Latest Results from the SEMATECH Berkeley Actinic Inspection Tool

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[b]SEMATECH

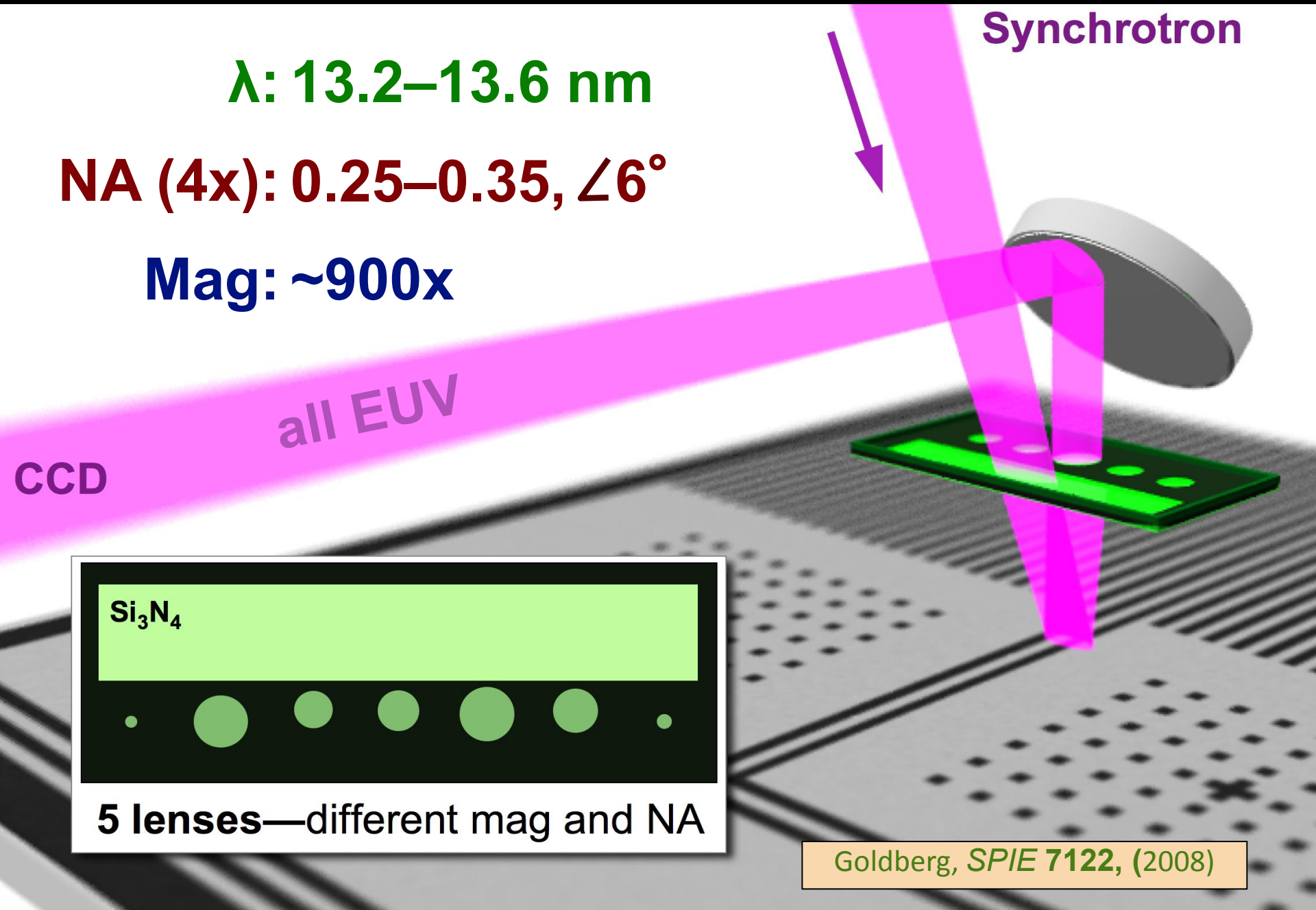
2010 – 2011

AIT upgrades

New experimental results

Beyond the AIT:
the SHARP microscope

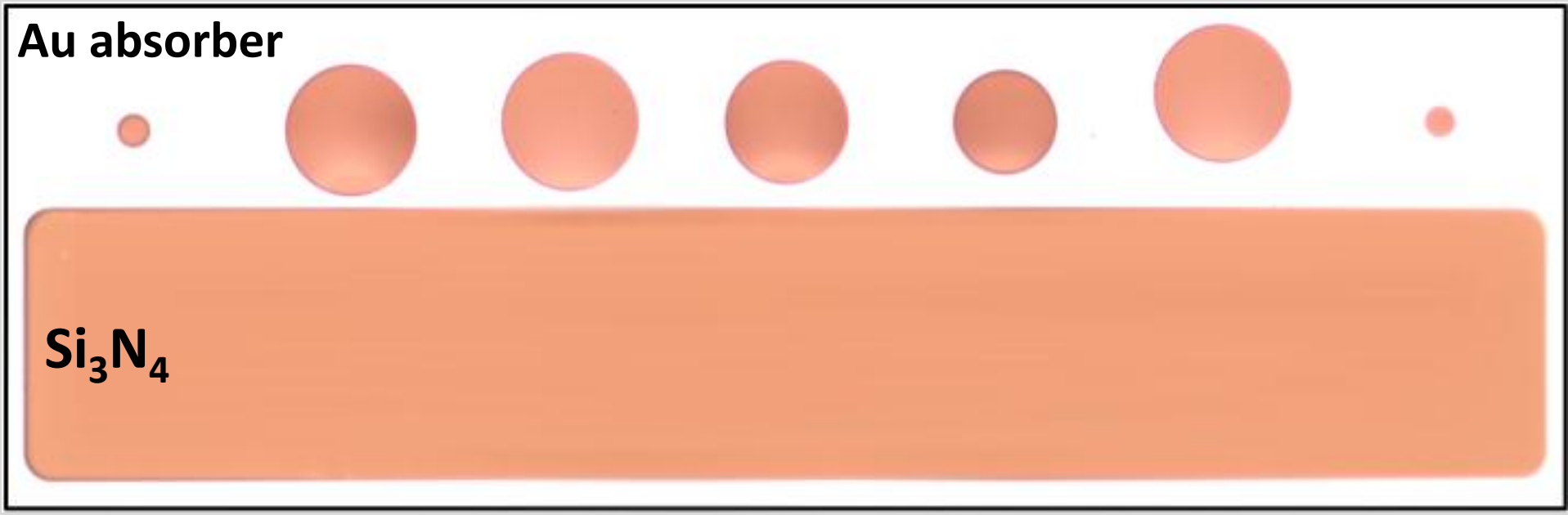
The SEMATECH Berkeley Actinic Inspection Tool (AIT)



Goldberg, *SPIE* **7122,** (2008)

Pre-2011 zoneplate array with Si_3N_4 membrane

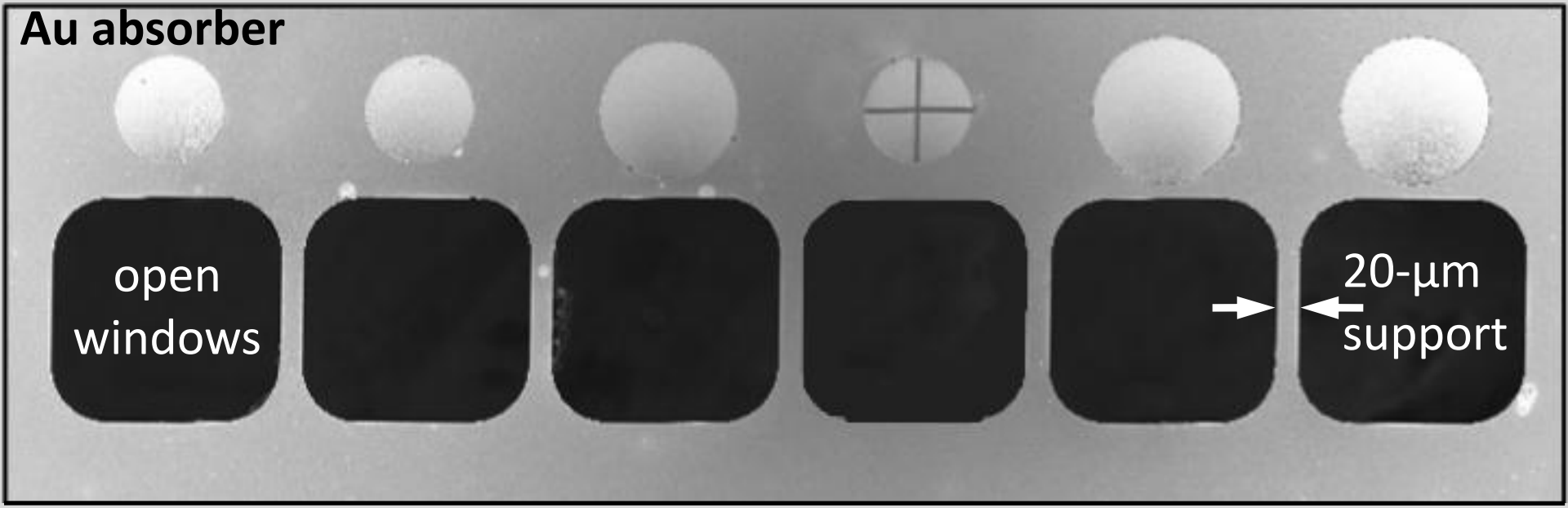
0.35	0.35	0.30	0.25	0.25 NA
1000x	907x	907x	907x	680x mag



visible-light microscope image

2011: Improved AIT zoneplate array

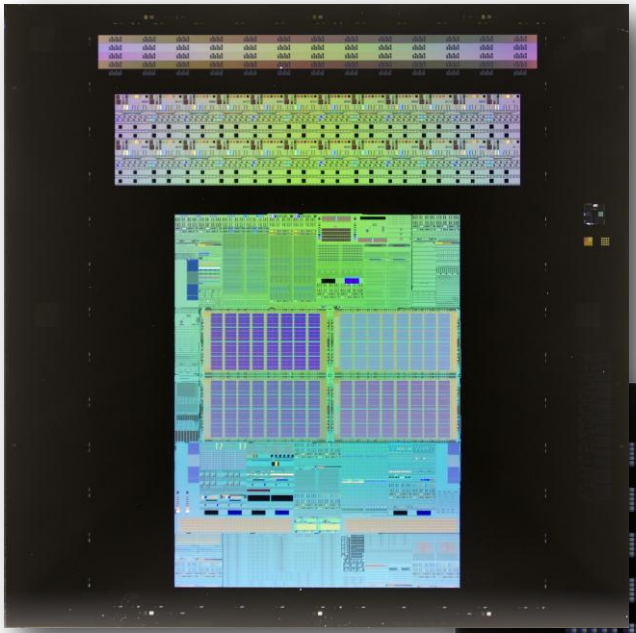
0.25	0.25	0.32	*alignment*	0.35	0.35 NA
907x	907x	907x		907x	907x mag

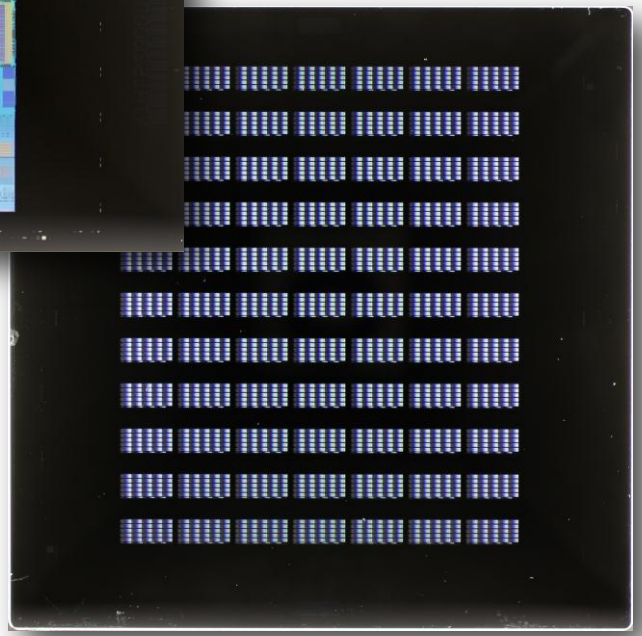


200 µm

SEM Micrograph

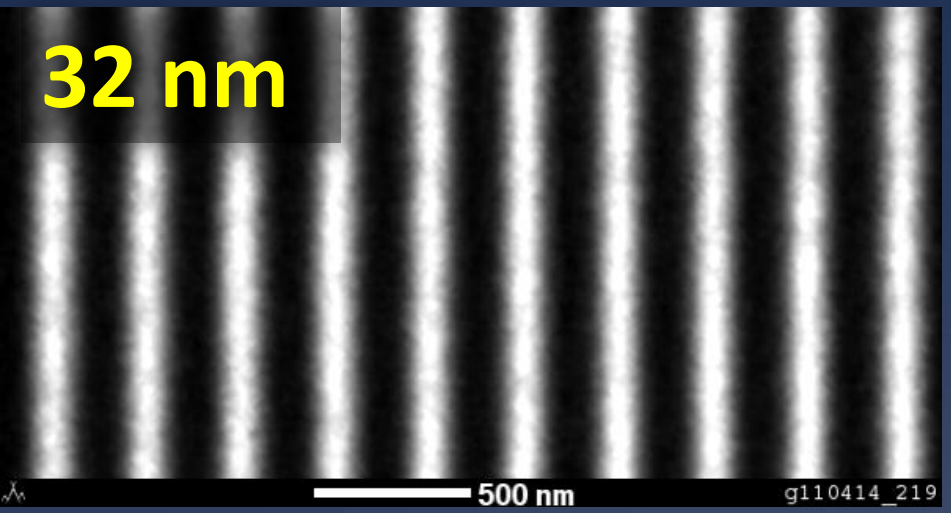
Mask images improve the reticle navigation

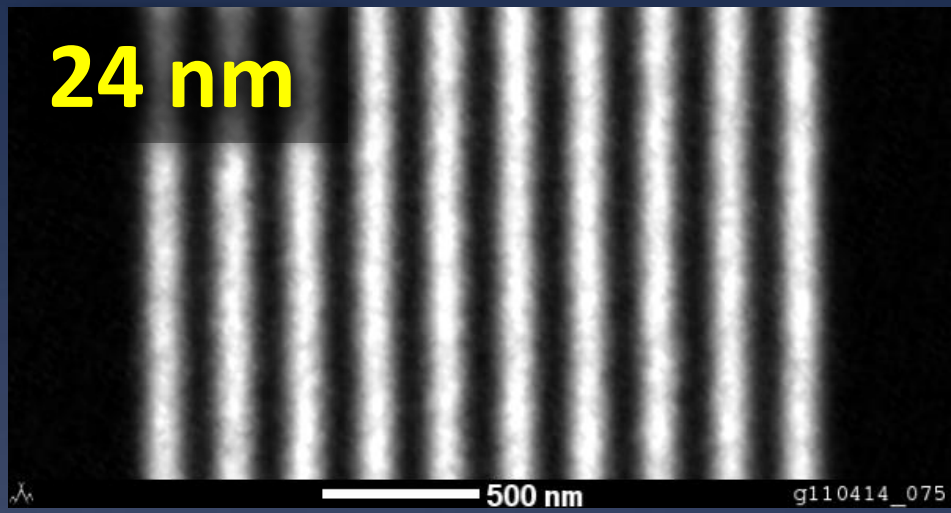


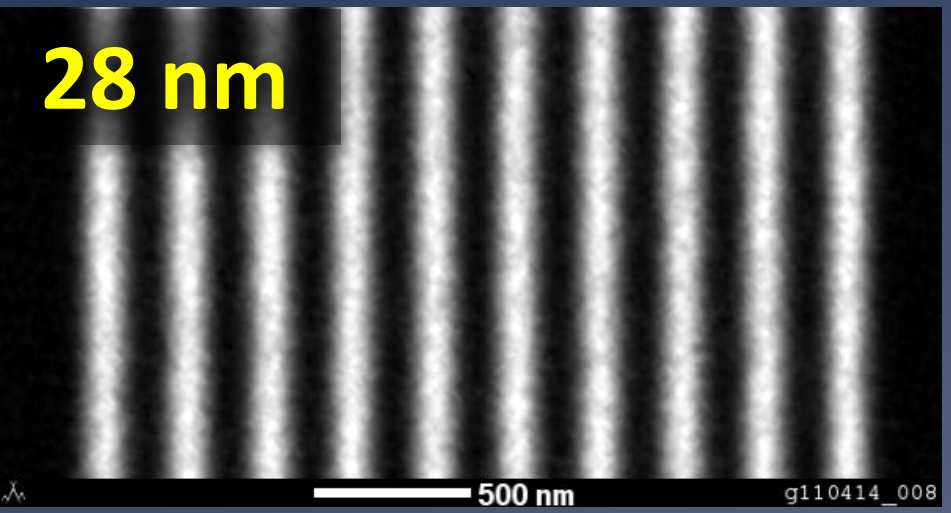


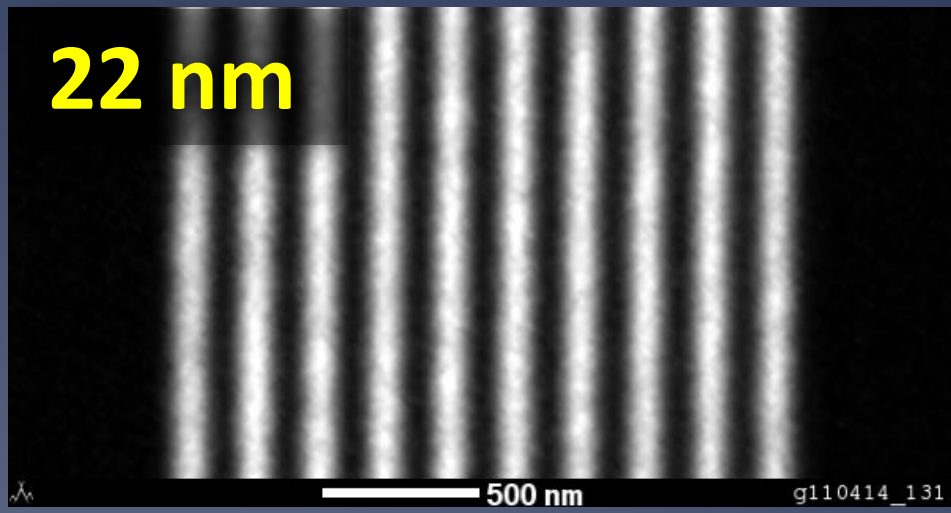
GLOBALFOUNDRIES

Mask Performance Evaluation





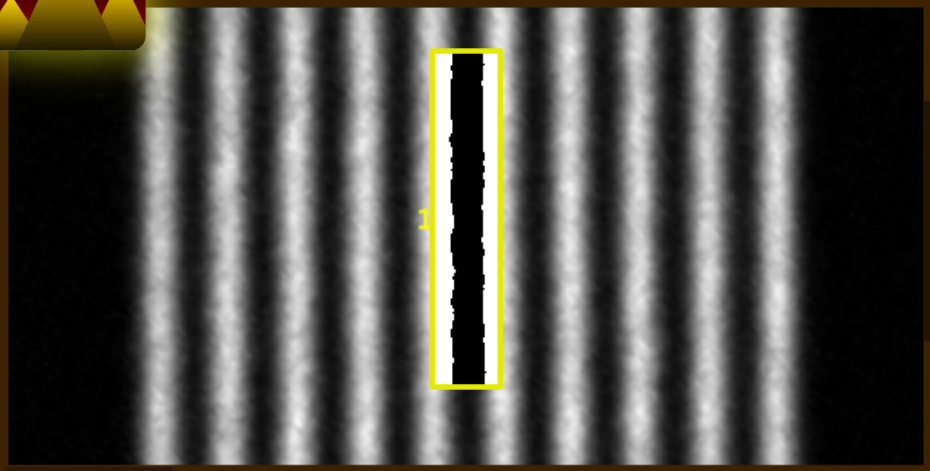




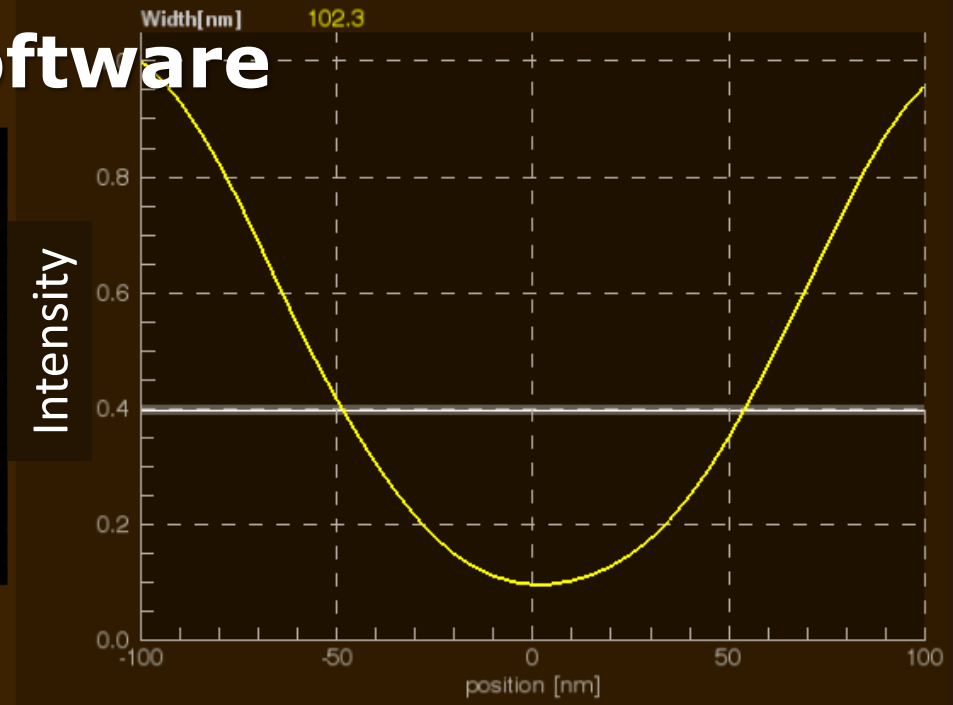
500 nm

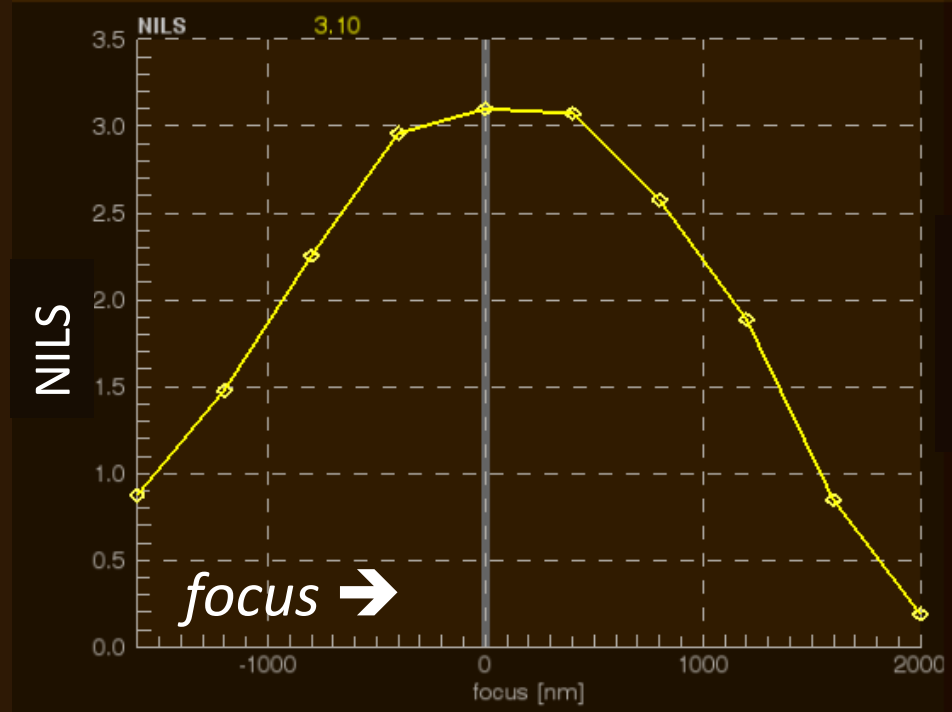
Mask: MET10 / Wallow, *et al.*, *unpublished 2011*

