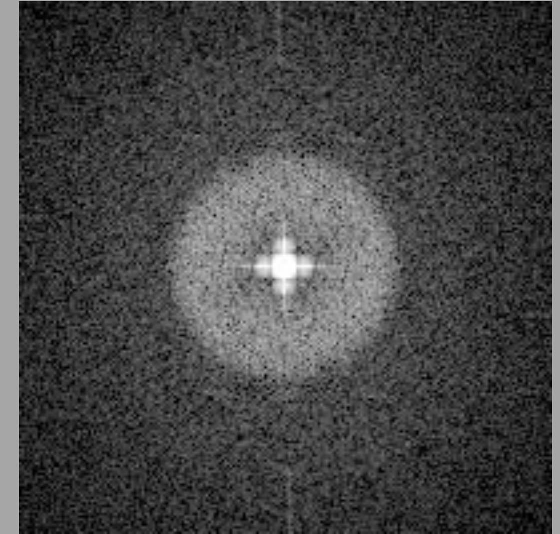




- 0.25 4x NA
- 0.55 4x/8x NA
- 0.5 4x NA



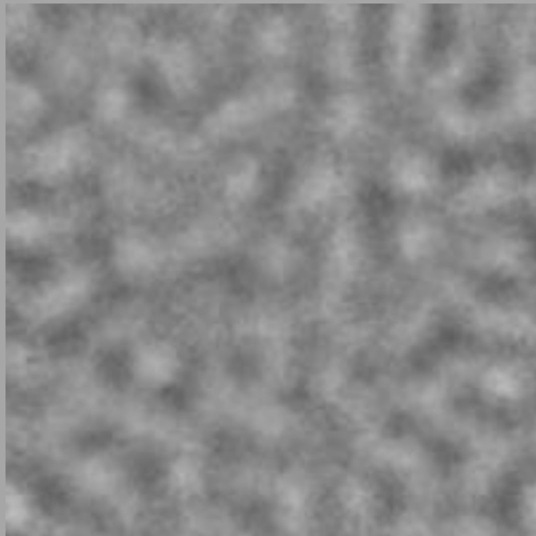
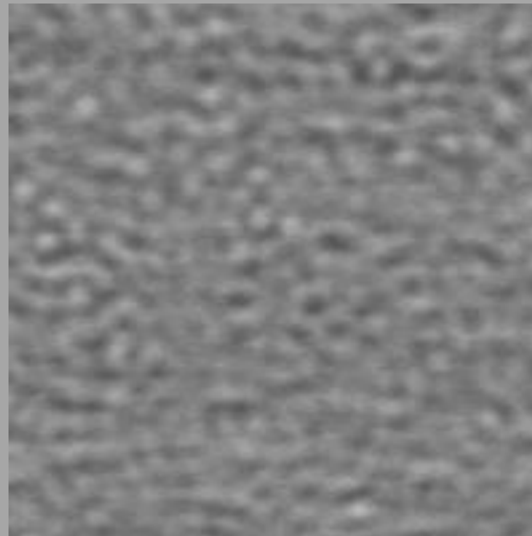
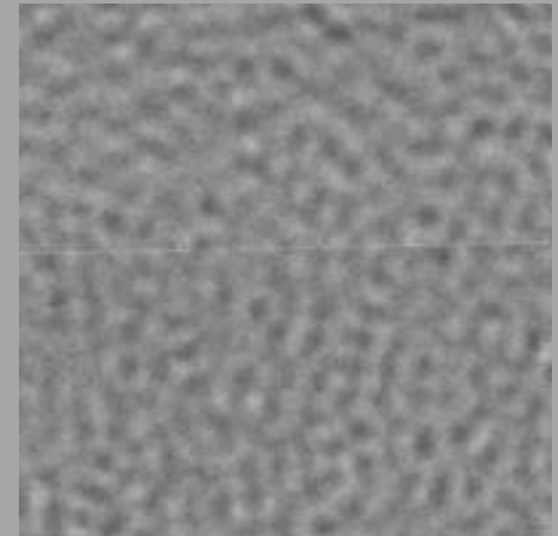




