Diffractive optics for EUV applications

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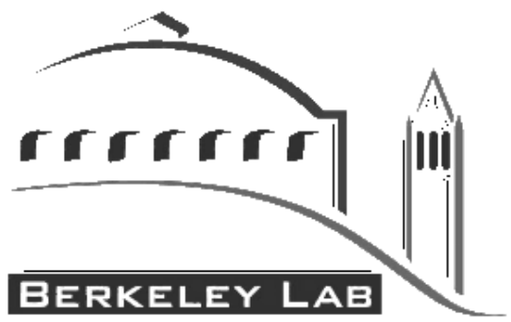
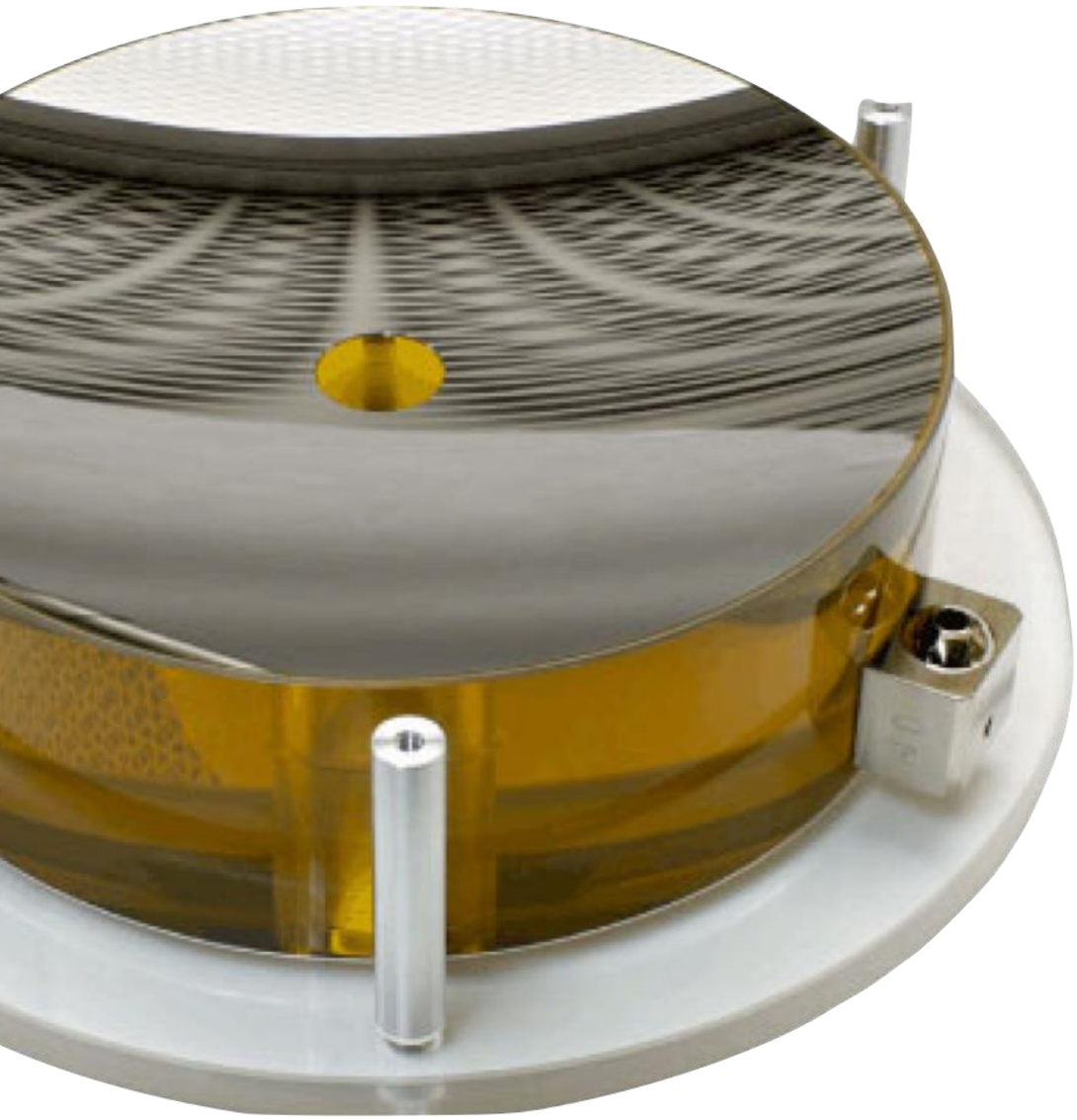
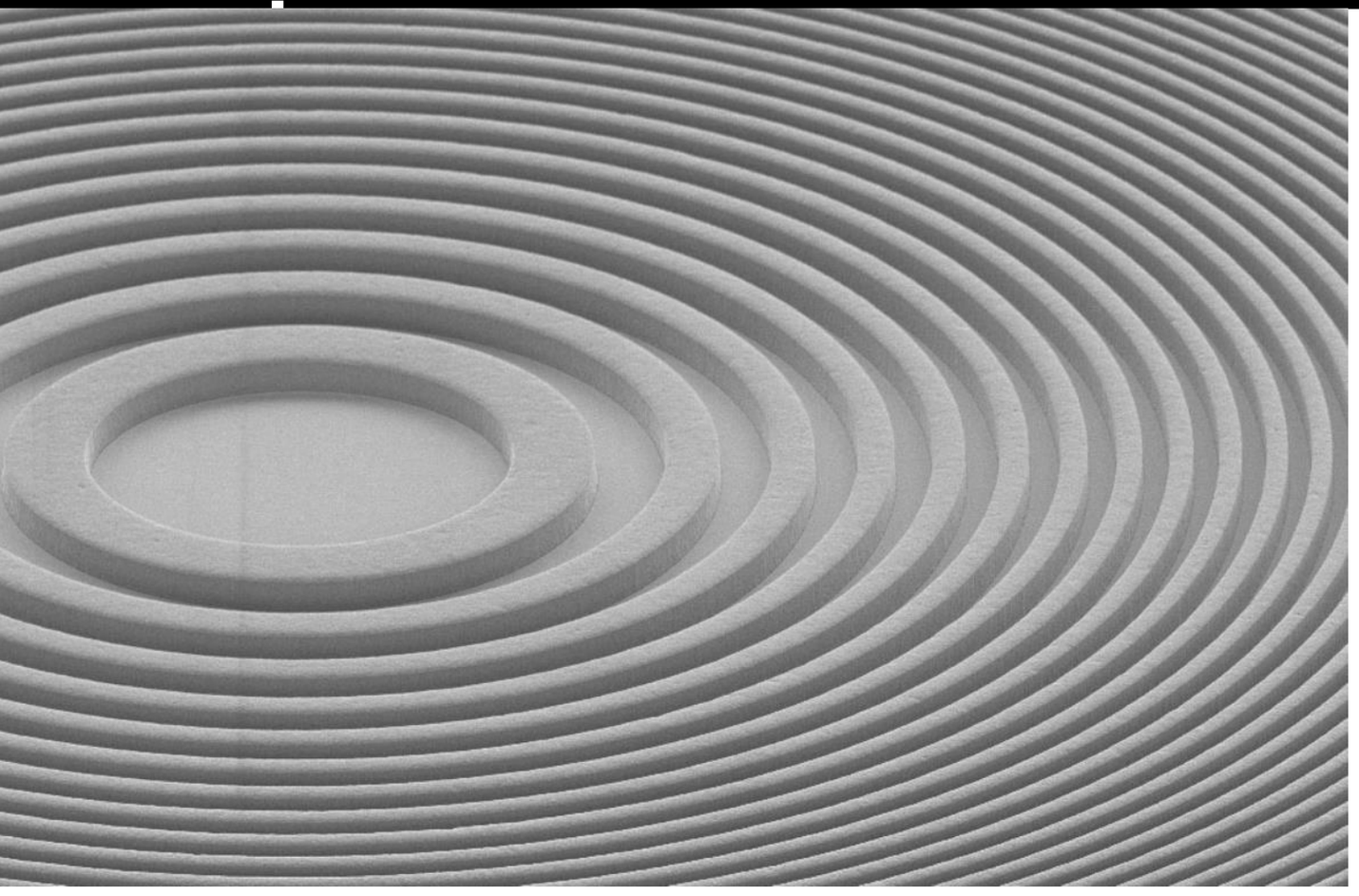