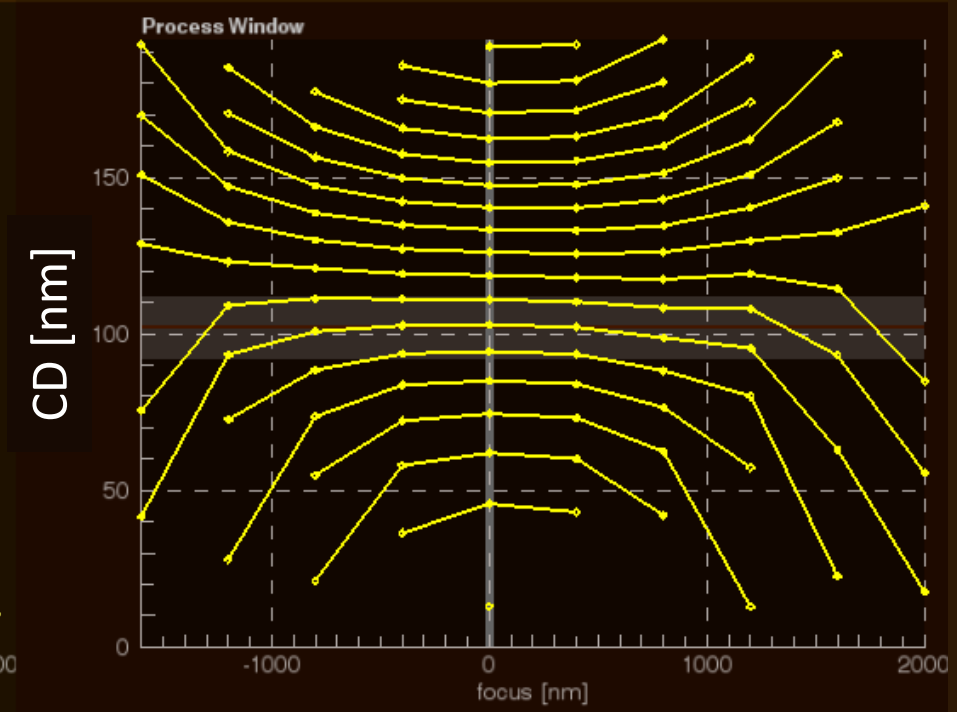
ThroughFocus© Software



detail







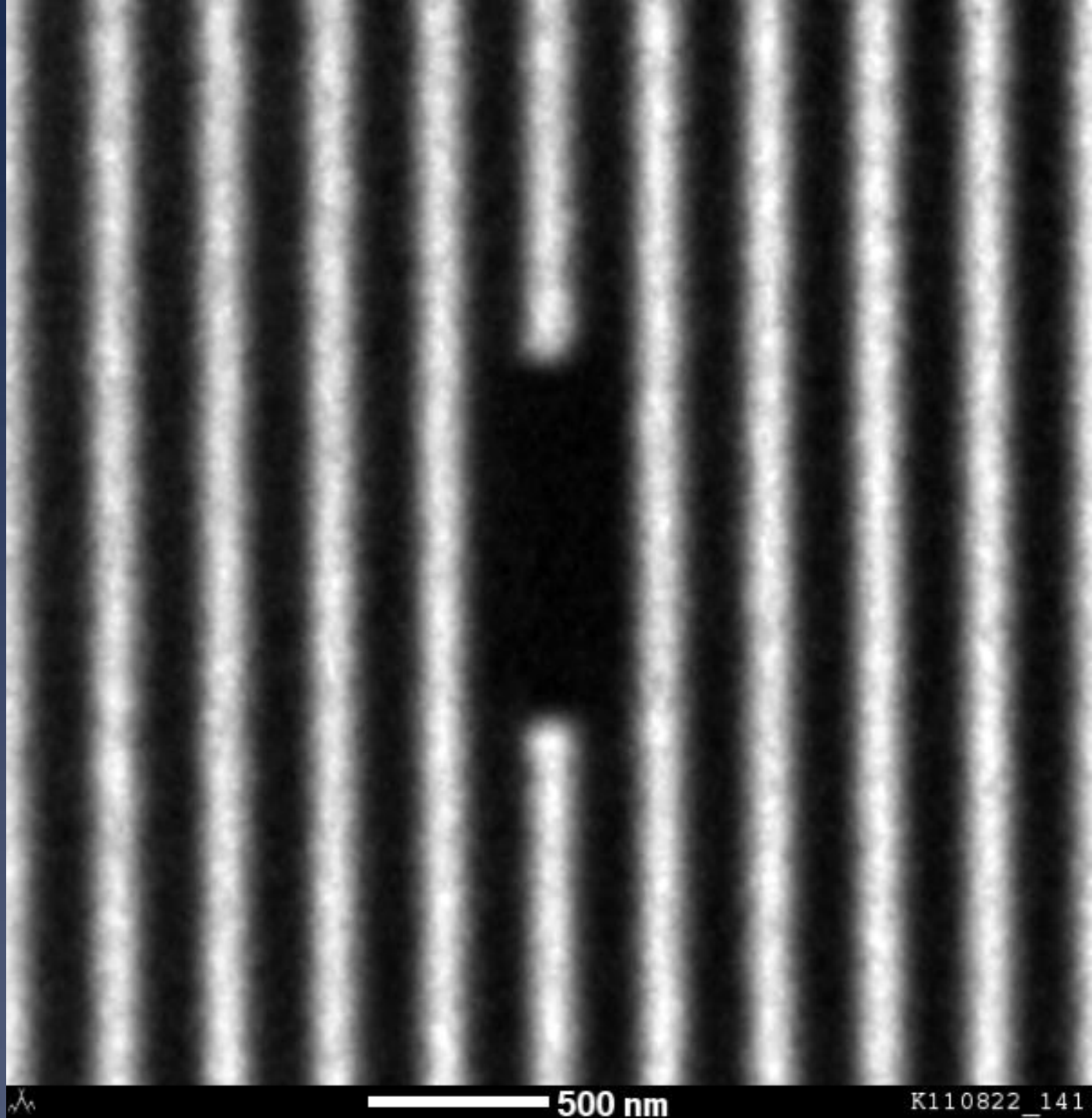
Defect Repair Studies

500 nm

16-09 / G4 / Site 8 / Site Loc 17

Mask: J7M29005NA

Gallagher, Lawliss, *unpublished 2011*



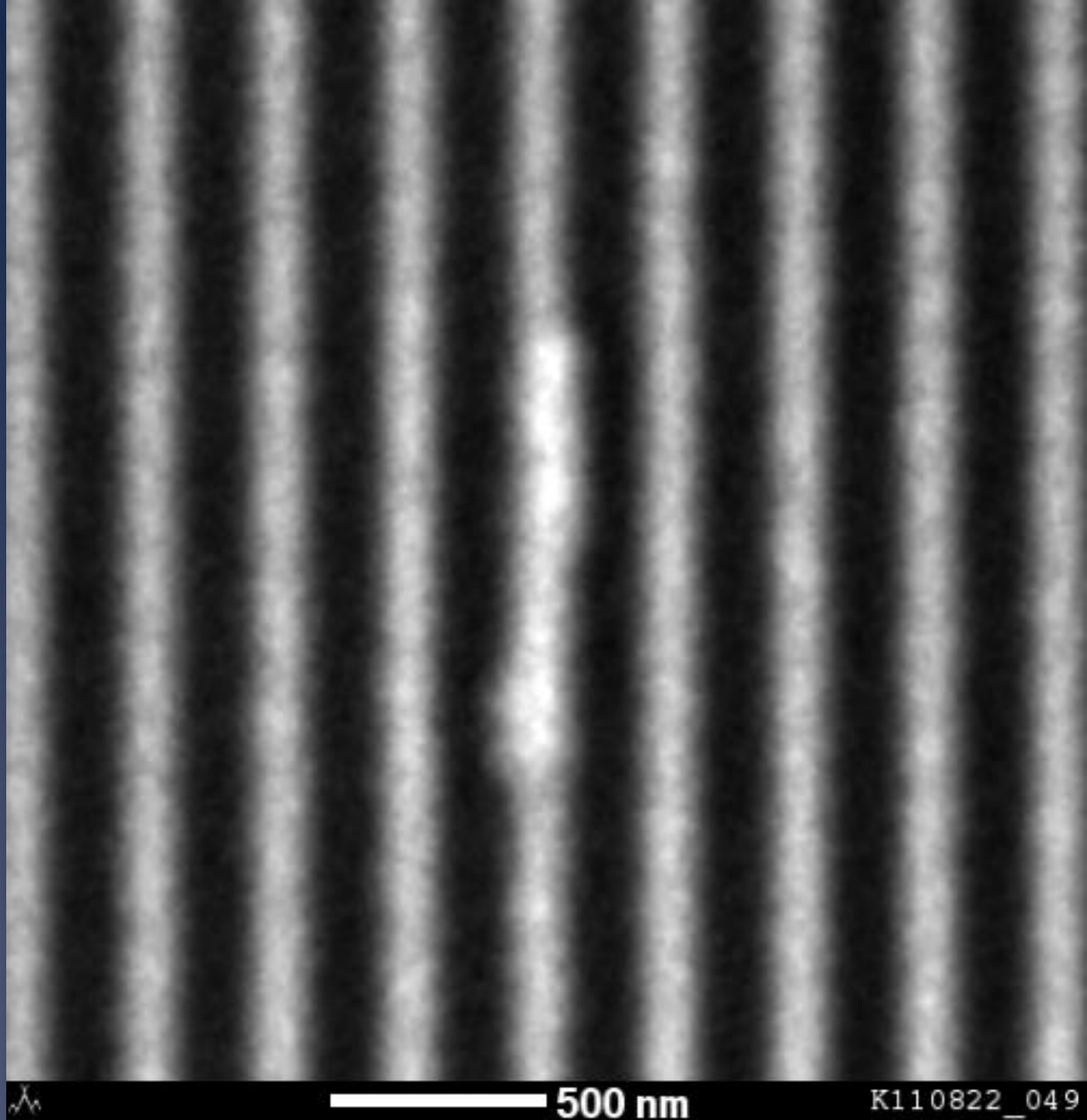
Defect Repair Studies

500 nm

16-09 / G4 / Site 3 / Site Loc 11

Mask: J7M29005NA

Gallagher, Lawliss, *unpublished 2011*



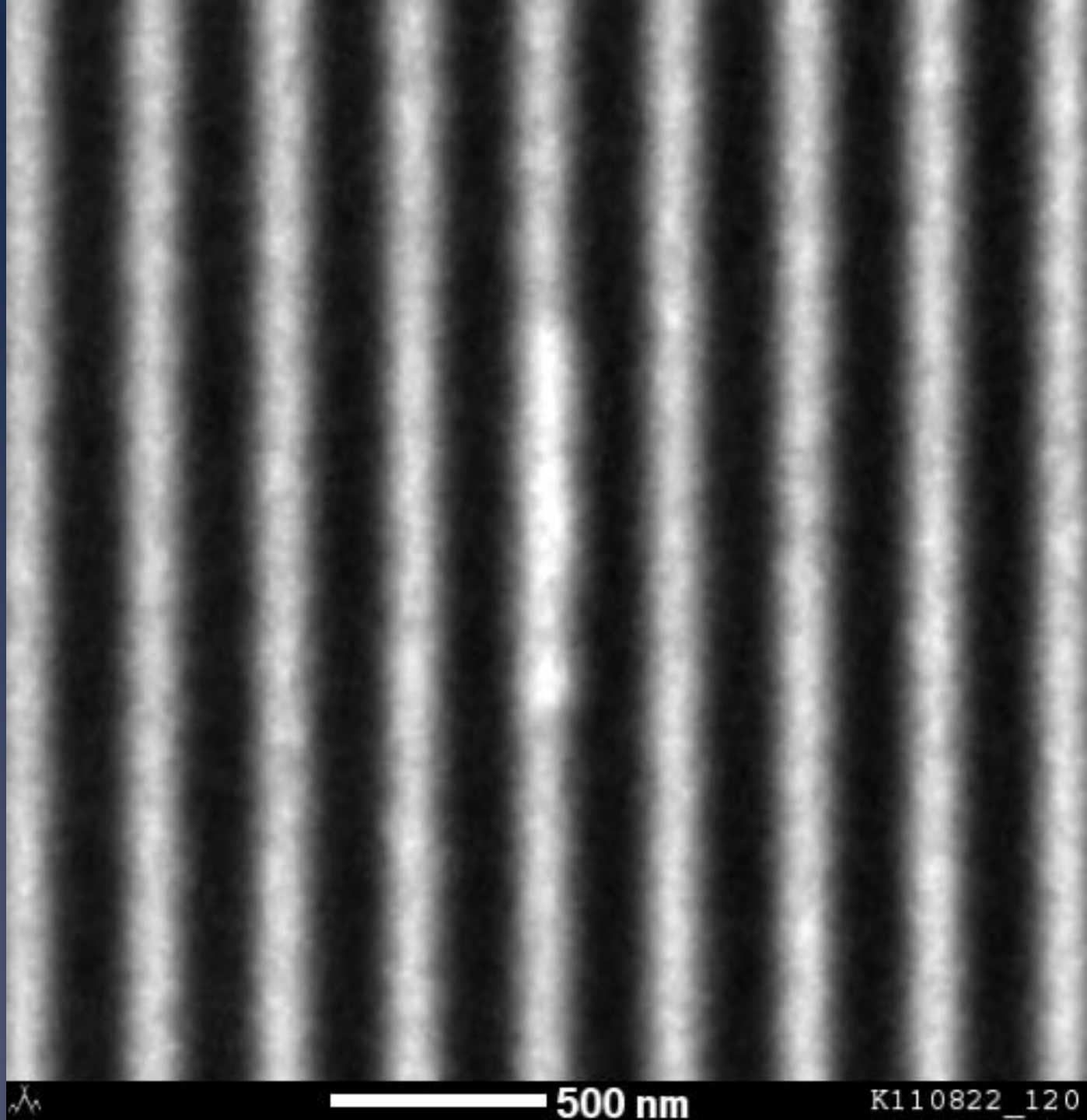
Defect Repair Studies

500 nm

16-09 / G4 / Site 7 / Site Loc 12

Mask: J7M29005NA

Gallagher, Lawliss, *unpublished 2011*



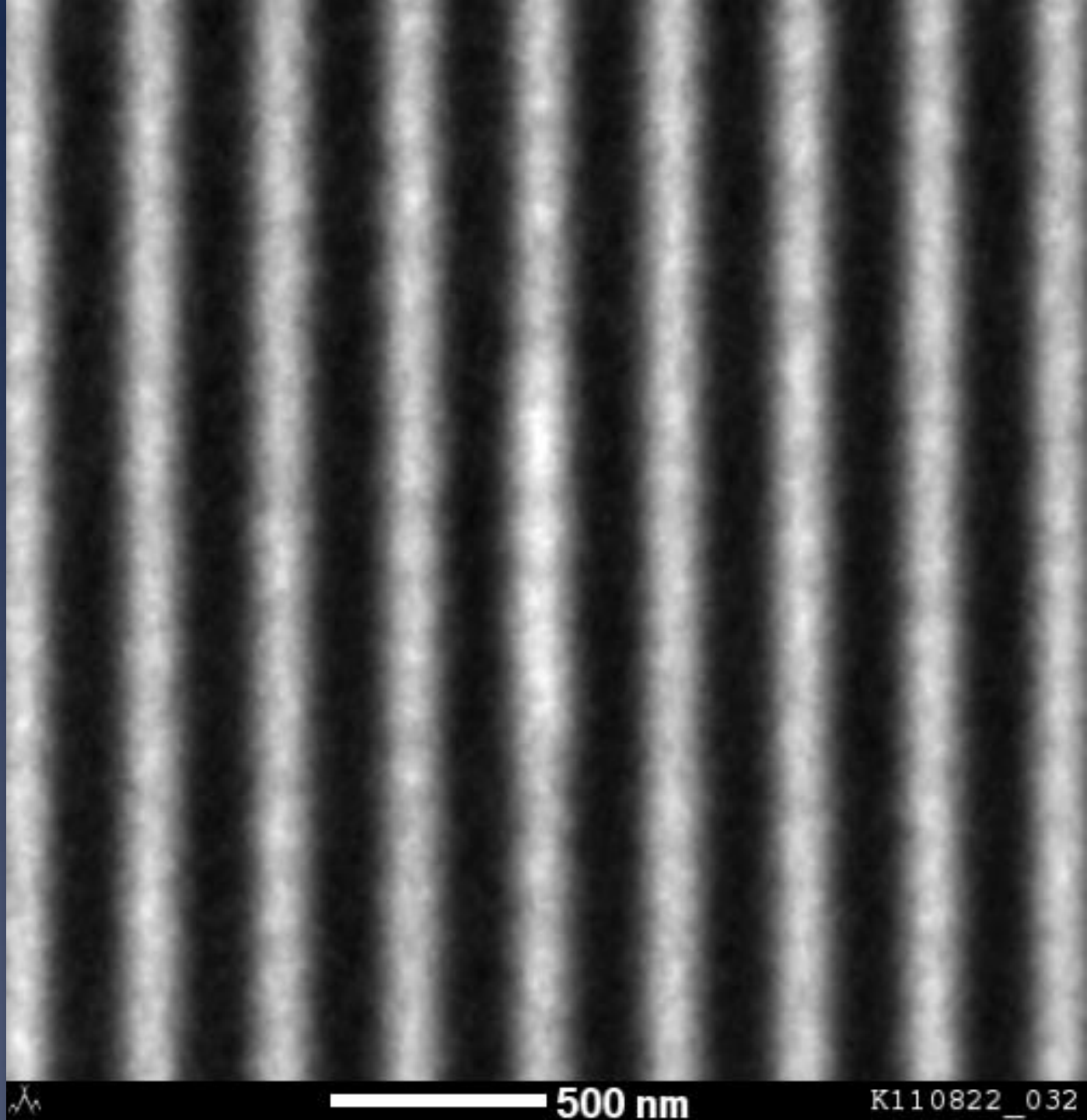
Defect Repair Studies

500 nm

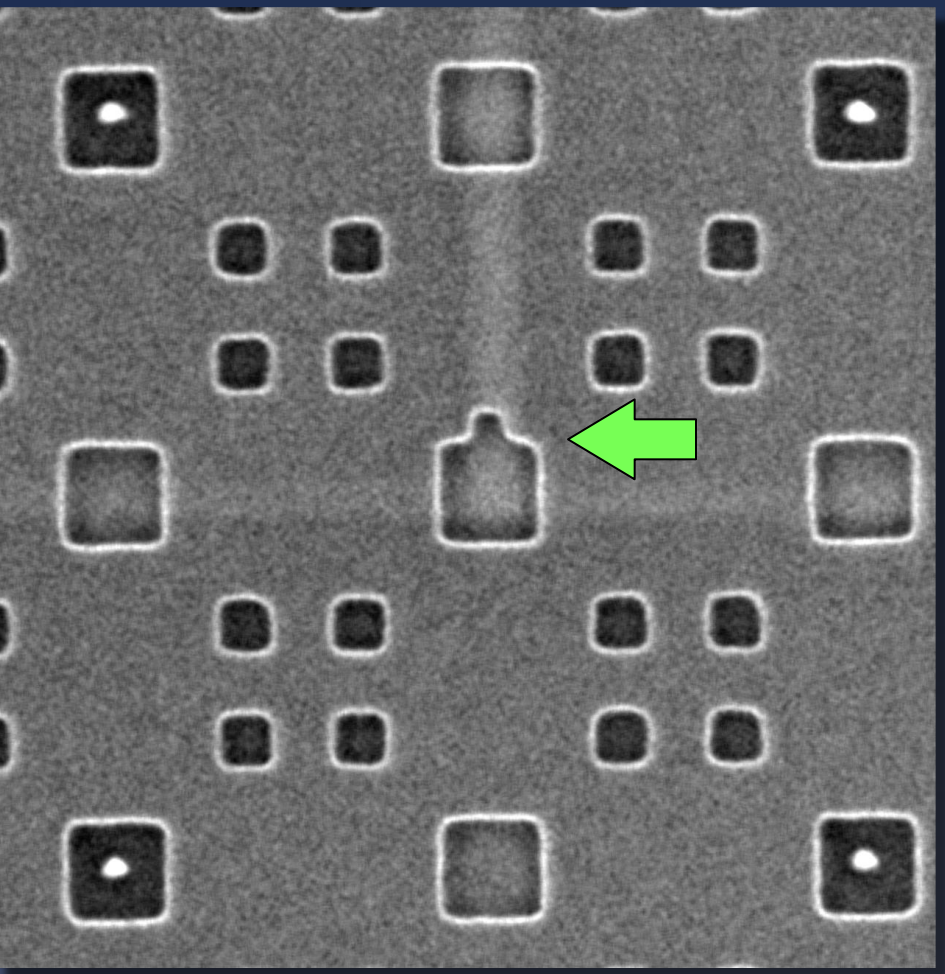
16-09 / G4 / Site 2 / Site Loc 6

Mask: J7M29005NA

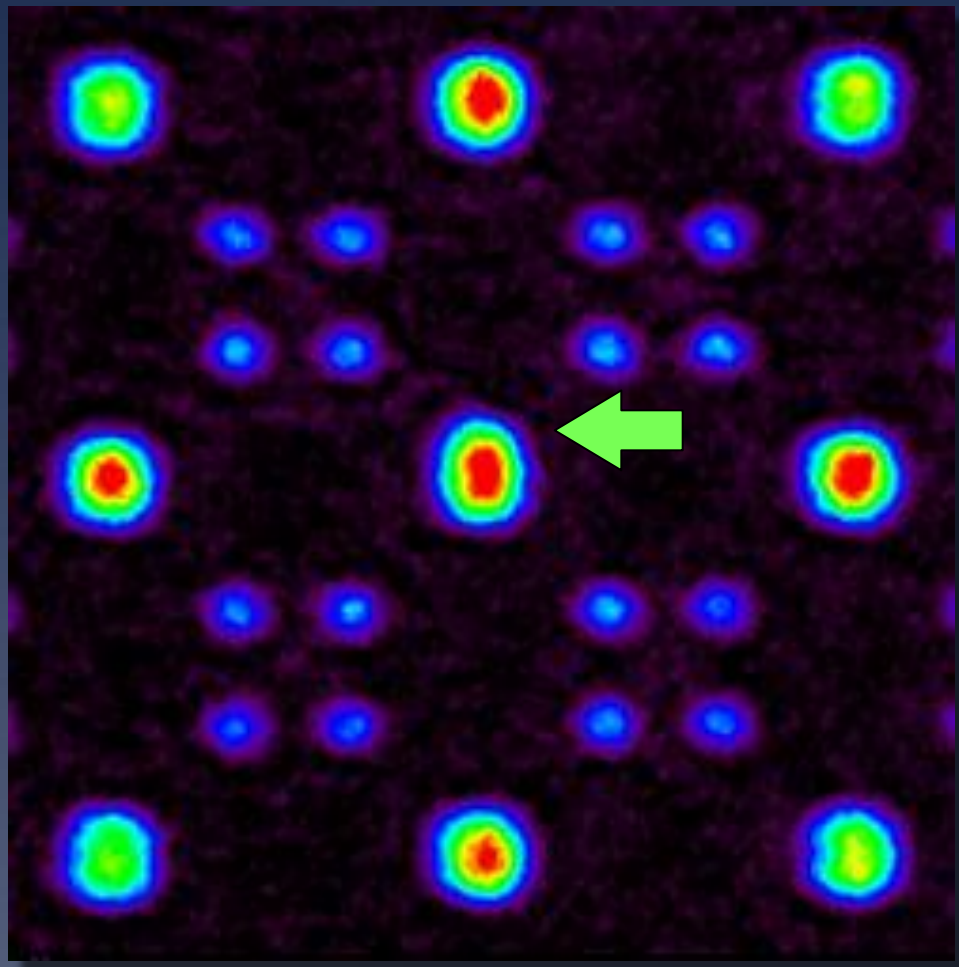
Gallagher, Lawliss, *unpublished 2011*



Programmed Pattern Defects



SEM



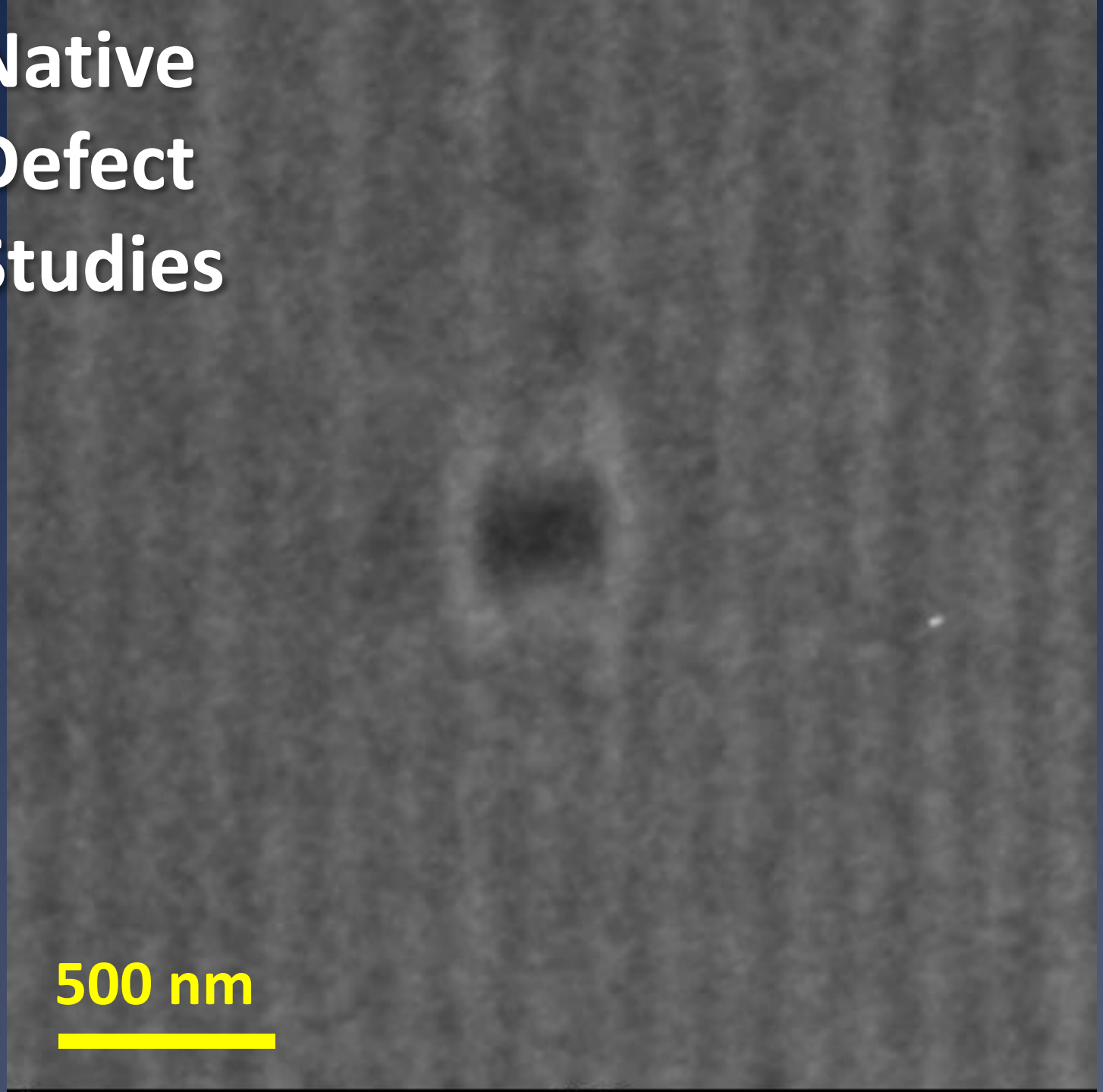
AIT (EUV)