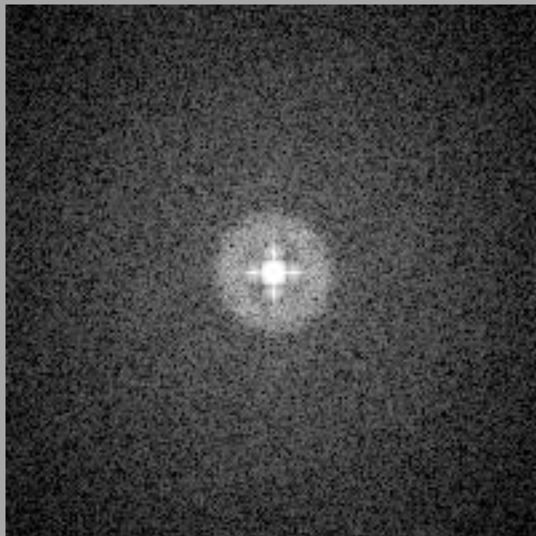
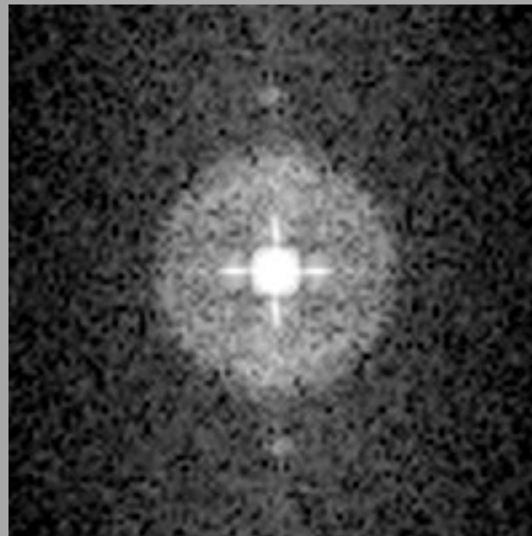
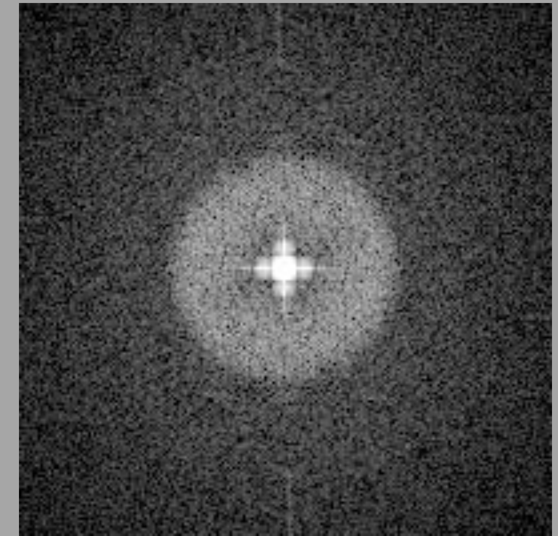
Log-scale power spectra

Contrast enhanced.

500 nm (4x)