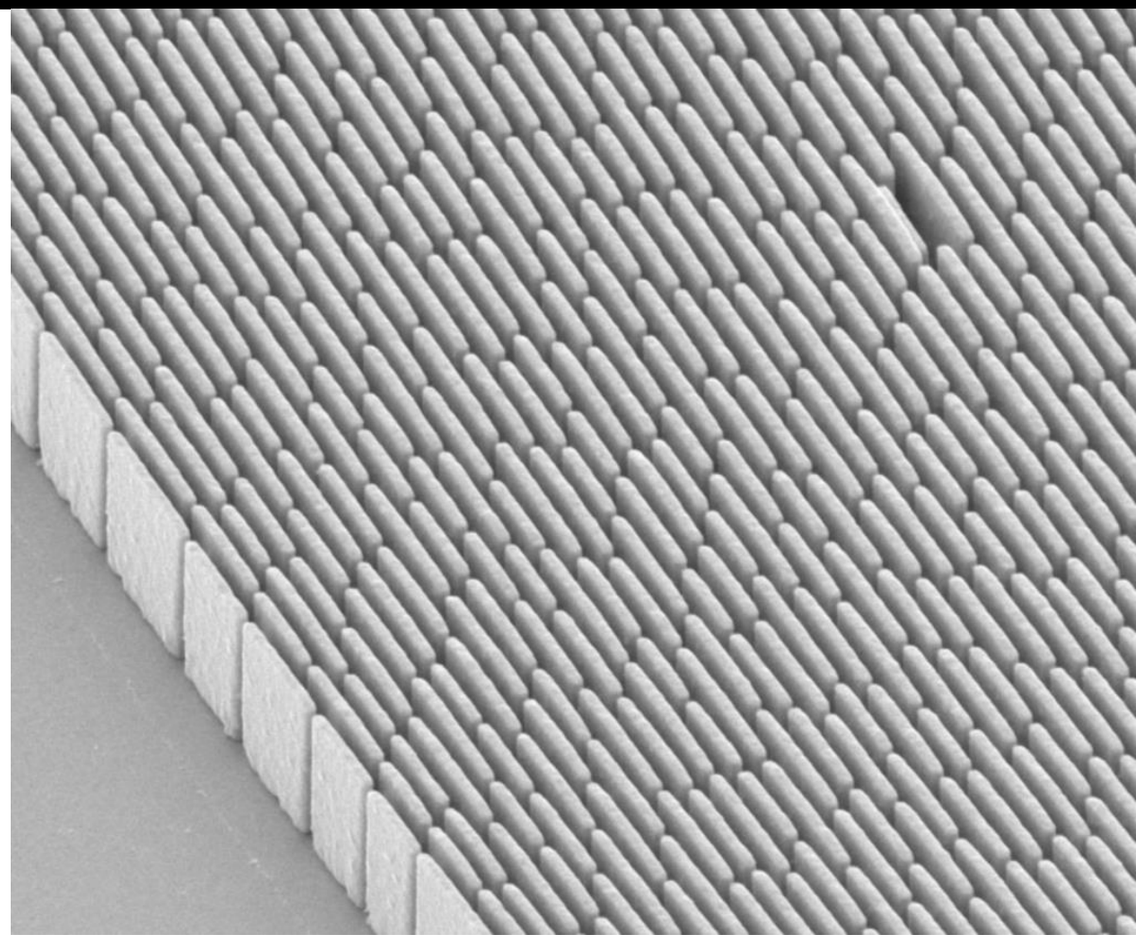
Reflective and diffractive



Reflective EUV optics driven by efficiency

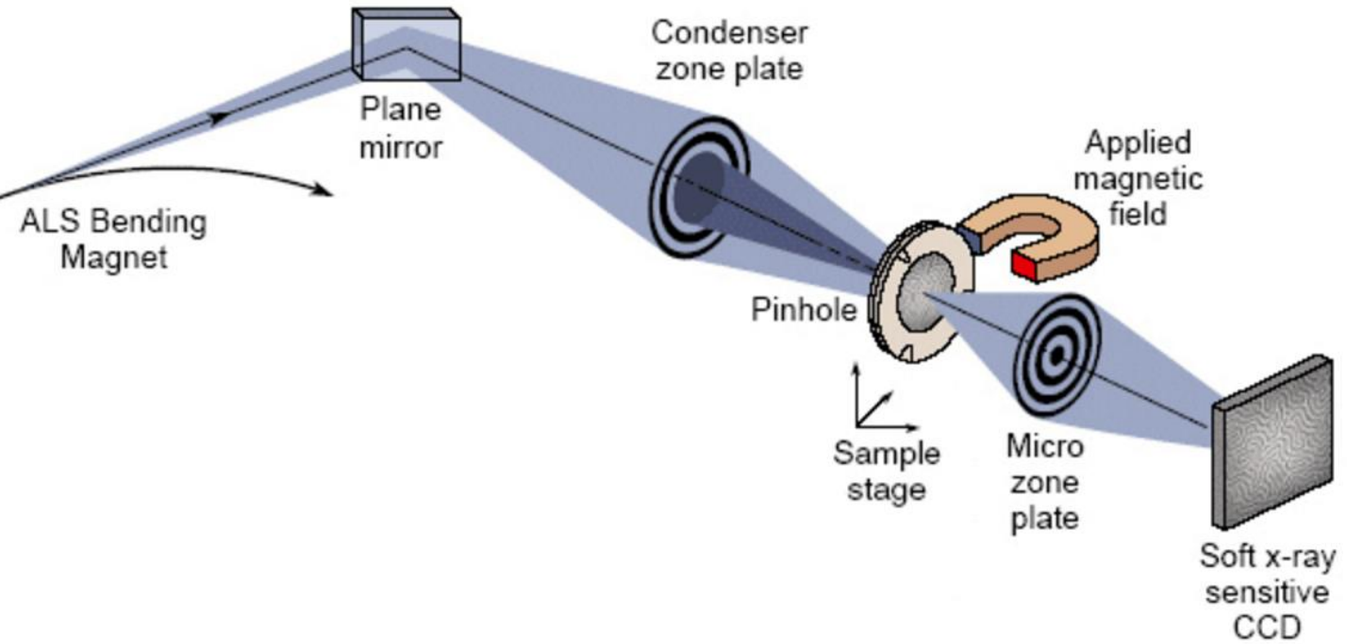
Reflective and diffractive

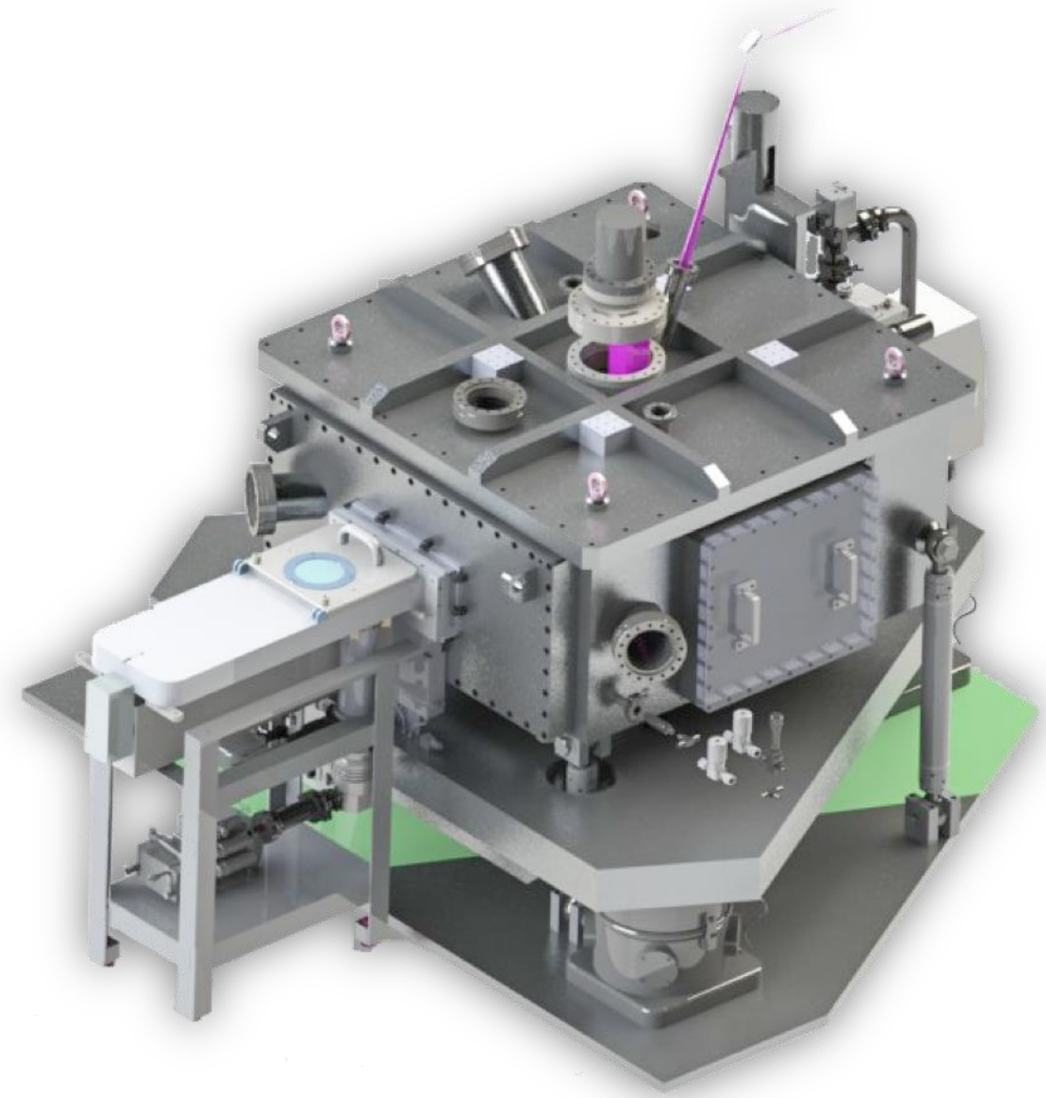




CXRO is a leading manufacturer of zone plates for x-ray and EUV regimes

Reflective and diffractive



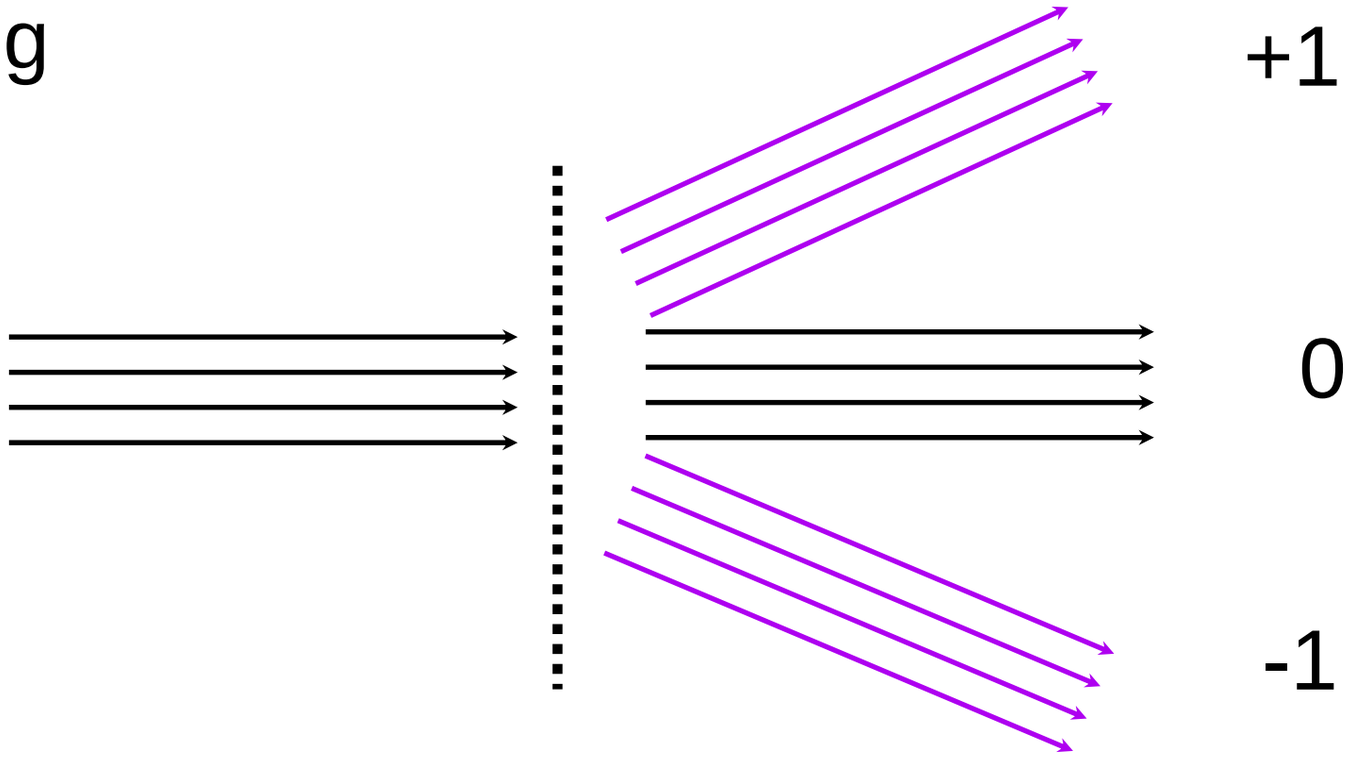


XM-1 soft x-ray microscope (BL 6.1.2)

SHARP EUV microscope (BL 11.3.2)