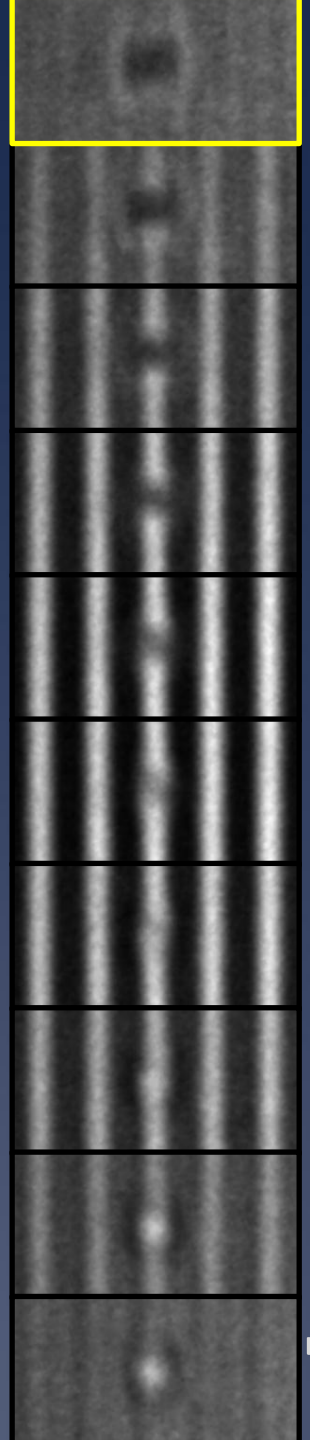
500 nm

Mask: SMOCOL2 / Gallagher, Badger, *unpublished 2011*

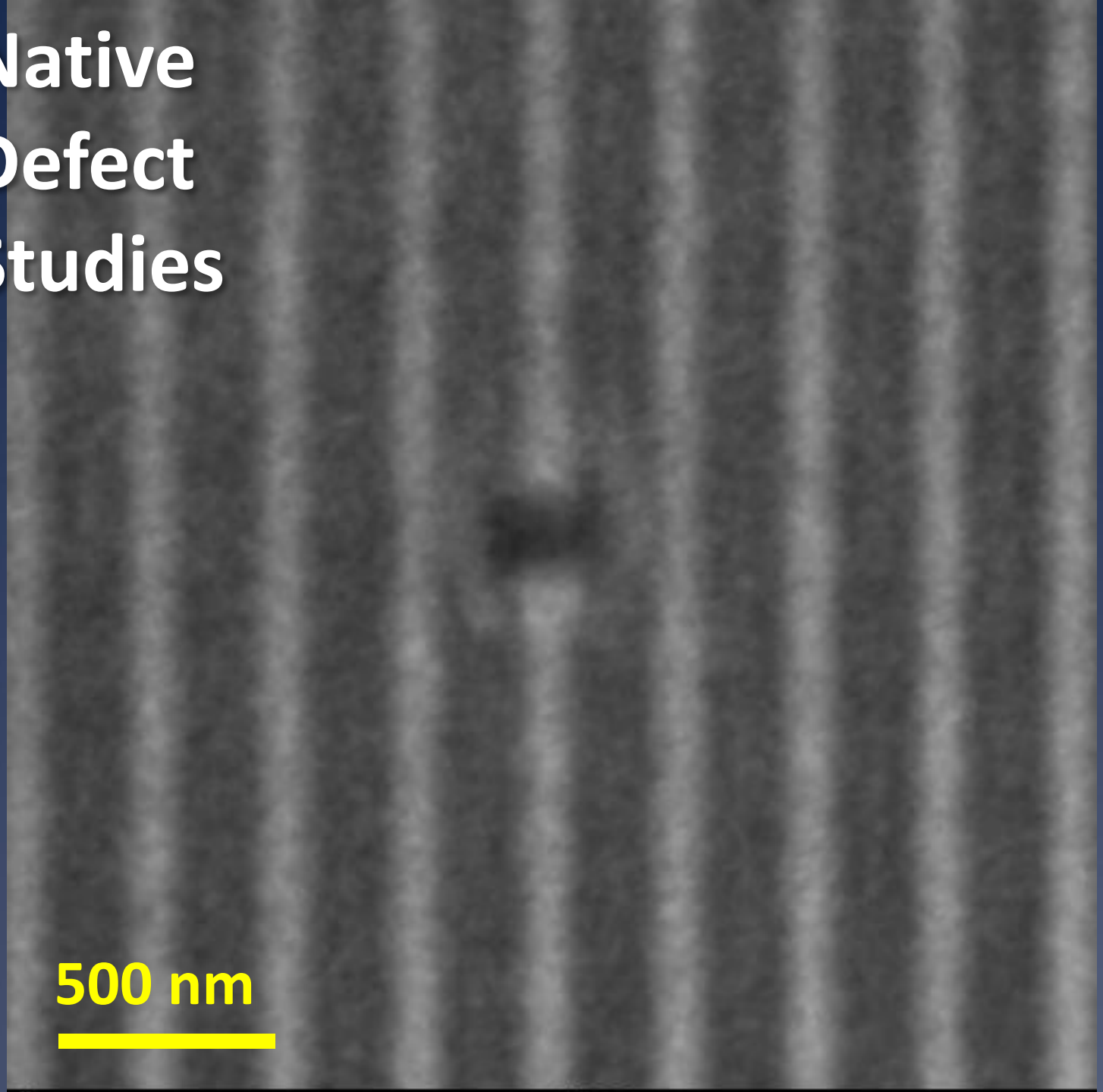
Defect A3-B30

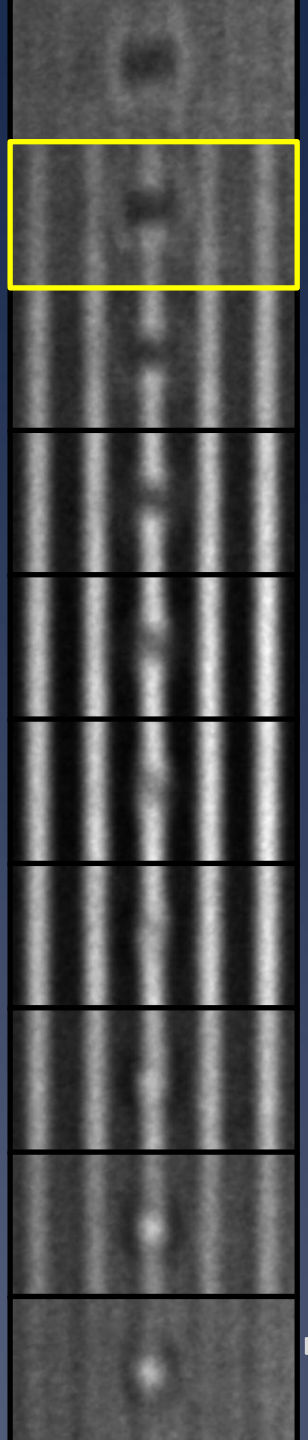
Native Defect Studies



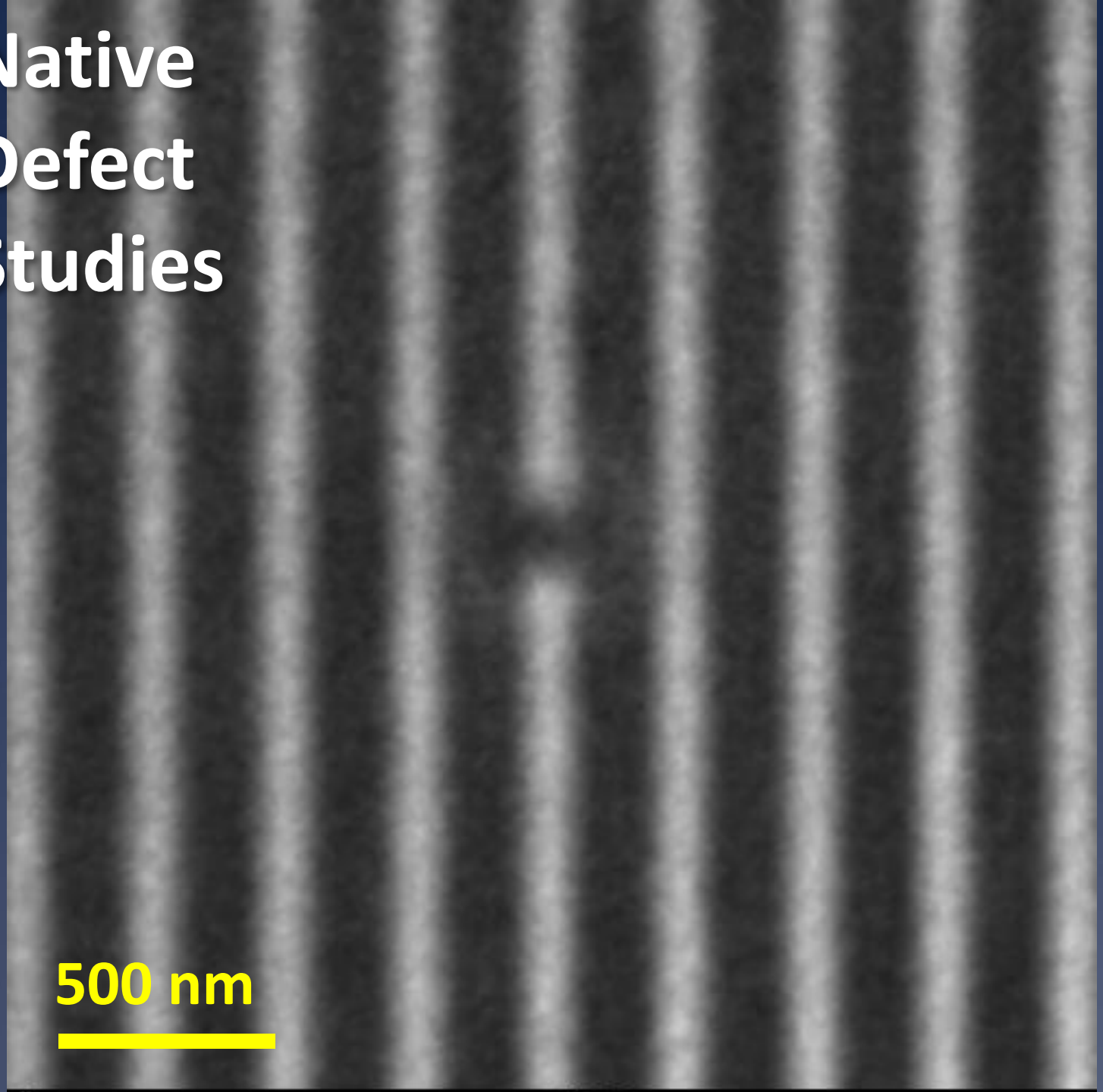


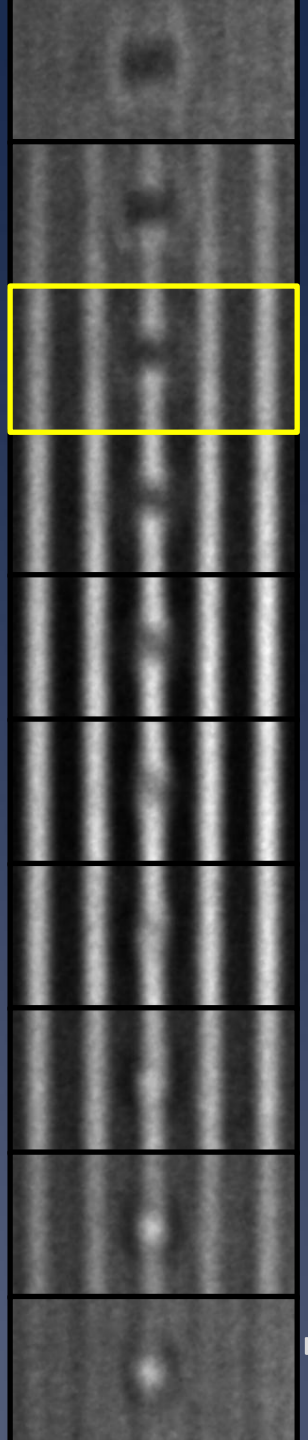
Native Defect Studies



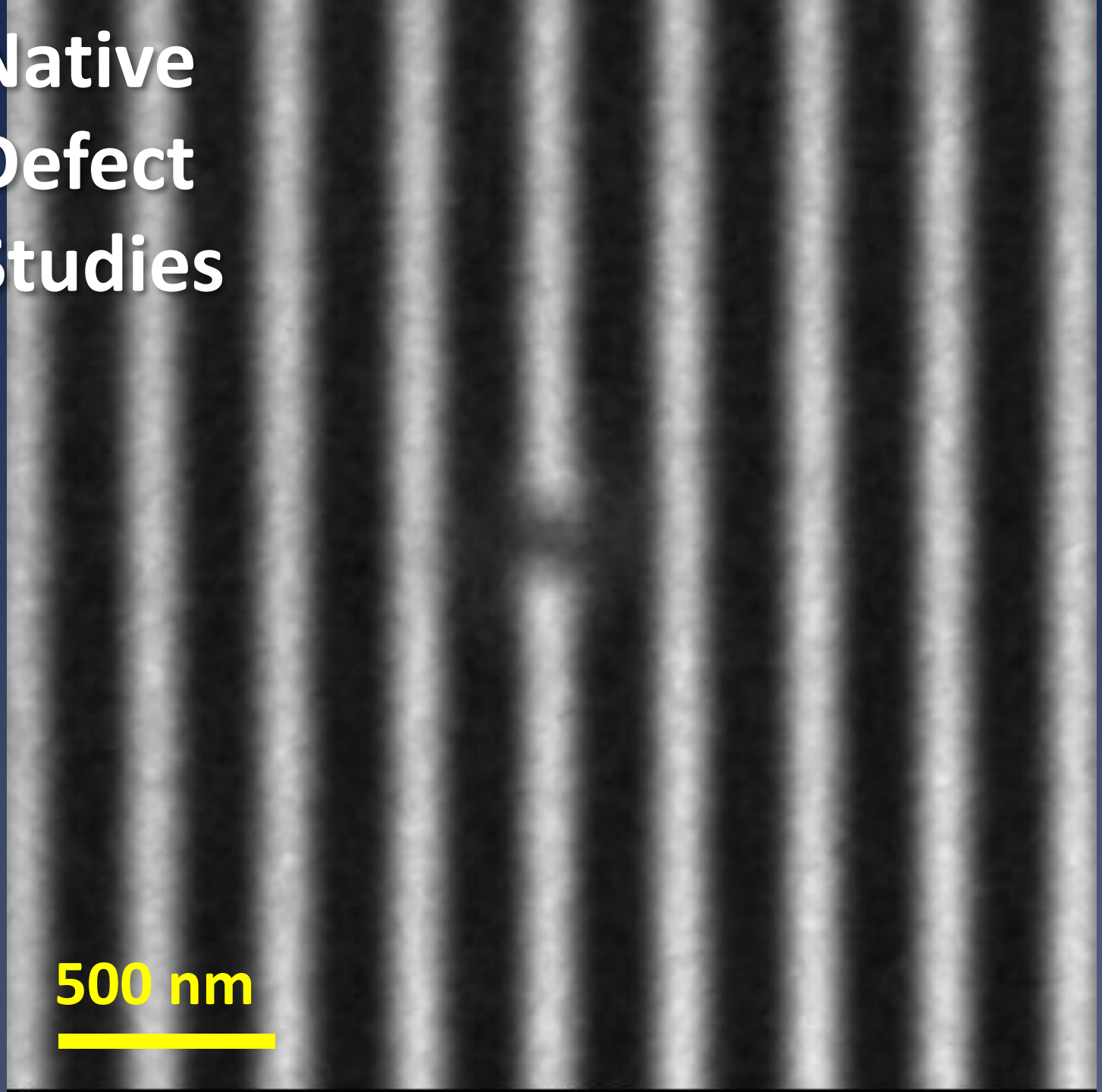


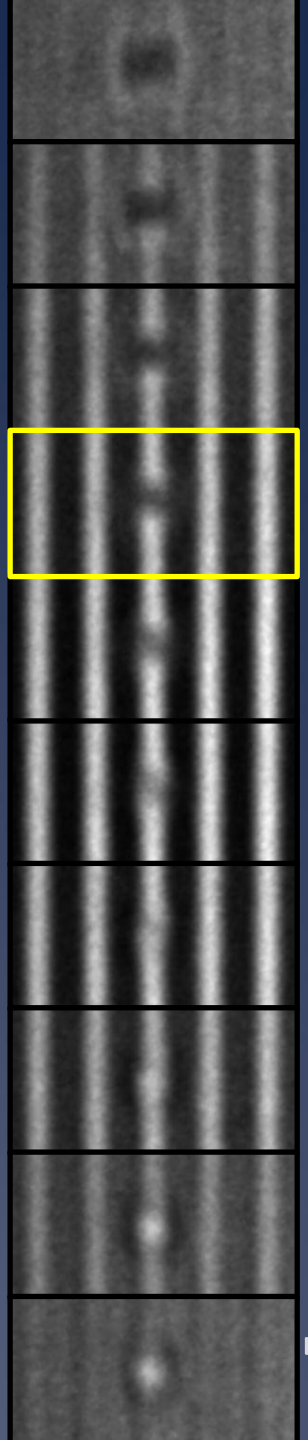
Native Defect Studies



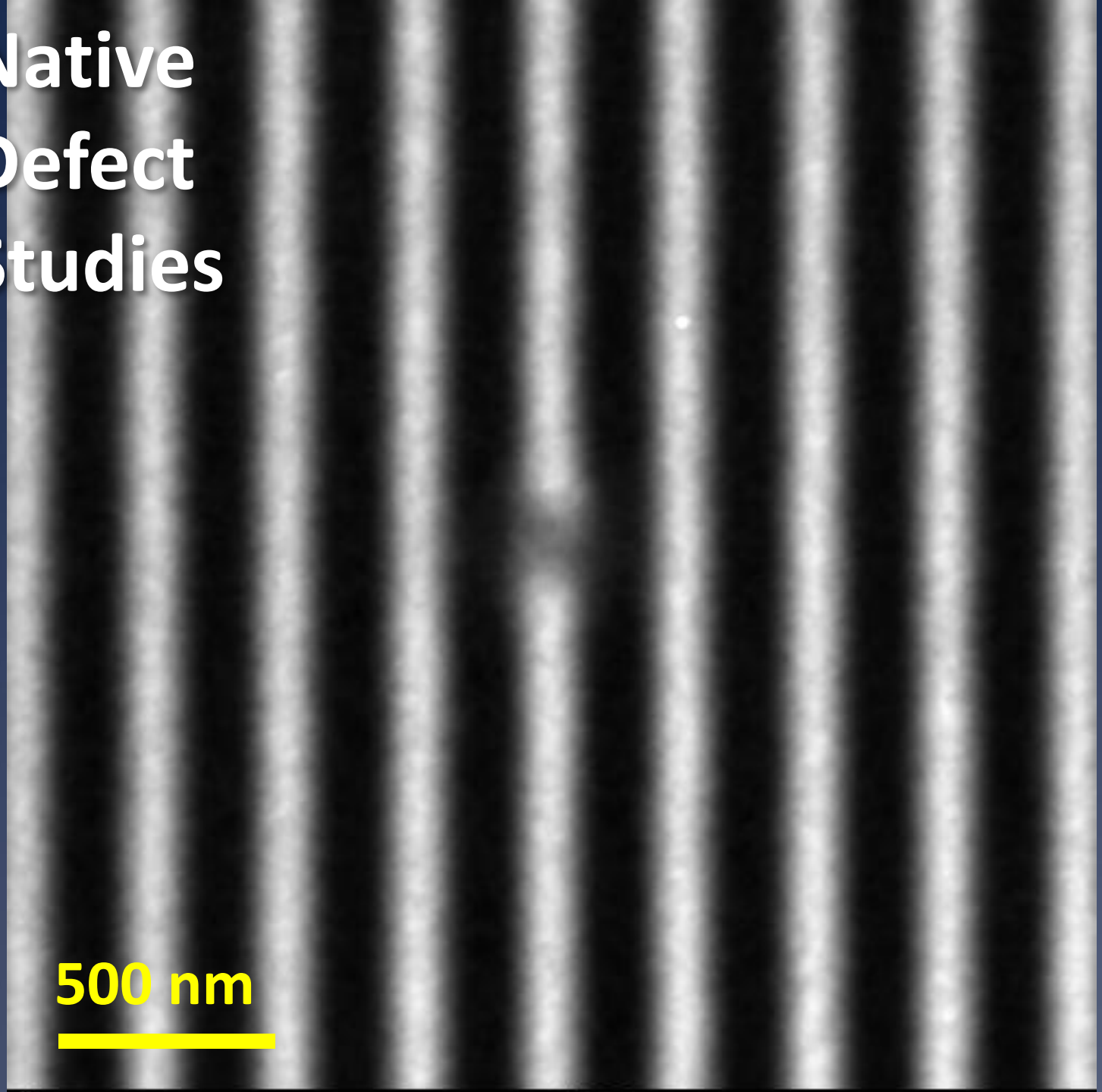


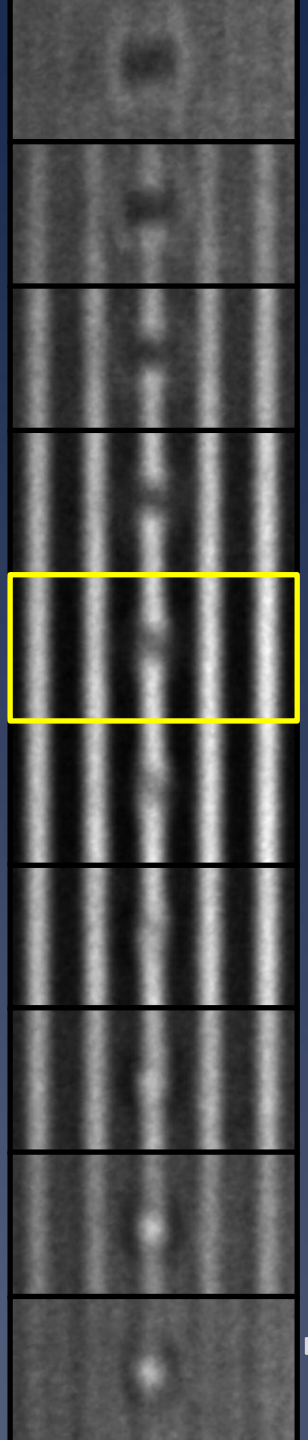
Native Defect Studies



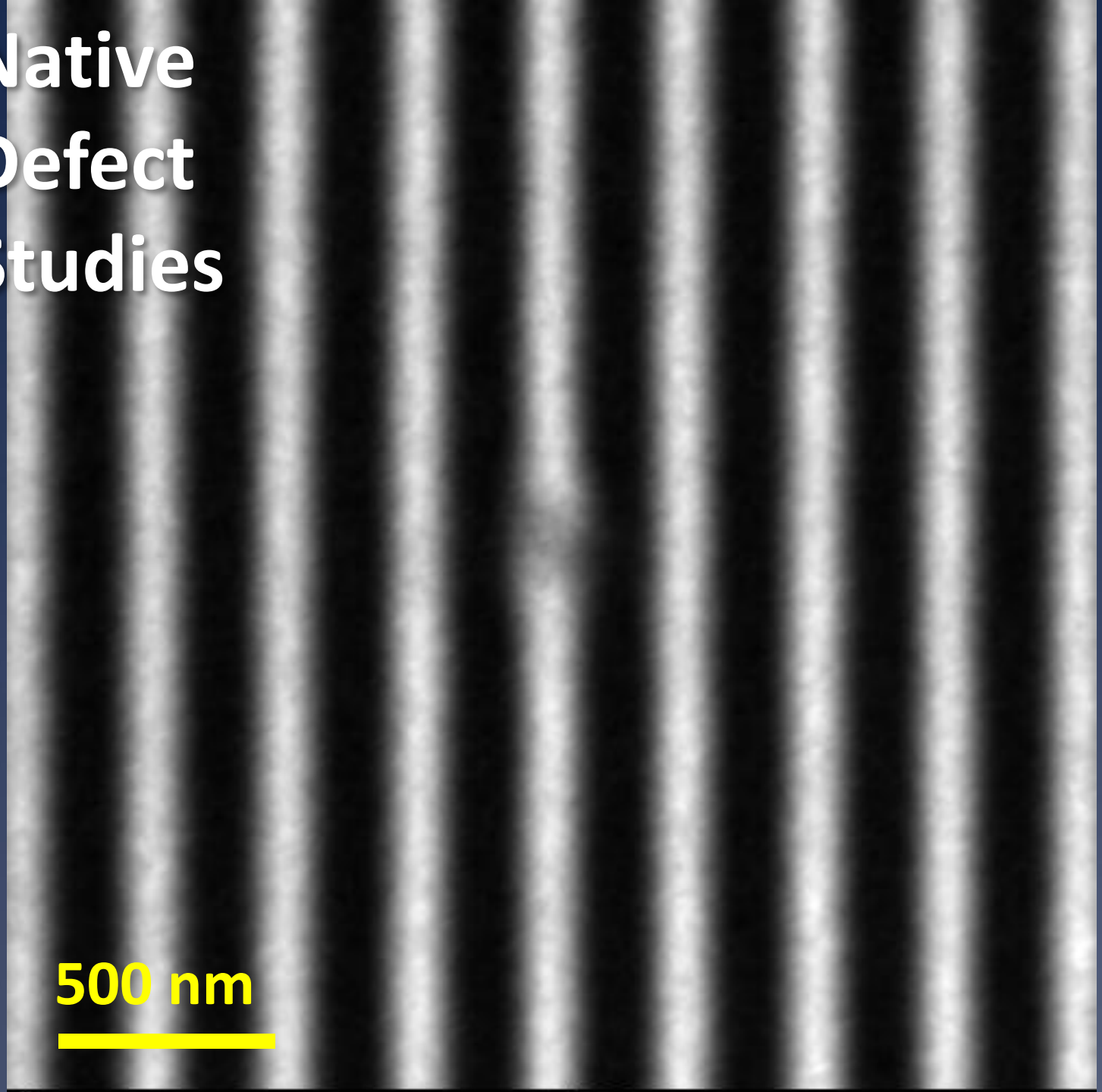


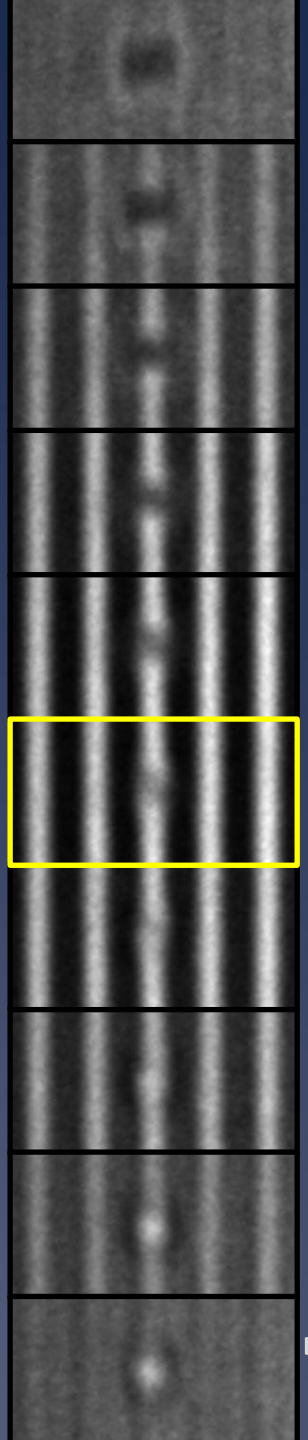
Native Defect Studies





Native Defect Studies





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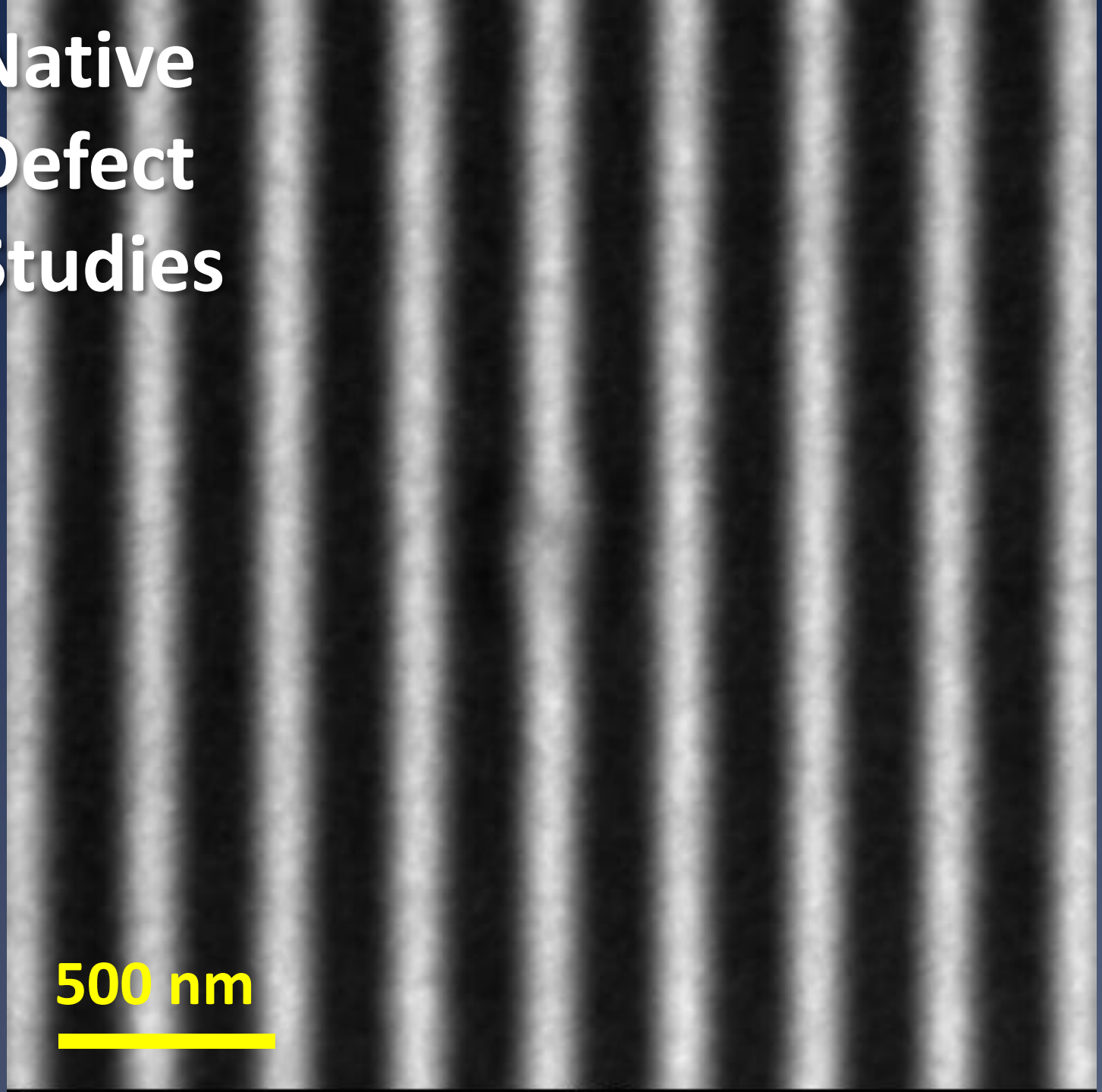

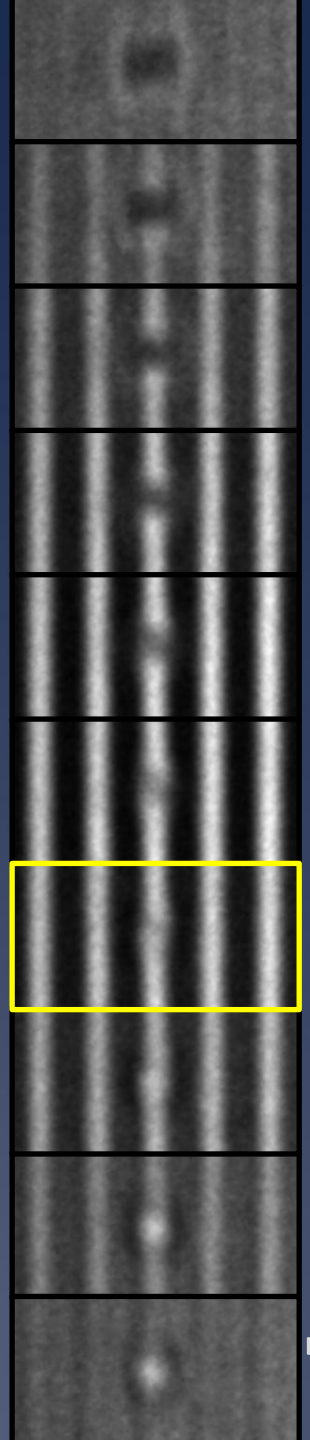

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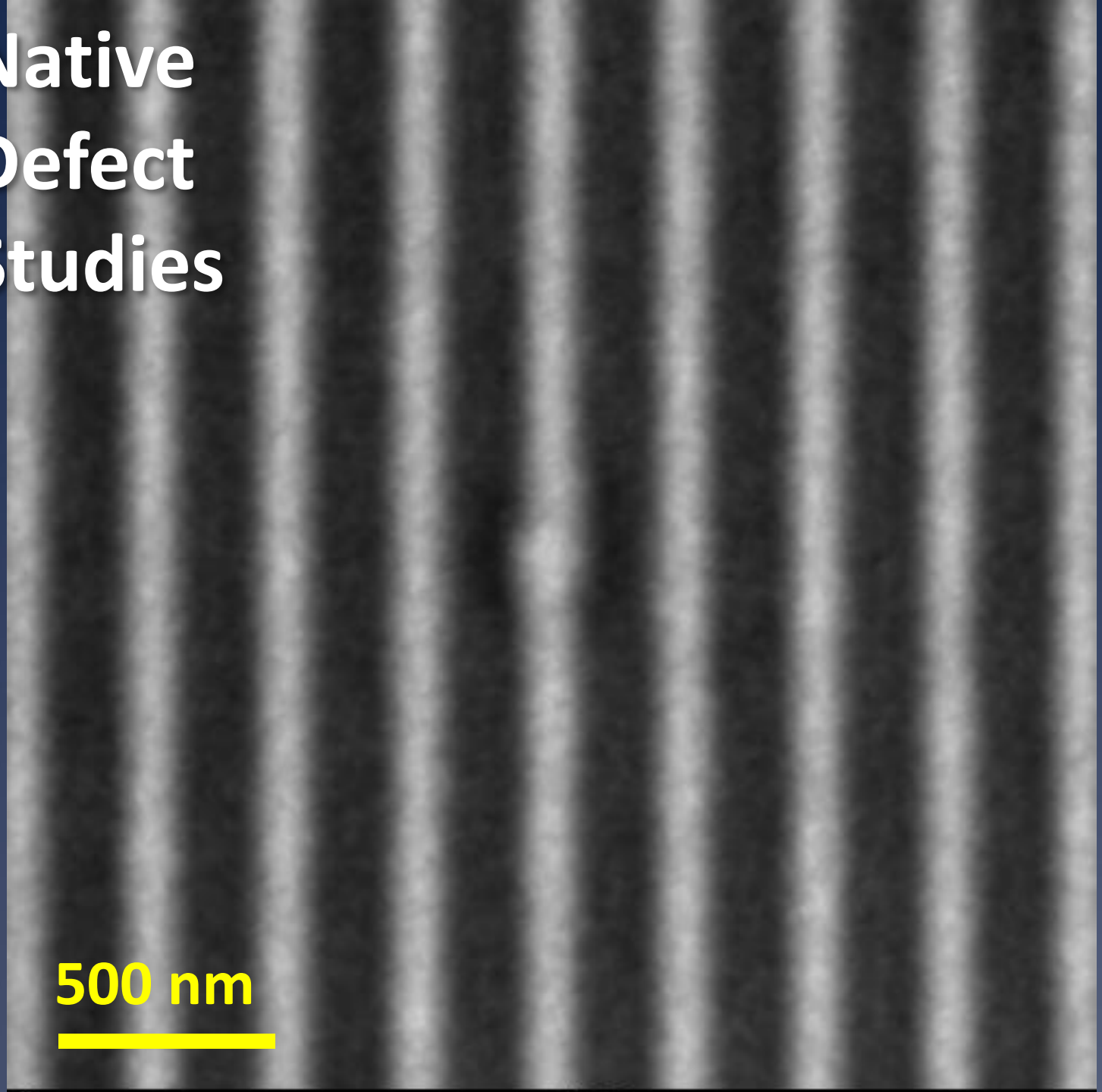

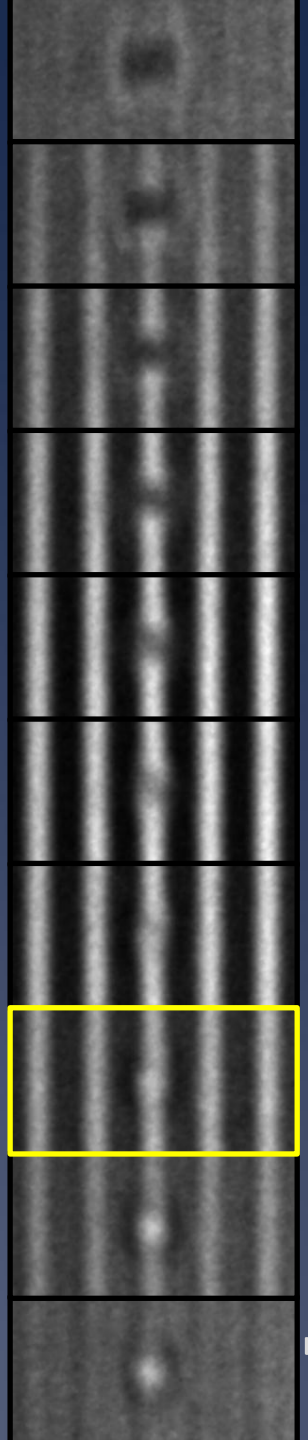

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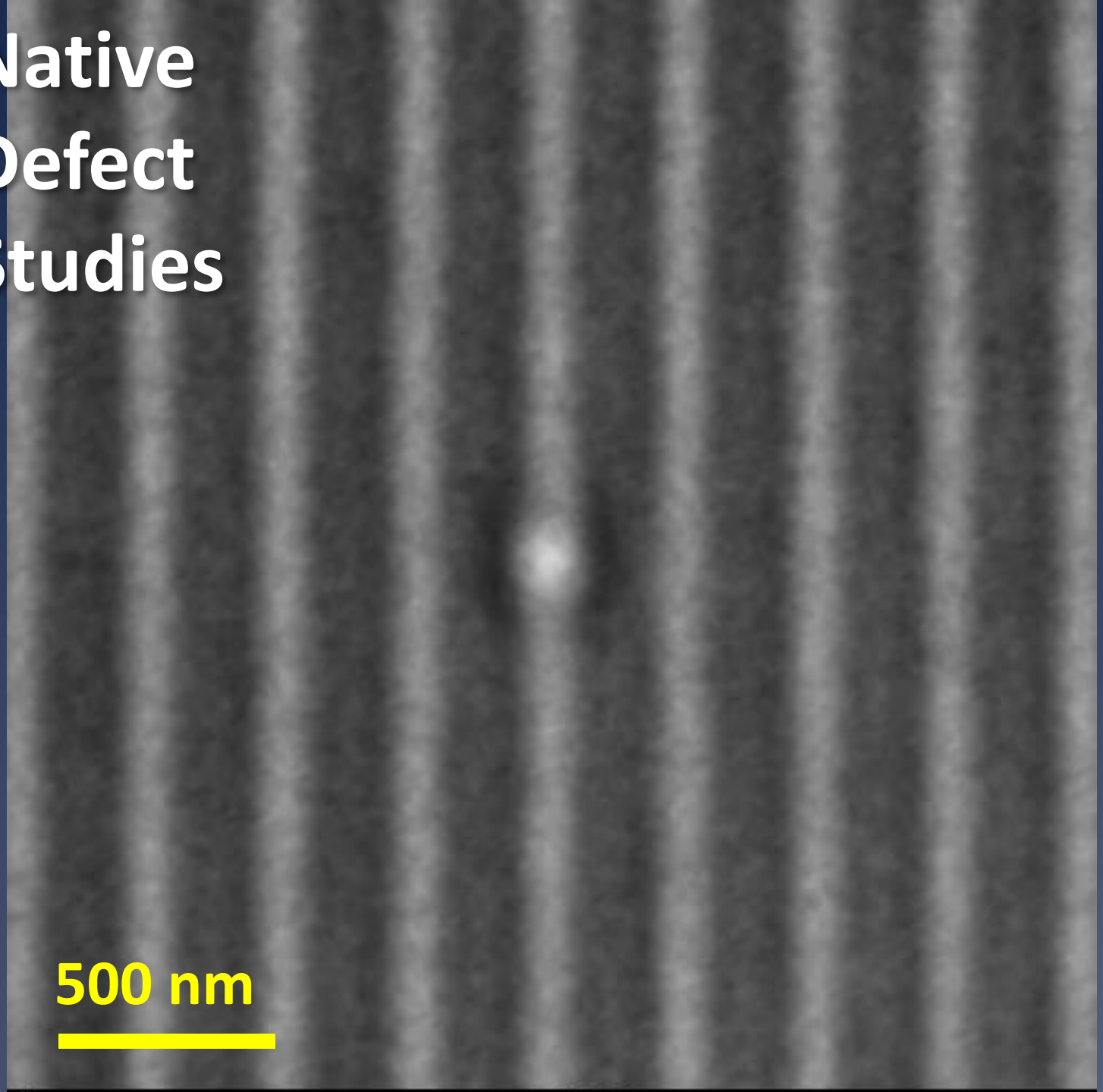

