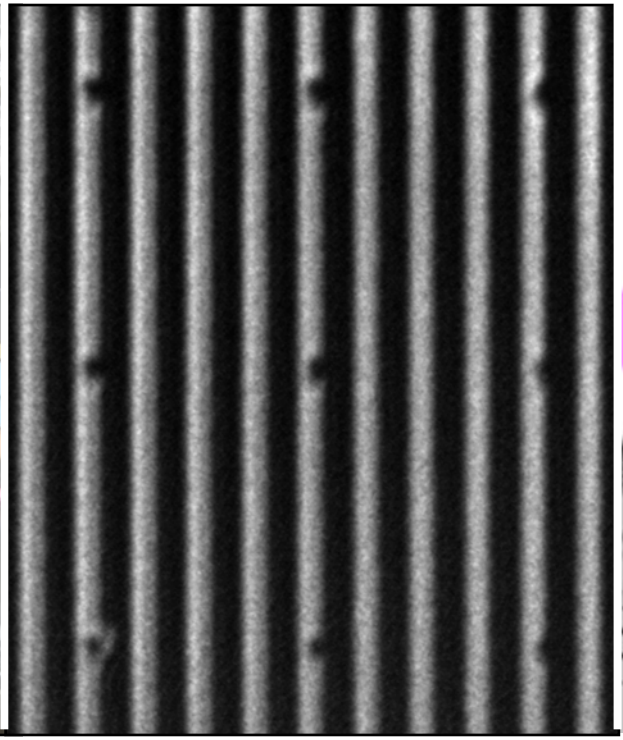
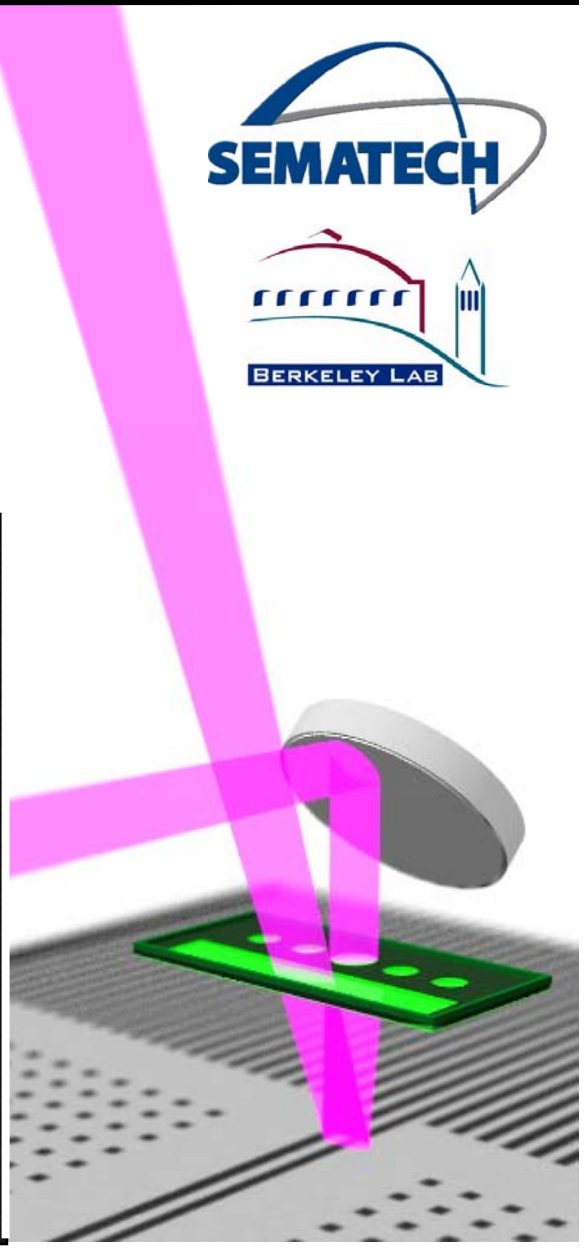
PROGRESS IN ACTINIC MASK IMAGING:
The closest look at lines, defects, and phase roughness

The SEMATECH Berkeley Actinic Inspection Tool

AIT

An EUV-wavelength mask imaging microscope





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PROGRESS IN ACTINIC MASK IMAGING:
The closest look at lines, defects, and phase roughness