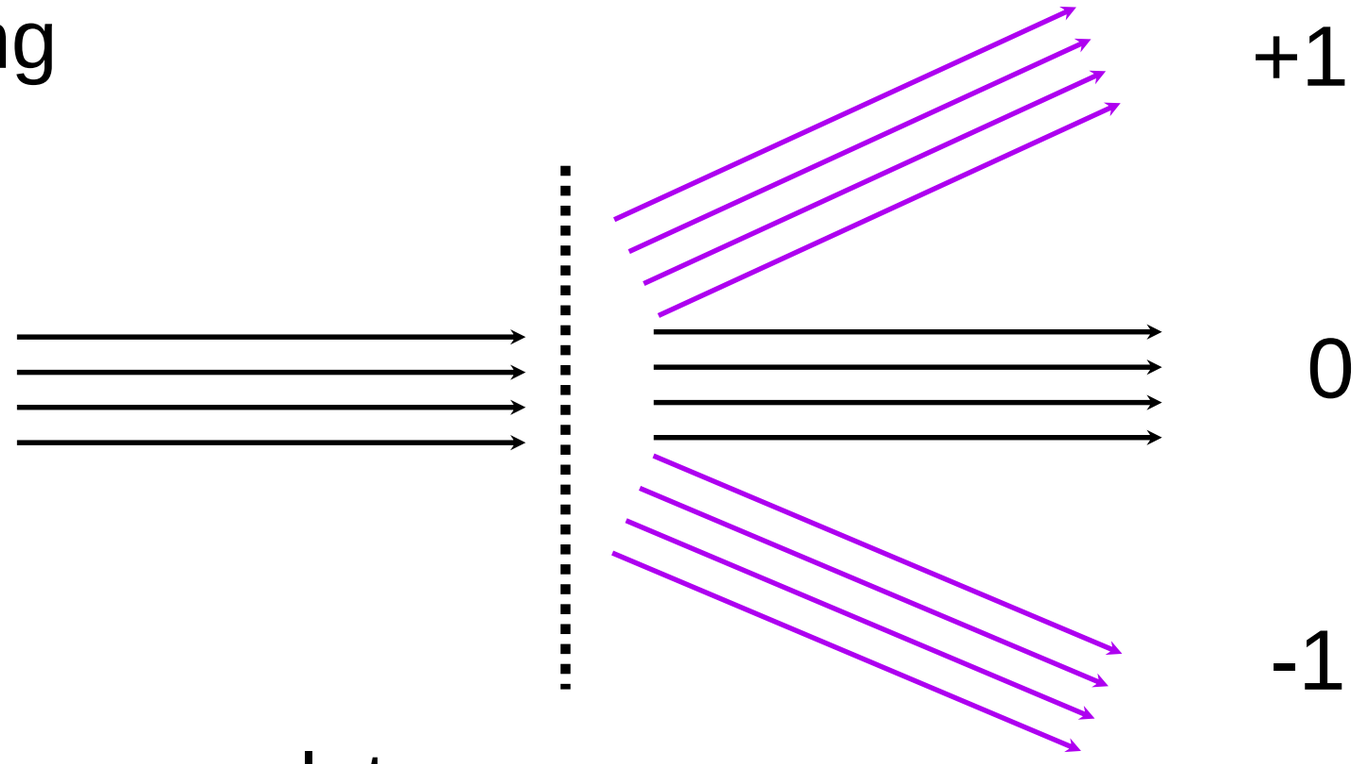
Zone plates

Diffraction grating

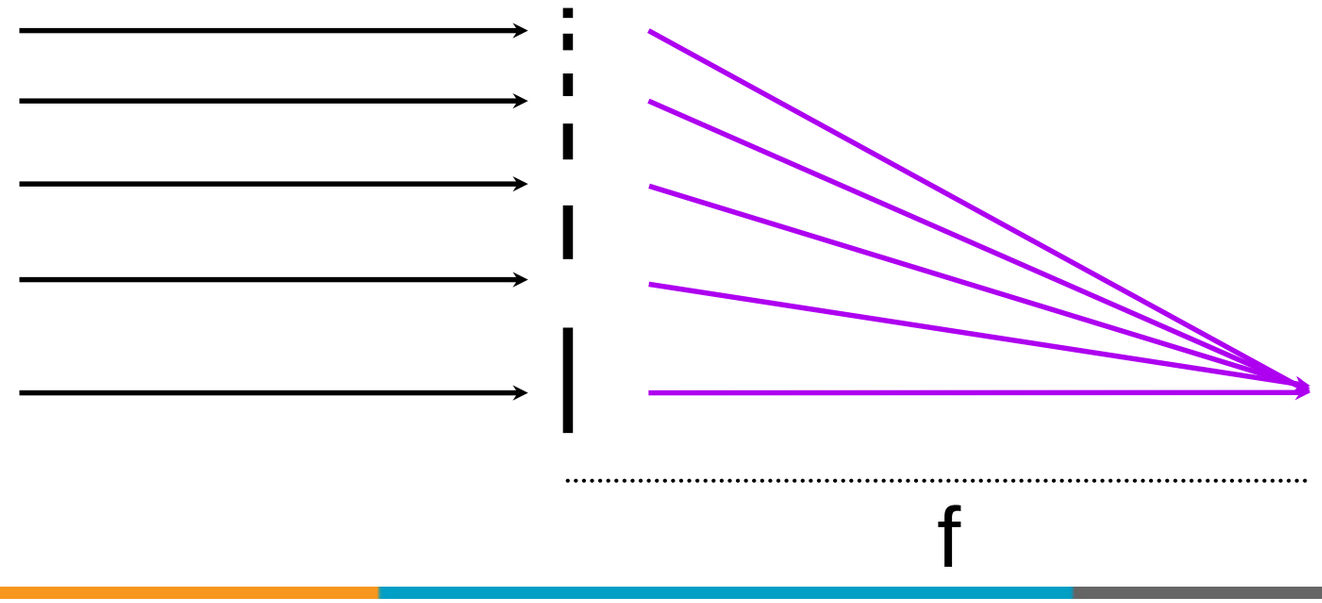


Zone plates

Diffraction grating

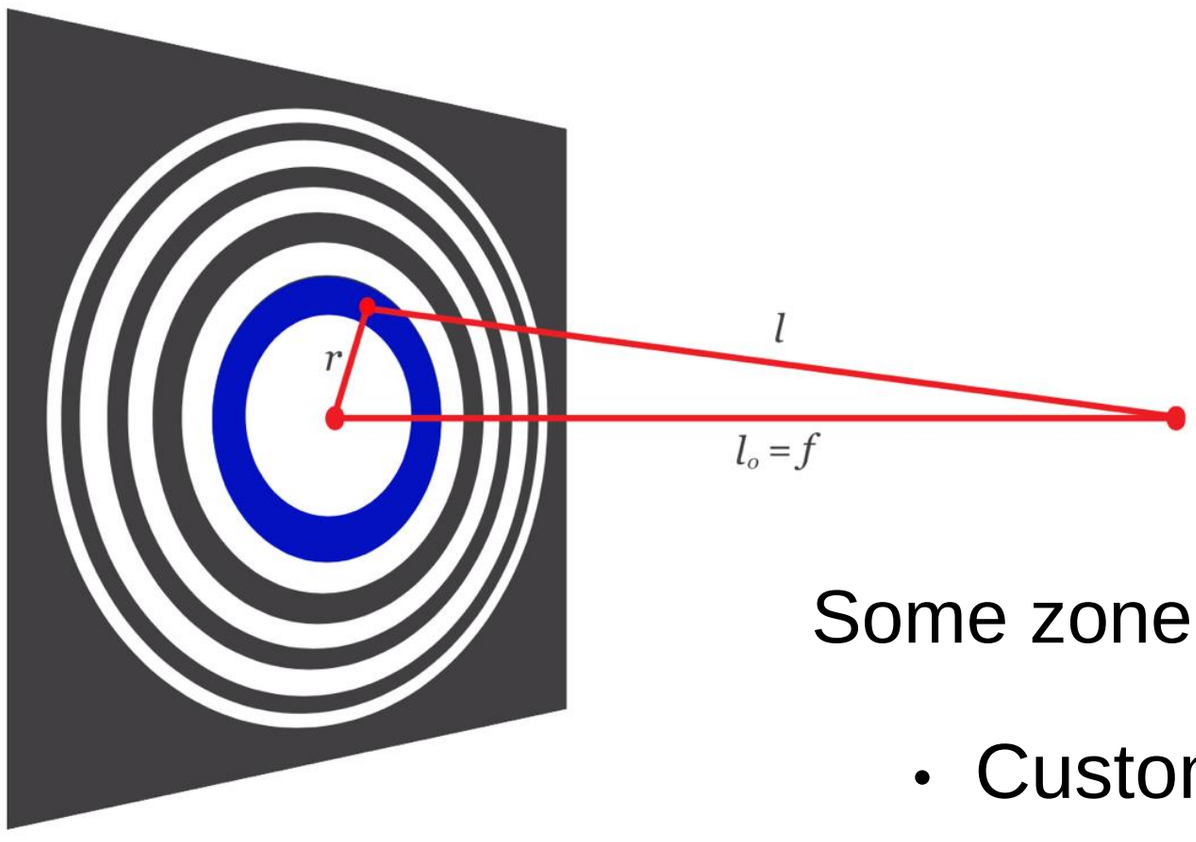


“Chirped” grating: zone plate



Zone plates

Zone plates: Customizable, diffractive lenses



Some zone plate properties:

- Customizable wavelength, size, and NA
- Resolution: $d_{min} \sim \Delta r$
- Bandwidth: $\lambda/\Delta\lambda = N$
- Efficiency: 10%

Design your own zone plate

THE CENTER FOR X-RAY OPTICS

zoneplate.lbl.gov

λ (μm)	Conjugates (μm)		Mag	NA (rad)		Res. (μm)		FOV		Zone plate (μm)				GDS
	o	i		o	i	o	i	∠ rad	μm	f	D	Δr	λ/Δλ	
0.010	6.667	20.00	3.0	0.1830	0.06193	0.033	0.10	0.026	0.17	5.00	2.482	0.020	30.60	Download

1. Wavelength

Wavelength (nm)

10 ✔

2. Conjugates

- ○ Image/object distances
- ◉ Magnification
- ○ Track length ($z_o + z_i$)

Magnification (abs. value)

3 ✔

3. Constraints

Specify ***two*** of the following. Your zone plate will appear above this form.

Resolution (nm) @

100 ✔ Image

Diameter (μm)

Bandwidth (λ/Δλ)

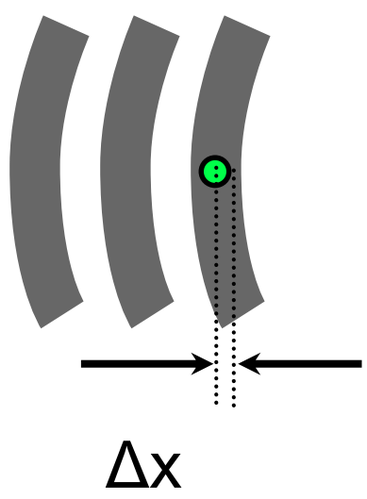
Focal length (μm)

5 ✔

Why zone plates?