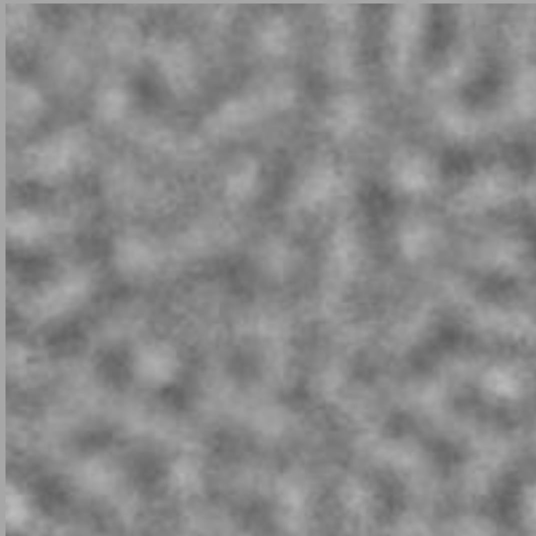
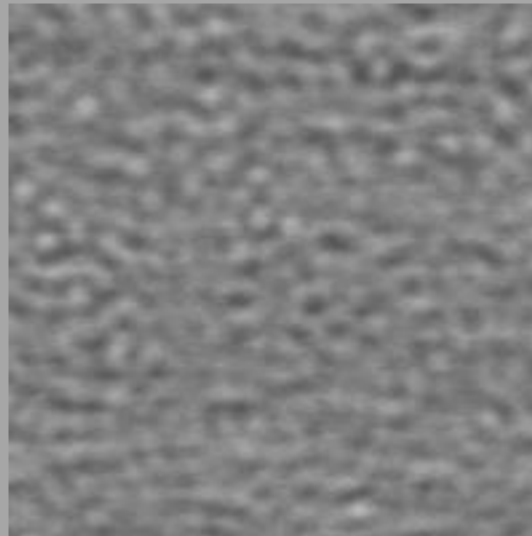
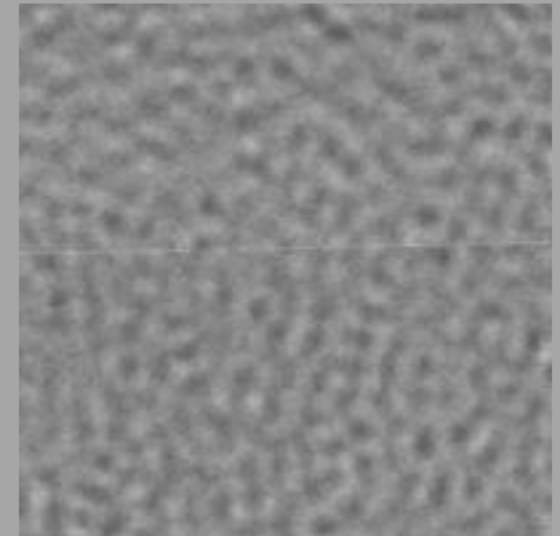
- 0.25 4x NA
- 0.55 4x/8x NA
- 0.5 4x NA

Log-scale power spectra

Contrast enhanced.

500 nm (4x)