LBNL: Kenneth A. Goldberg, Iacopo Mochi
Patrick Naulleau, Simi George

SEMATECH: Sungmin "Sean" Huh

with highlights from

Intel: Ted Liang, Pei-Yang Yan

GlobalFoundries: Bruno LaFontaine, Tom Wallow

UC Berkeley: Chris Clifford

AIT: An EUV Zoneplate Microscope

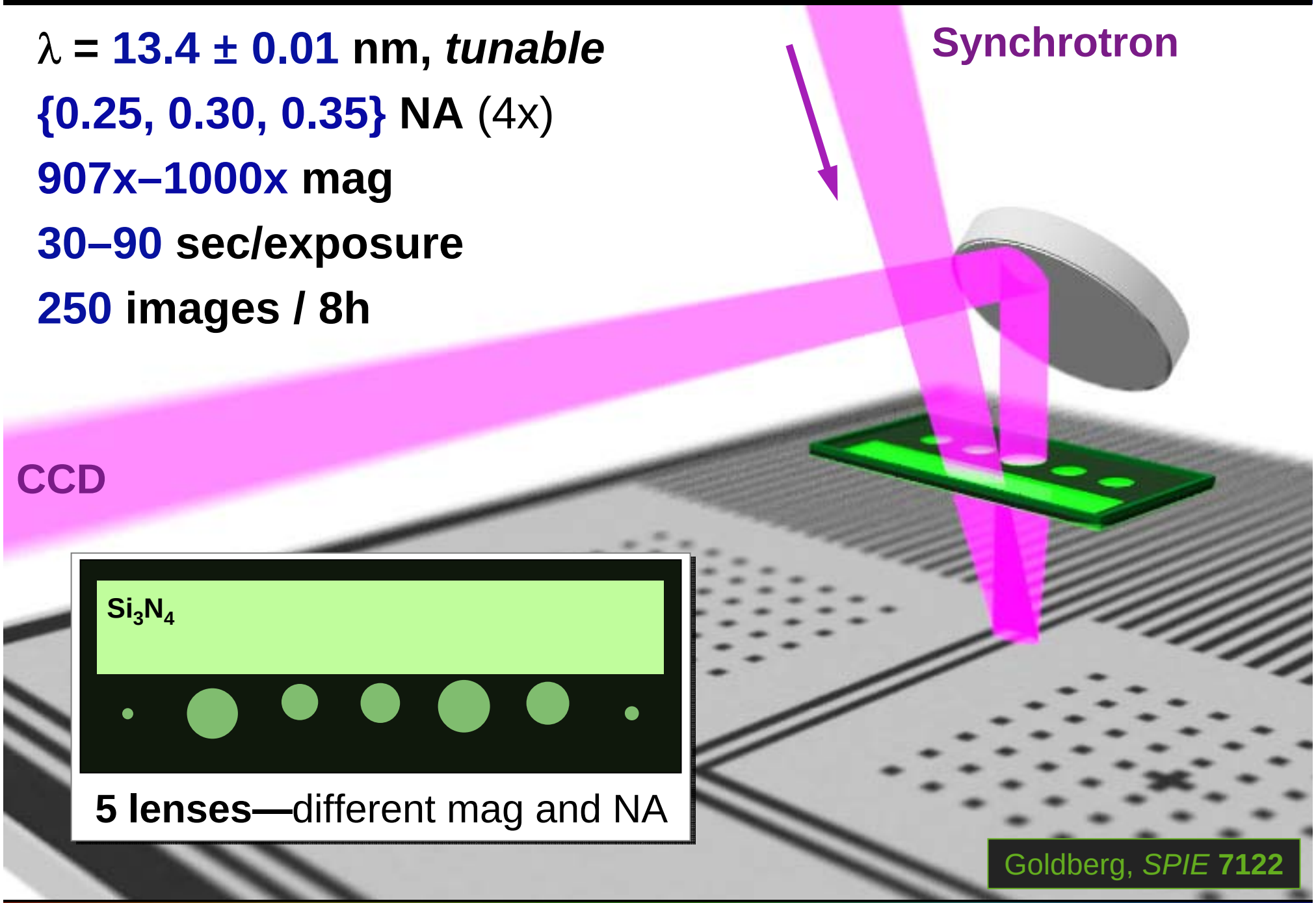
λ = **13.4 ± 0.01 nm, *tunable***

{0.25, 0.30, 0.35} NA (4x)

907x–1000x mag

30–90 sec/exposure

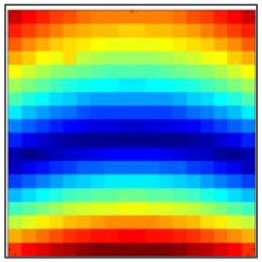
250 images / 8h



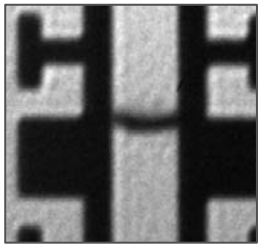
5 lenses—different mag and NA

Goldberg, *SPIE* **7122**

The AIT is used in every aspect of mask research

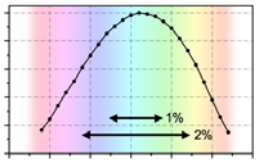


AIT Alignment

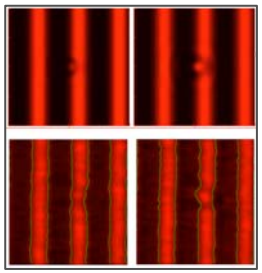


Native Pattern Defects

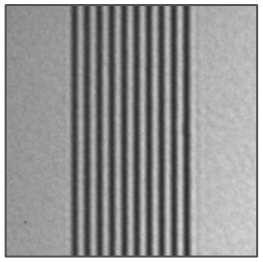
Native Blank Defects



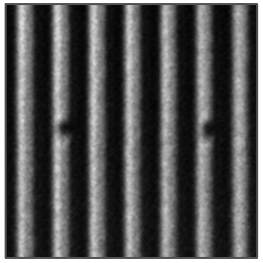
Wavelength Sensitivity



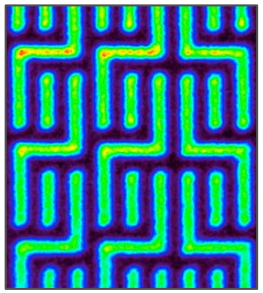
Calibrating Modeling



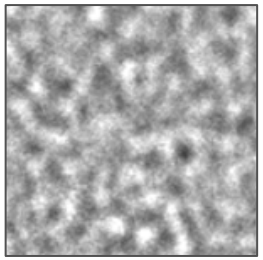
Line Profiles (NILS, CD, LWR)