Quality control

Zone plate

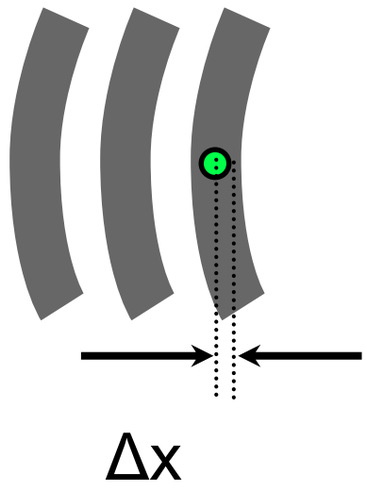


$$\Phi = 2\pi\Delta x/T$$

Phase errors set by
zone registration error

Quality control

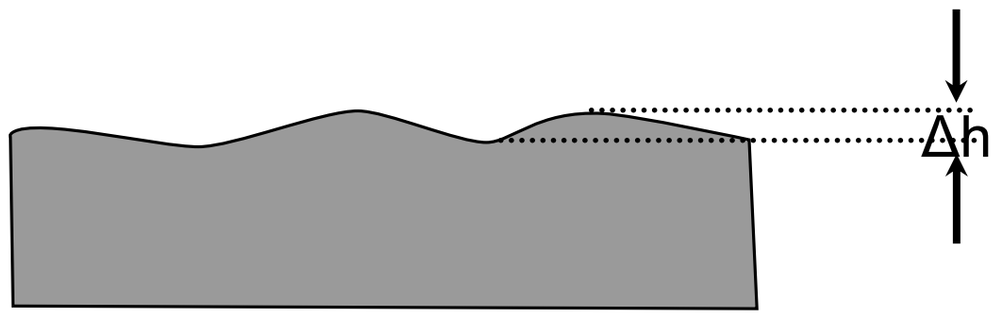
Zone plate



$$\Phi = 2\pi\Delta x/T$$

Phase errors set by
zone registration error

Mirror



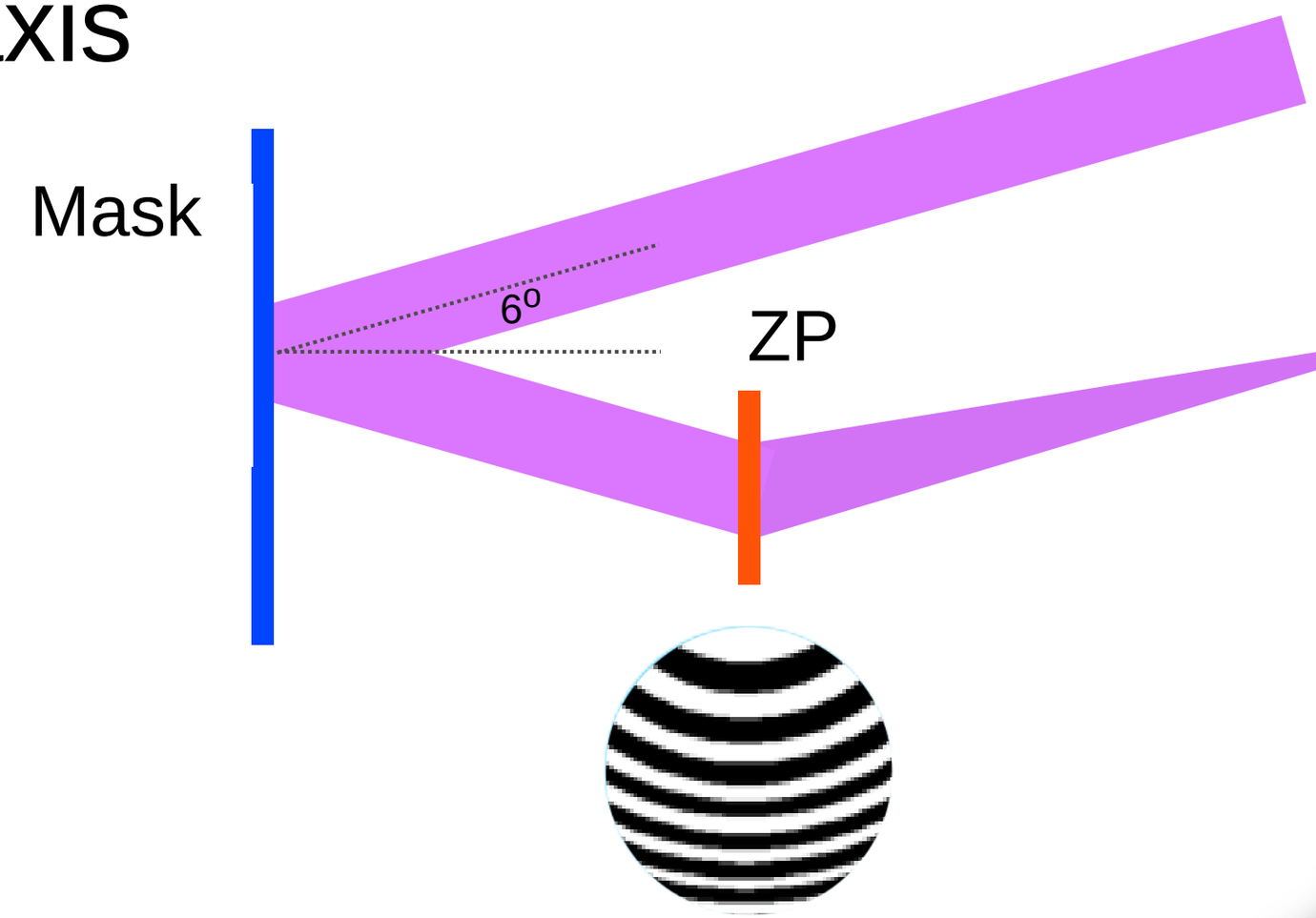
$$\Phi = 4\pi\Delta h/\lambda$$

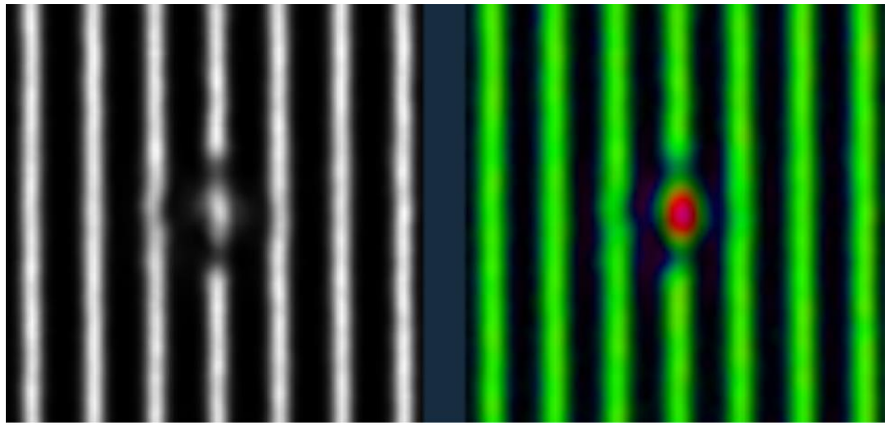
Phase errors surface height error

Customized geometries

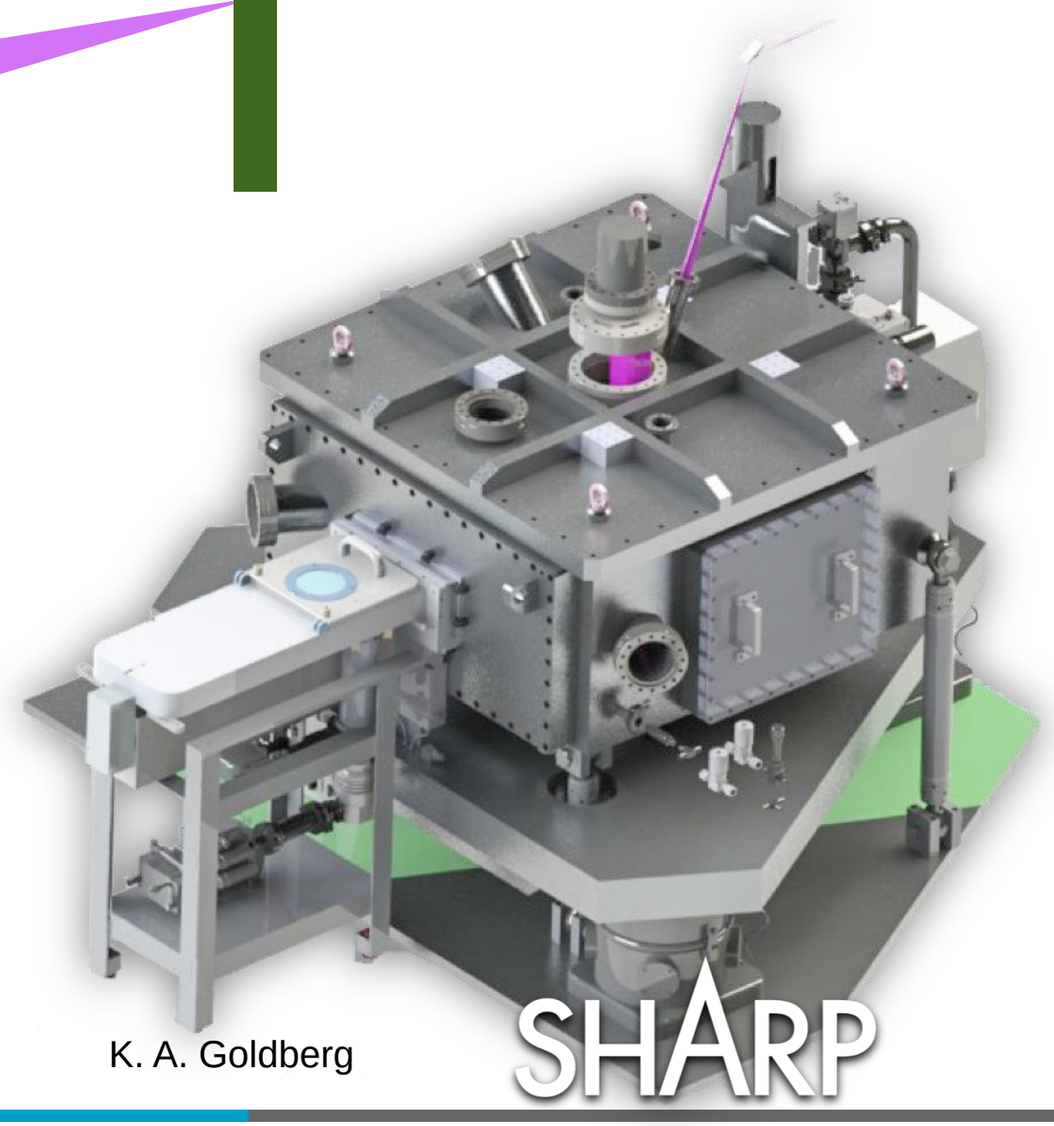
SHARP EUV defect review

Off-axis





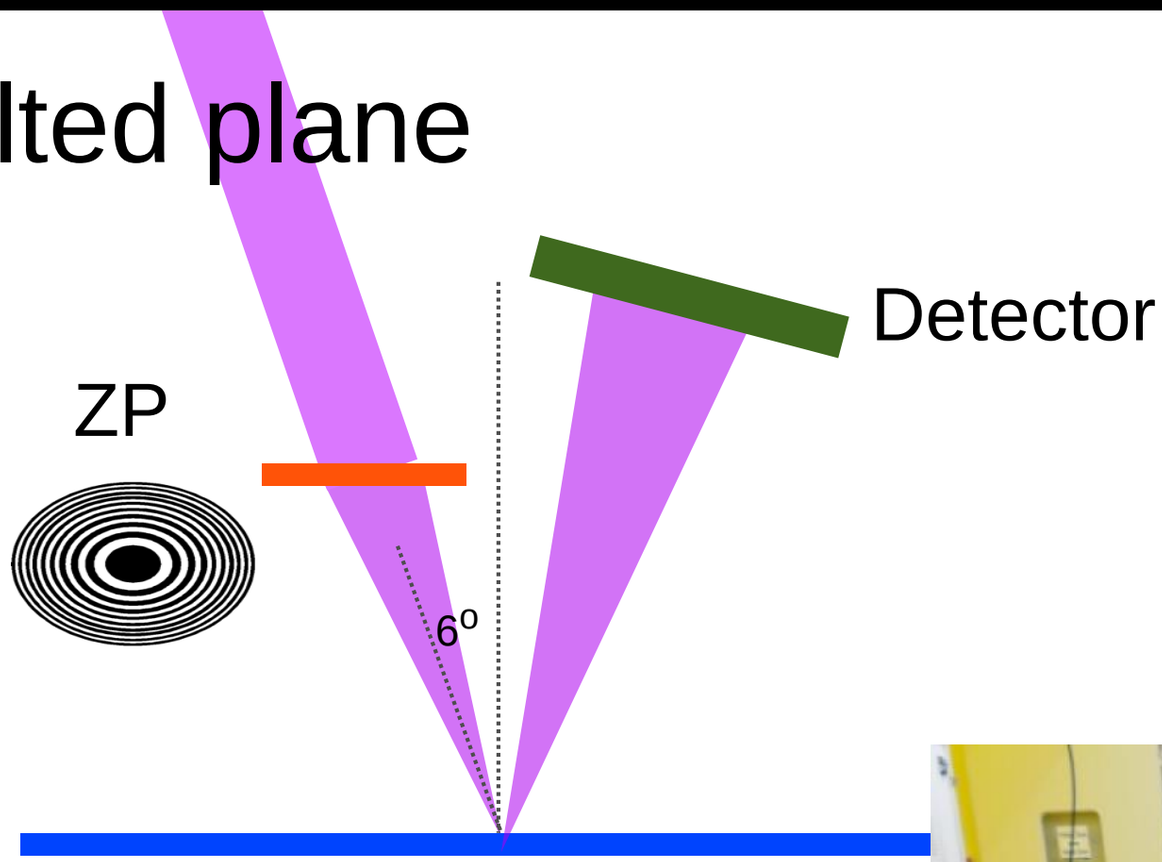
Defects in 200-nm lines

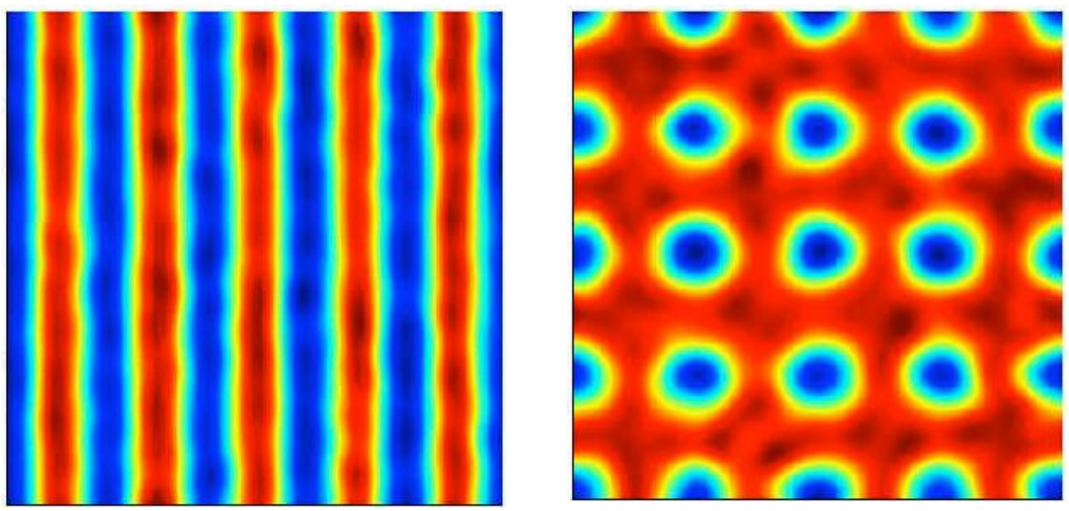