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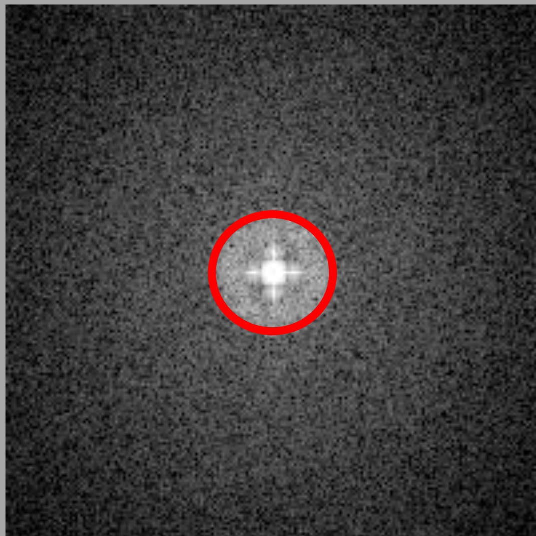
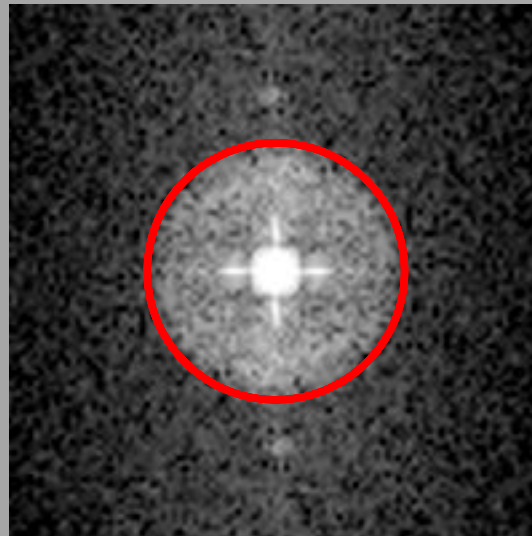
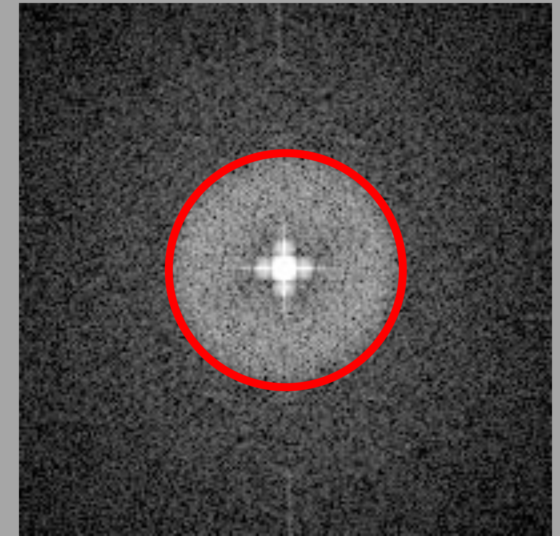
- 0.55 4x/8x NA
- 0.5 4x NA

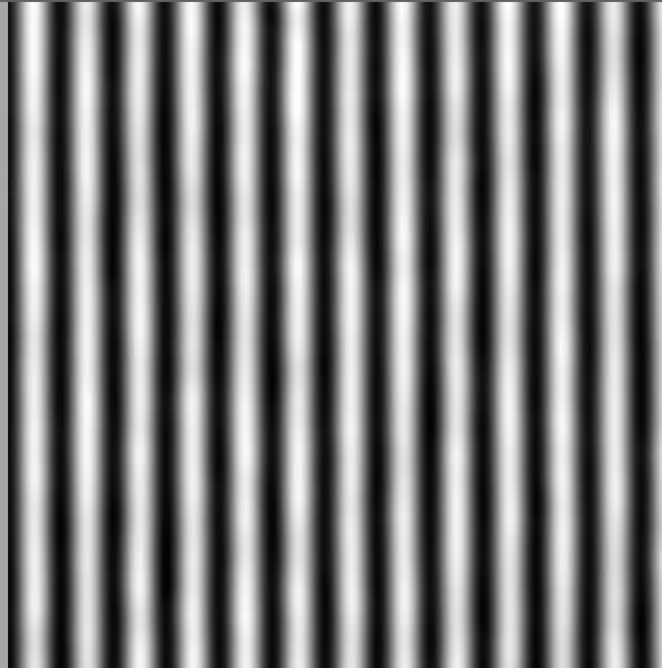
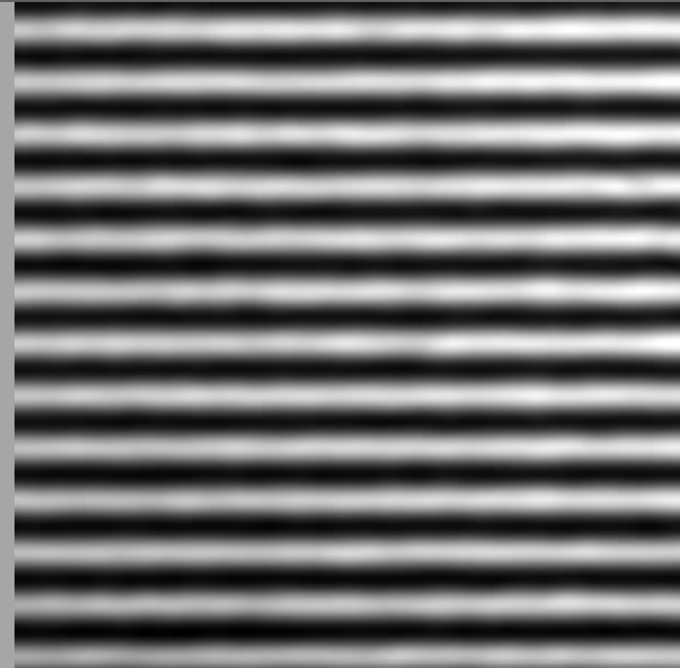
Log-scale power spectra