Programmed Defects



OPC Calibration

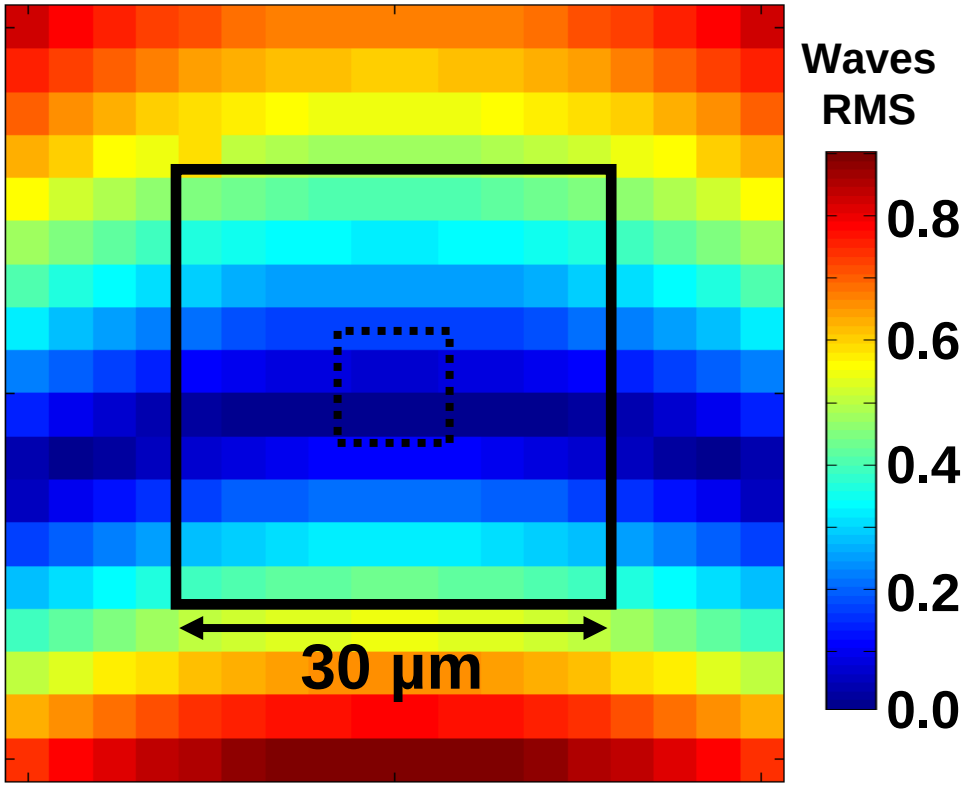


ML Phase Roughness

Deducing aberrations from contact pattern images enables fine alignment of the AIT