K. A. Goldberg

EMDRS EUV defect review

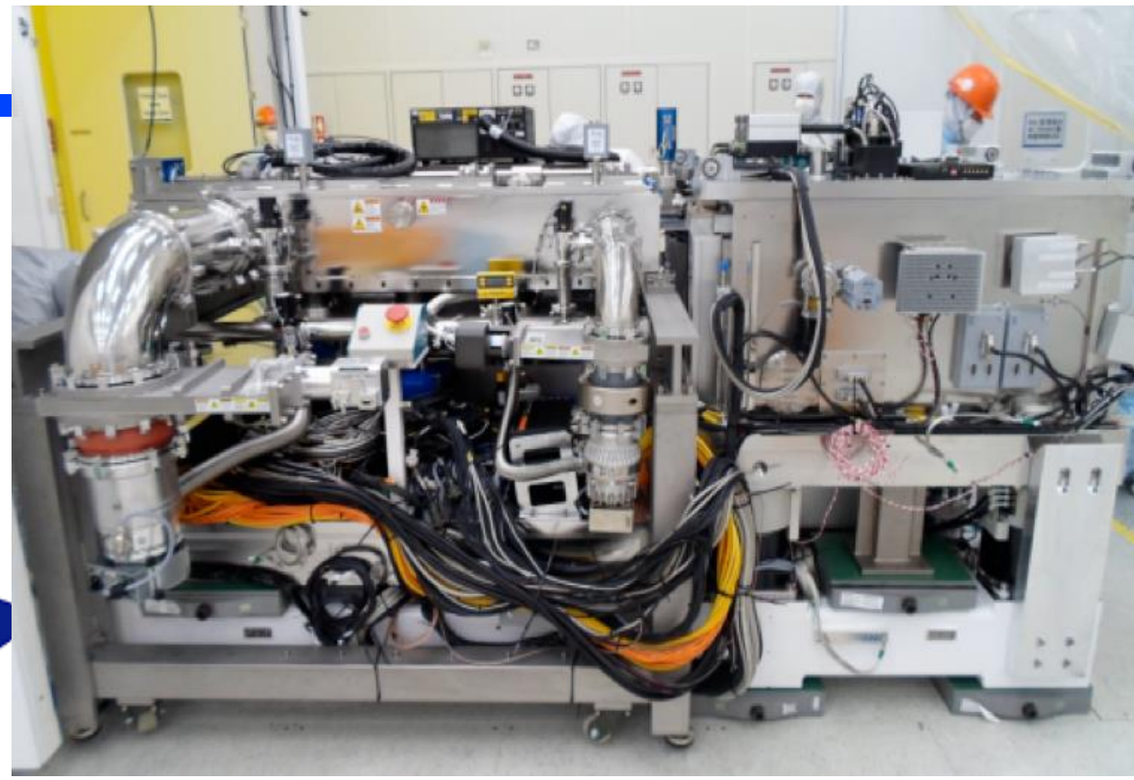
On-axis, tilted plane



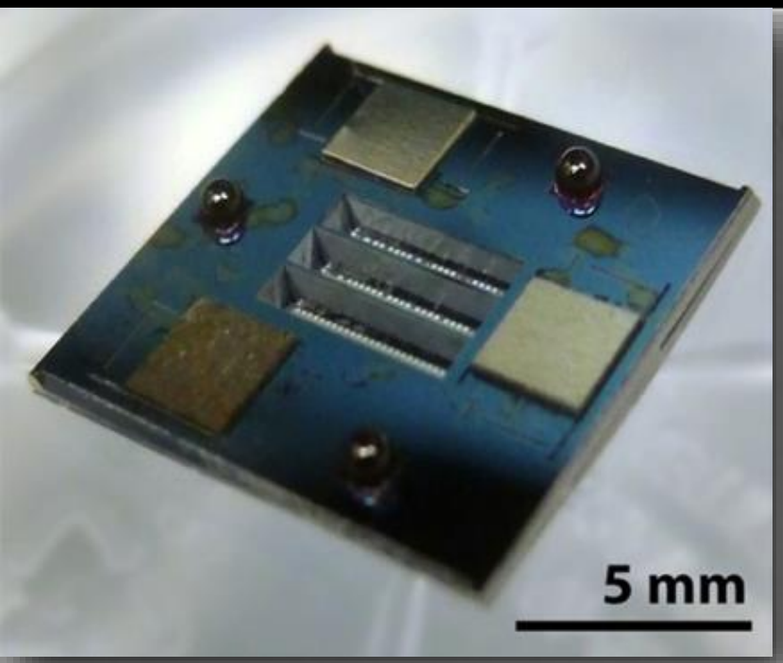


Aerial images of 16-nm lines and 22-nm contacts

SAMSUNG



Compact optics

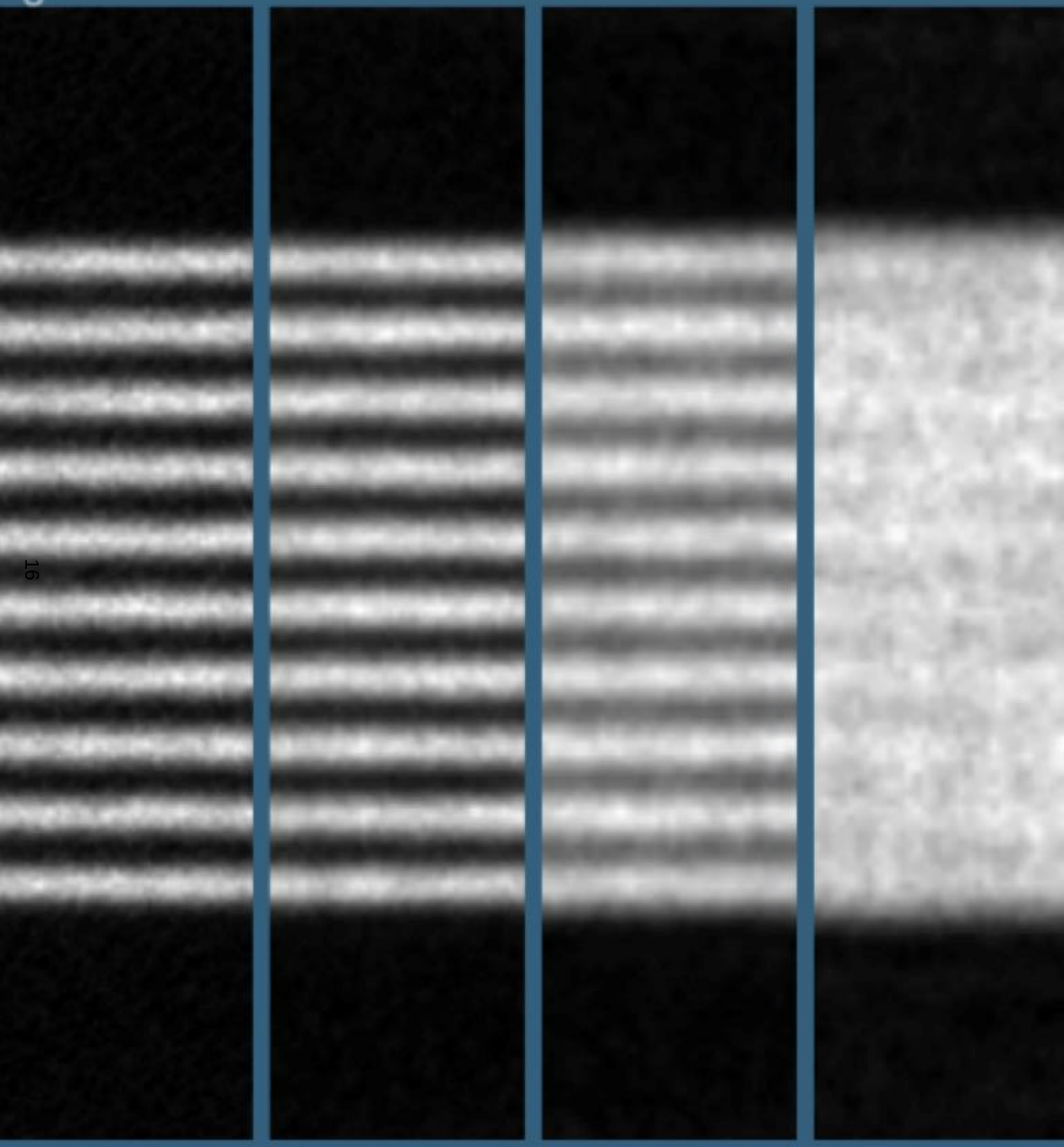


SHARP zone plate mask with
over 70 zone plates

SHARP

15.5

62



0.625

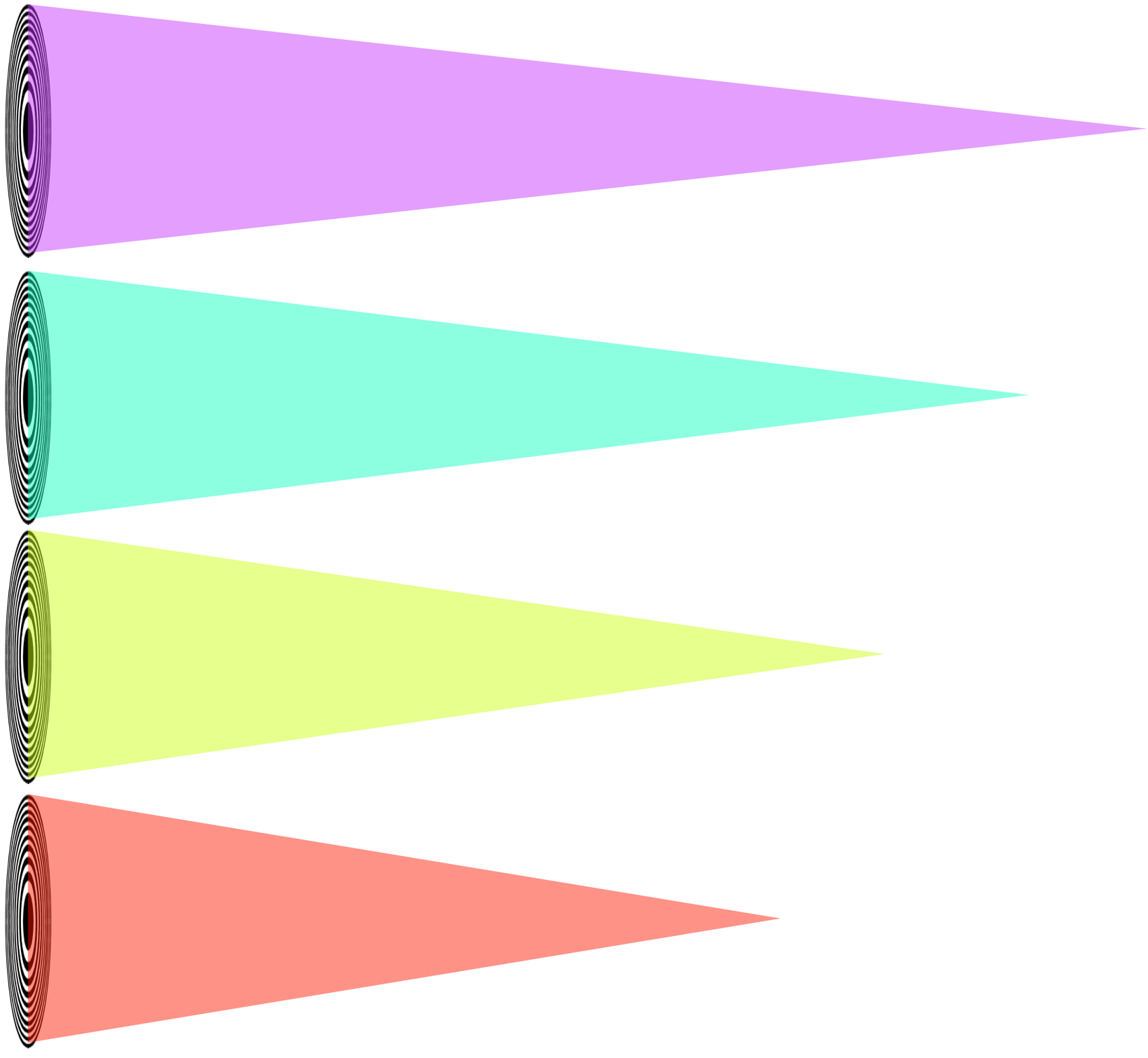
0.50

0.33

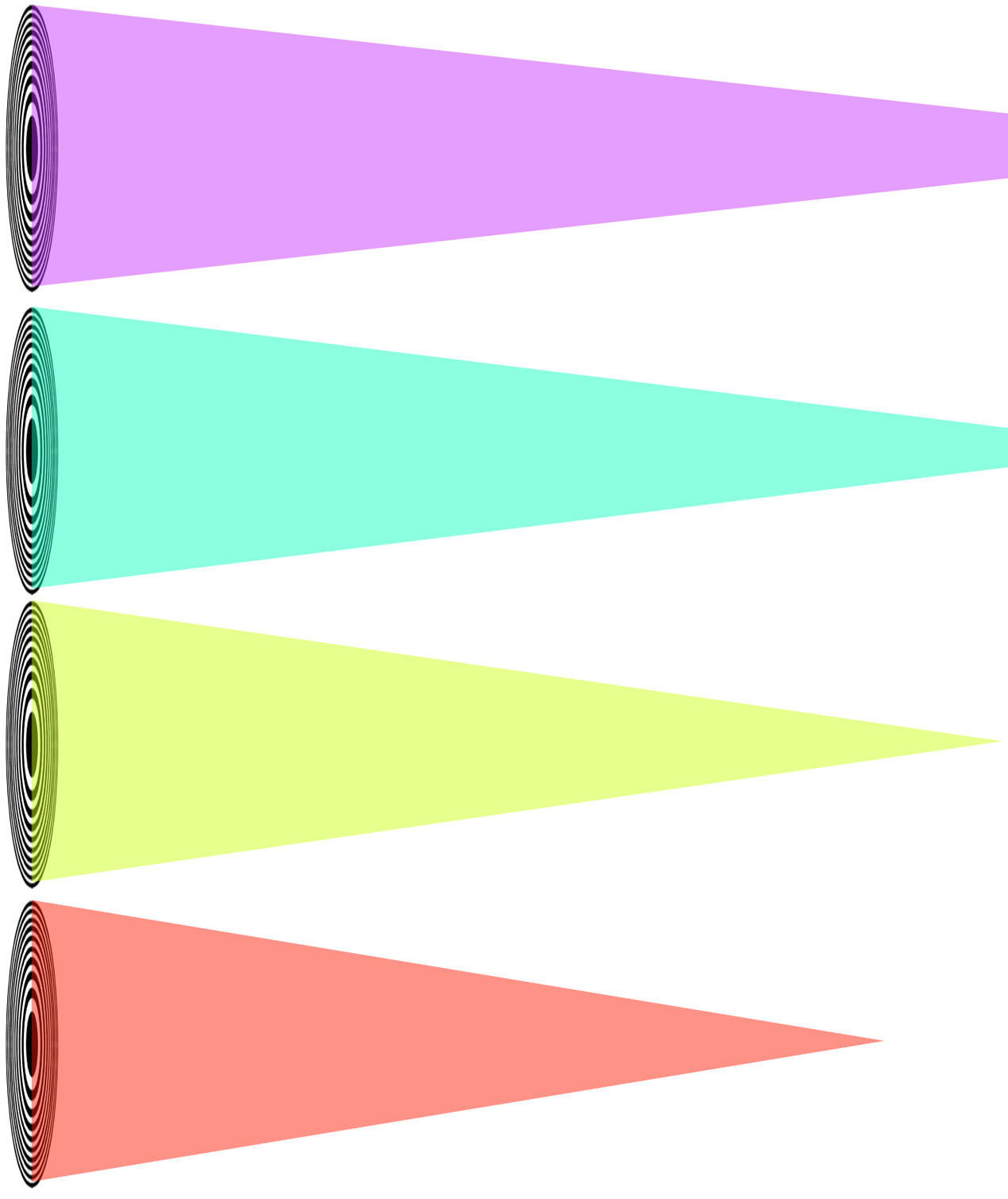
0.25

4xNA σ = 0.8

Operate at multiple wavelengths



Operate at multiple wavelengths



- Wafer inspection

- Beyond 13.5

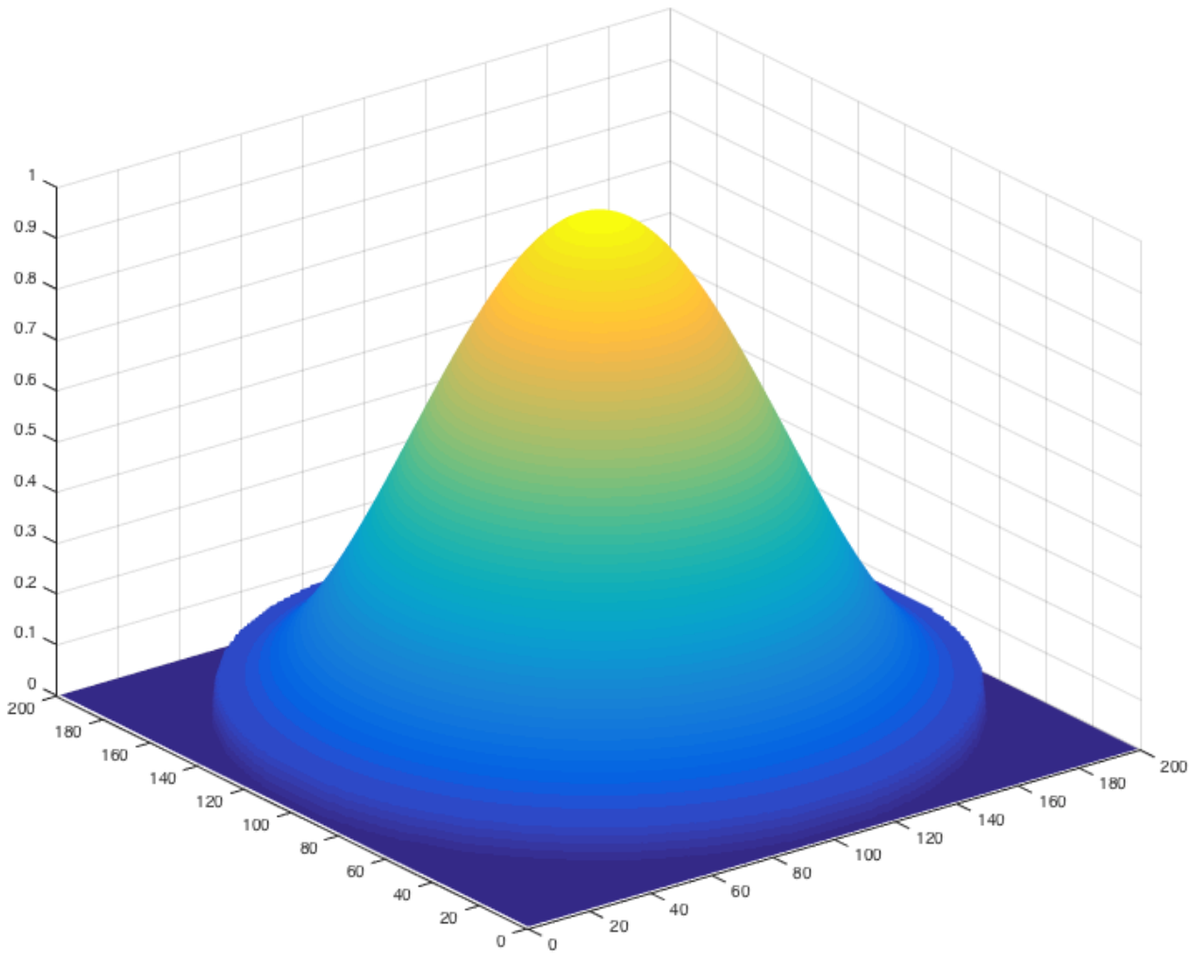
$$d_{\min} \geqq k_1 \frac{\lambda}{NA}$$