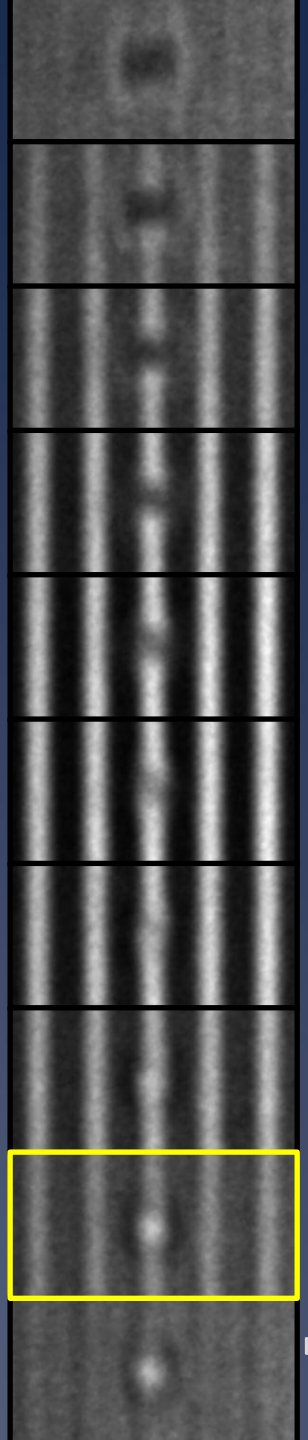

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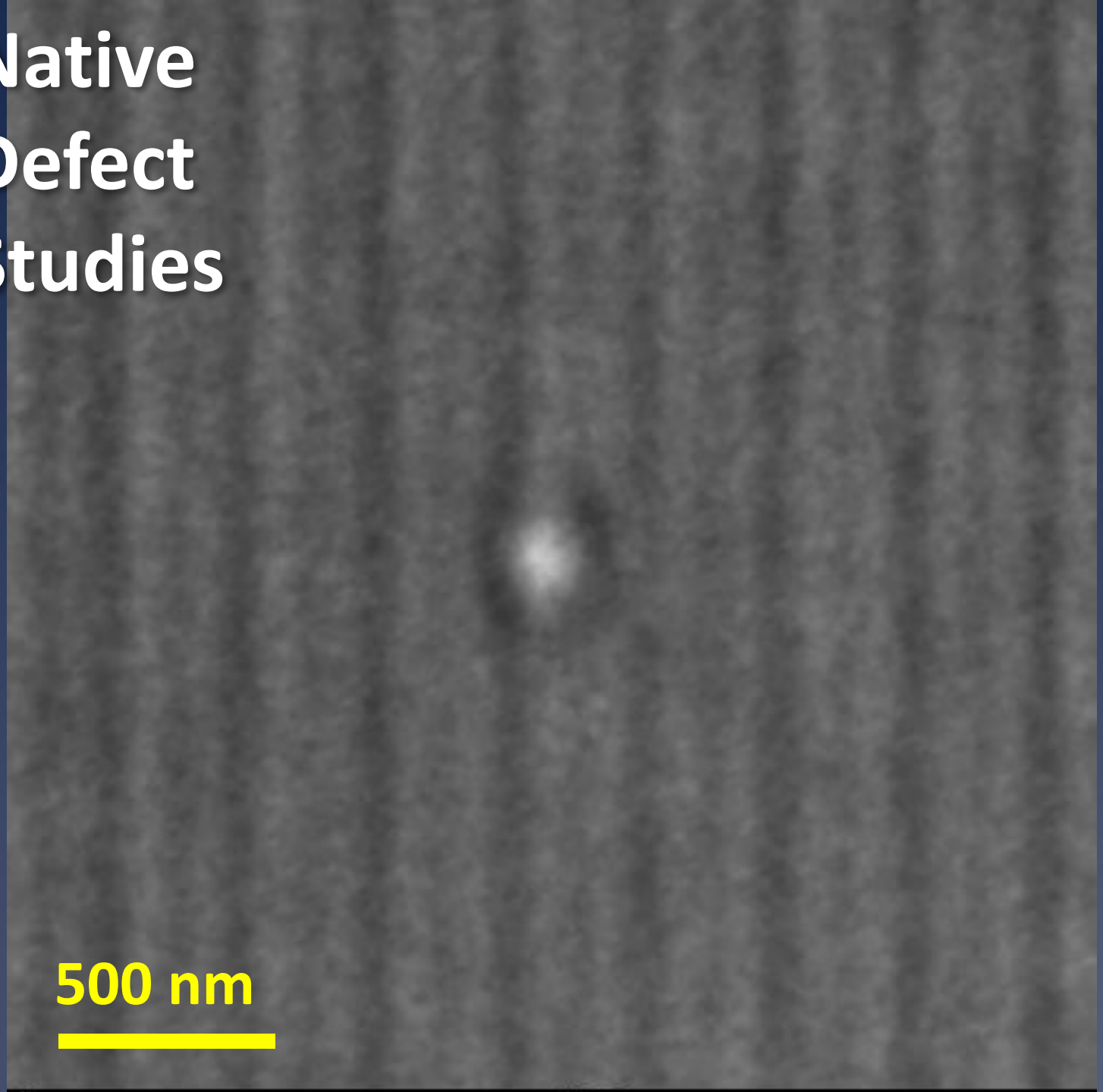
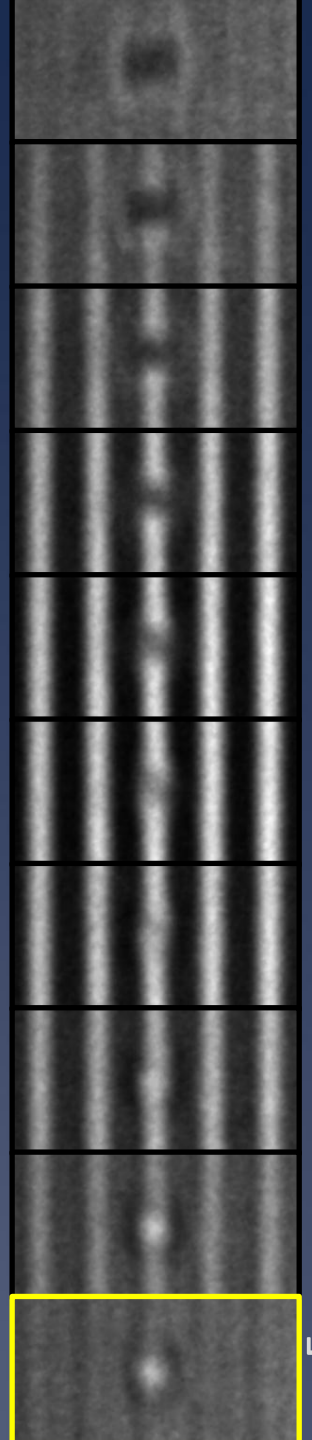
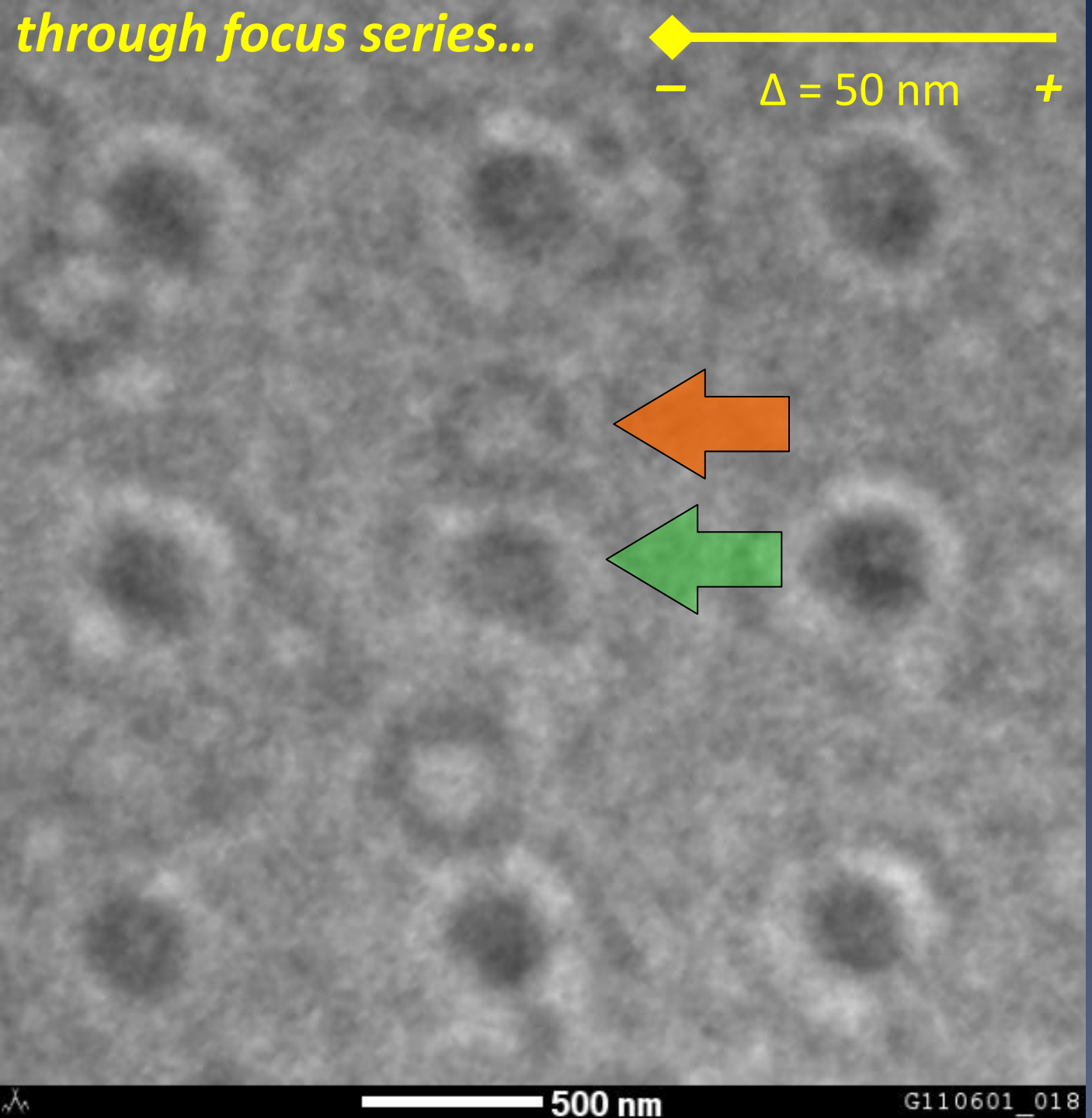




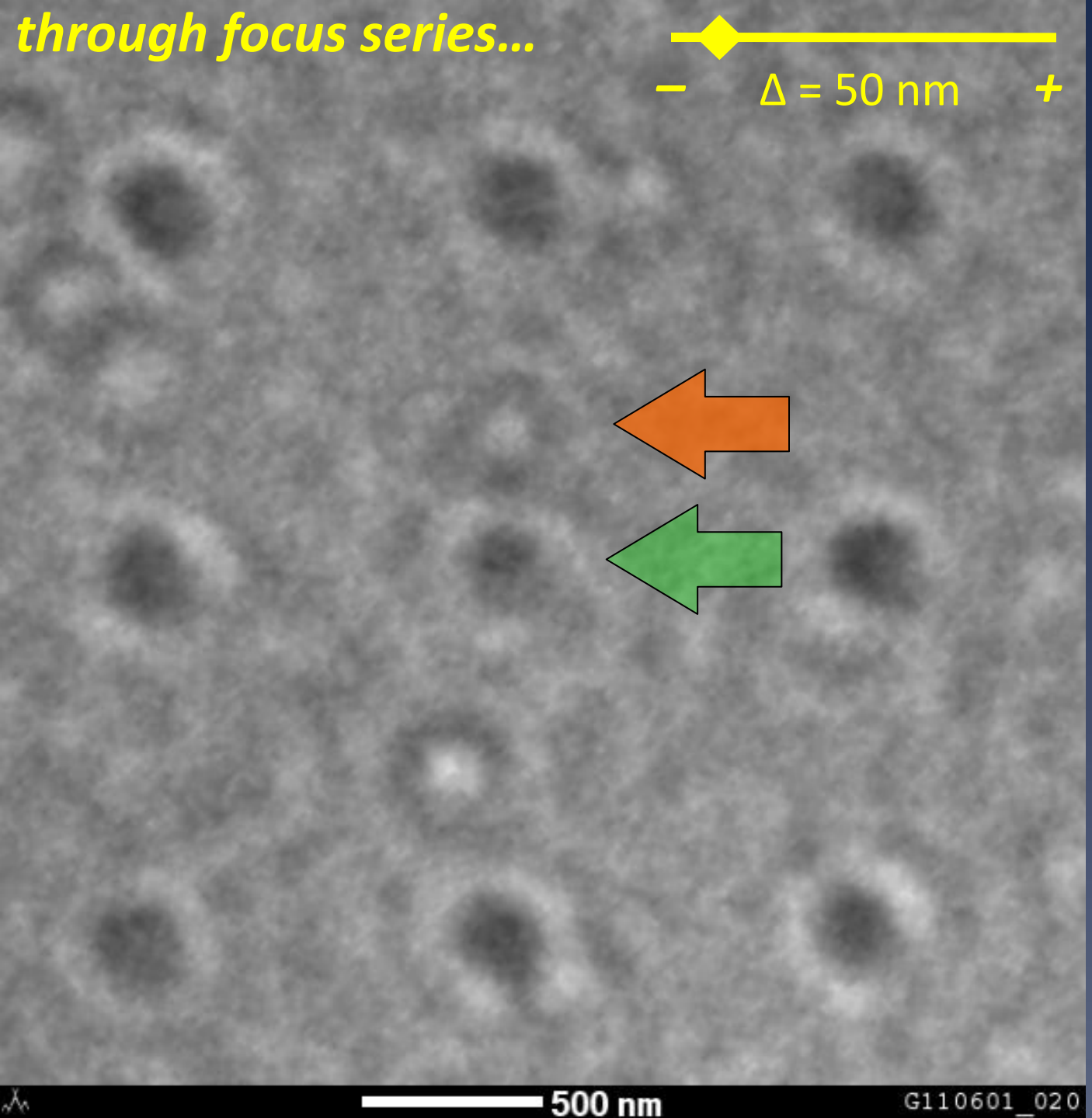


SEMATECH

Phase Defect Studies

- *bump*
- *pit*

Mask: AGC1008005
Kwon, *et al.*, *unpublished 2011*



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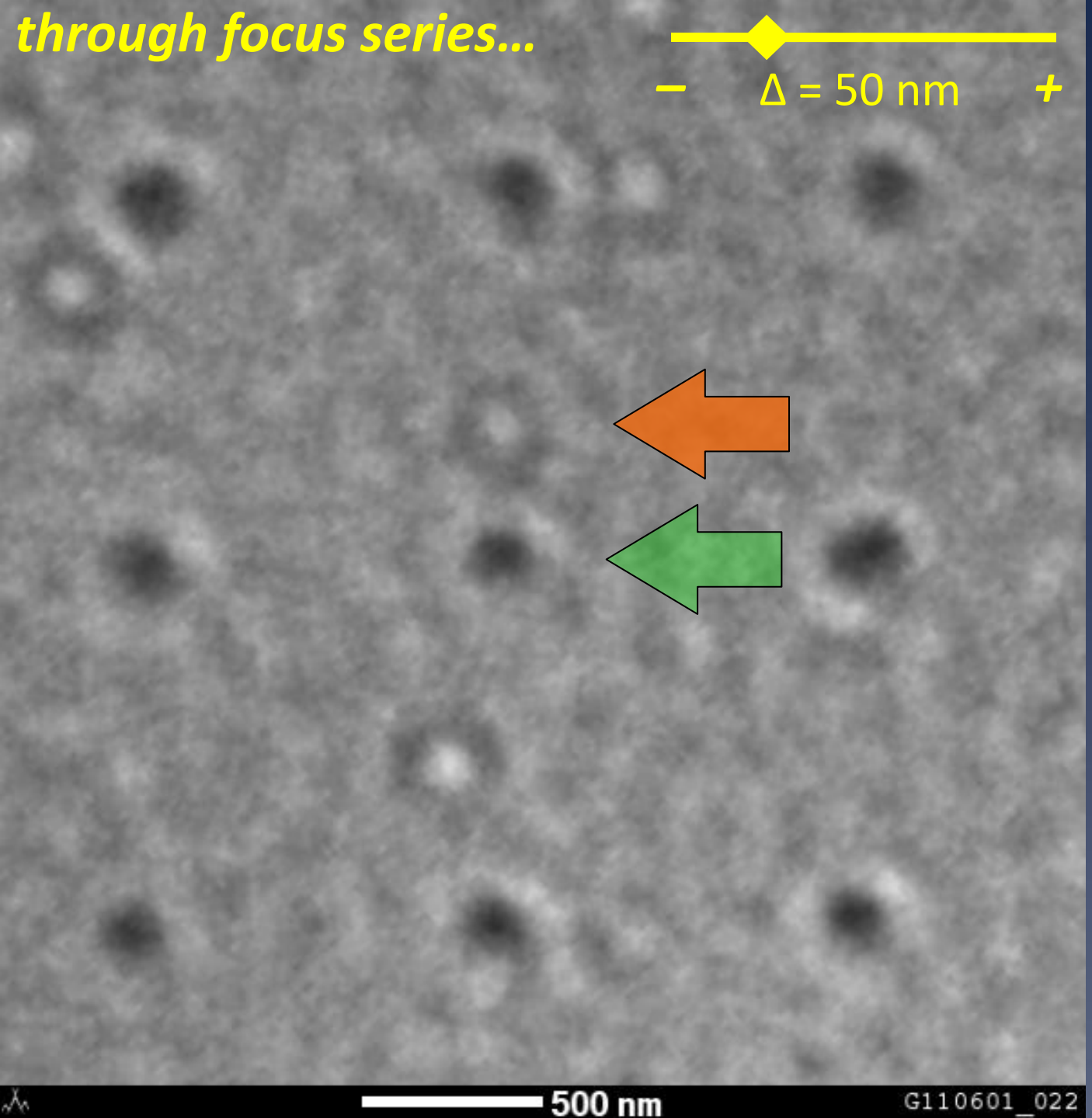

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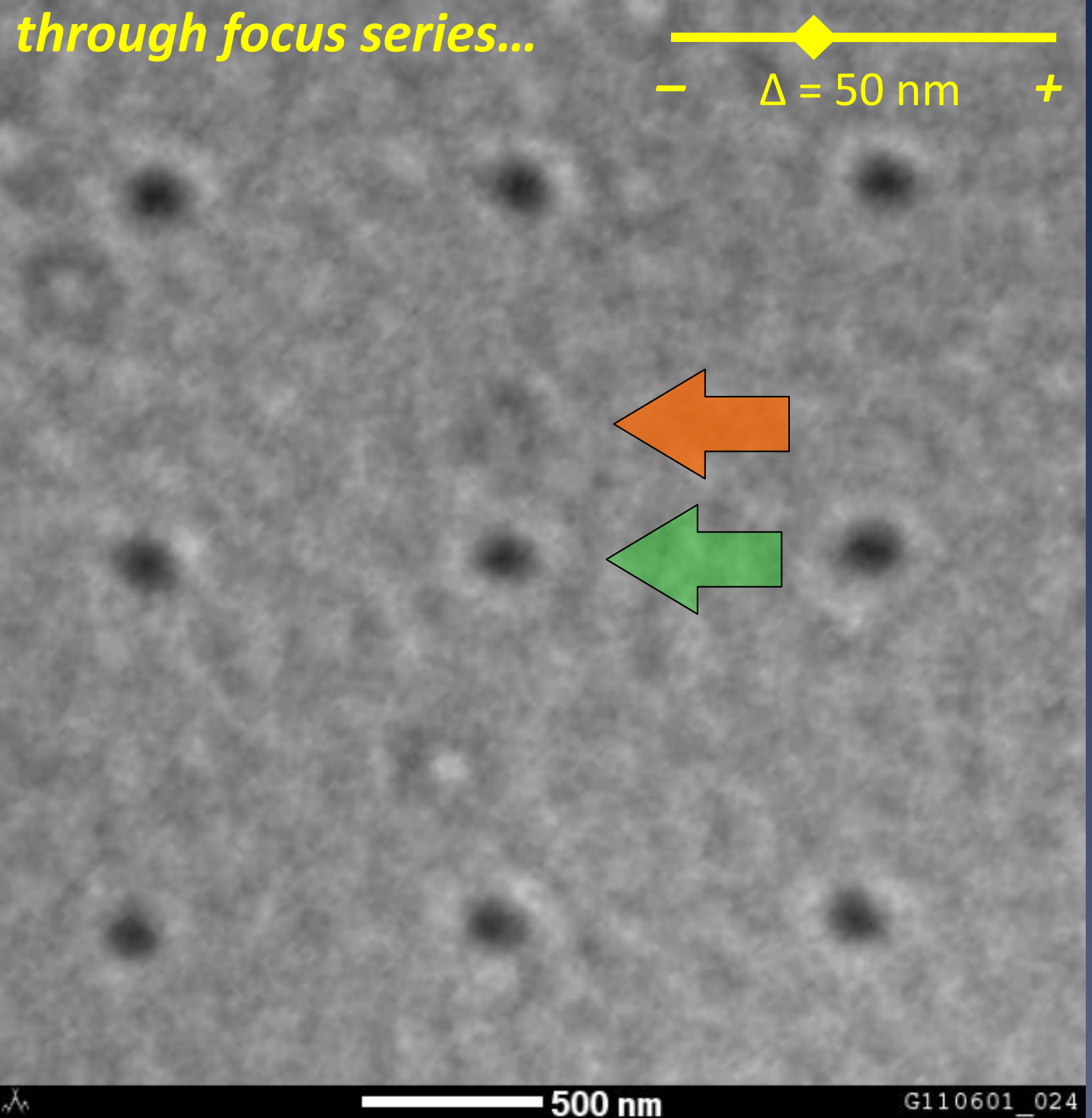

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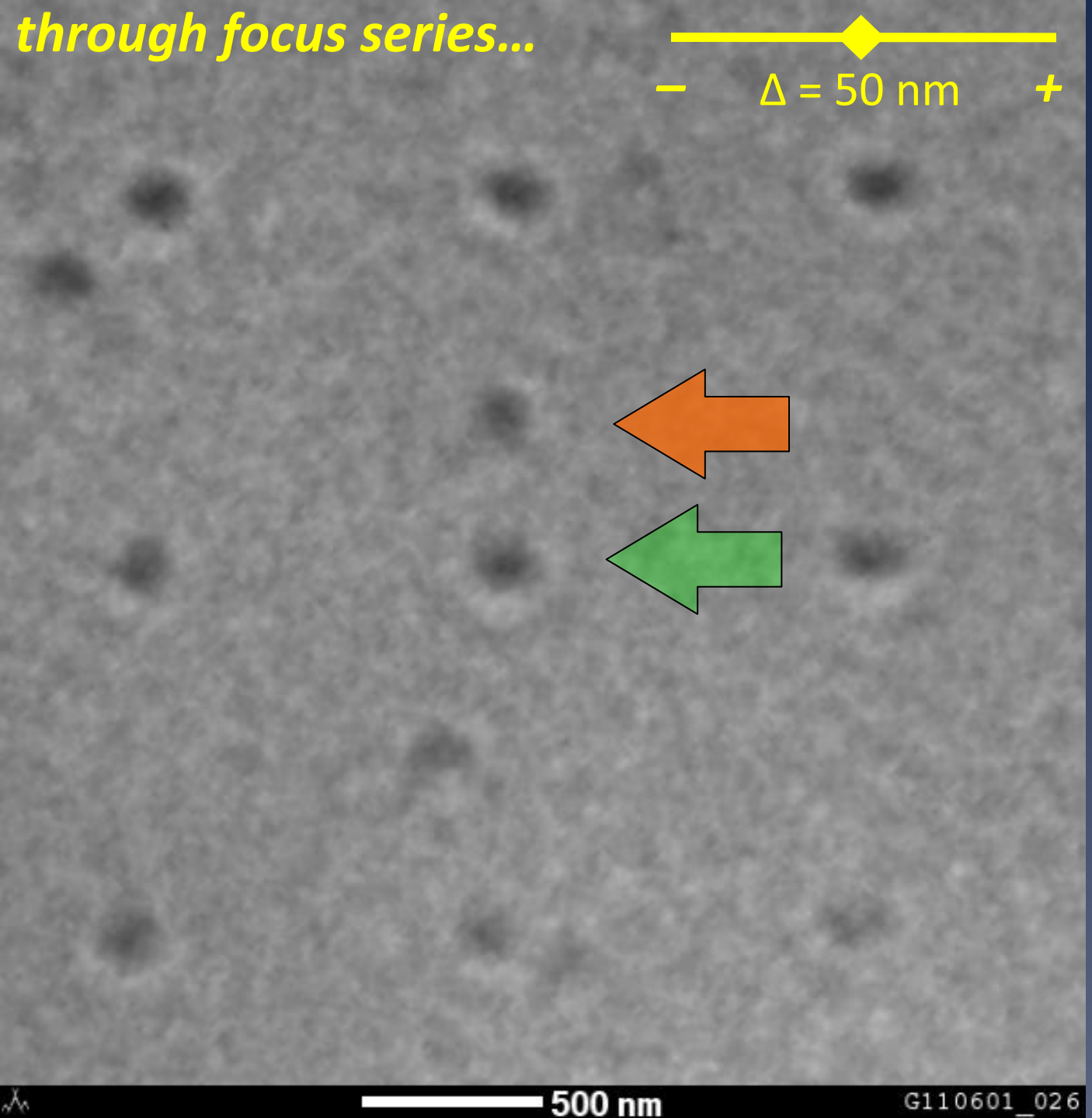

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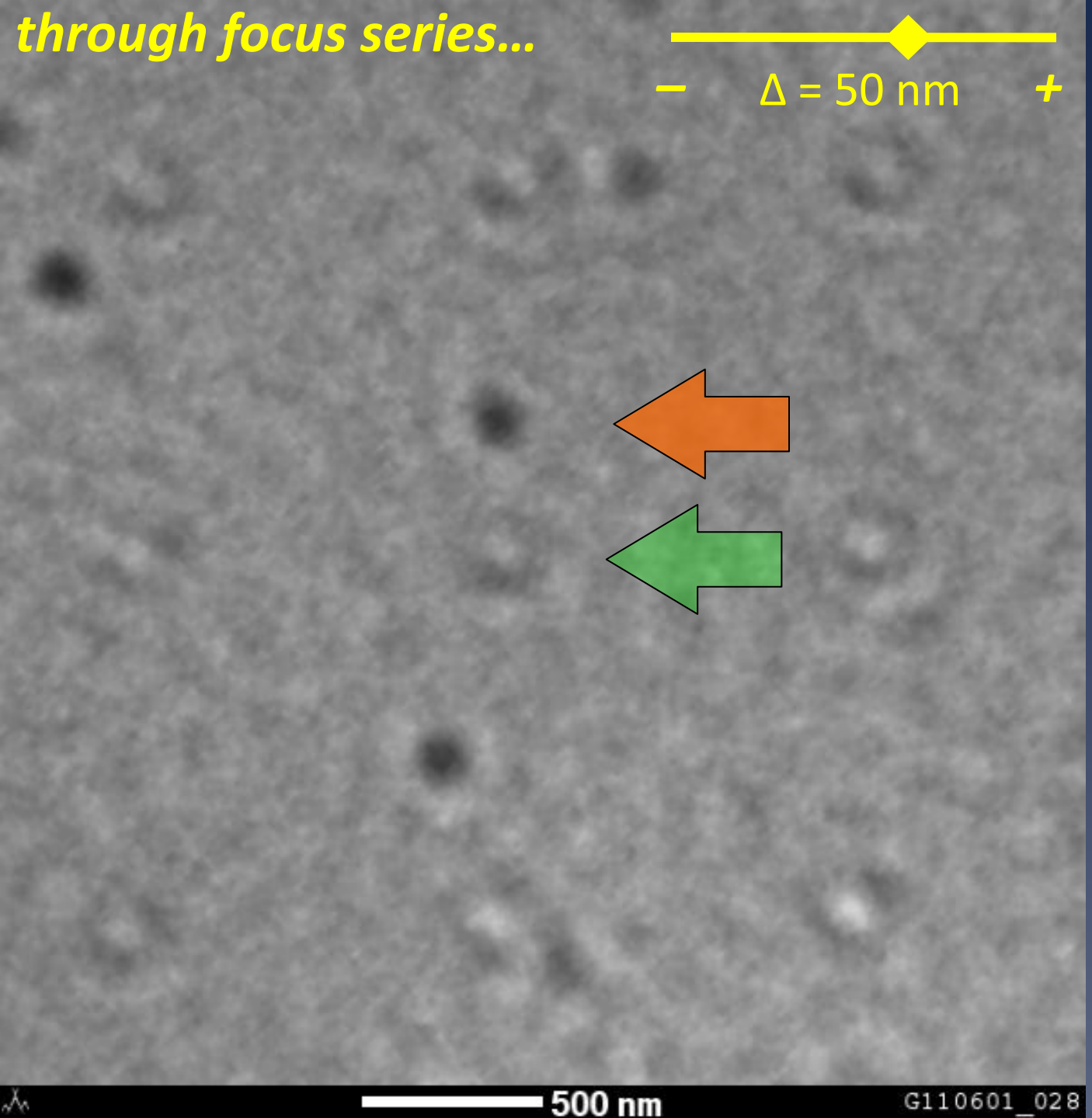