15-nm lines (1x)

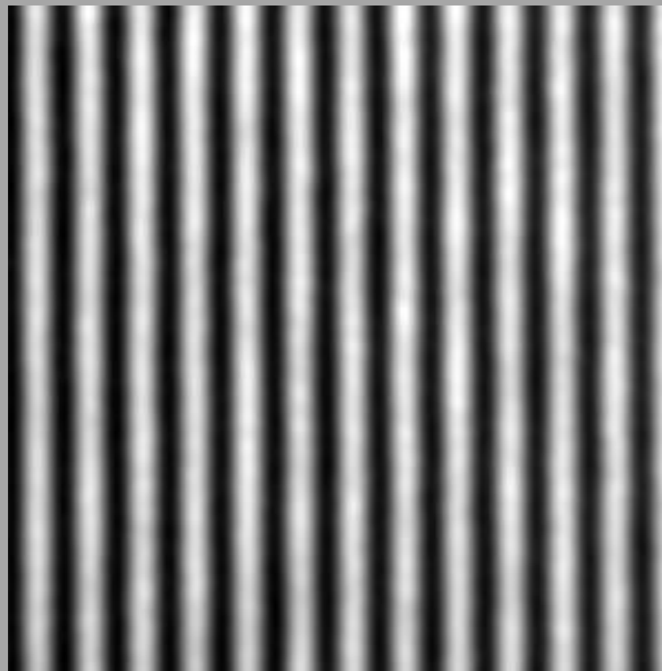
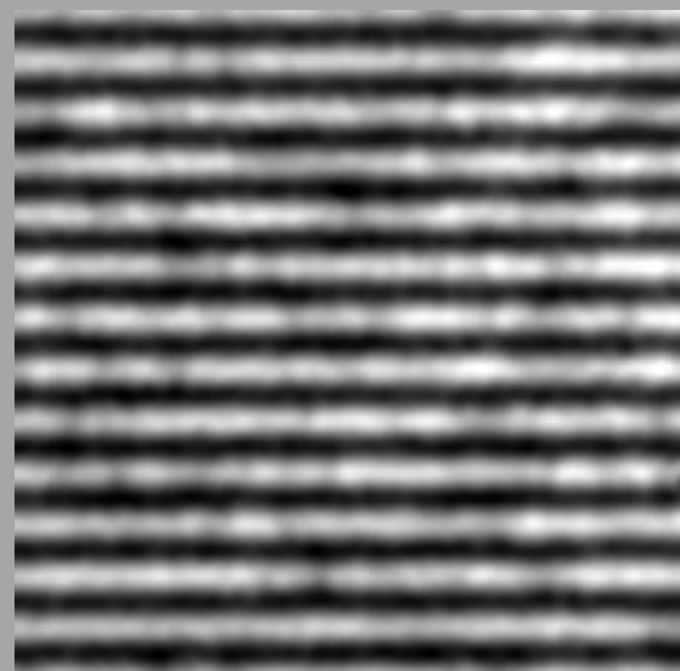
Contrast enhanced.