Customized pupil functions (amplitude and phase)

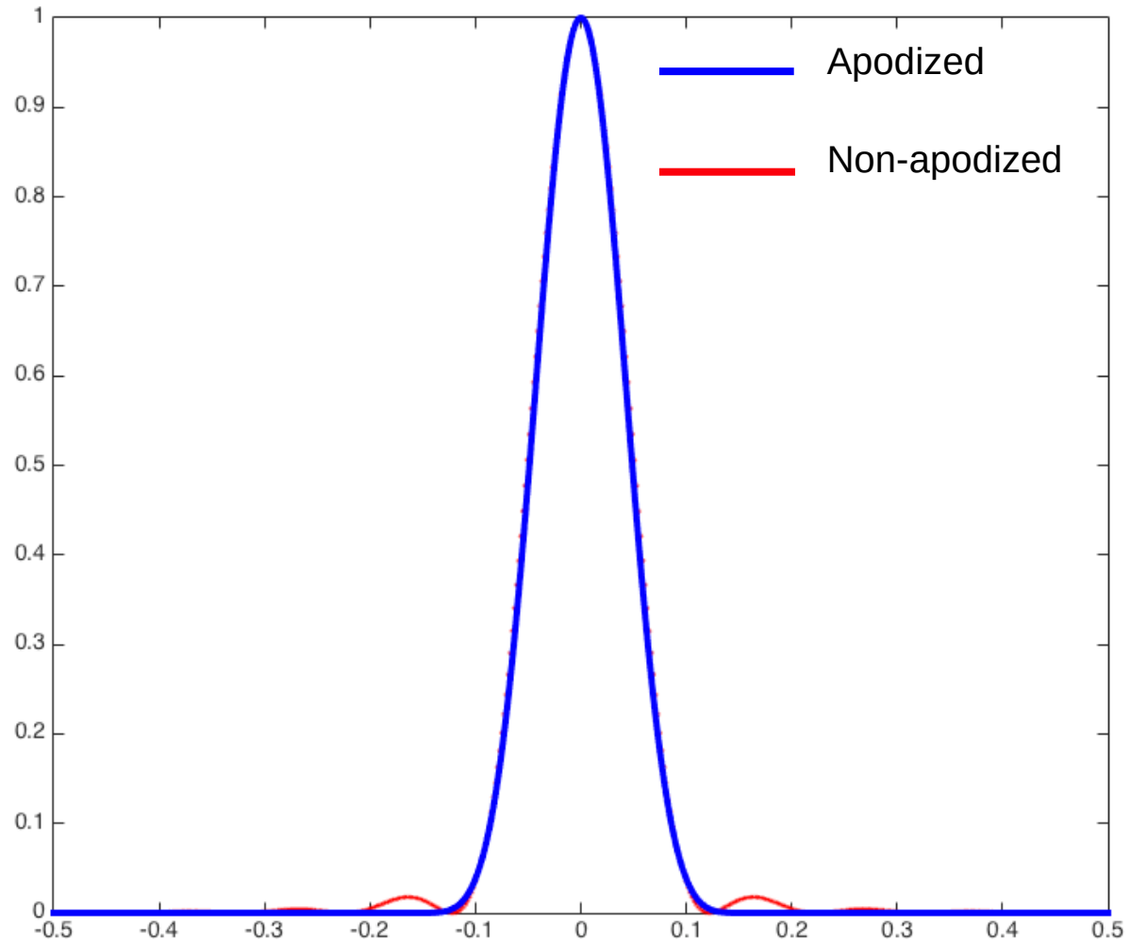
Hamming window apodization

Basic idea: Apodize zone plate pupil function with a window function to suppress PSF side lobes.