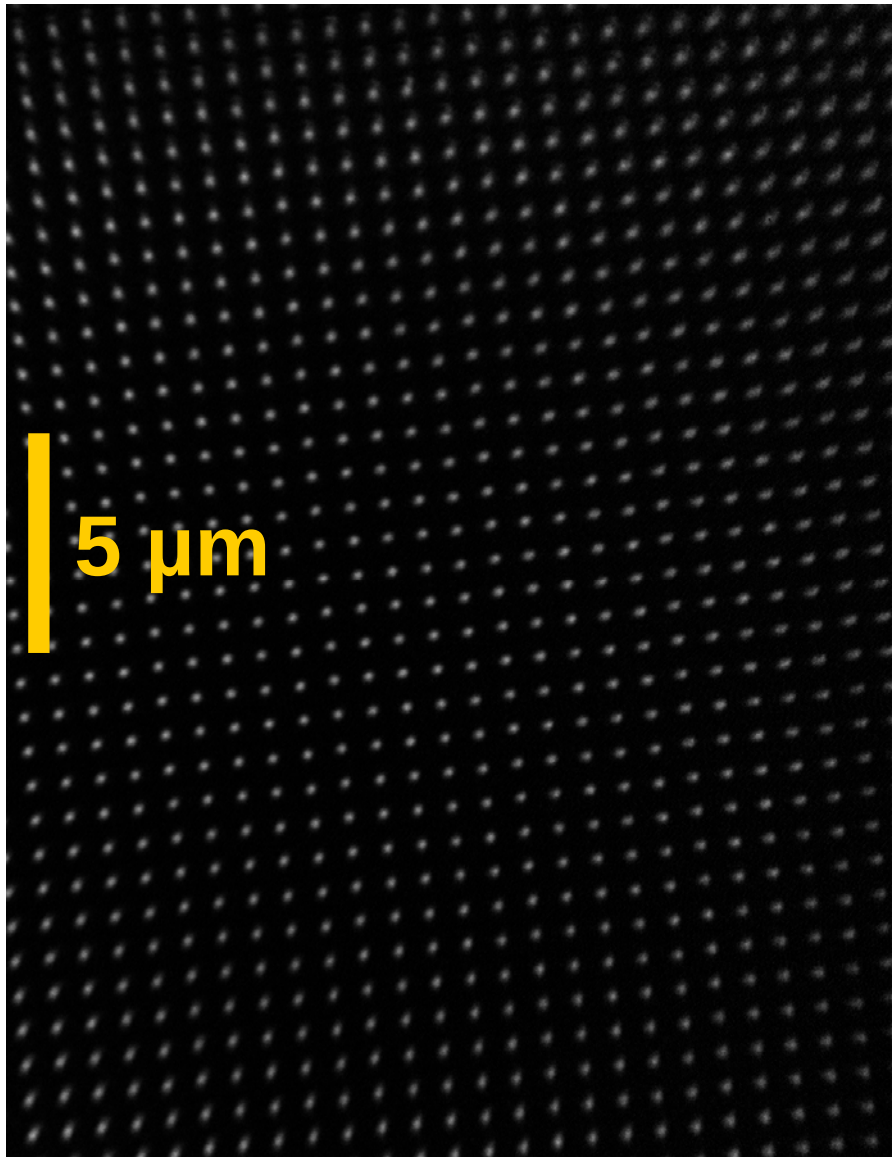
Zoneplate field of view

Field-dependent Aberration Model



mask image area

175-nm contacts



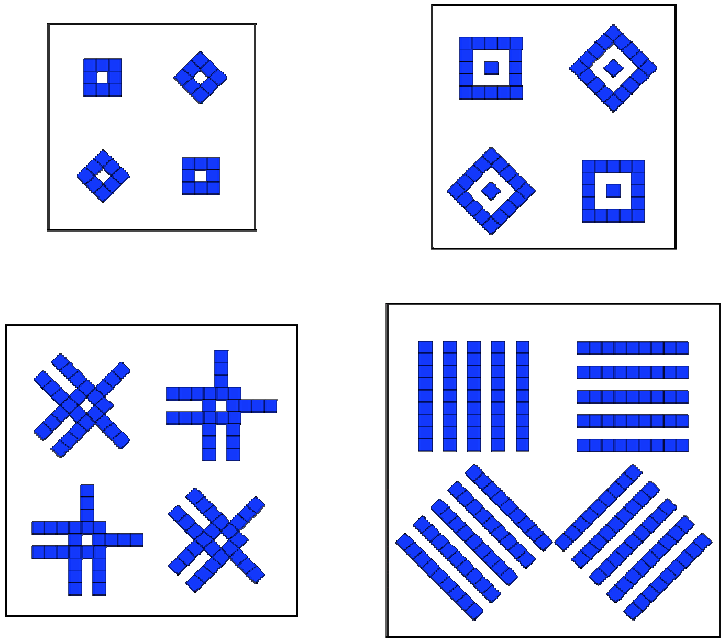
AIT (EUV) image