- 0.55 4x/8x NA
- 6° CRA

anamorphic

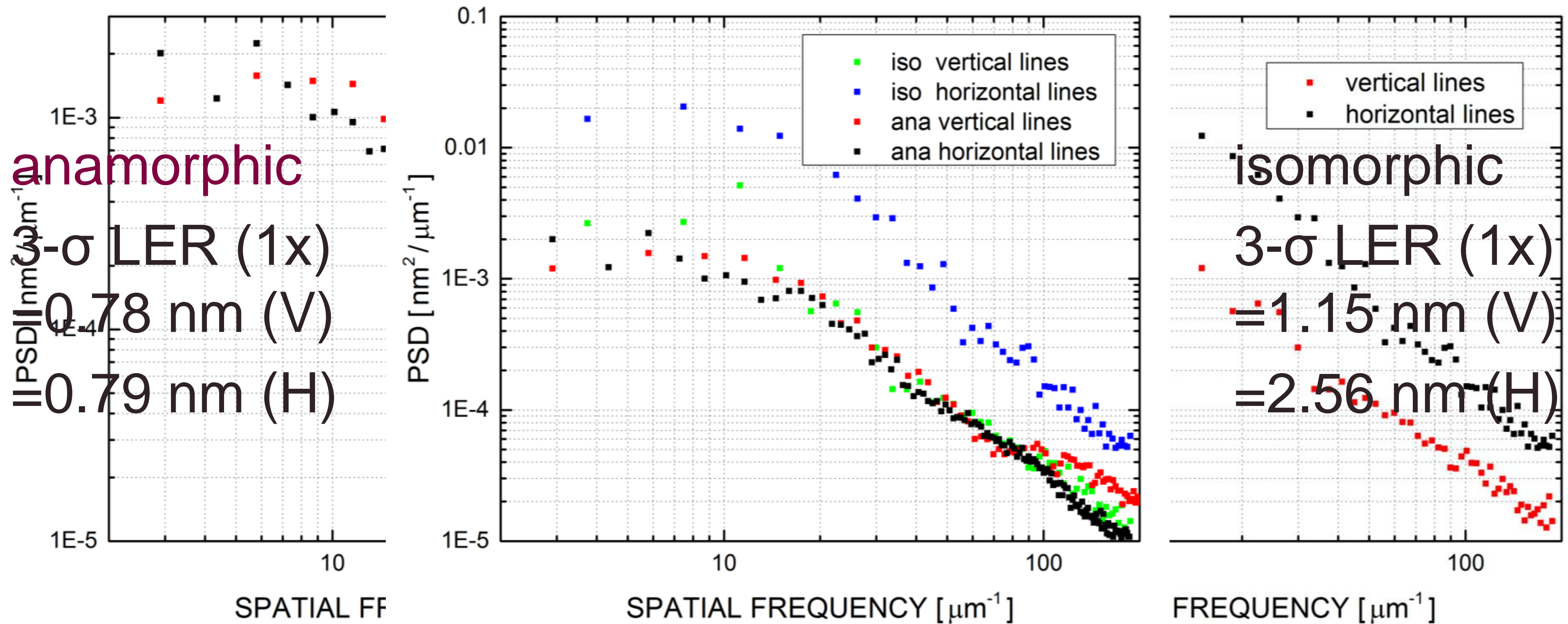
- 0.5 4x NA
- 8° CRA

200 nm

15-nm lines (1x)

Power Spectral Density



anamorphic

3-σ LER (1x)

=0.78 nm (V)

=0.79 nm (H)

isomorphic

3-σ LER (1x)

=1.15 nm (V)

=2.56 nm (H)