ZP apodization function



ZP Point spread function

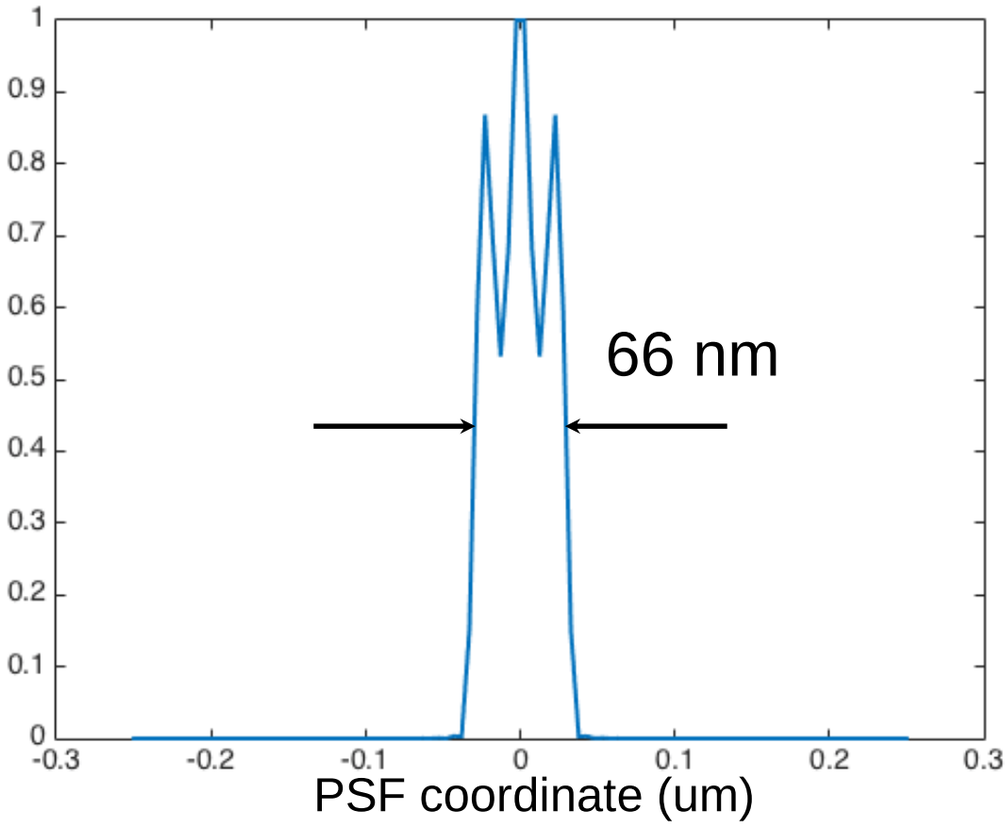


*Apodized ZP is 45% larger than non-apodized ZP

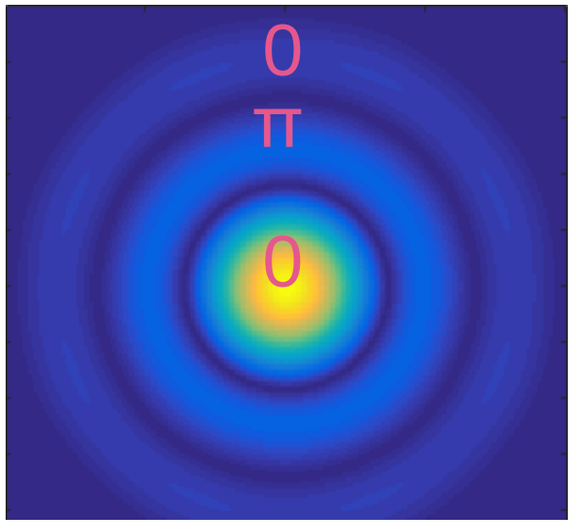
STXM/Ptychography

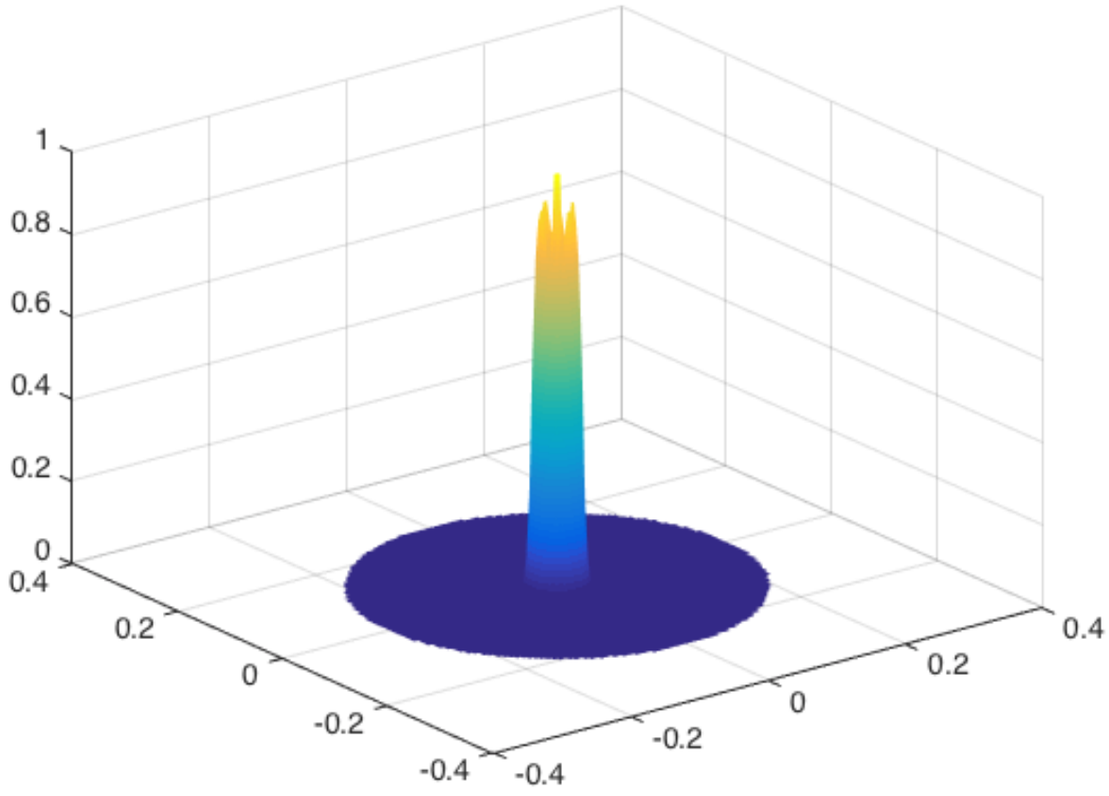
Bessel ZP 66-nm PSF

λ = 5 nm
f = 2 mm
NA = 0.122

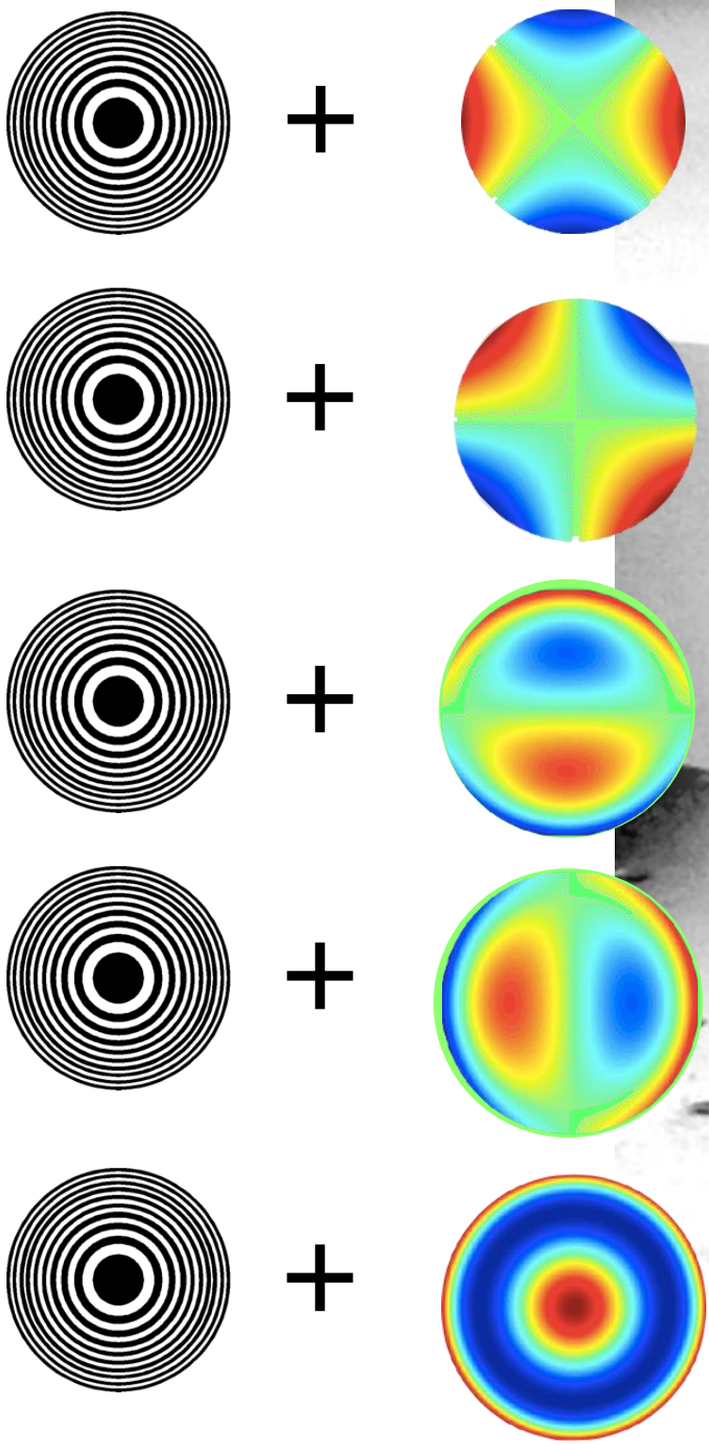


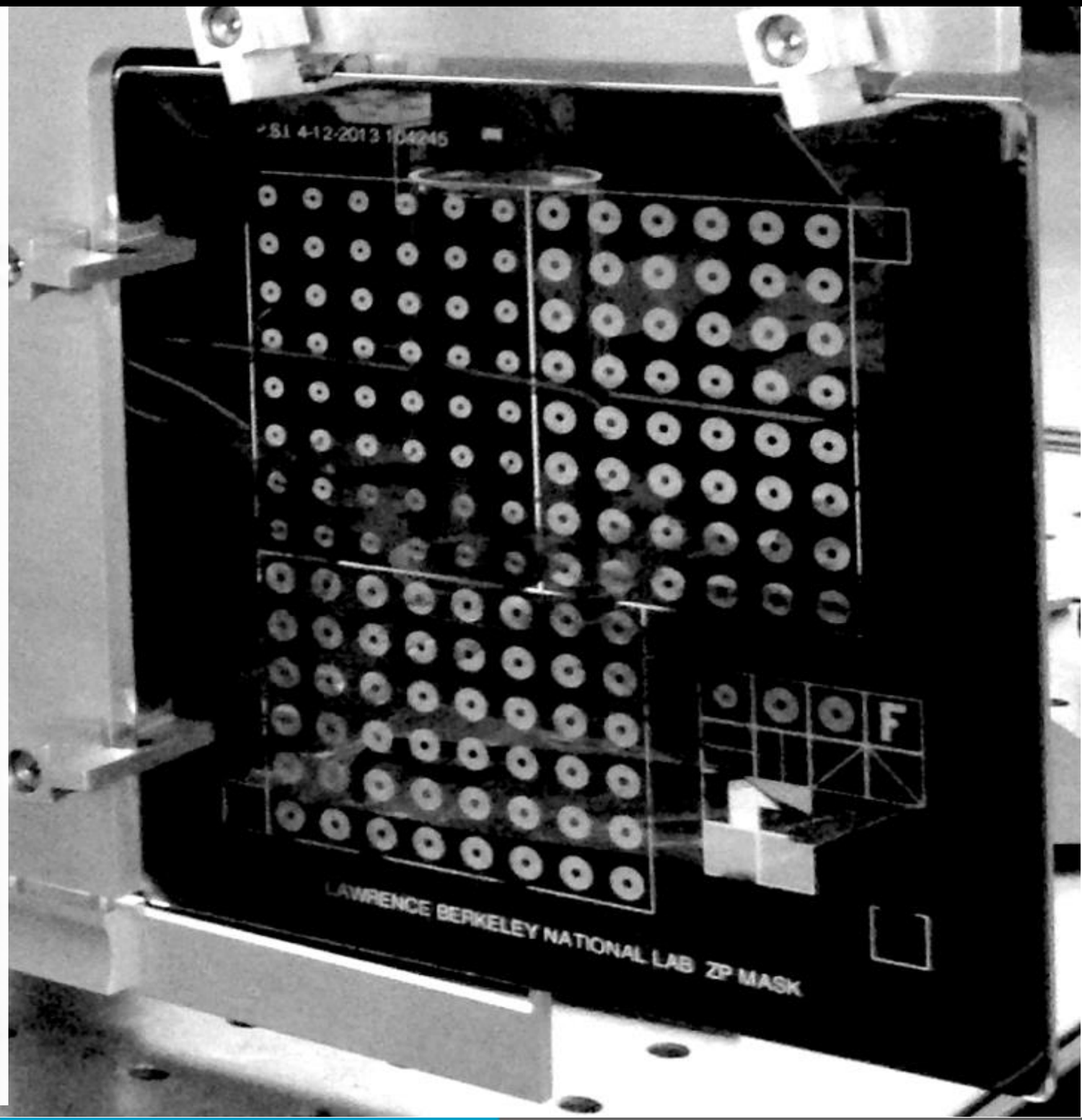
ZP Pupil



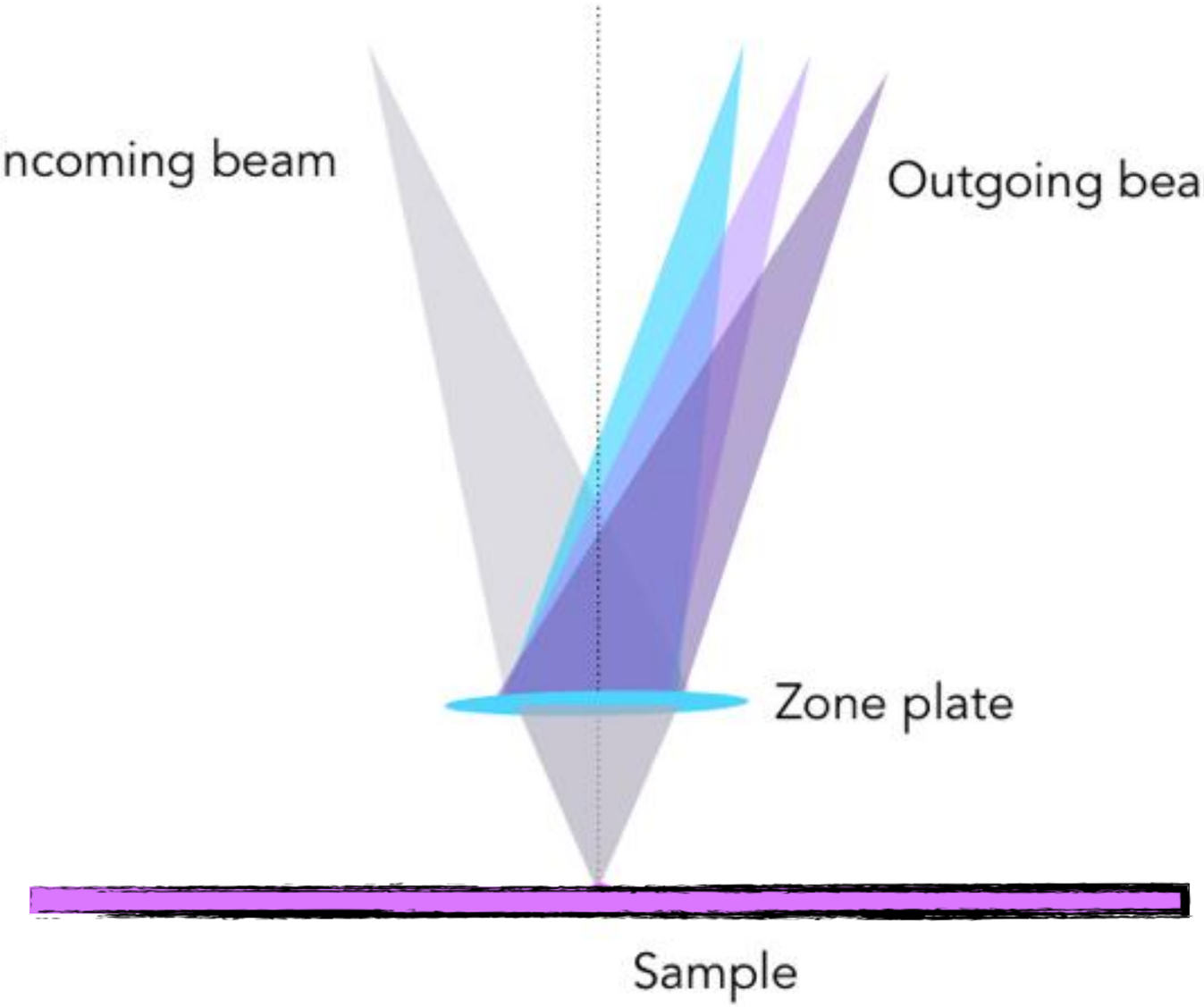


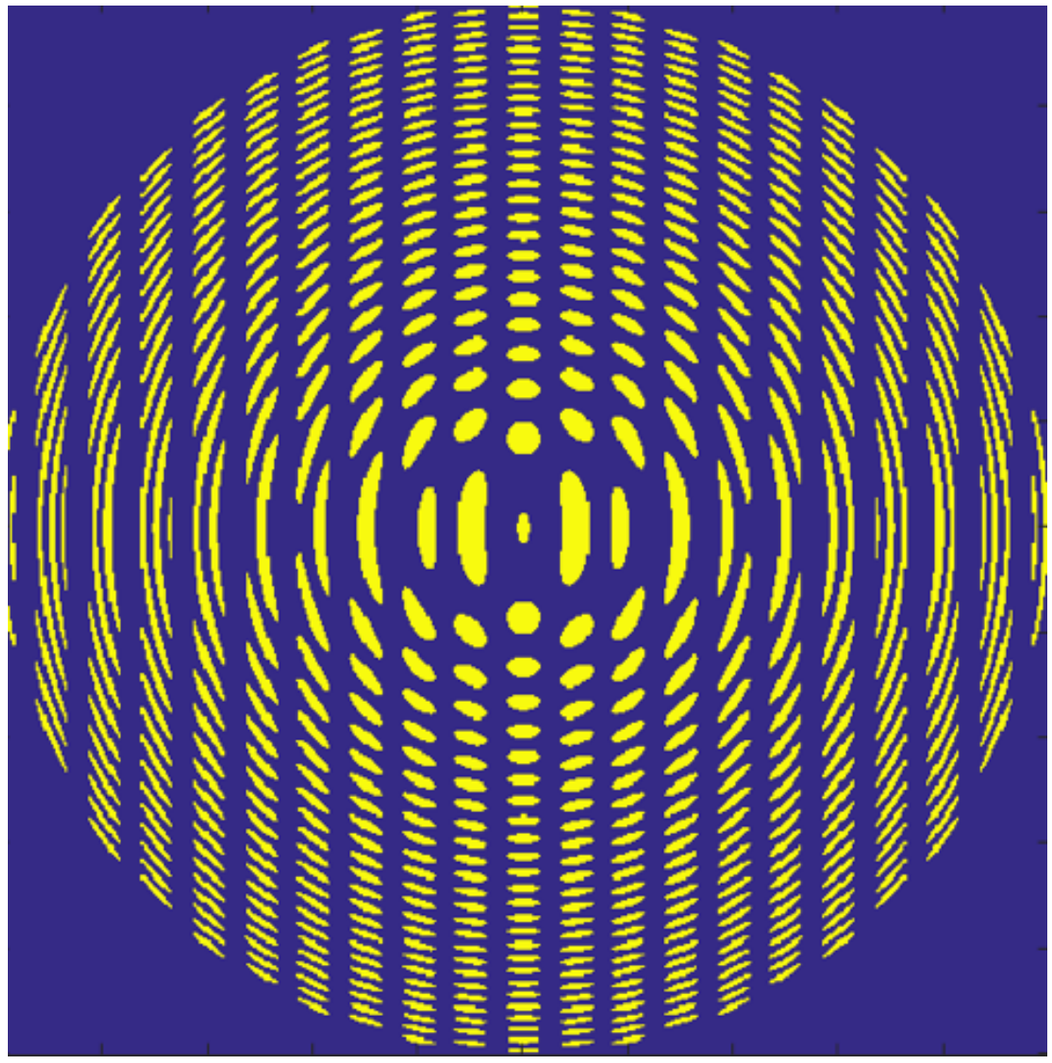
AIS Wavefront sensor





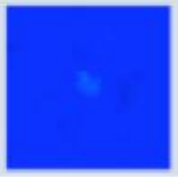
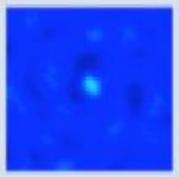
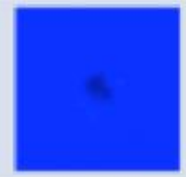
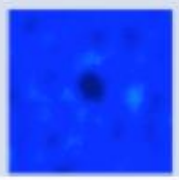
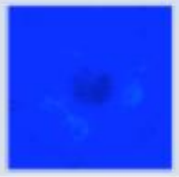
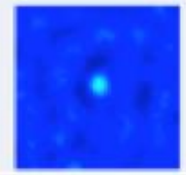
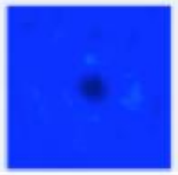
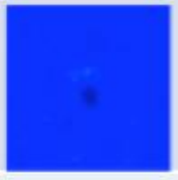
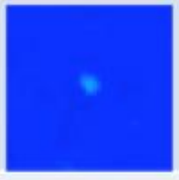
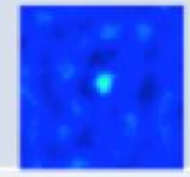
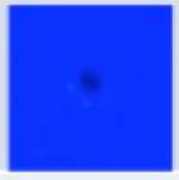
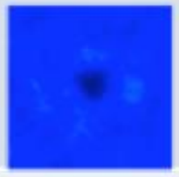
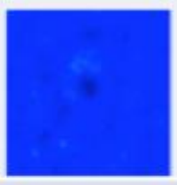
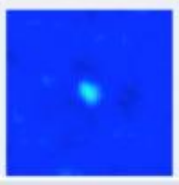
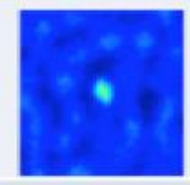
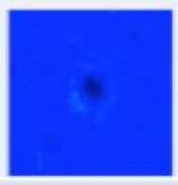
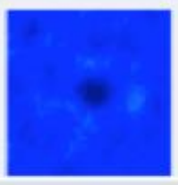
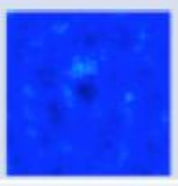
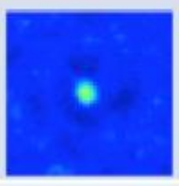
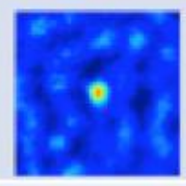
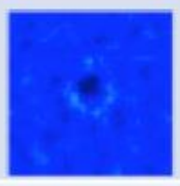
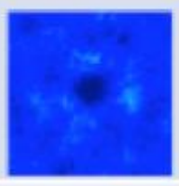
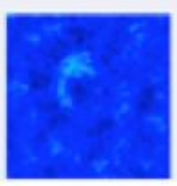
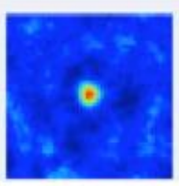
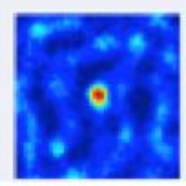