Analyze through-focus data to reveal aberrations → optimize alignment

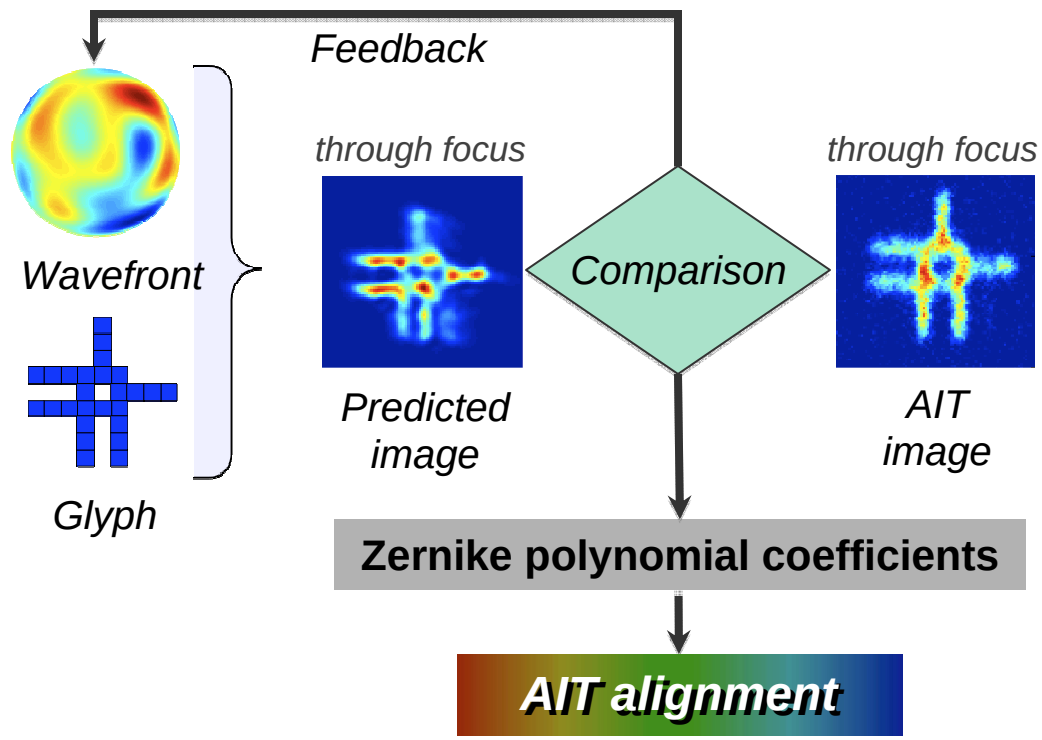
Mochi, *SPIE* **7271**

Alignment based on aberration-sensitive patterns