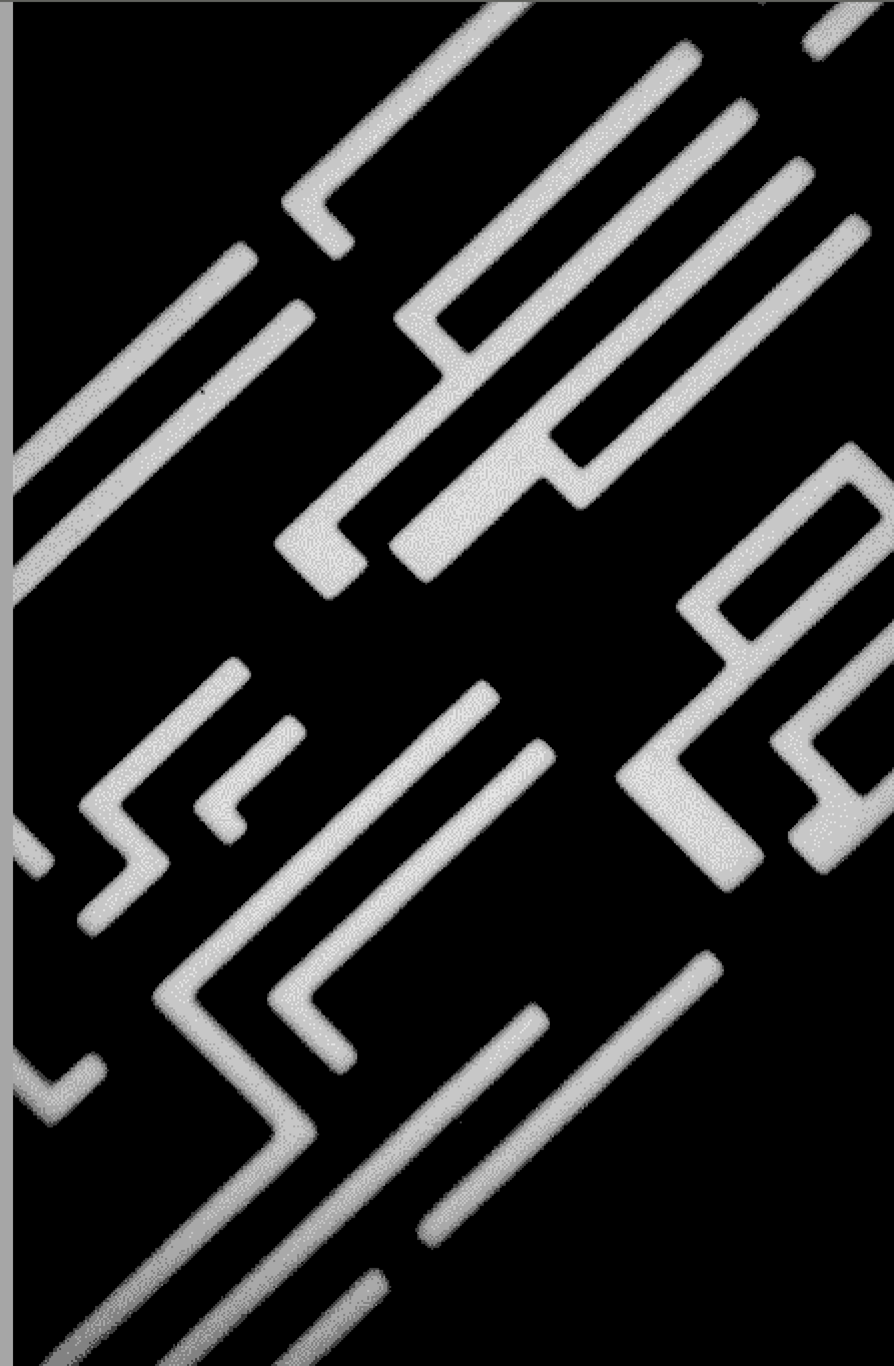
- 0.55 4x/8x NA
- 6° CRA, anamorphic

- 0.5 4x NA
- 8° CRA

Summary

SHARP High-NA Actinic Reticle Review Project

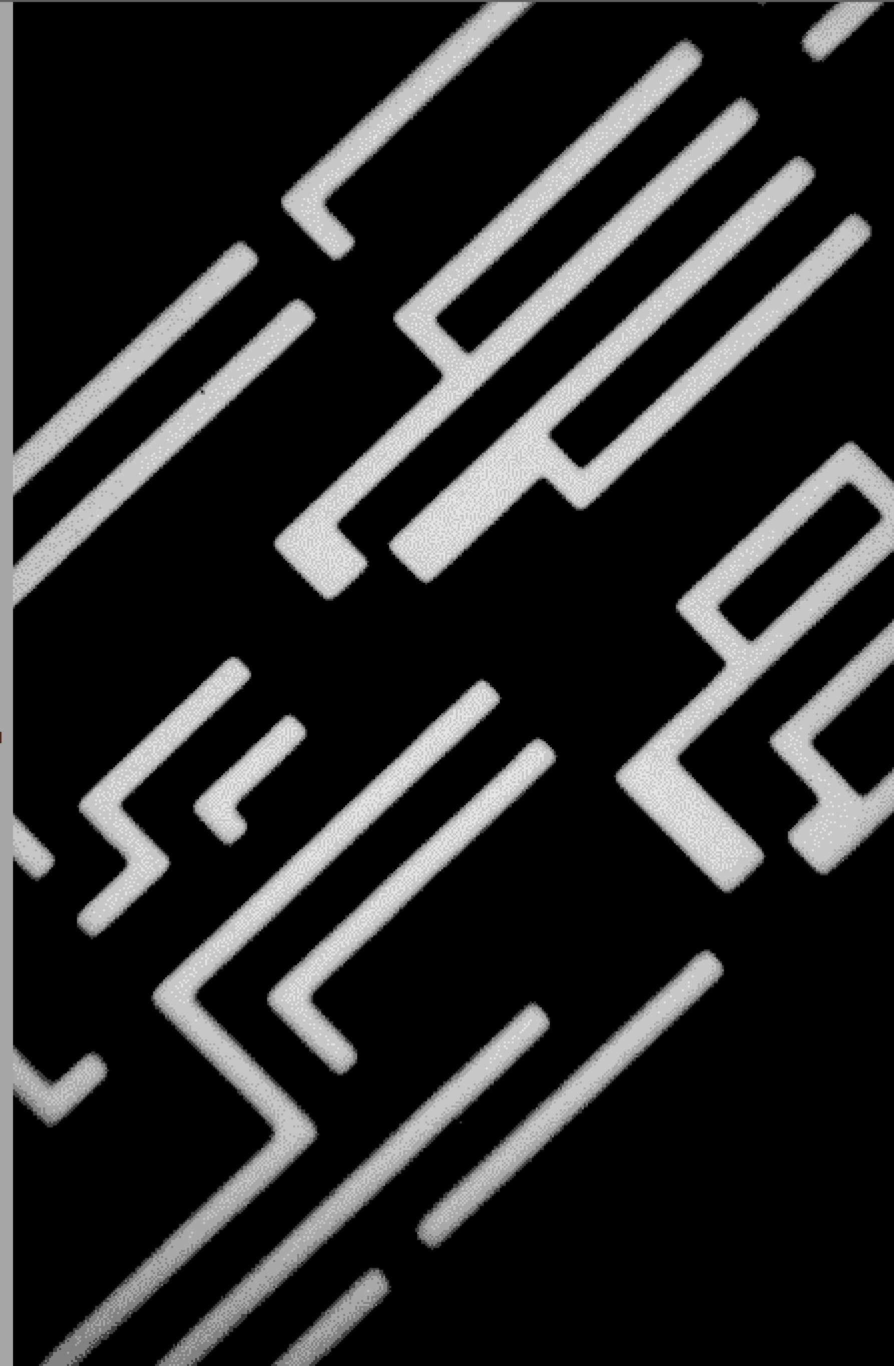
- Emulation of imaging in EUV scanner
- Emulation of anamorphic imaging
- Uniform imaging performance and transfer of roughness in anamorphic imaging mode



Thanks to our users.

Thanks to INTEL for funding SHARP operations.

EUV infrastructure at Berkeley is funded through the EUREKA program.



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