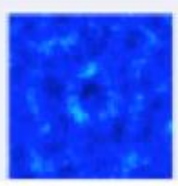
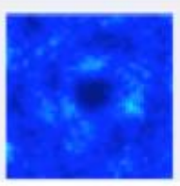
RIXS zone plate





Phase contrast imaging for defect inspection

Henry Wang

Method \ Defocus	-4 um	-2 um	0 um	+2 um	+4 um
0°/100%					
90°/100%					
90°/69%					
90°/41%					
90°/20%					
90°/8%					

Phase contrast imaging for defect inspection

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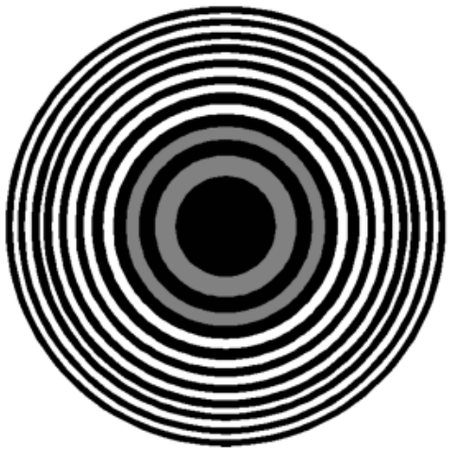
Henry Wang

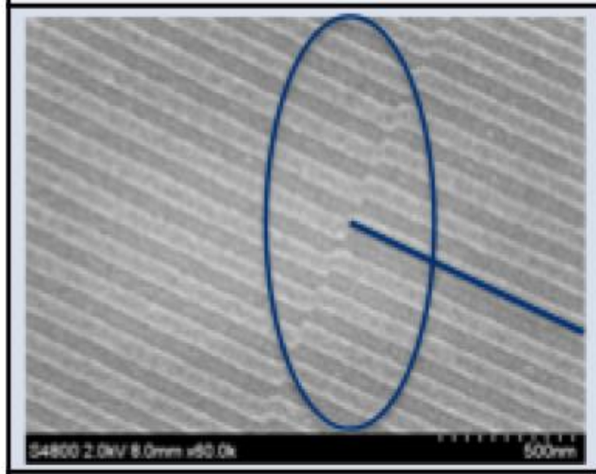
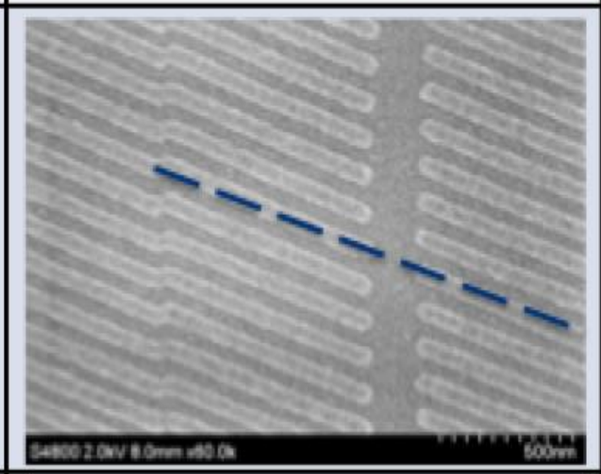
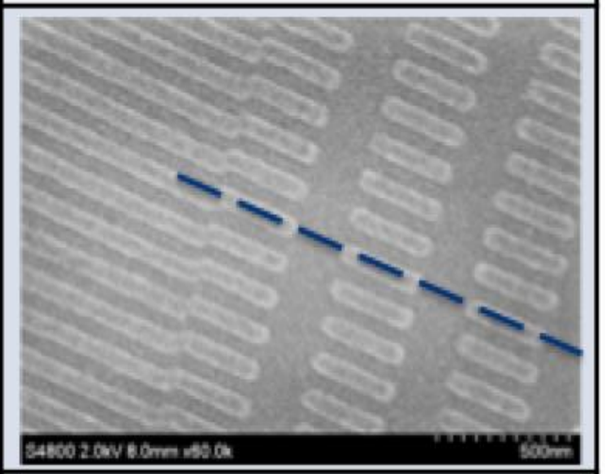
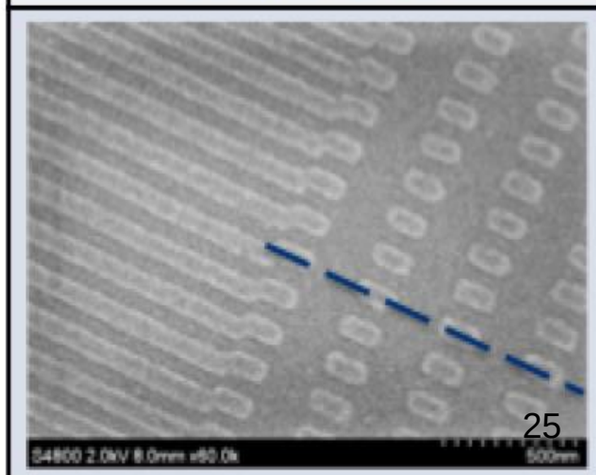
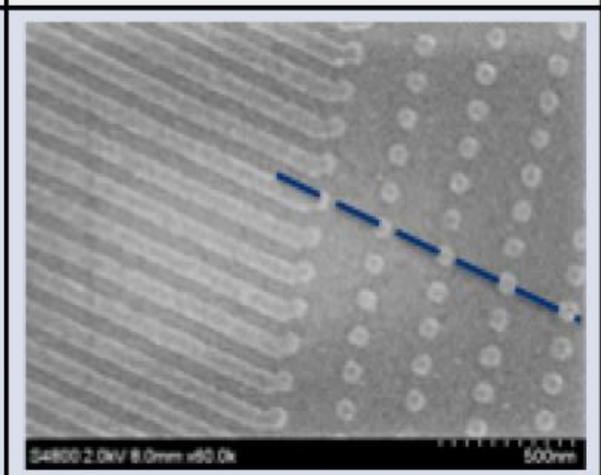
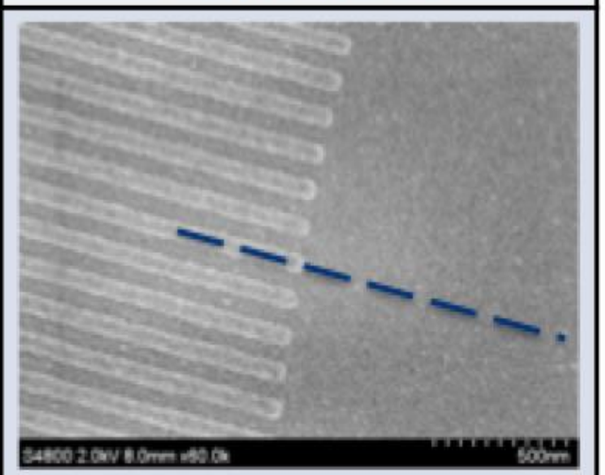
Phase contrast

Centrally apodized



PC + apodization

Custom ZPC pupil function encoded in zone plates

90°/ 100%	90°/ 69%	90°/ 41%
		
90°/ 20%	**90°/ 8%**	**Dark field**
		

EUV phase zone plates

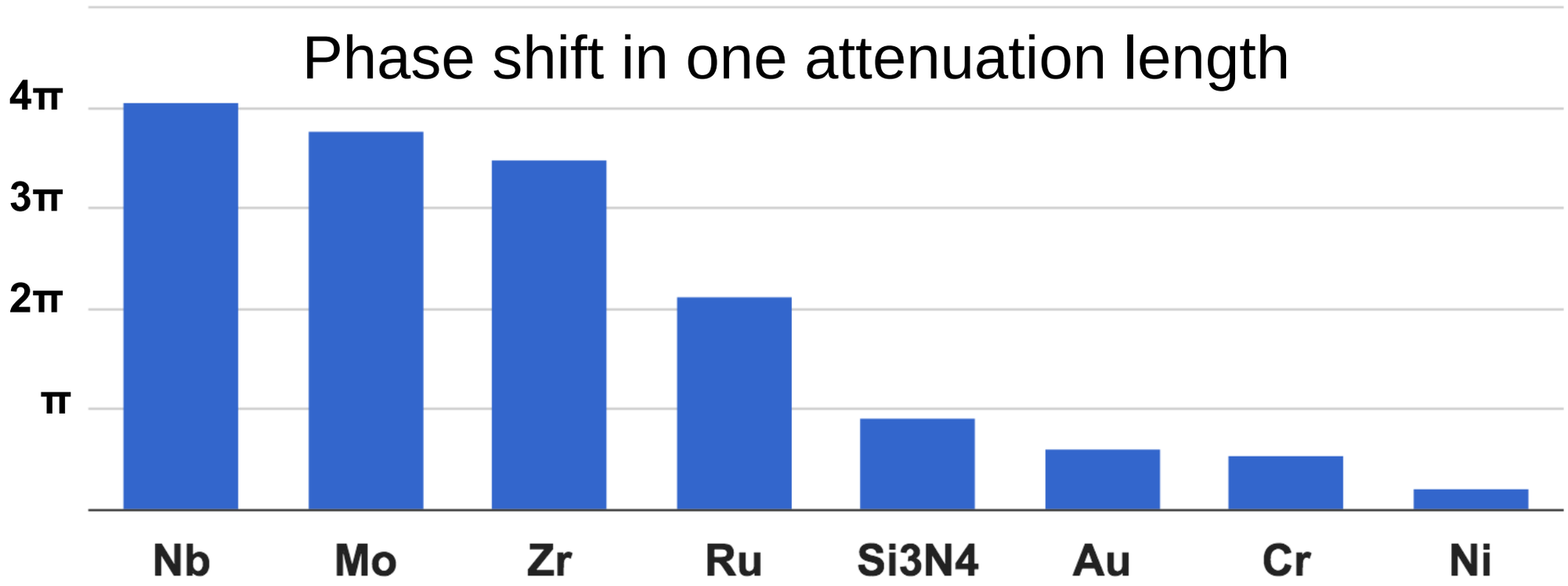
Normal amplitude zone plates have 10% efficiency...

Can increase efficiency using phase-shifting materials

$$n = 1 - \delta + i\beta$$

phase shift

absorption



EUV phase zone plates

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Material	Thickness for π phase shift	ZP Efficiency
Mo	89 nm	32%
Ru	59 nm	27%
Si_3N_4	251 nm	17%
Ni	130 nm	10%

Zone plate optics

- Quality control is easier (registration vs. polishing)
- Fully customizable pupil function and operating geometry
- Fabrication is quick and inexpensive
- Compact
- Can operate at multiple wavelengths
- Phase materials can increase ZP efficiency