SEMATECH

Phase Defect Studies

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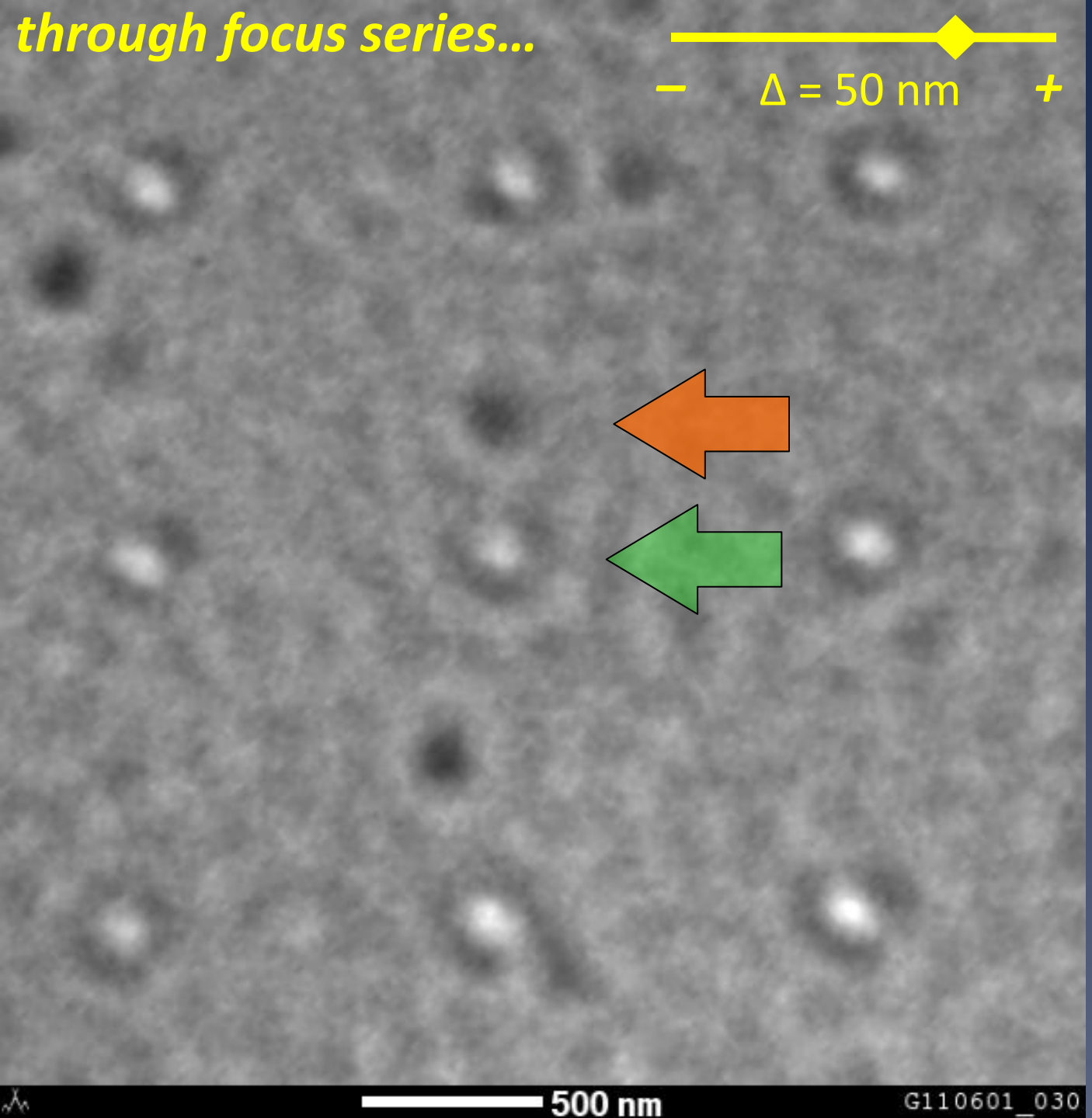

SEMATECH

Phase Defect Studies

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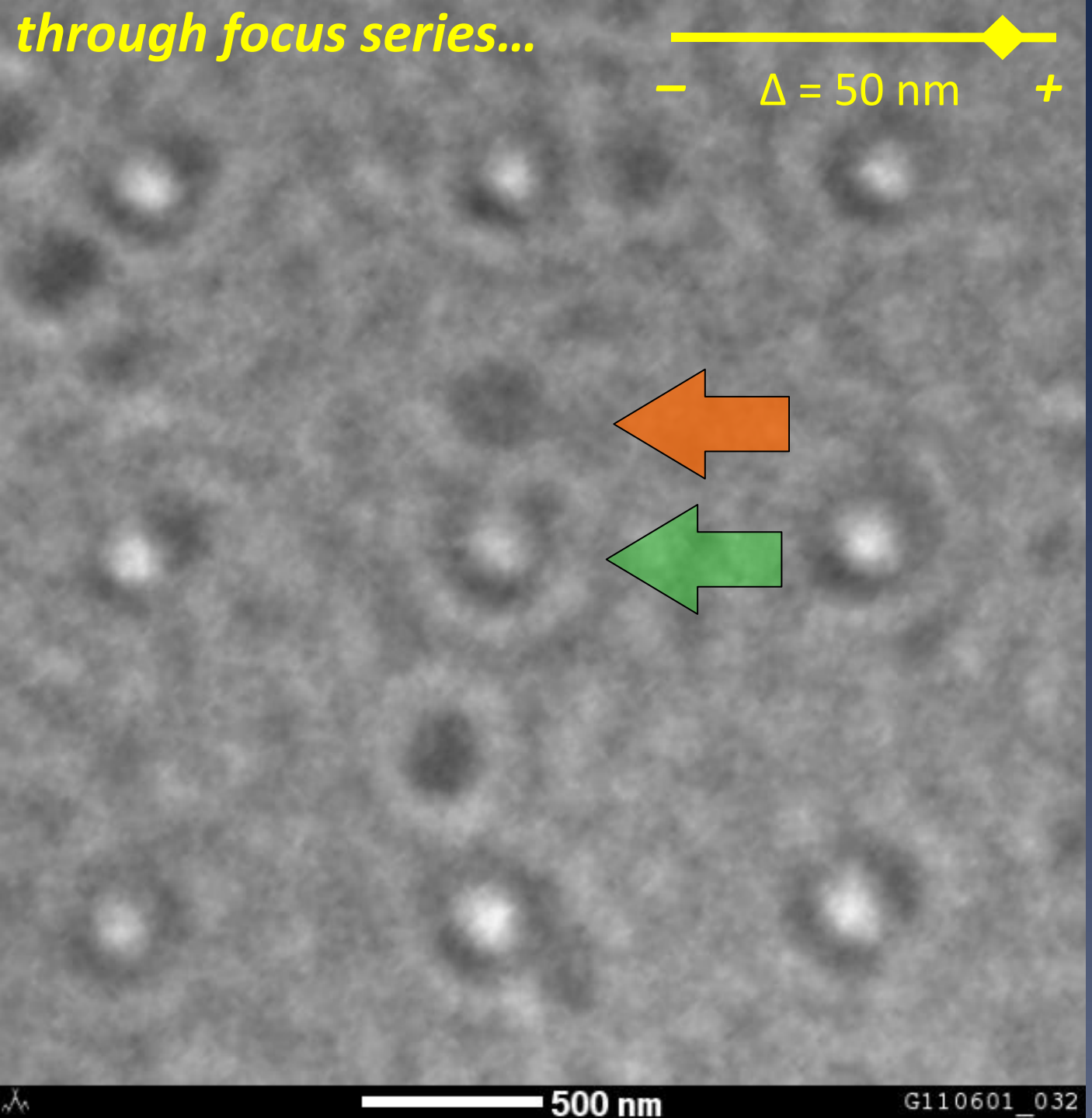

SEMATECH

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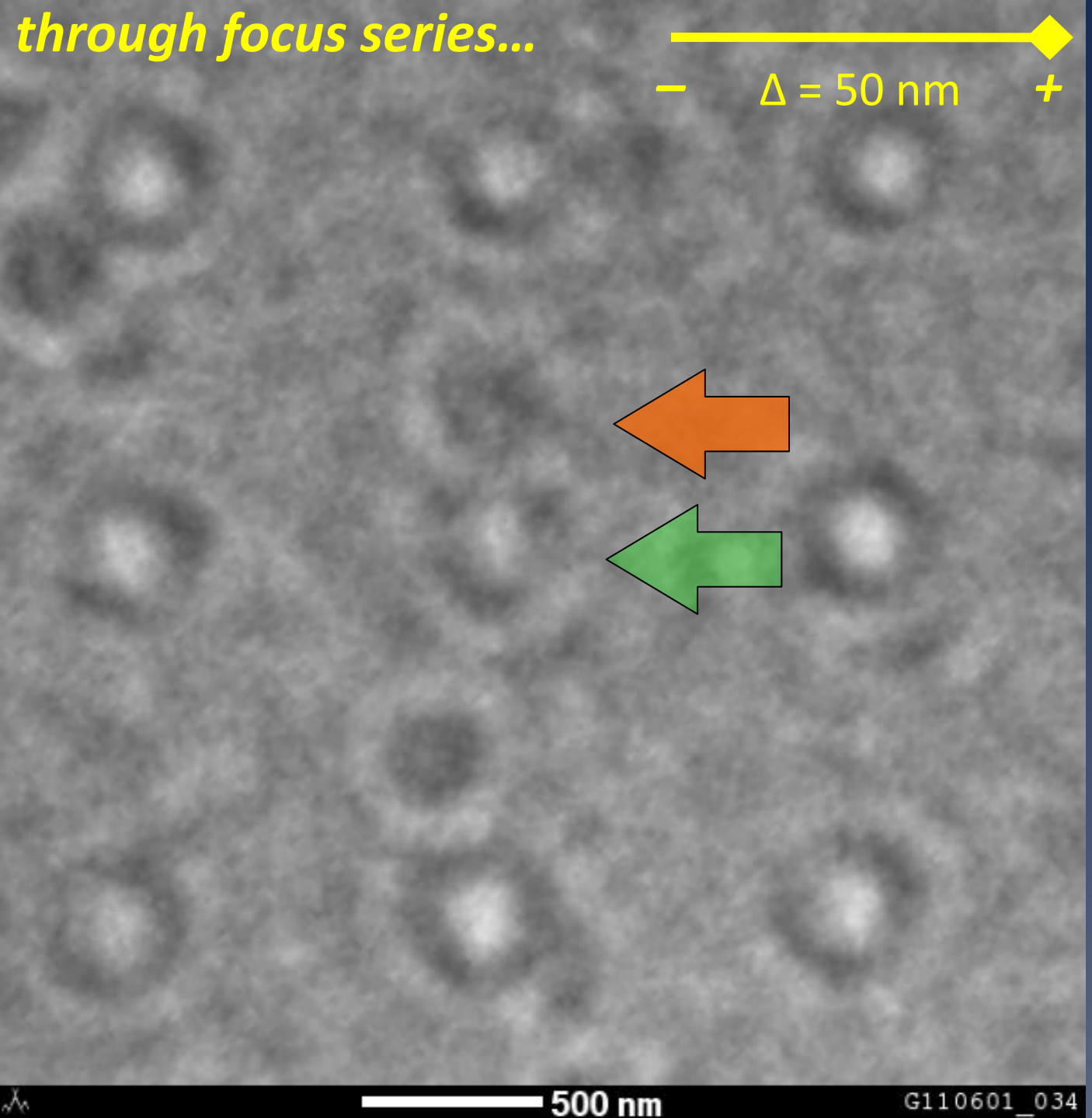
Kwon, *et al.*, *unpublished 2011*



SEMATECH

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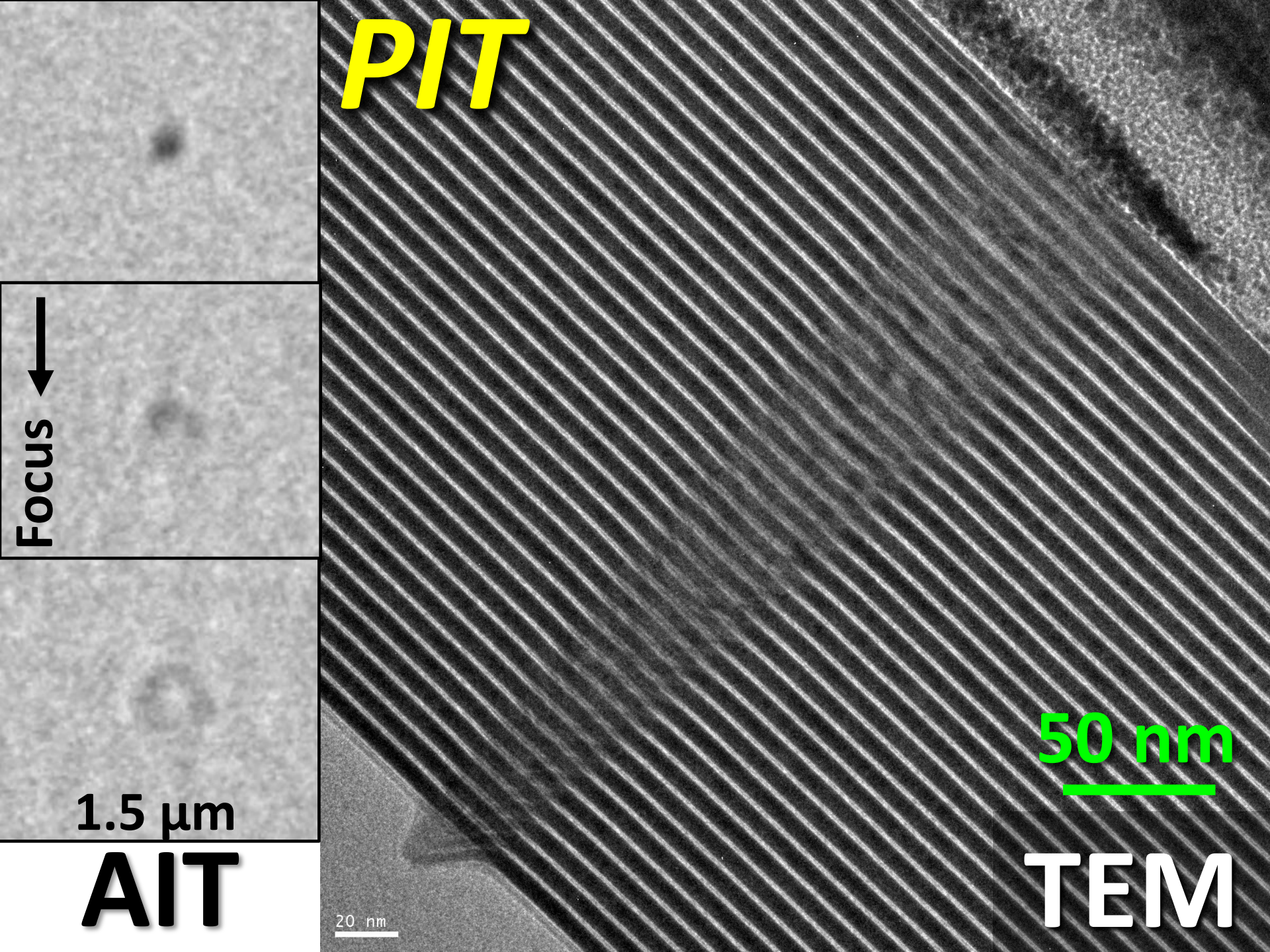
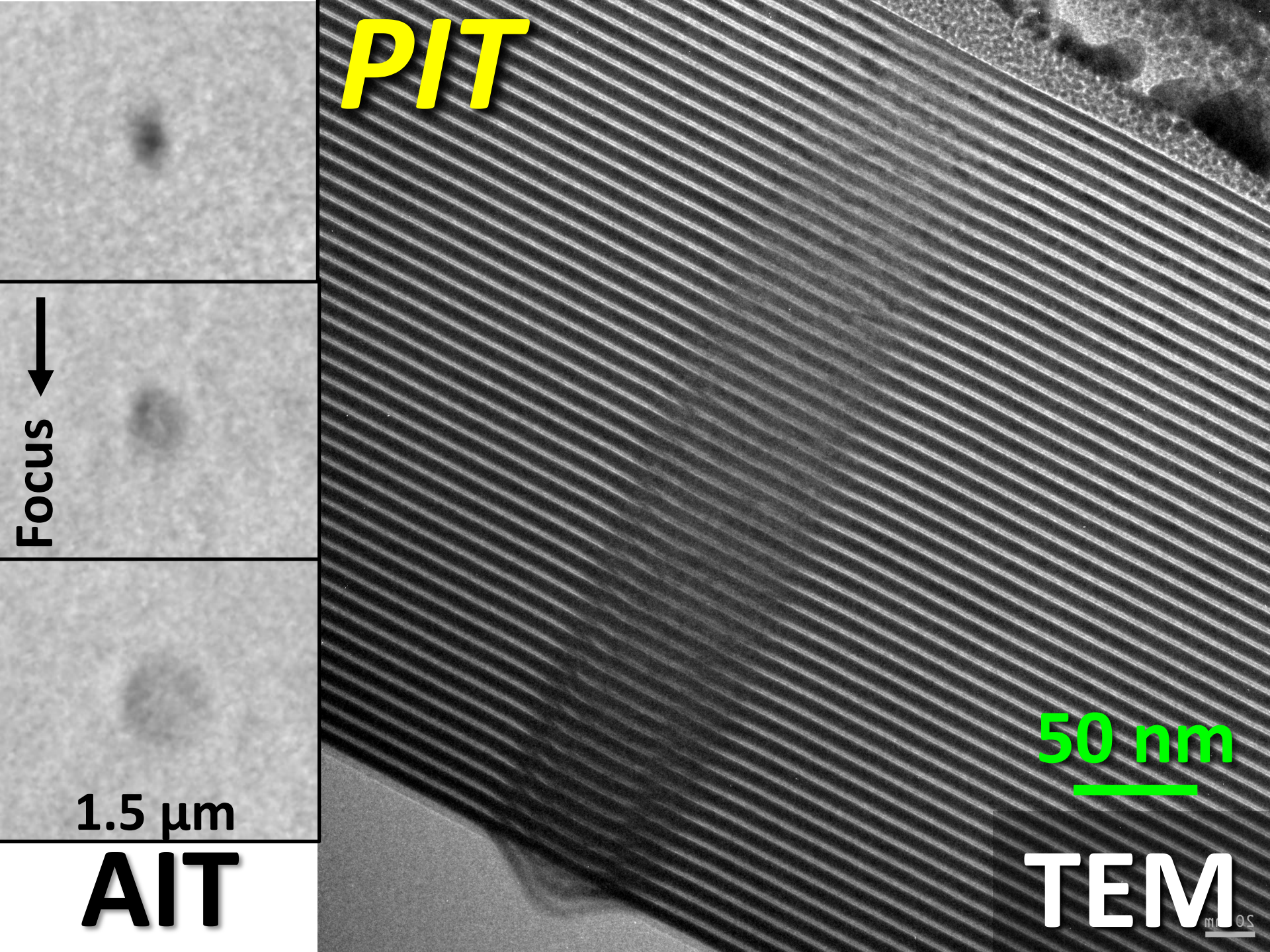
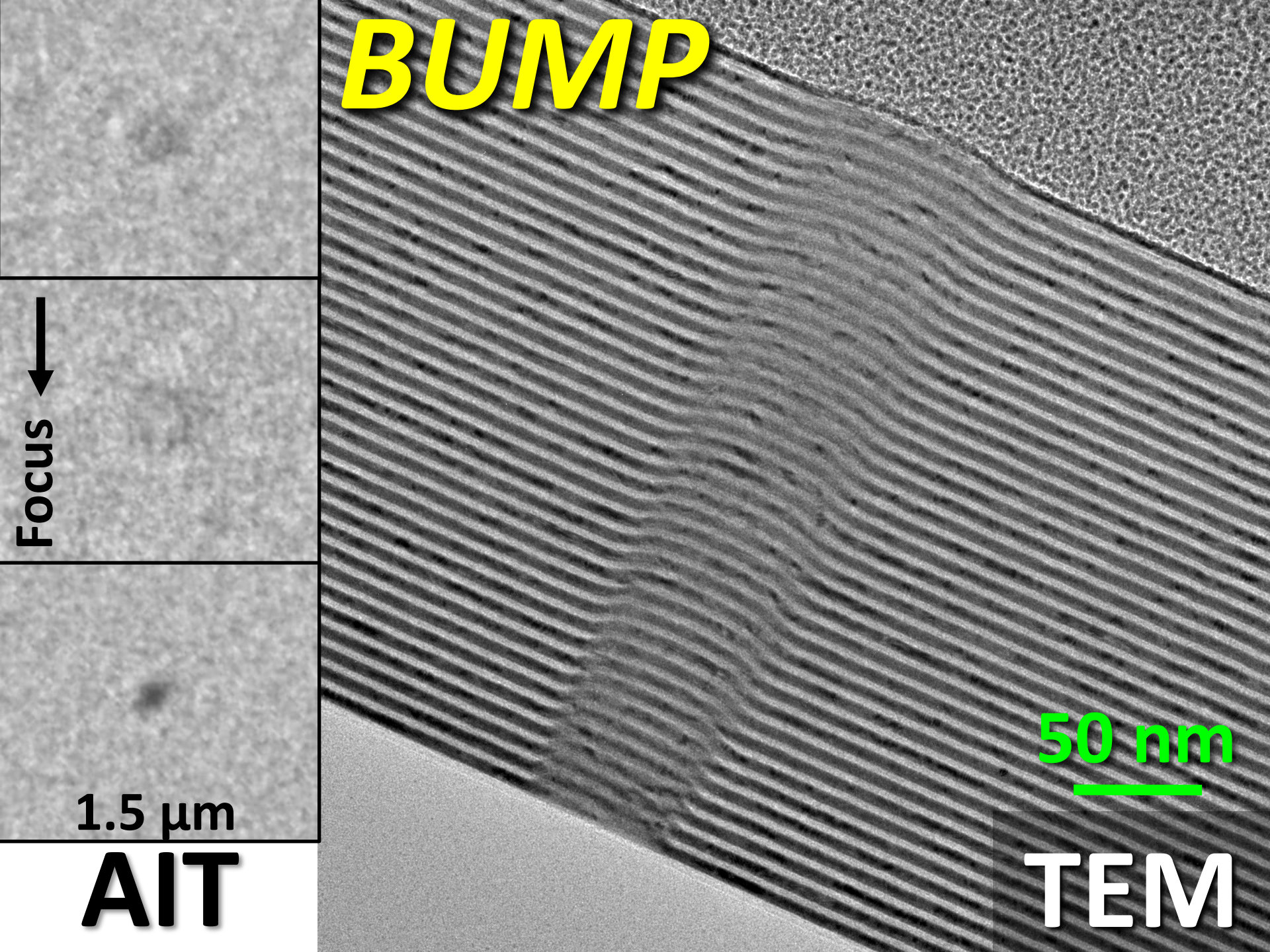

PIT
Focus
1.5 µm
AIT
50 nm
TEM
20 nm


PIT
Focus
1.5 µm
AIT
50 nm
TEM


BUMP
Focus
1.5 µm
AIT
50 nm
TEM

Phase Structure Studies

EUVL Alternating Phase Shift Mask

Pei-Yang Yan[1], Alan Myers[1], Yashesh Shroff[1], Manish Chandhok[1], Guojing Zhang[1], Eric Gullikson[2], and Farhad Salmassi[2]

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ABSTRACT

Extreme ultra-violet Lithography (EUVL) alternating phase shift mask (APSM) or other optical enhancement techniques are likely needed for 16nm (half pitch) technology generation and beyond. One possible option is the combination of EUVL and APSM. The fabrication of EUVL APSM is more difficult than either the fabrication of an EUVL binary mask or a conventional optical APSM mask. In the case of EUVL APSM, the phase difference in the two regions (0 and 180-degree phase regions) is created by a phase step in the substrate prior to the multilayer (ML) coating. The step height that induces 180-degree phase mismatch in the ML is determined by $\{\lambda/(4\cos\theta)\}(2m+1)$, where m are integers (0, 1, 2, ...). In this experiment, we targeted for a step height with m=1. The same mask design also contains the standard binary structures so that the comparison between the EUVL APSM and the EUVL binary mask can be performed under the same illumination and wafer process conditions. The EUVL APSM mask was exposed using Nikon's EUV1 scanner in Kumagaya Japan. The wafer level results showed higher dense line resolution for EUVL APSM as compared to that of EUVL binary mask. APSM also showed improved line width roughness (LWR) and depth of focus (DoF) as compared to the best EUVL binary results obtained with C-dipole off-axis illumination (OAI). The wafer CD resolution improvement obtained by APSM in this experiment is partially limited by the resist resolution and the mask phase edge spread during ML deposition. We believe that wafer CD resolution and can further be improved with imaging imbalance compensation mask design and improvements in resist resolution and the phase generation portion of the mask fabrication process. In this paper, we will discuss in detail the mask fabrication process, wafer level data analysis, and our understanding of EUVL APSM related issues.

Keywords: Extreme ultra-violet lithography (EUVL), EUVL Alternating phase shift mask (EUVL APSM). Phase error, EUVL mask, EUVL multilayer.

1. INTRODUCTION

EUVL technology is targeted for 10nm logic technology node high volume production in 2015 followed by the 7nm node in 2017. EUVL APSM for these technology generations could provide a larger process window than that of conventional binary EUVL. It also provides advantages in reducing the required dose-to-target, which in turn, will increase the wafer throughput. Although the resolution limit of EUVL using a conventional binary EUVL mask can be further pushed by using off axis illumination (OAI) , its limitation for isolated and semi-isolated lines and other non-optimized half pitch (HP) patterns will prevent the extension of such enhancement for a variety of pattern designs. Fig. 1, shows a simulation of aerial image contrast as a function of HP for EUVL APSM with conventional illumination of σ=2 and for EUVL binary

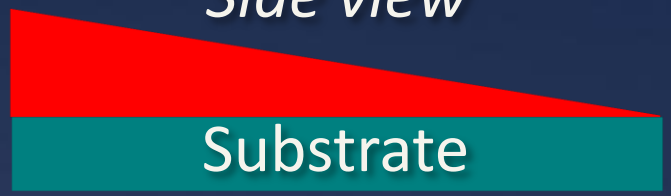
Fig. 1 Schematics of EUVL APSM phase layer design and fabrication, (a) side view and (b) top view.