Aberration-sensitive test patterns



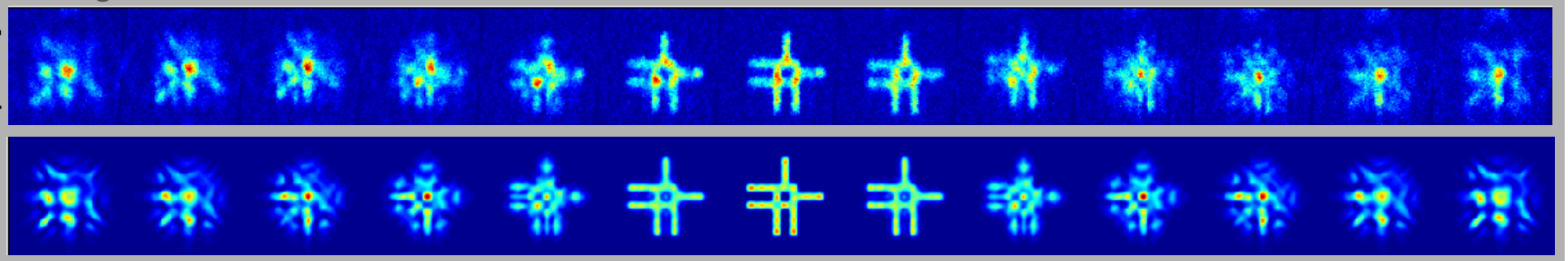
Wavefront search



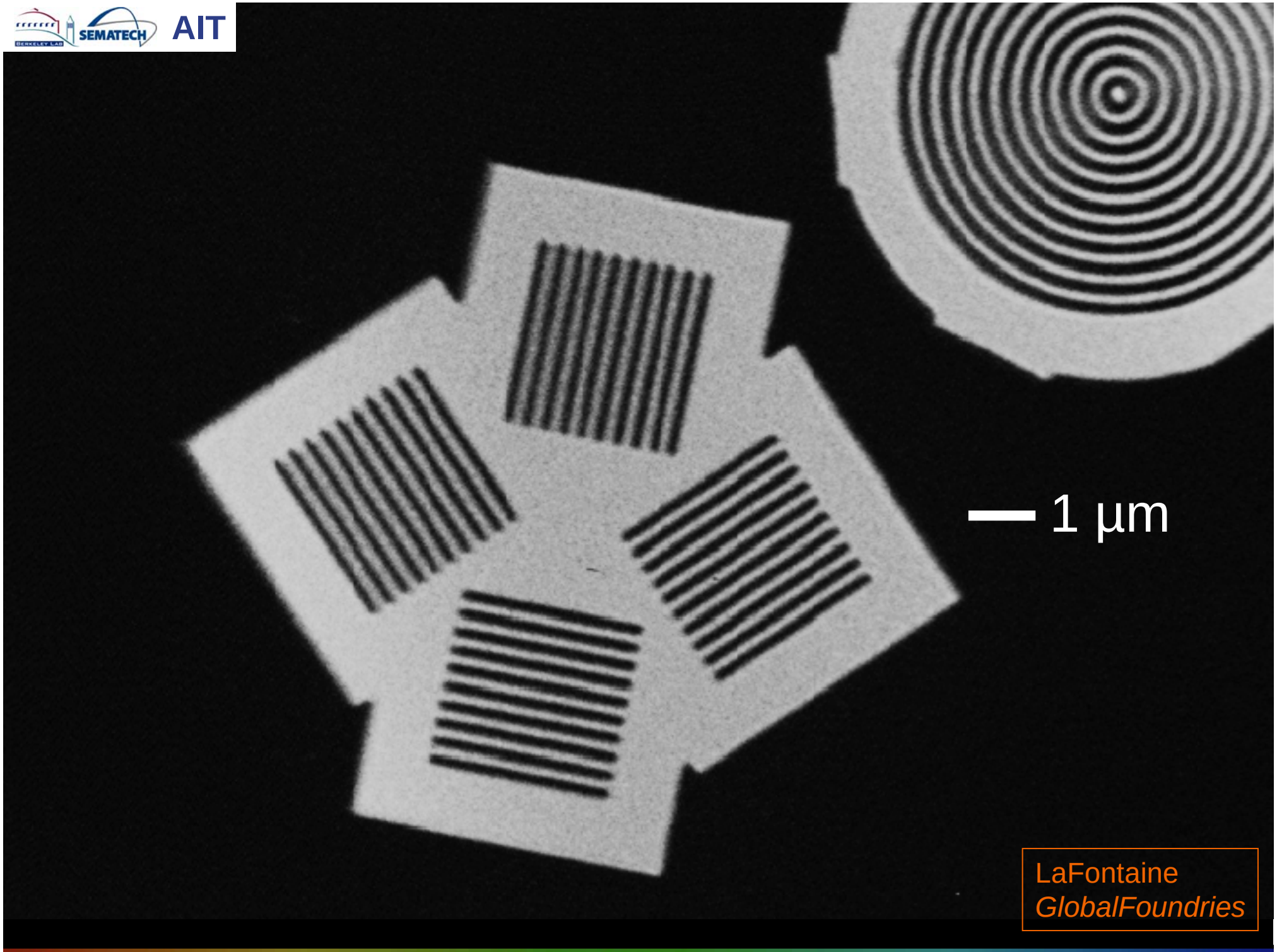
through-focus series

AIT data

Fit



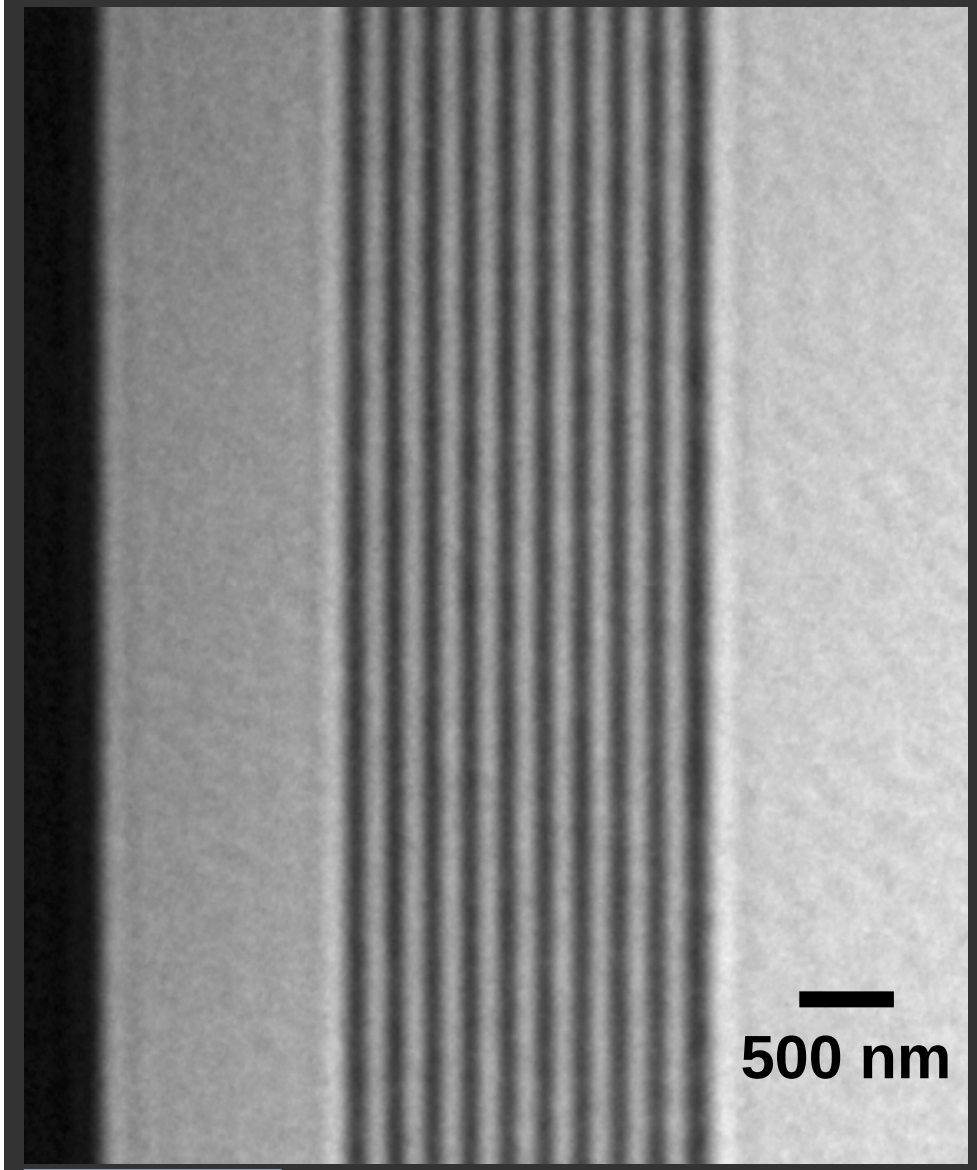
Mochi, *EIPBN 2009*



LaFontaine
GlobalFoundries

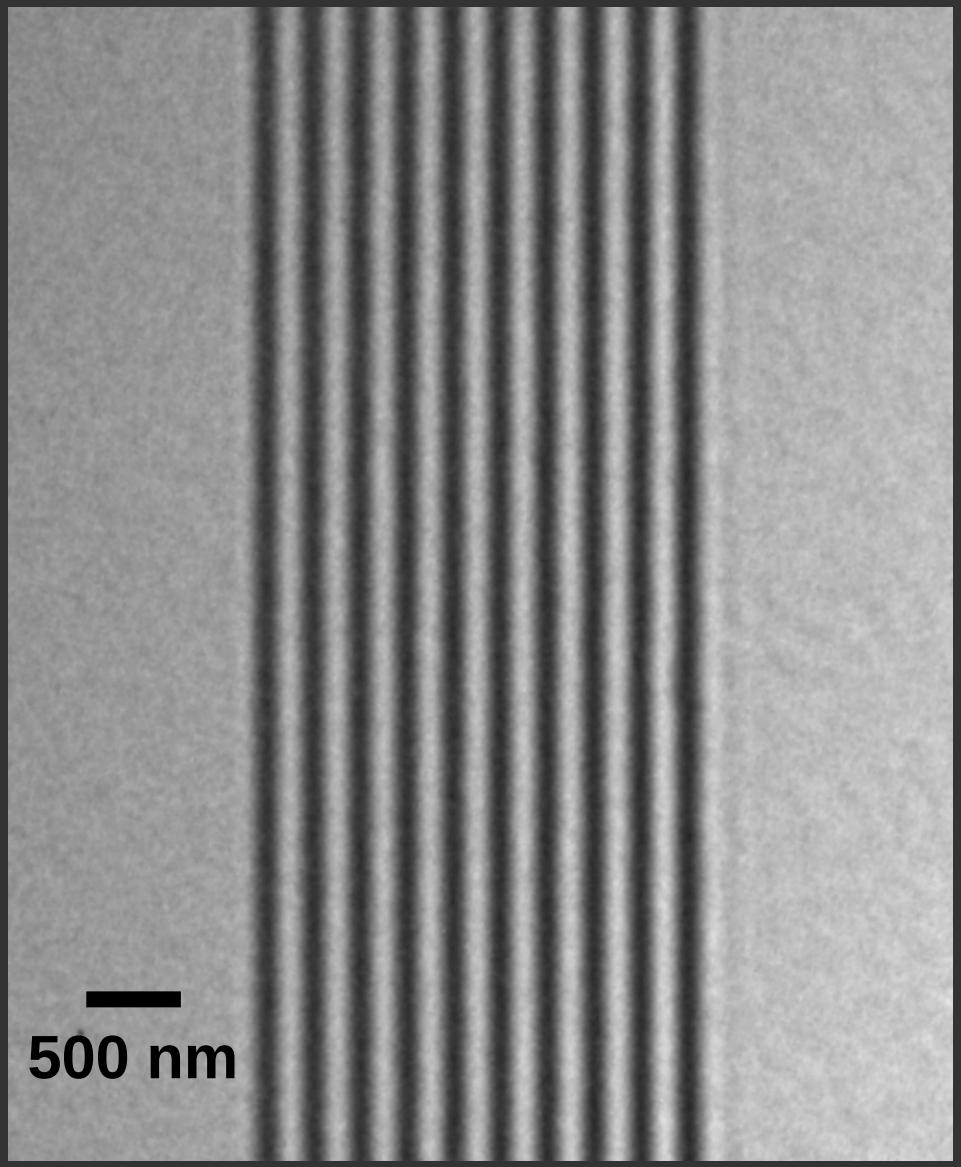
LWR Uncertainty < 9 nm 3σ, mask

100 nm (25 nm @ 4x)



Yan, *Intel*

125 nm (31 nm @ 4x)