Extreme Ultraviolet (EUV) Lithography II, edited by Bruno M. La Fontaine, Patrick P. Naulleau, Proc. of SPIE
Vol. 7969, 79690G · © 2011 SPIE · CCC code: 0277-786X/11/$18 · doi: 10.1117/12.884790

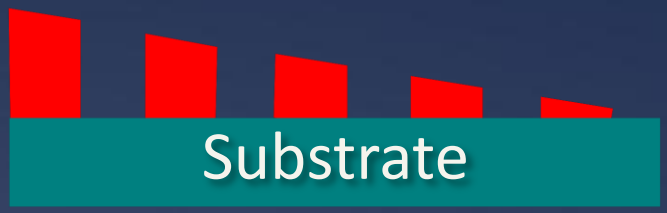
Mask: APSM
Yan, *et al.*, *SPIE 2011*

Side view

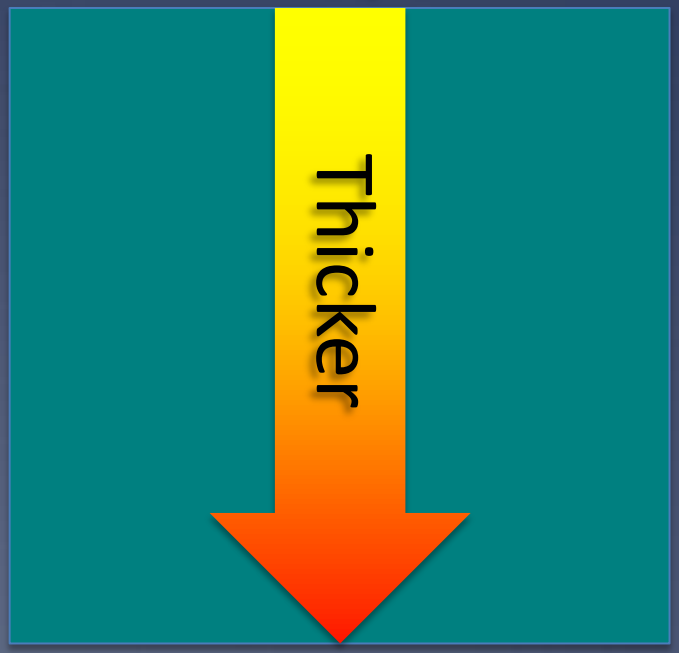
Phase layer →



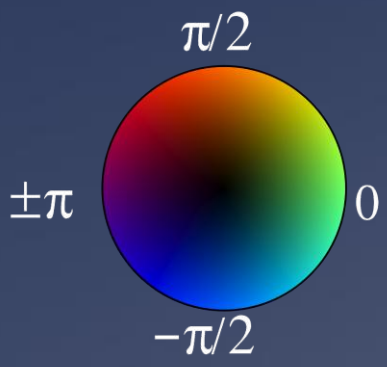
Patterned phase layer →

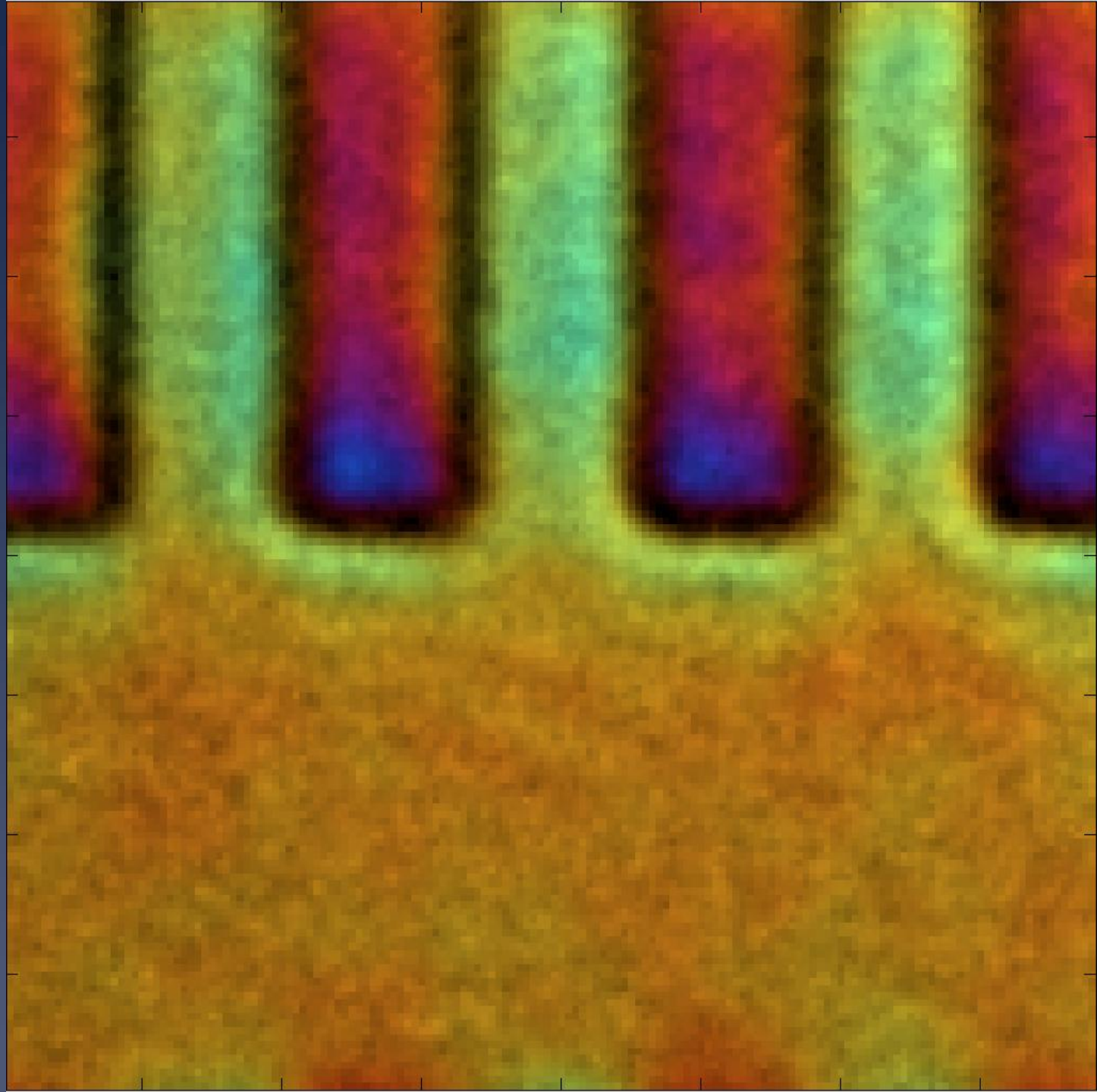


Mask top view

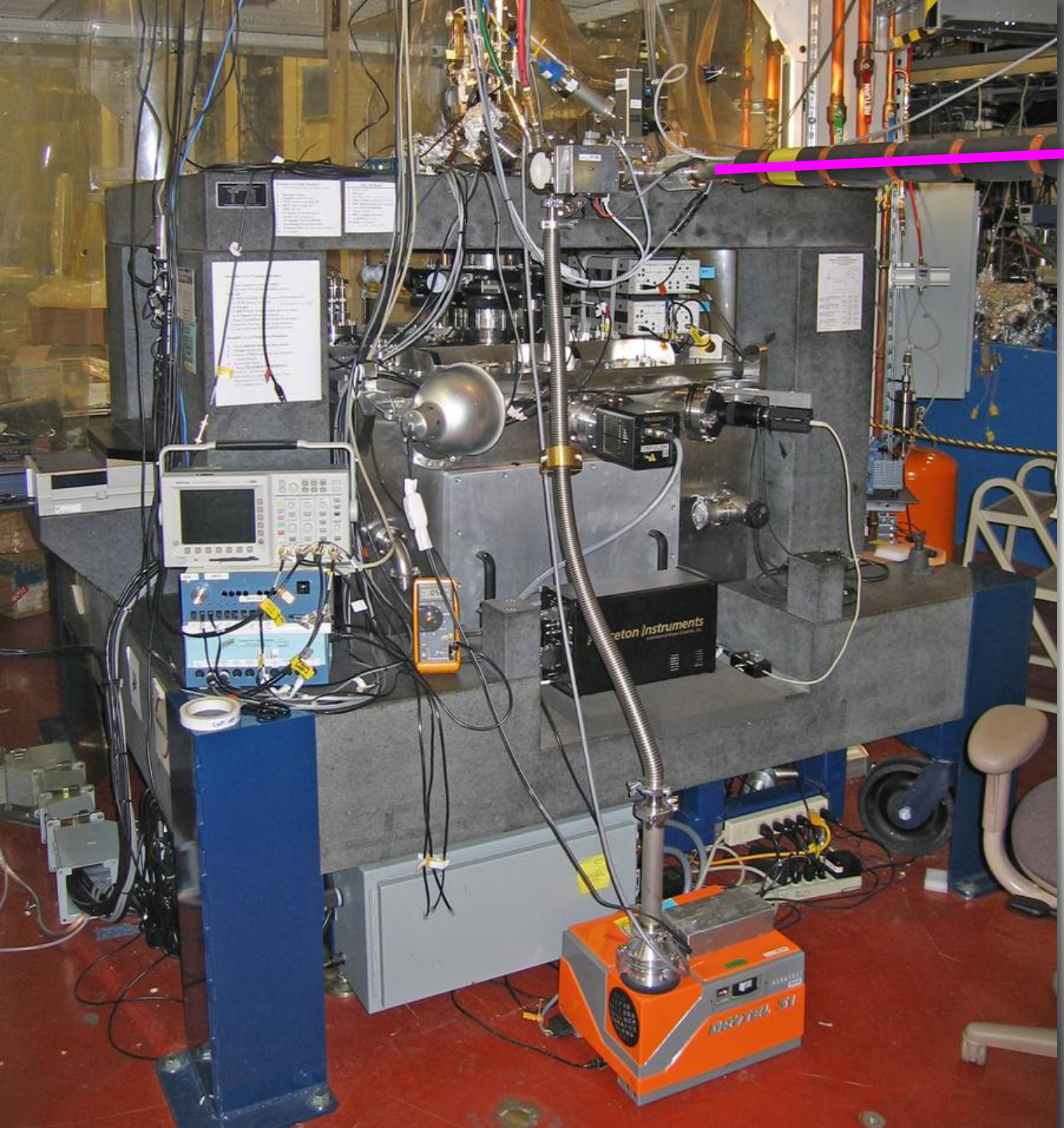


Phase Structure Studies





Mask: APSM
Yan, *et al.*,
unpublished 2011



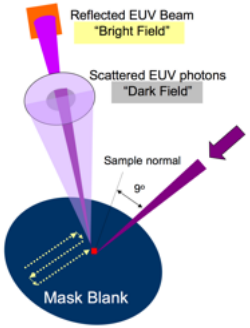
The AIT

The AIT is over 6 years old.

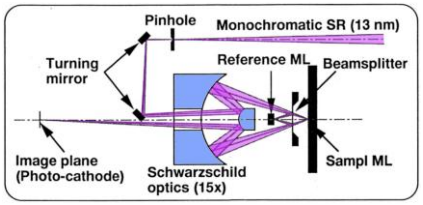
That's 65 in *litho* years.

Photo: Stefan Tell

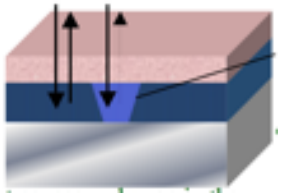
14+ years of actinic mask inspection/imaging



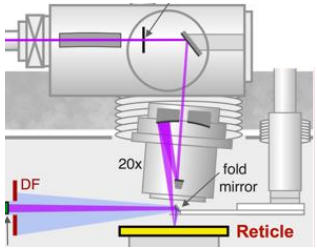
EUV LLC/LBNL



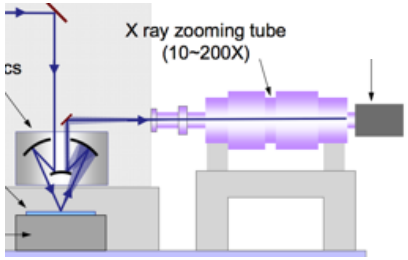
NTT



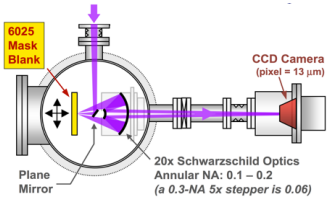
Lucent



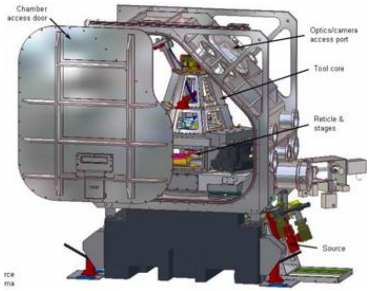
SEMATECH/LBNL



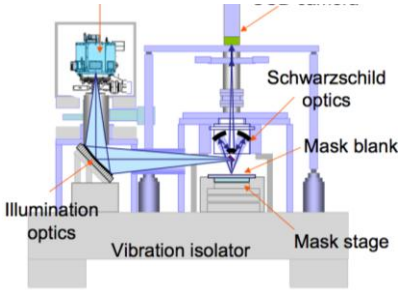
U. Hyogo



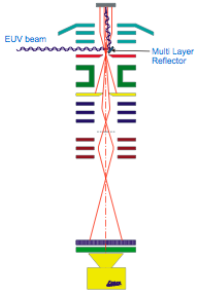
MIRAI



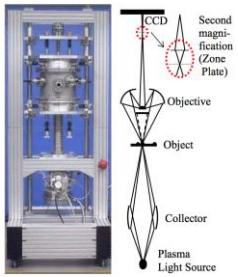
Exitech



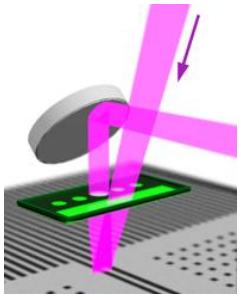
MIRAI II/Selete



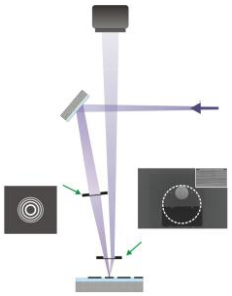
U. Bielefeld



Fraunhofer Institute

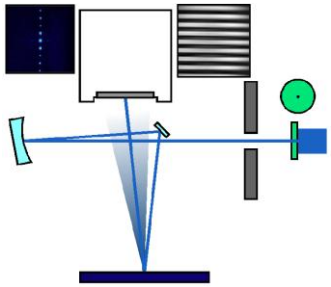


SEMATECH/LBNL



Colorado State

INVENT/CNSE



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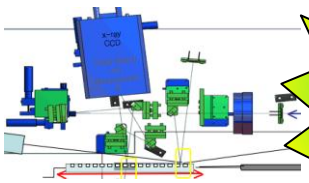
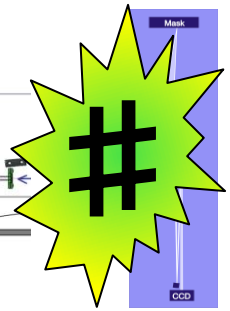


Hanyang



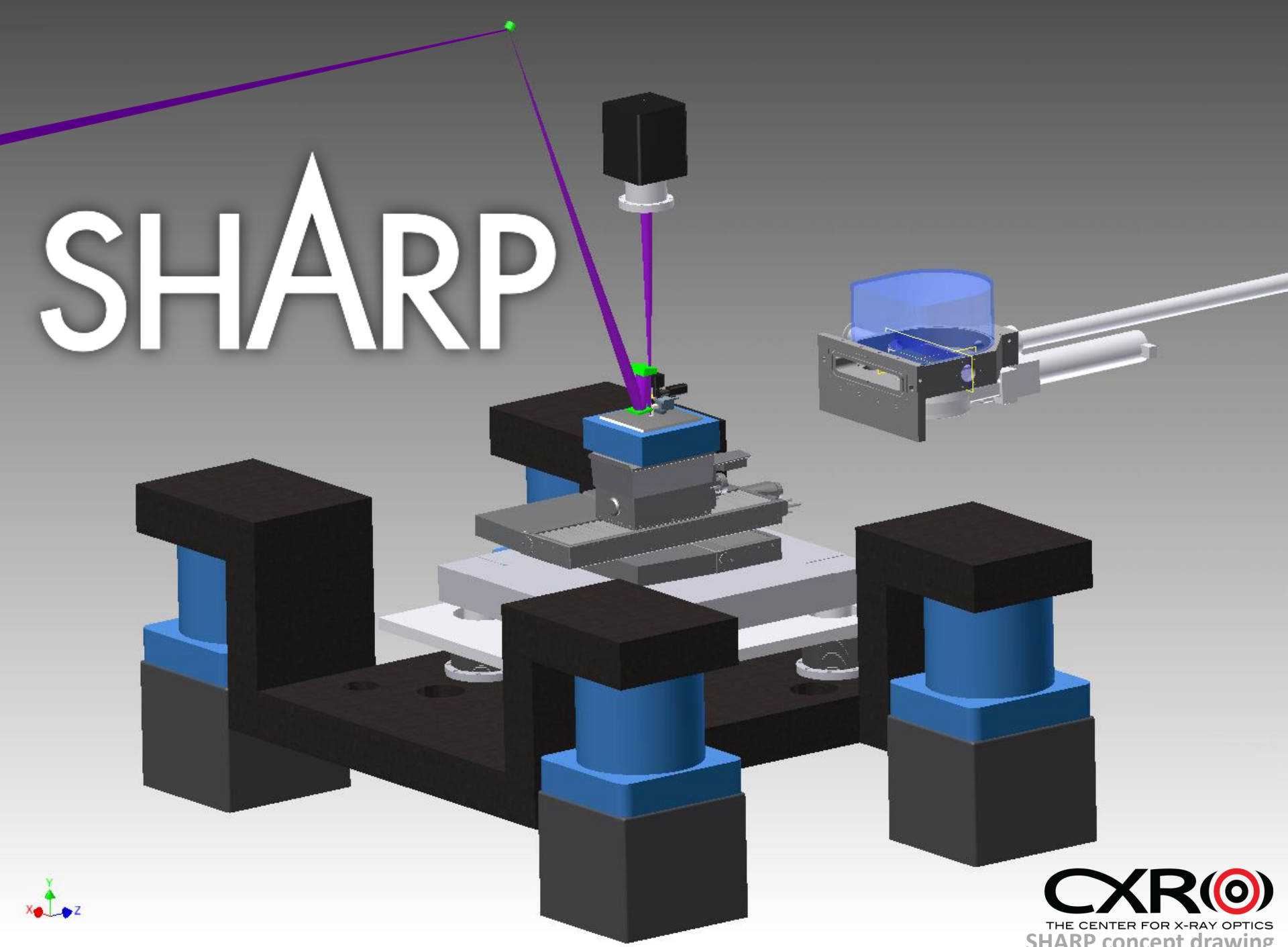
SEMATECH/LBNL 2012

Zeiss 2014

Review: Goldberg, *JVST B* **28** (6), C6E1-10 (2010)

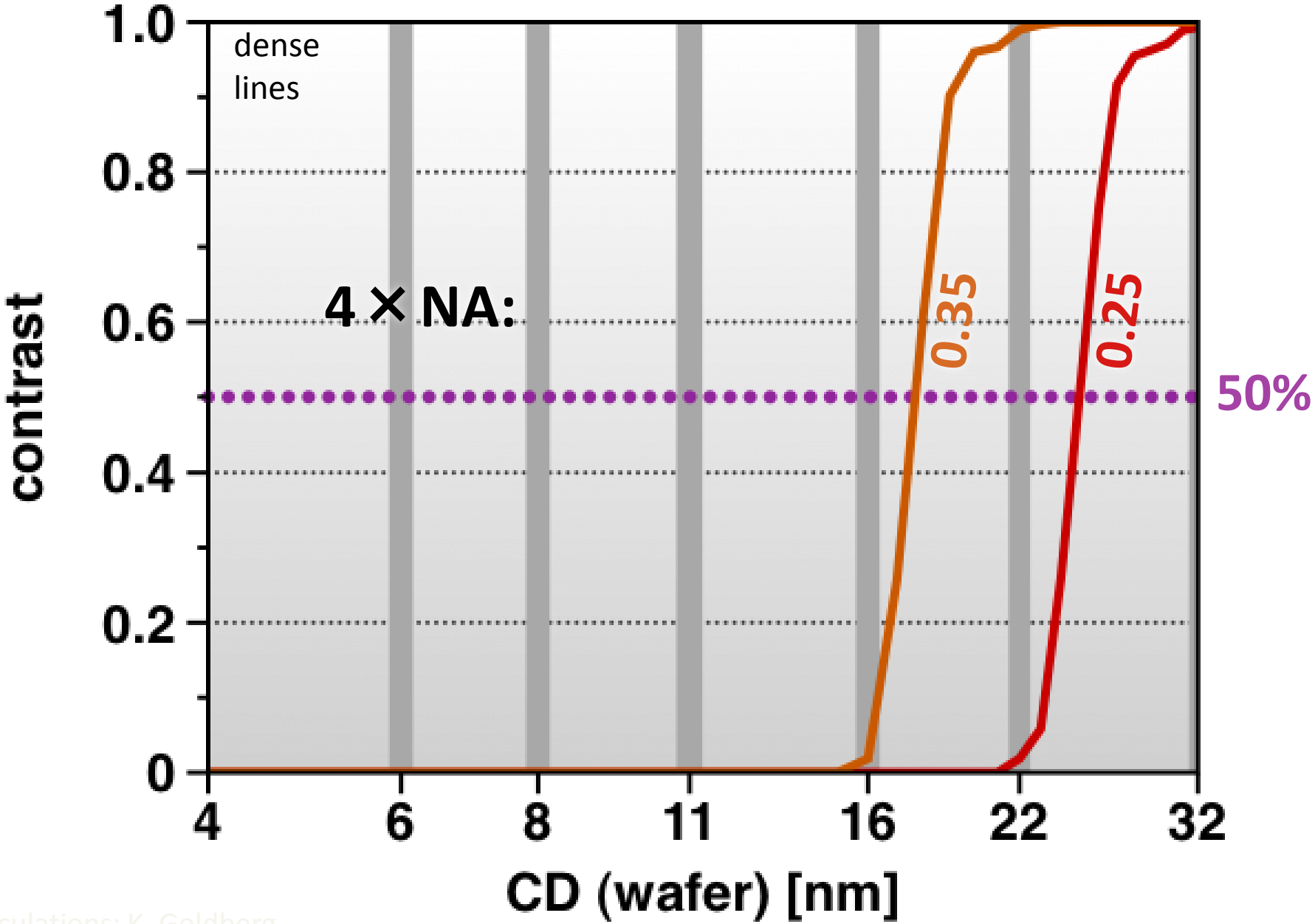
SHARP

SEMATECH HIGH-NA ACTINIC
RETICLE REVIEW PROJECT



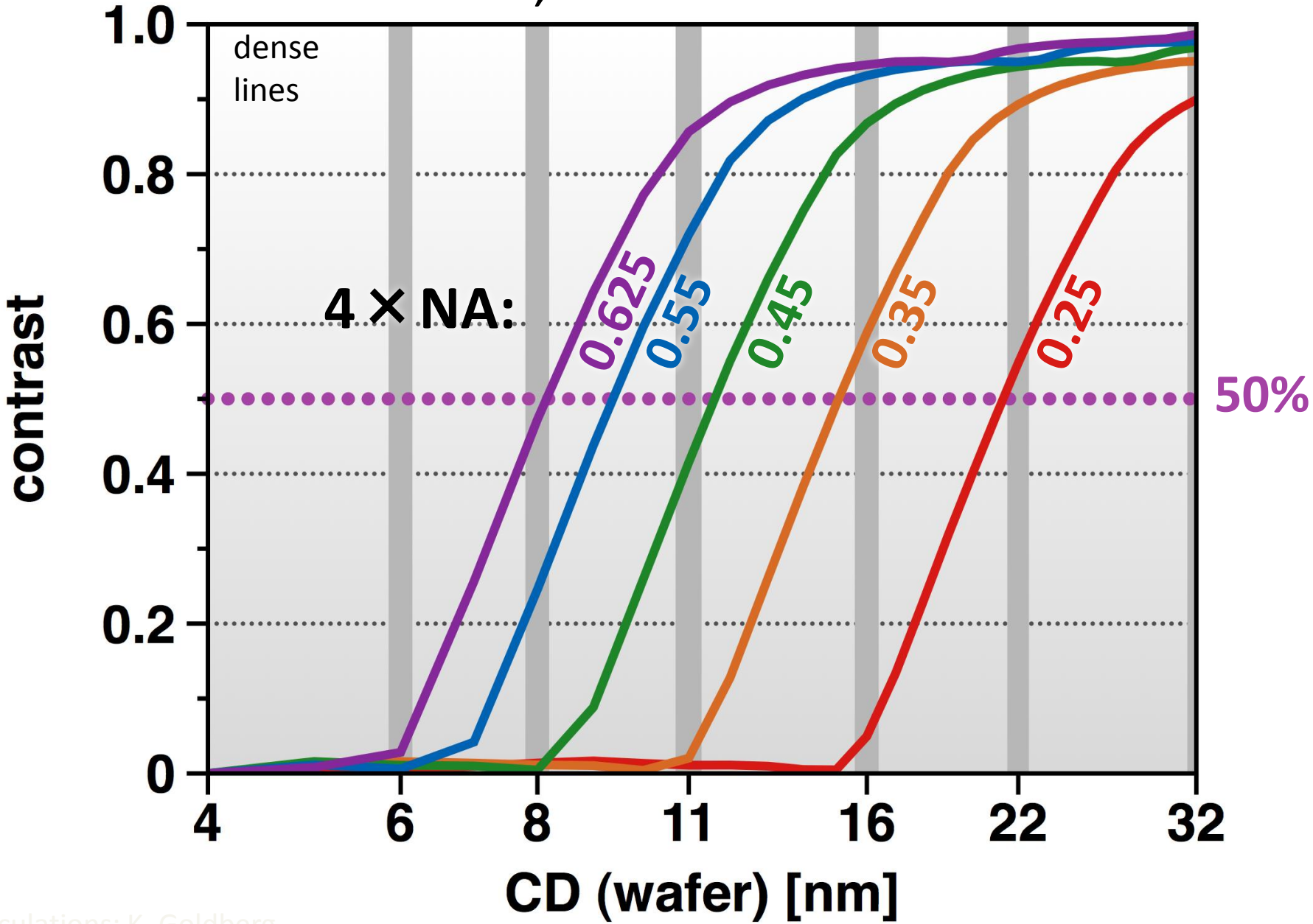
SHARP concept drawing

At σ ≈ 0.2, AIT sees ≥ 16 nm

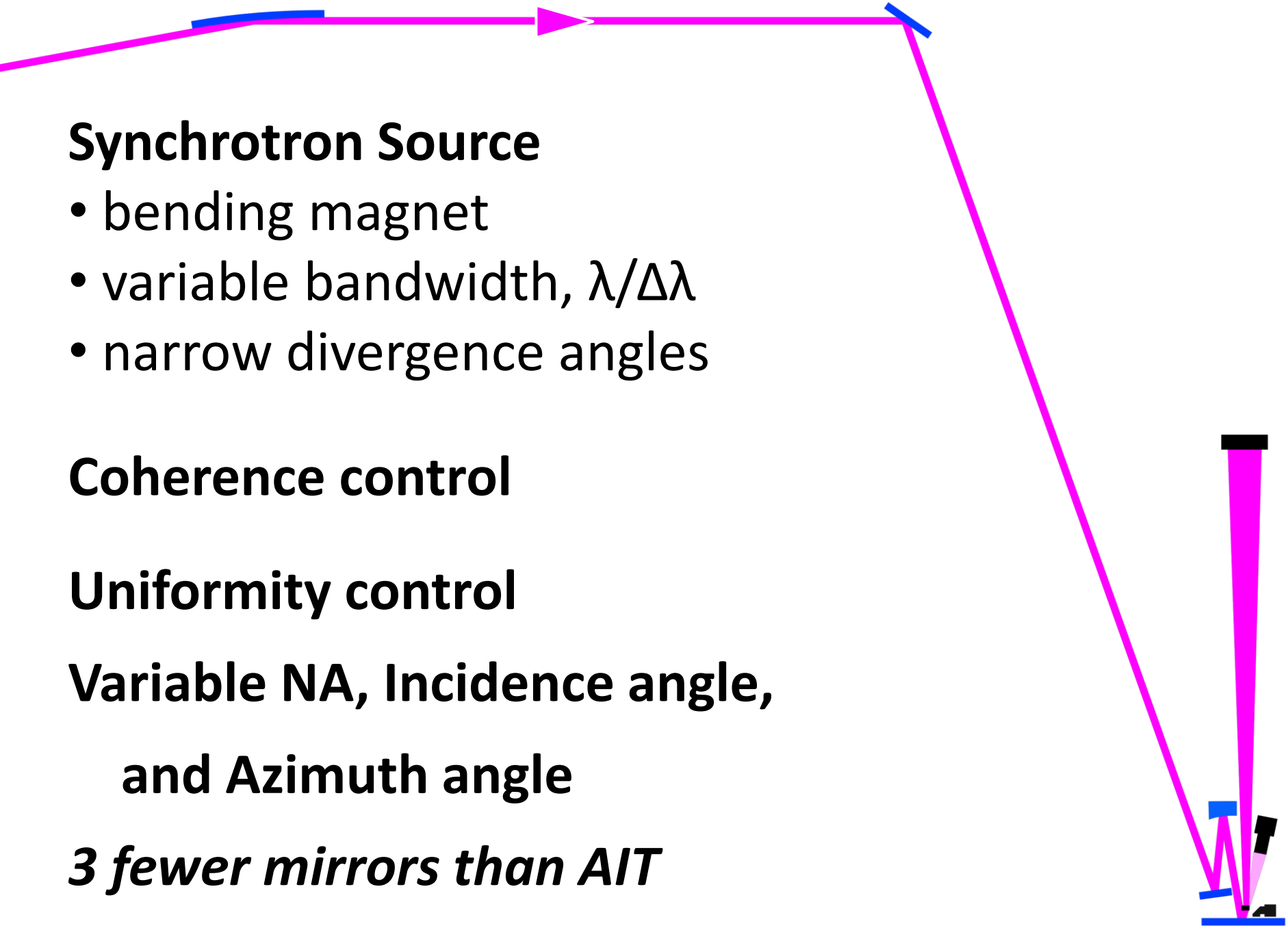


Calculations: K. Goldberg

At σ = 0.8, SHARP will see > 6 nm



Calculations: K. Goldberg



Synchrotron Source

- bending magnet
- variable bandwidth, $\lambda/\Delta\lambda$
- narrow divergence angles

Coherence control

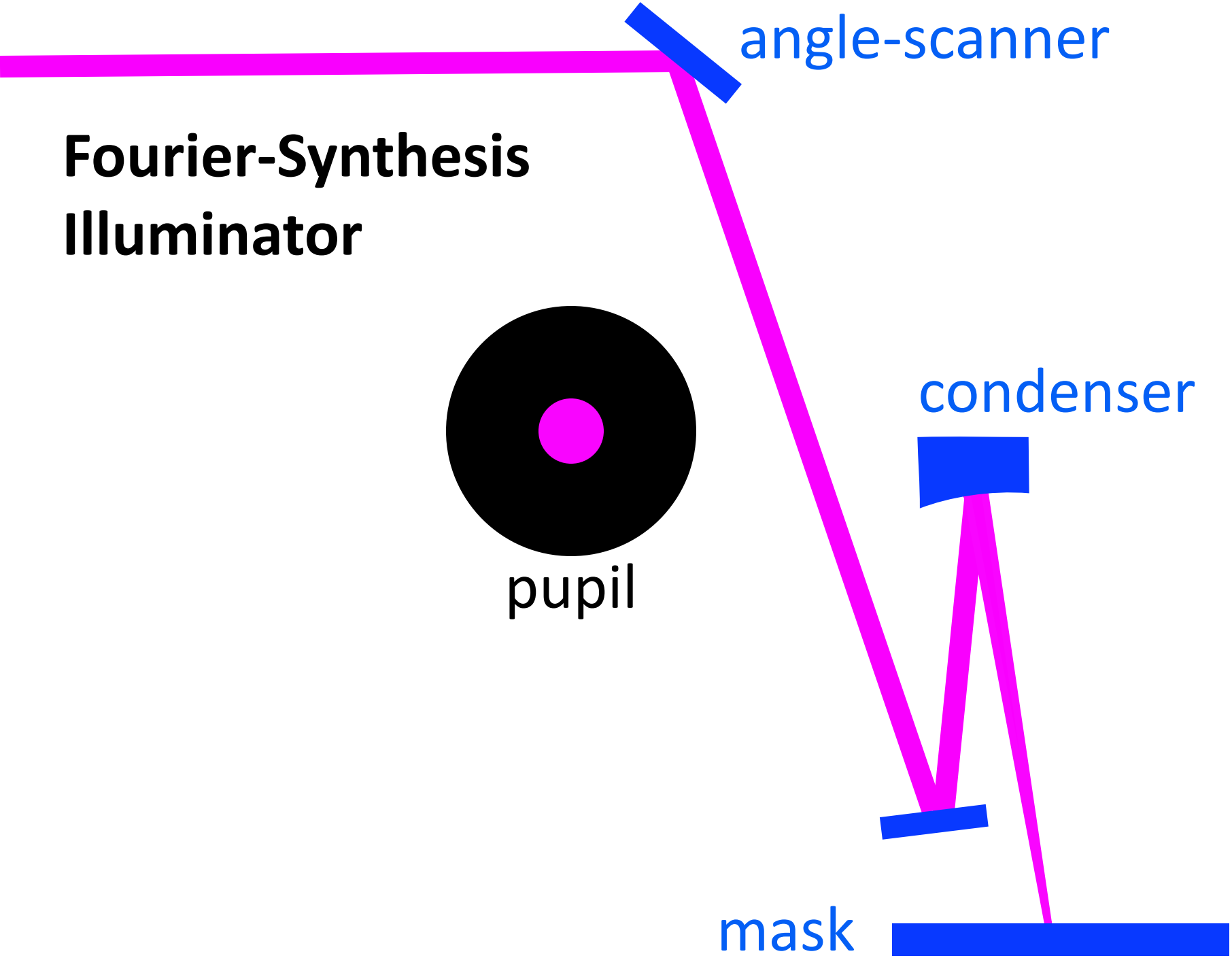
Uniformity control

Variable NA, Incidence angle,

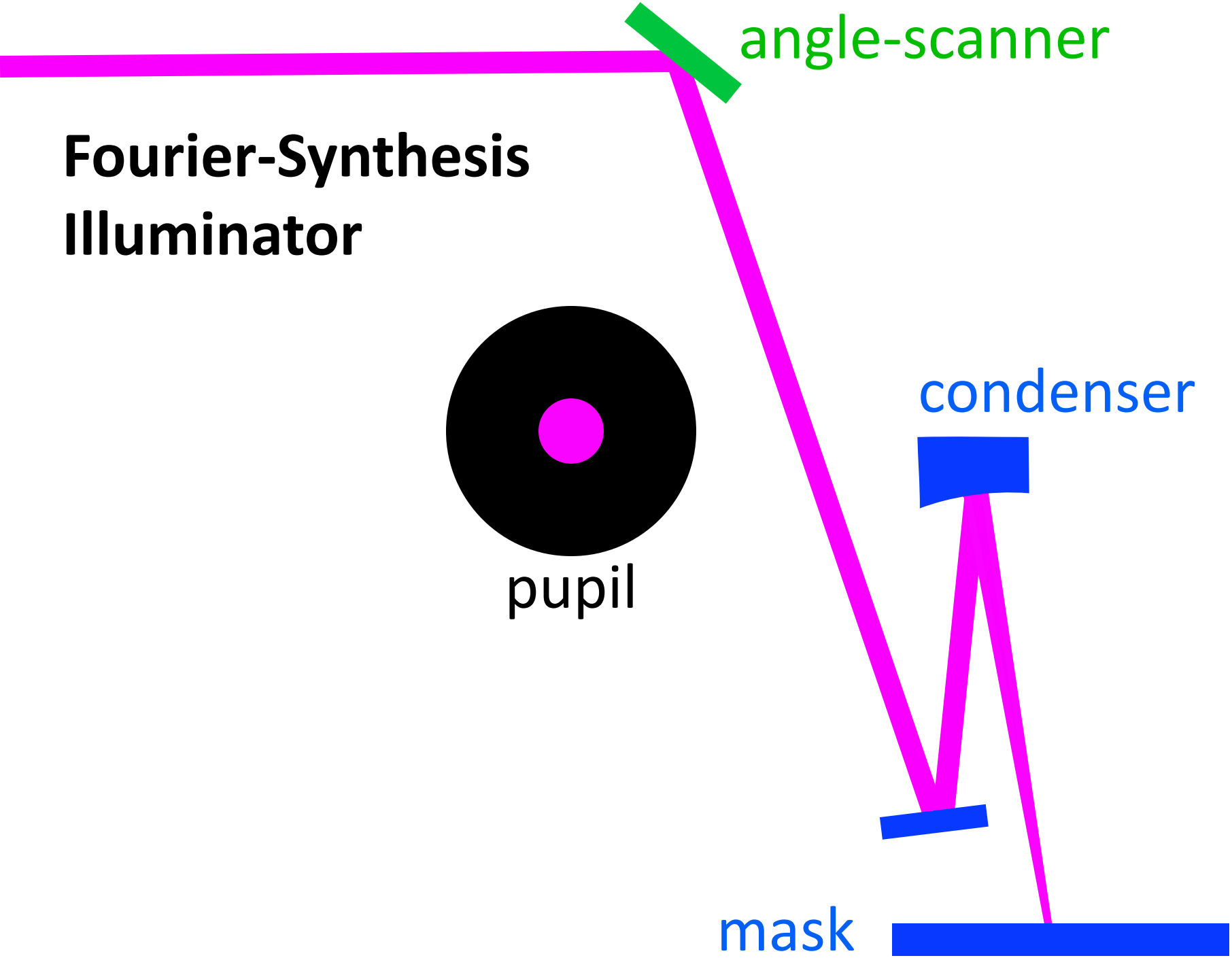
and Azimuth angle

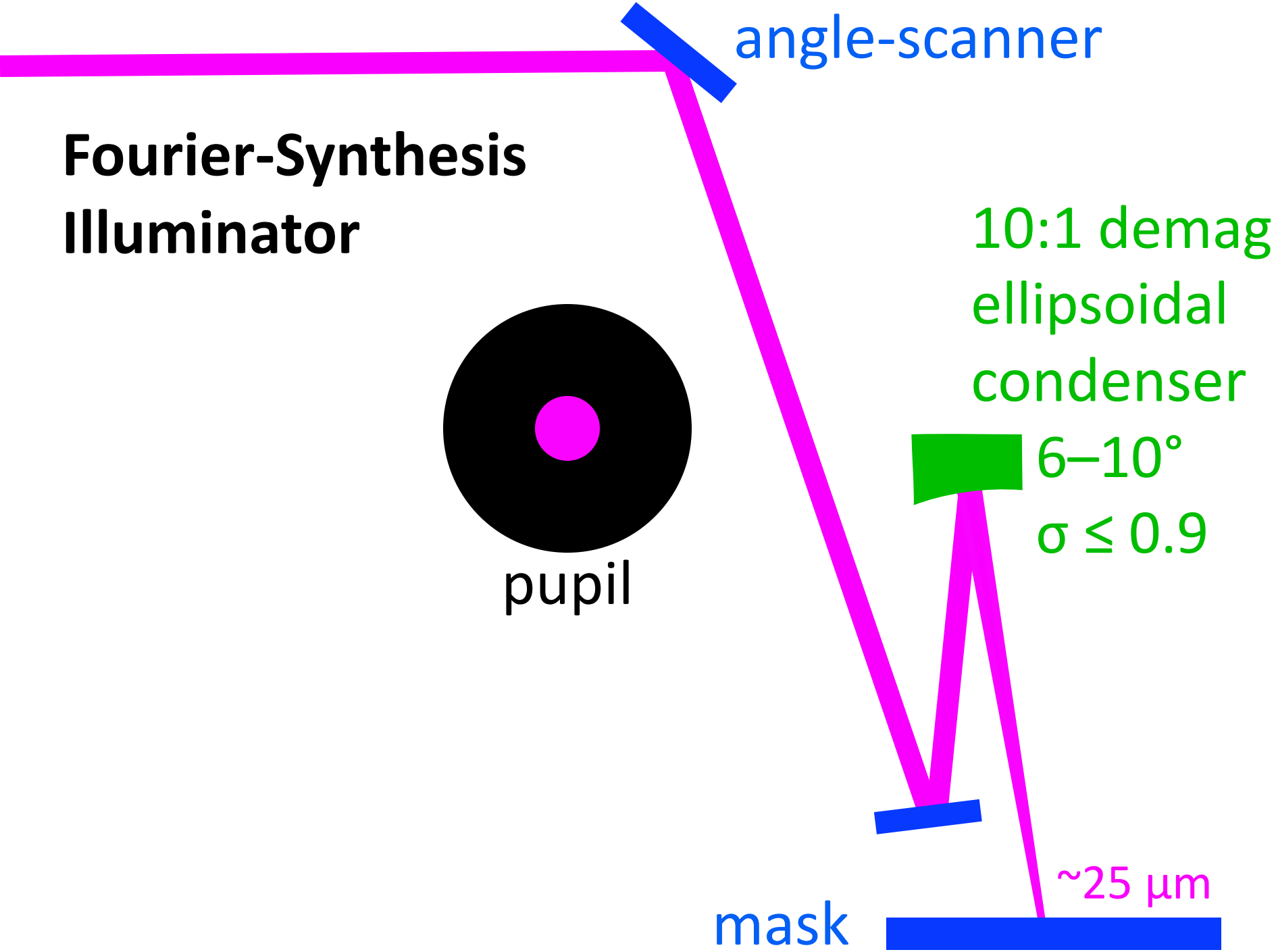
3 fewer mirrors than AIT

Fourier-Synthesis Illuminator

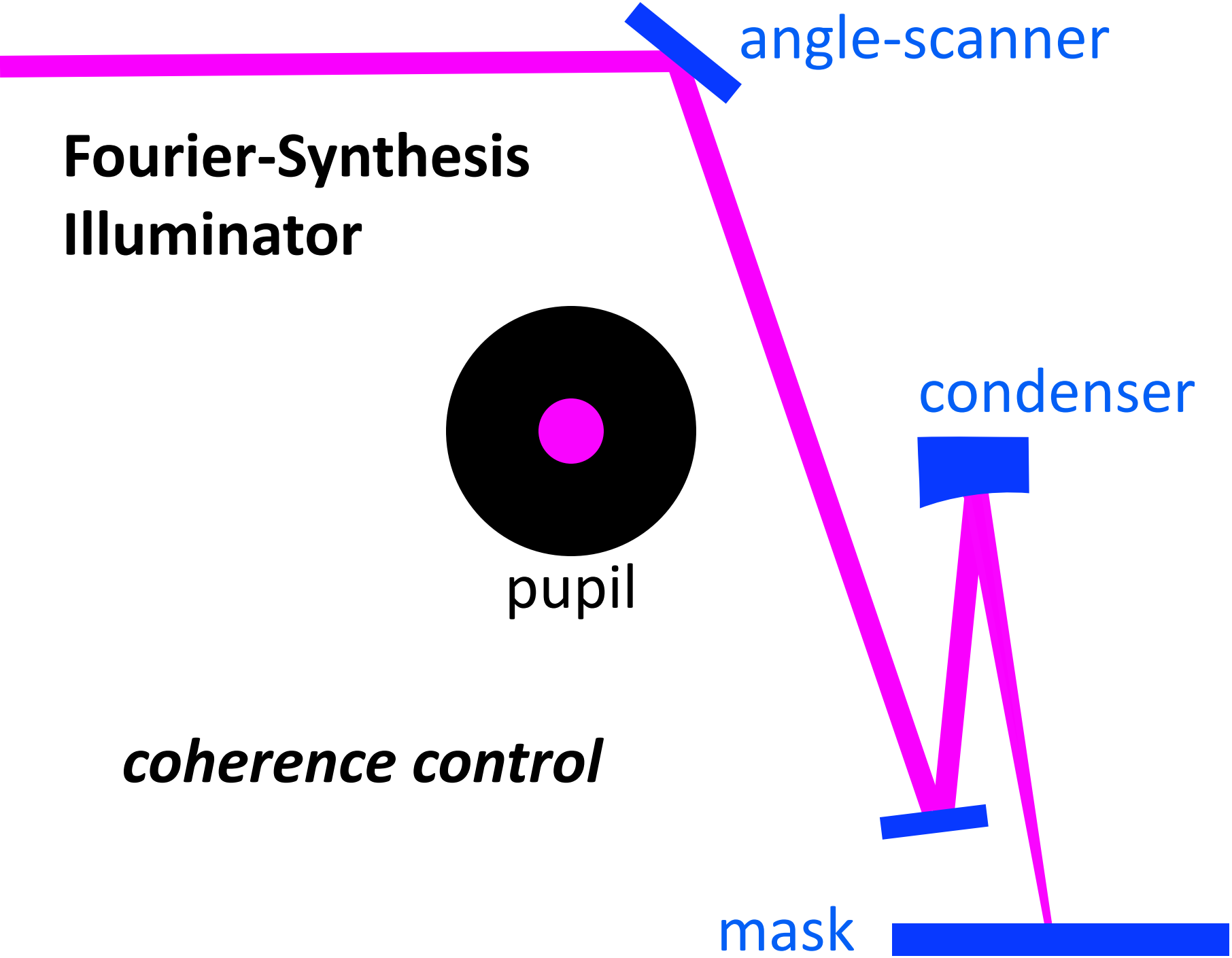


Fourier-Synthesis Illuminator



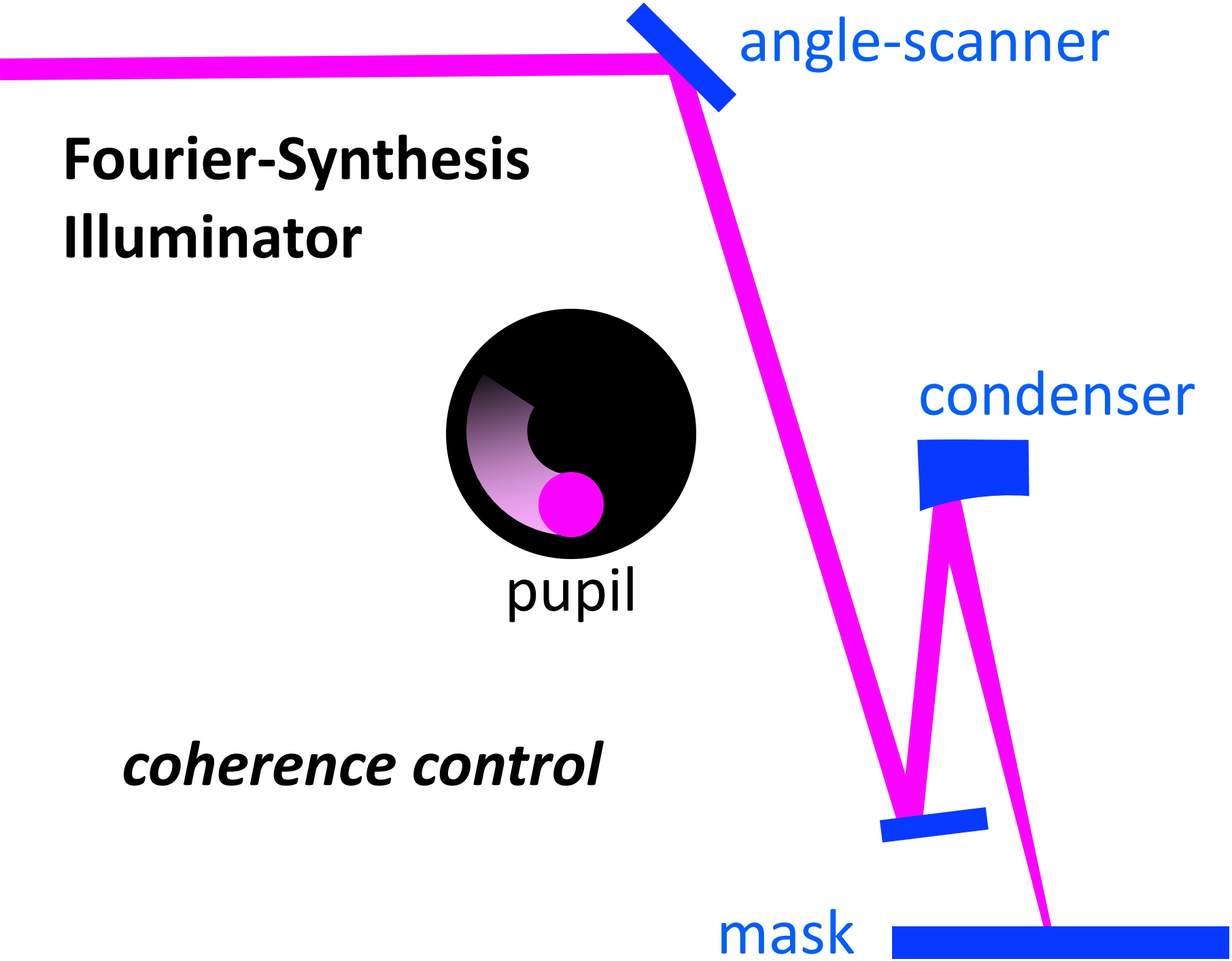

Fourier-Synthesis
Illuminator
angle-scanner
10:1 demag
ellipsoidal
condenser
6–10°
σ ≤ 0.9
pupil
~25 µm
mask

Fourier-Synthesis Illuminator



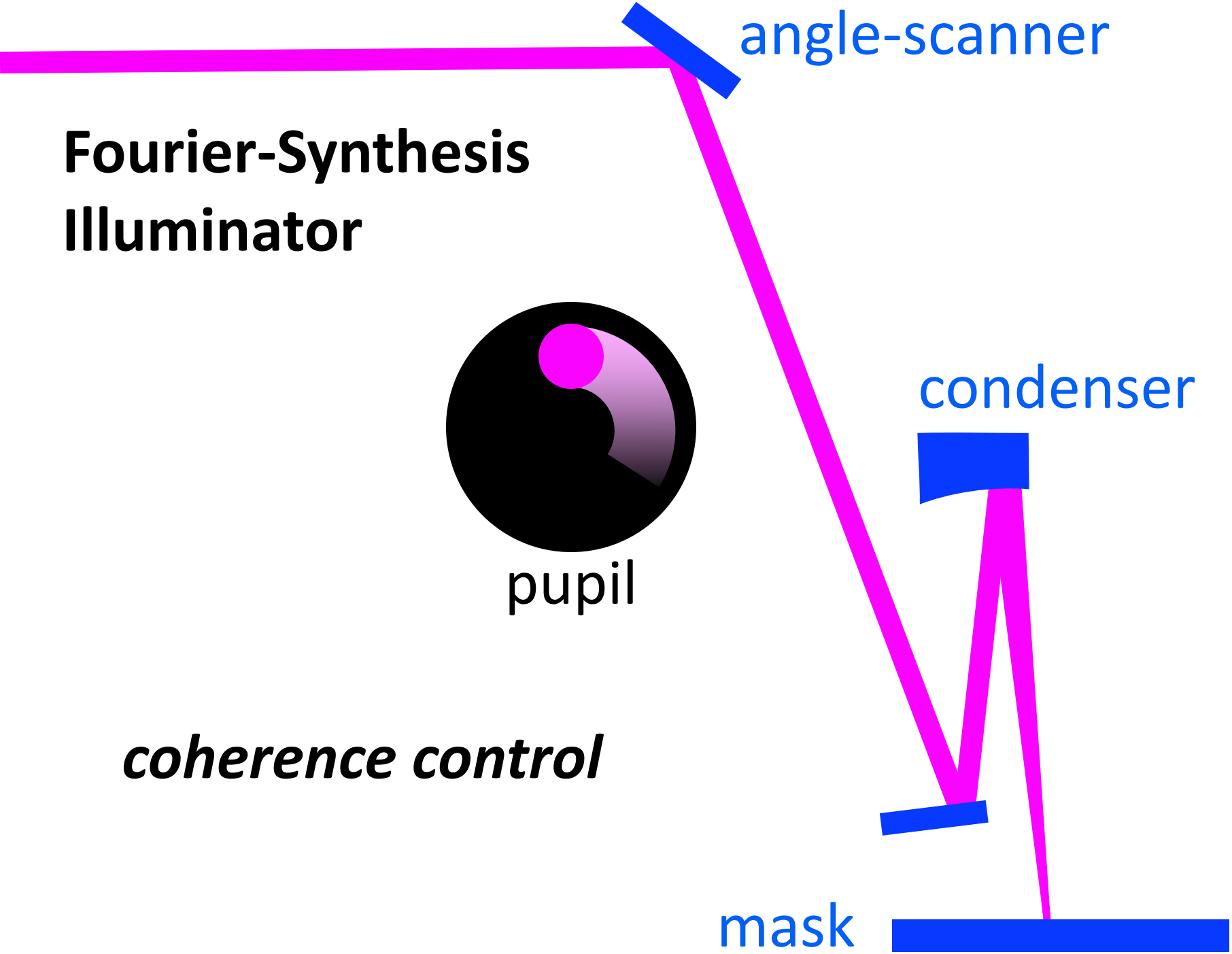
coherence control

Fourier-Synthesis Illuminator



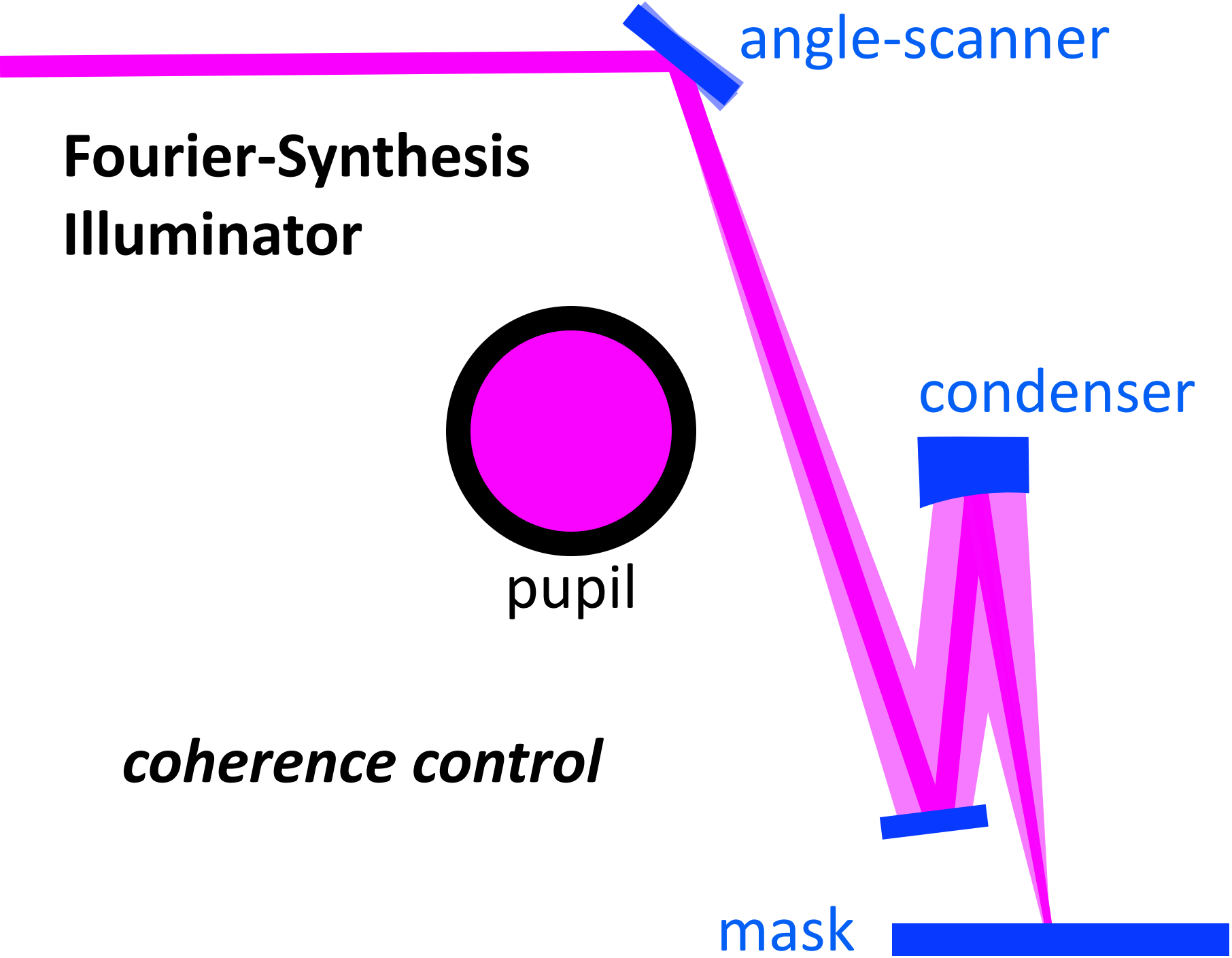
coherence control

Fourier-Synthesis Illuminator



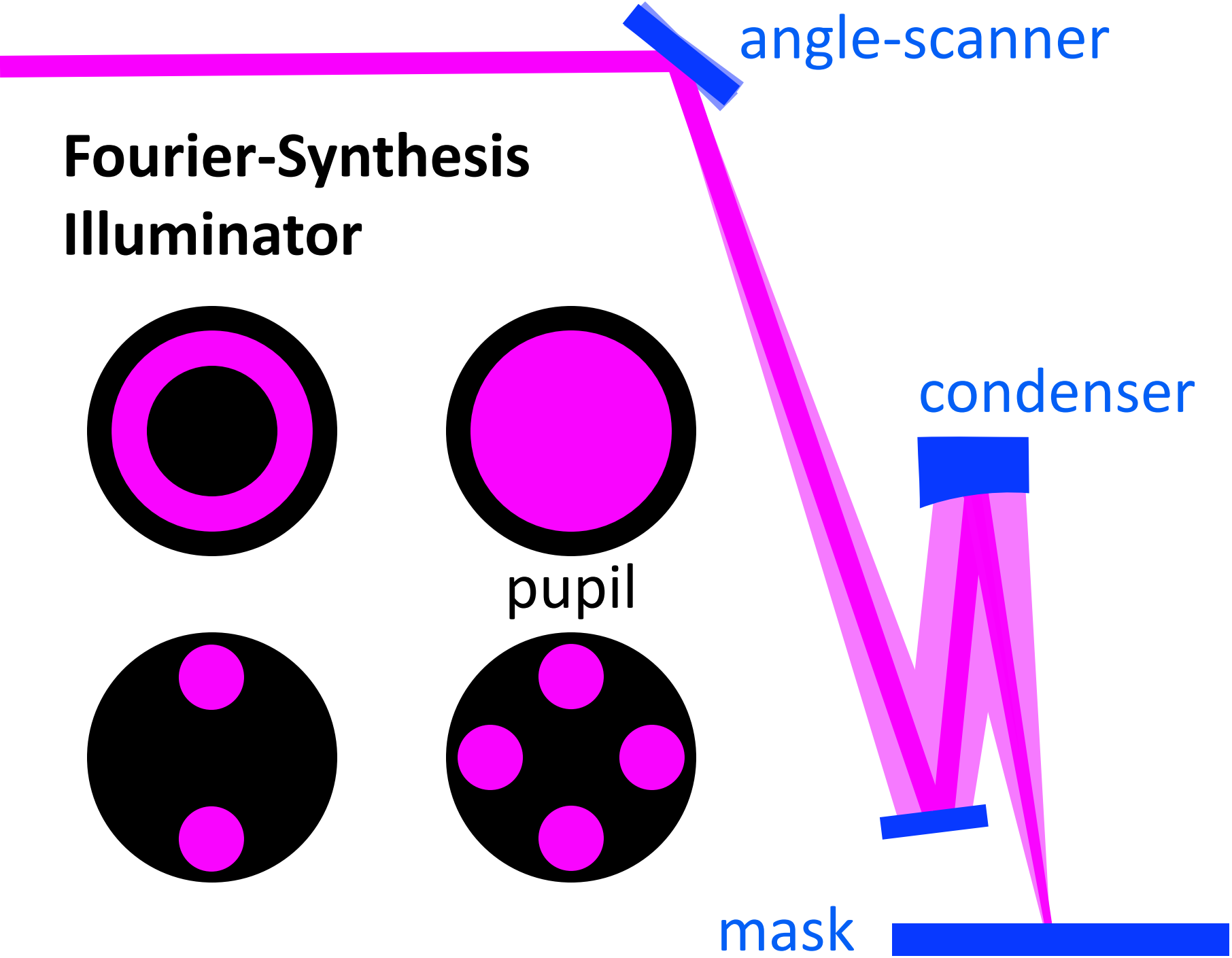
coherence control

Fourier-Synthesis Illuminator

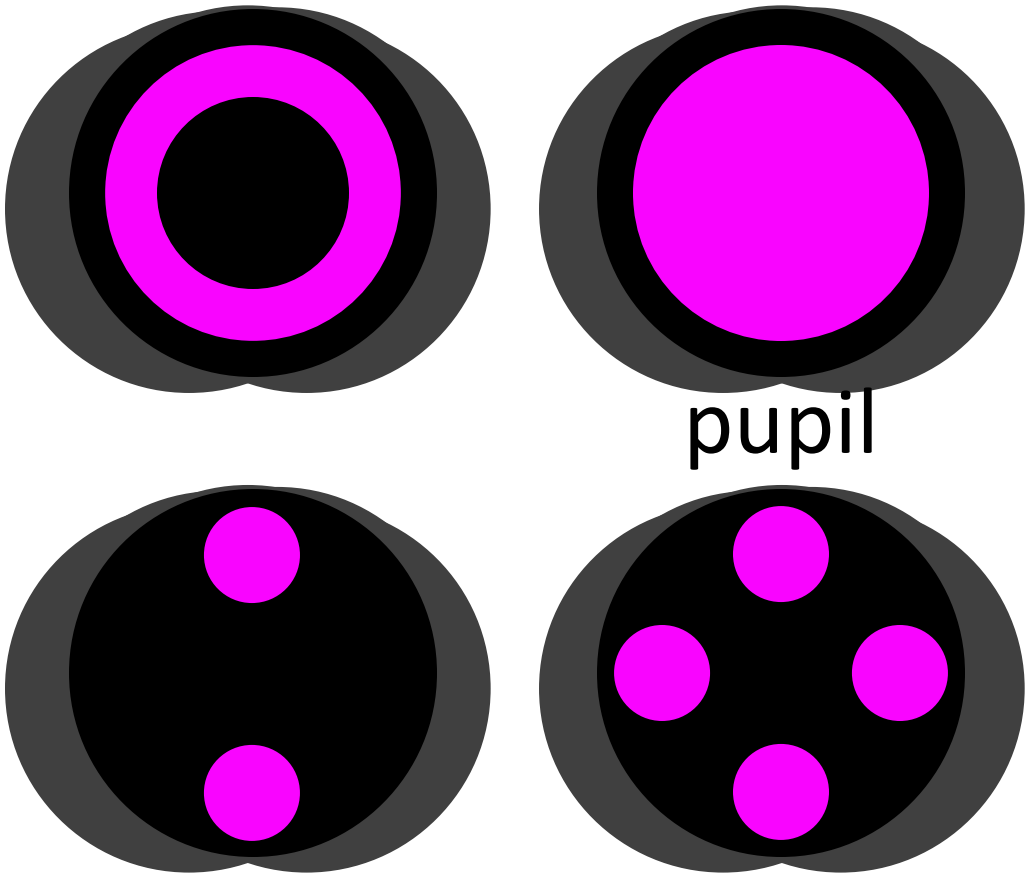


coherence control

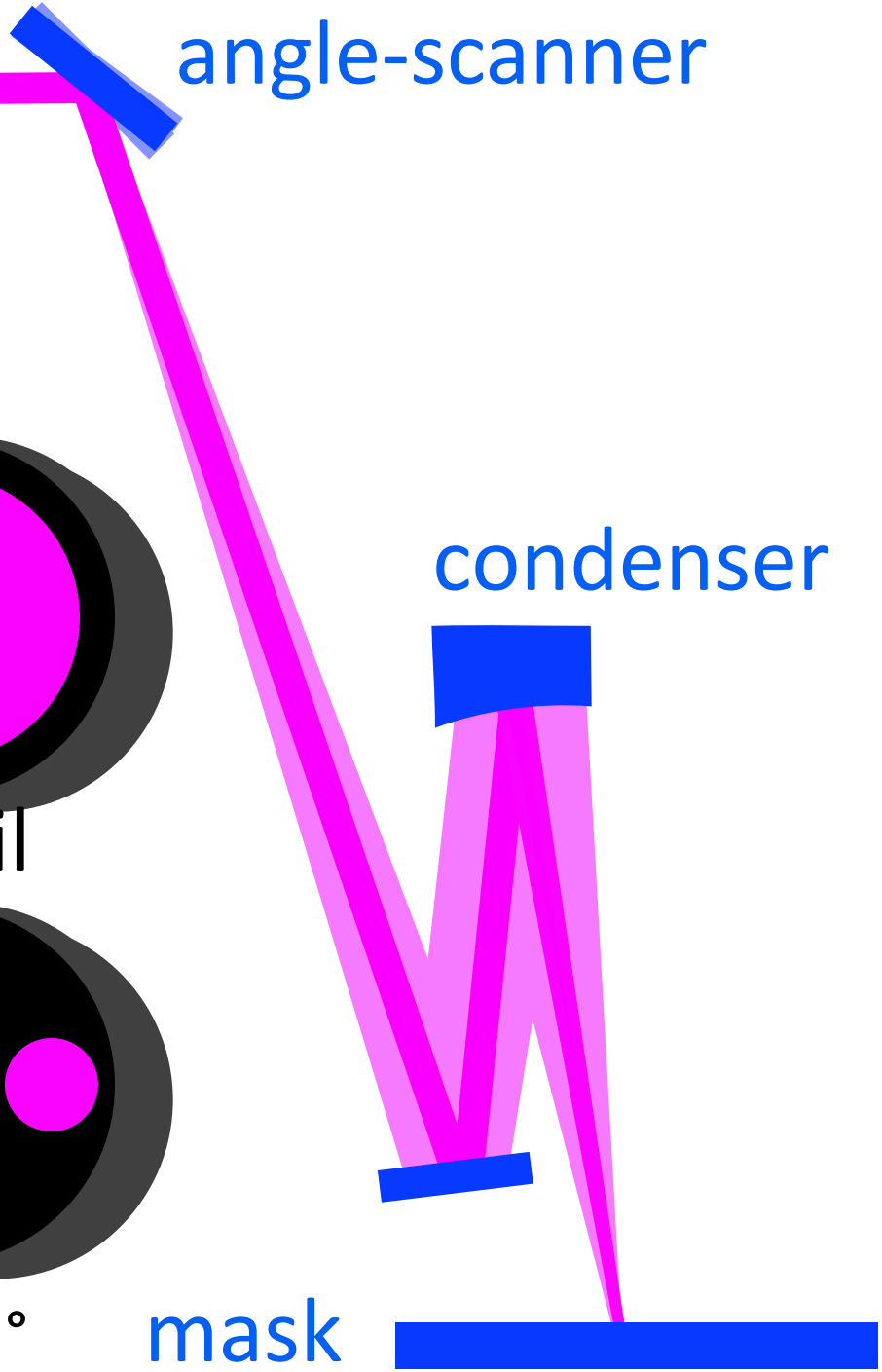
Fourier-Synthesis Illuminator



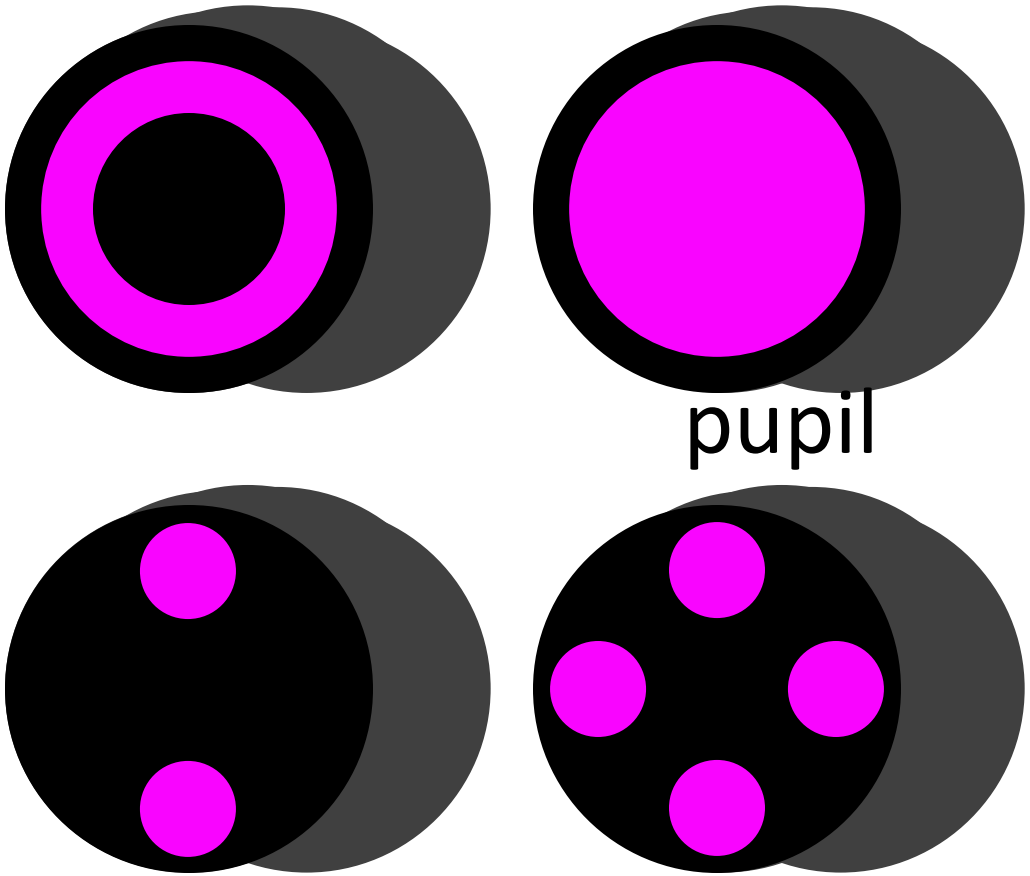
Fourier-Synthesis Illuminator



adjustable azimuth ±25°



Fourier-Synthesis Illuminator



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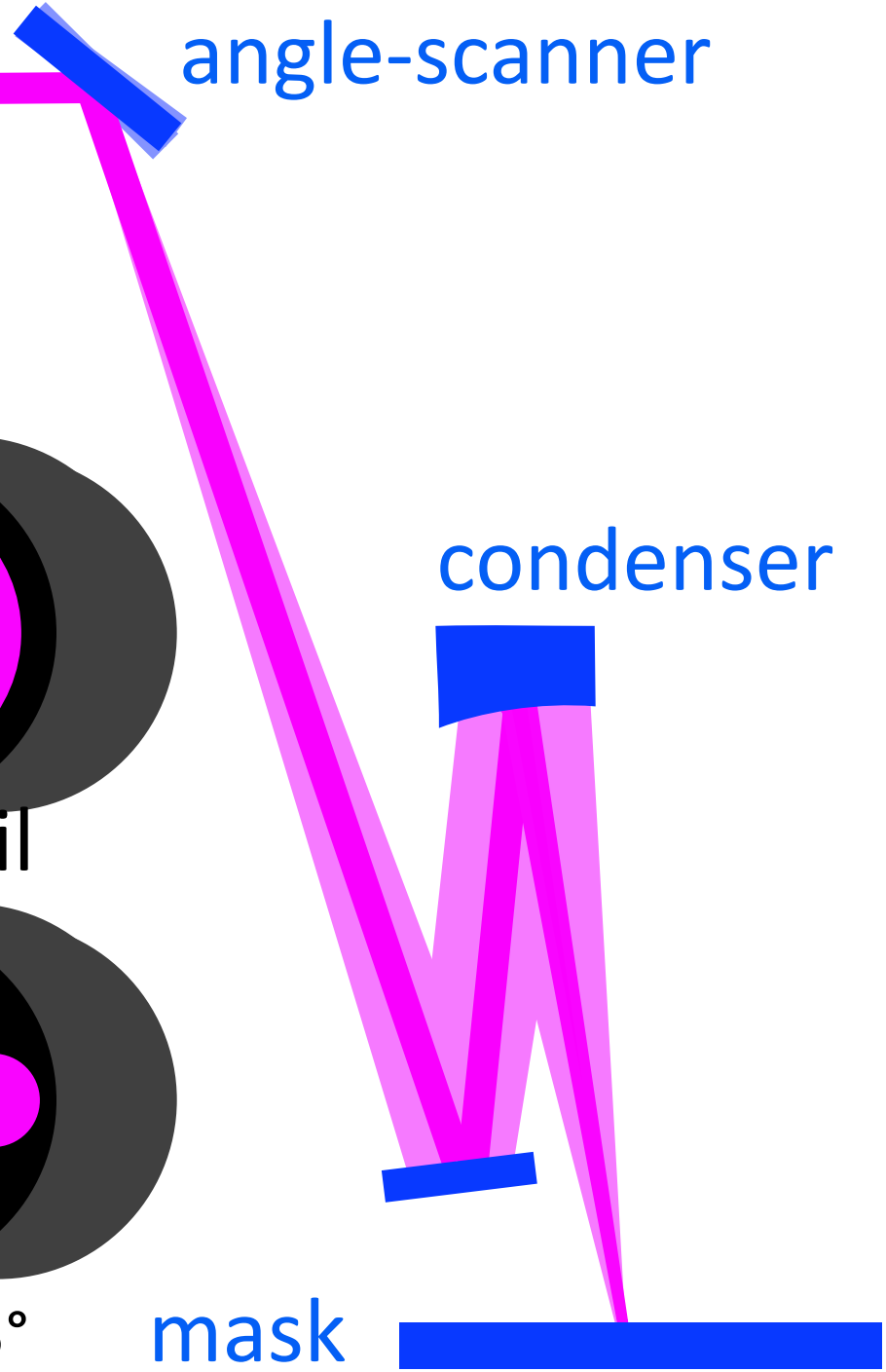
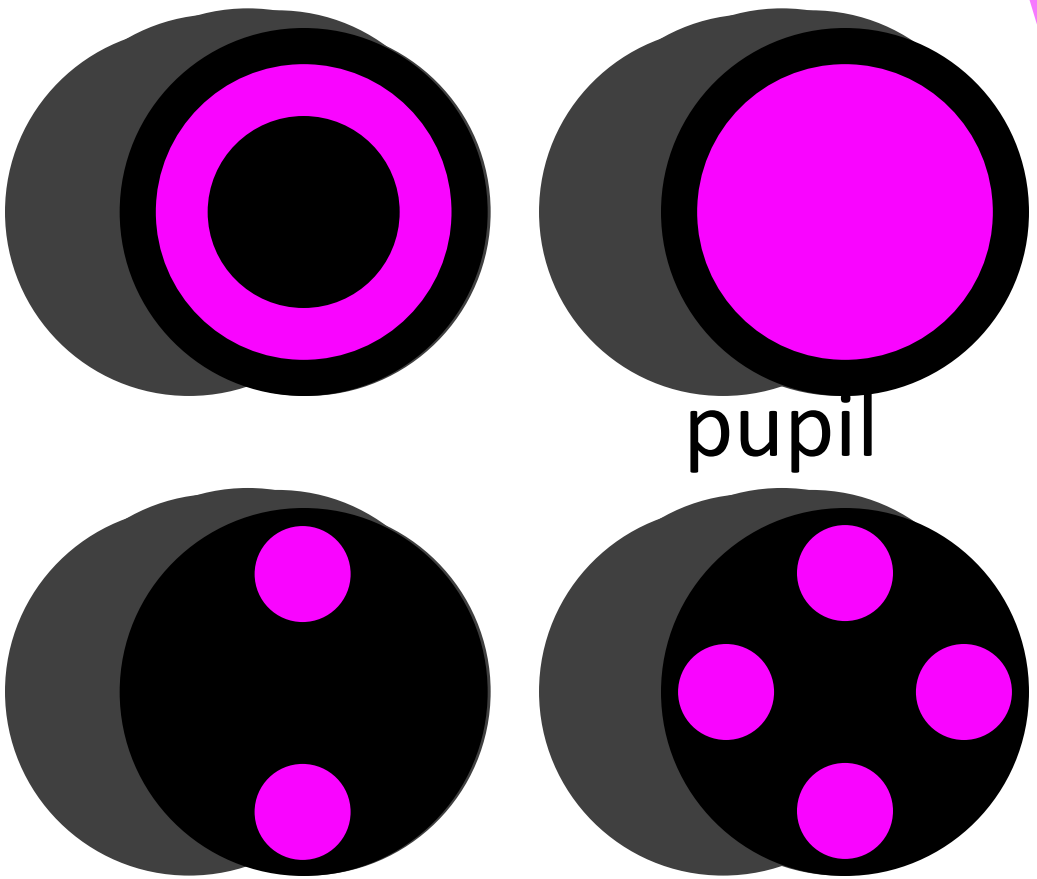
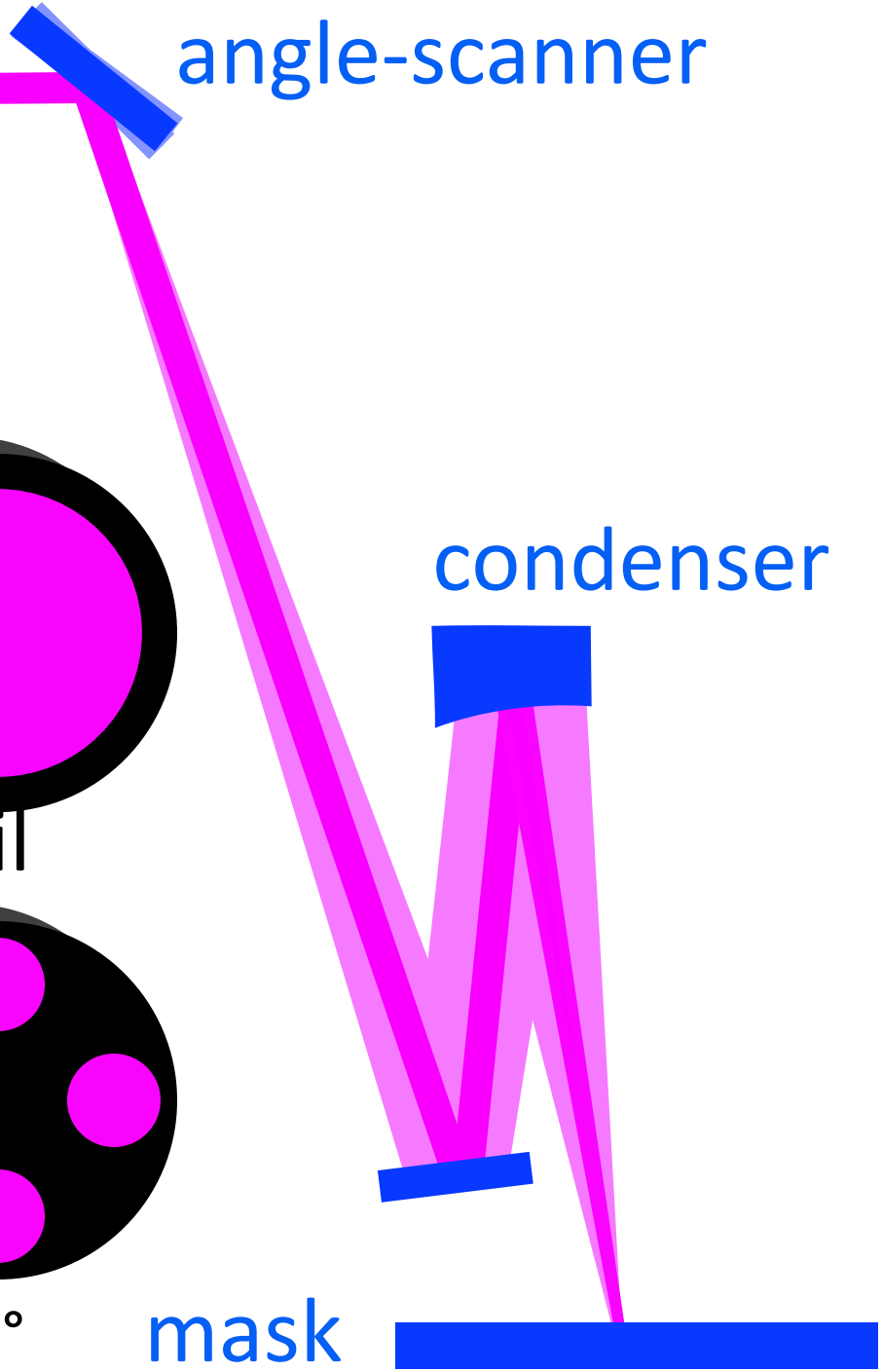


Fourier-Synthesis Illuminator





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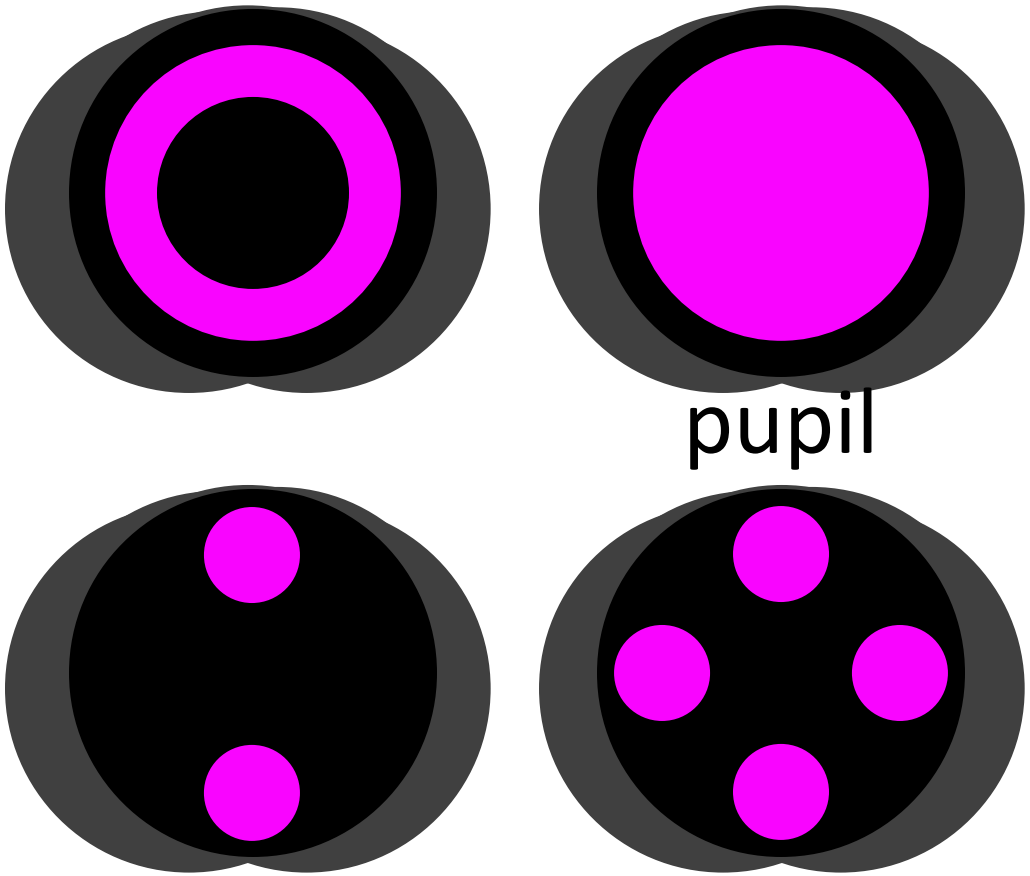

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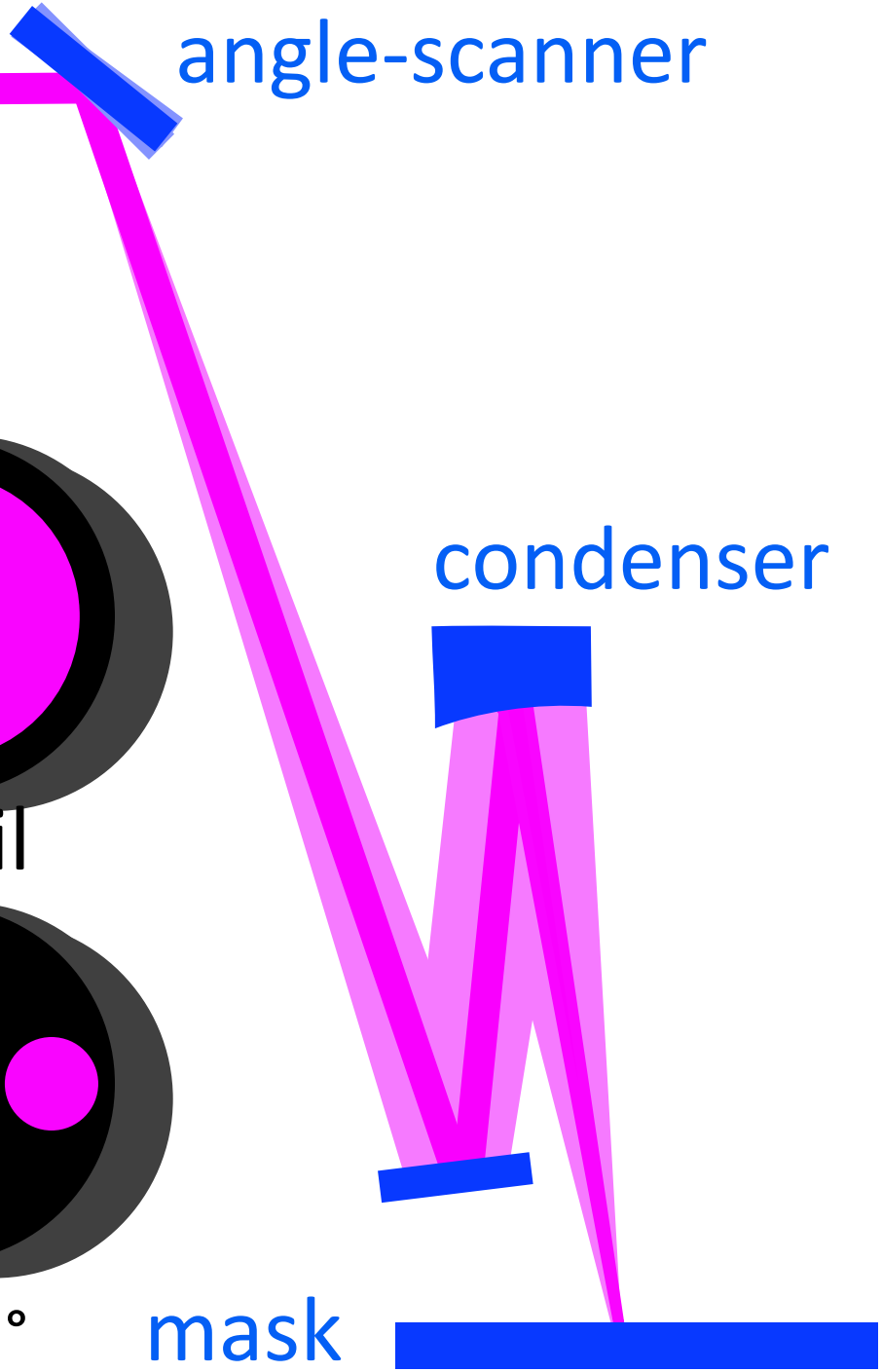
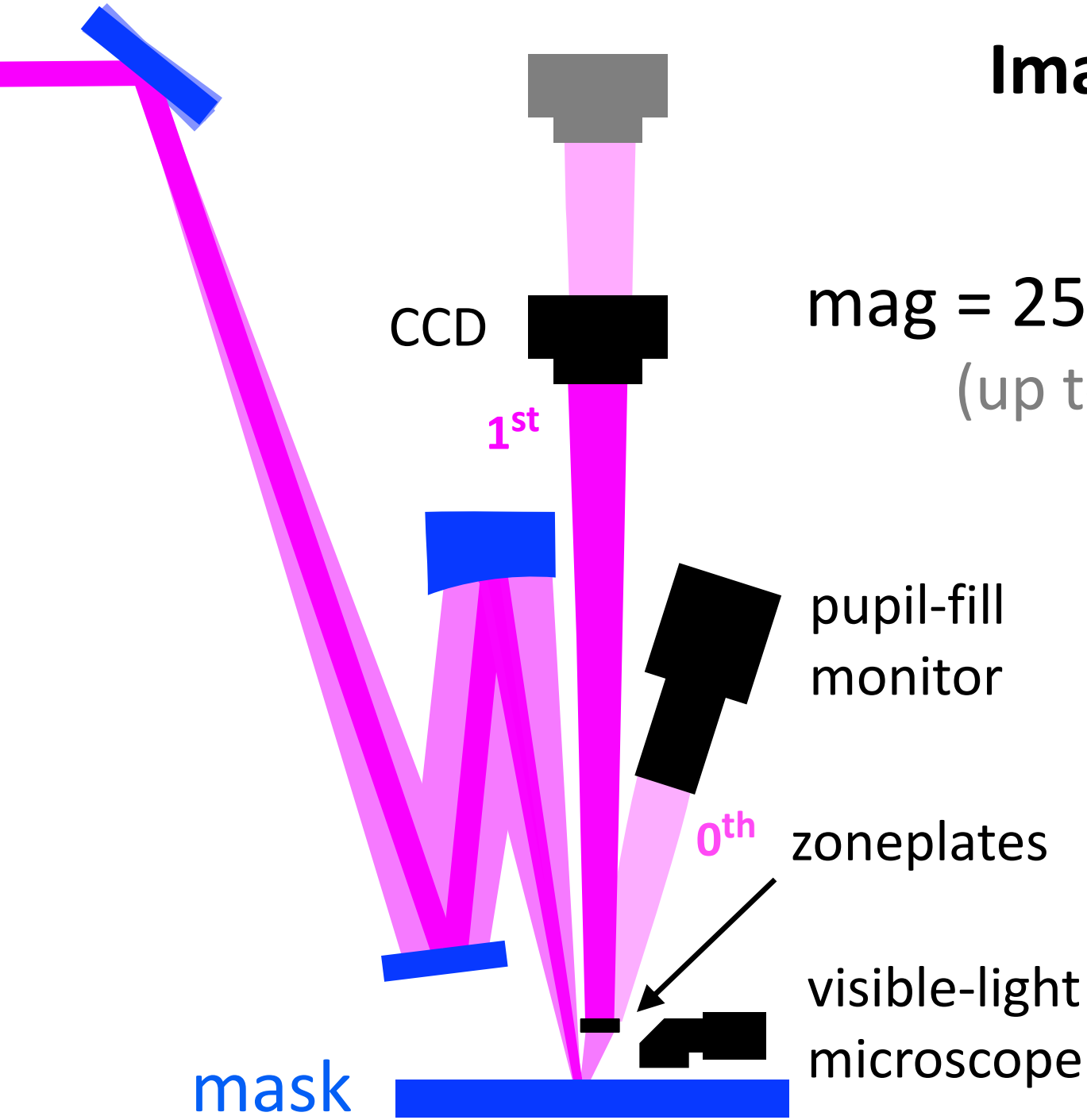


Imaging System



mag = 250–1800 ×

(up to ~8000 ×)

AIT	SHARP
> 16 nm	> 6 nm
low σ	σ ≤ 0.9
6° *fixed*	6–10°

The AIT team

CXRO
THE CENTER FOR X-RAY OPTICS

Iacopo Mochi
Project Scientist

James Macdougall
Graduate Student

Nathan Smith
Engineering Associate

Seno Rekawa
Chief Engineer

Ken Goldberg
Principal Investigator

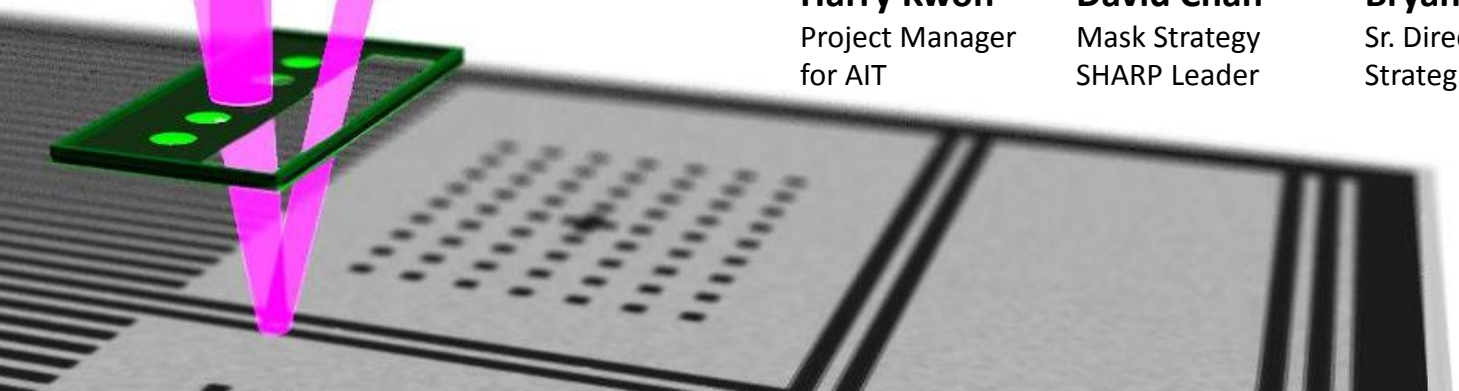
SEMATECH

Harry Kwon
Project Manager for AIT

David Chan
Mask Strategy
SHARP Leader

Bryan Rice
Sr. Director of Strategic Initiatives

Stefan Wurm
Director of Lithography



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