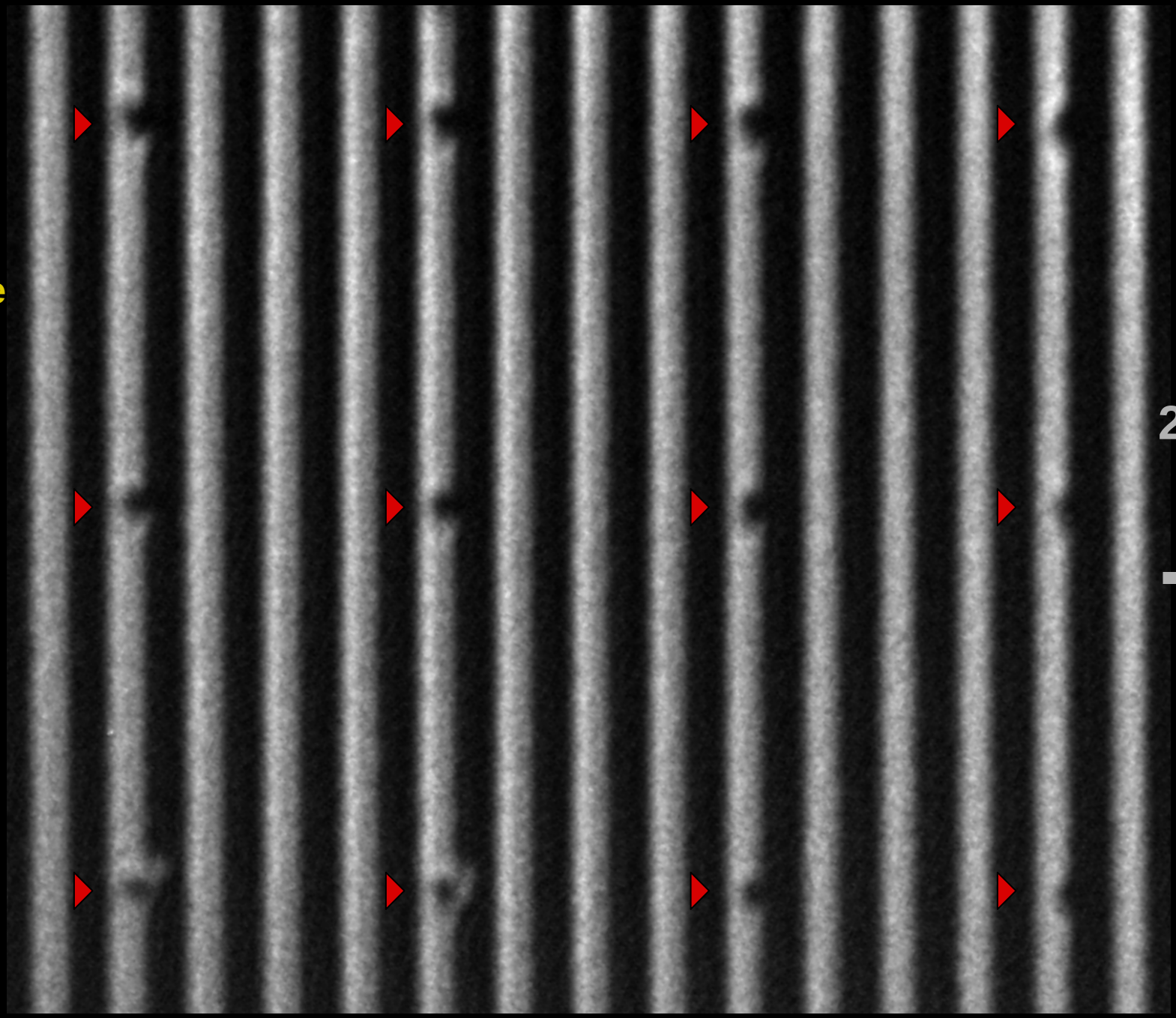
Goldberg, *EIPBN 2009*

AIT (EUV) images

Defect arrays assess sensitivity *LARGE defects*

EUV aerial image

buried substrate phase defects



250 nm CD

1 µm

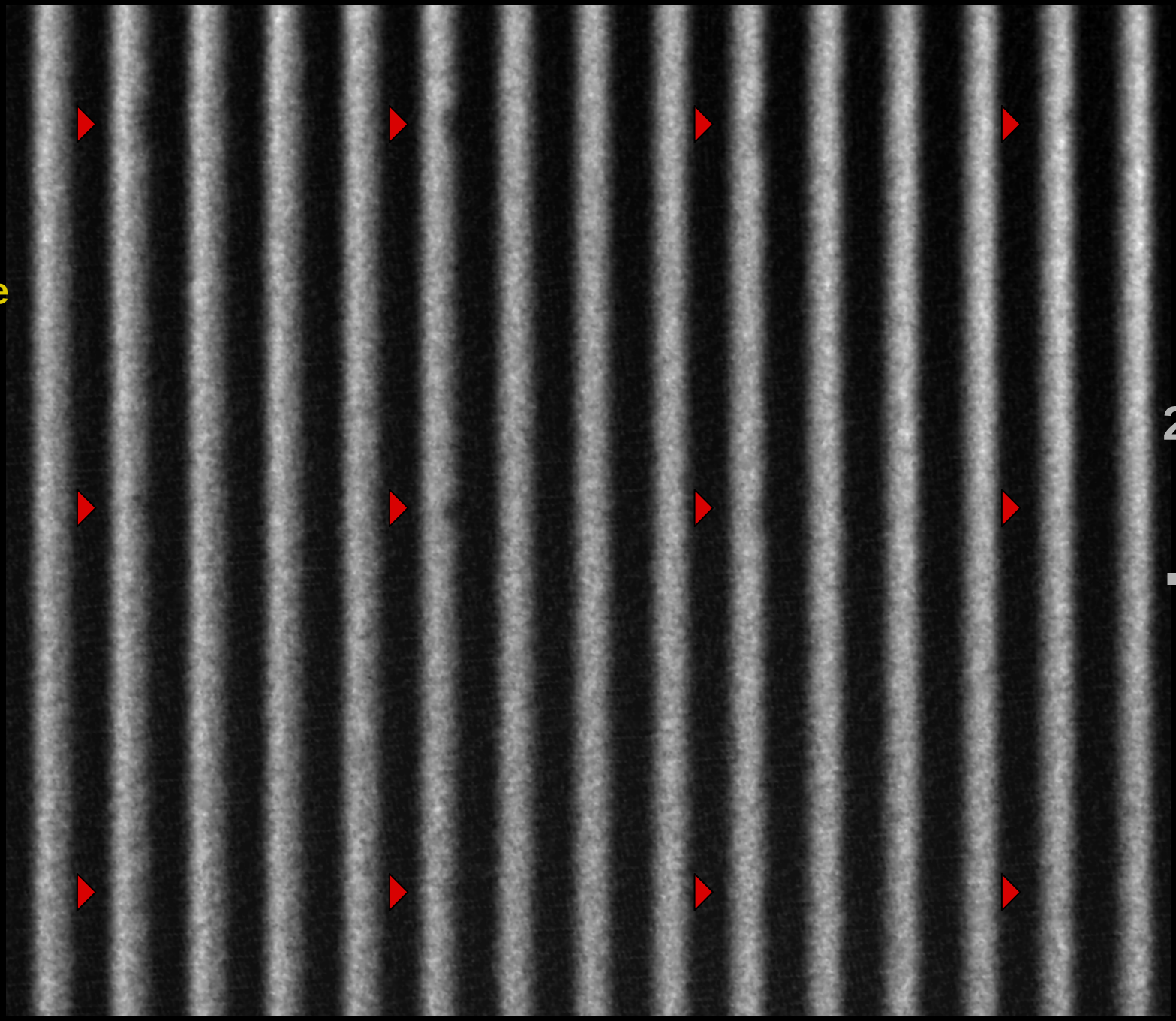
Liang *Intel*

Clifford *EIPBN 2009*

Defect arrays assess sensitivity *SMALL defects*

EUV aerial image

buried substrate phase defects



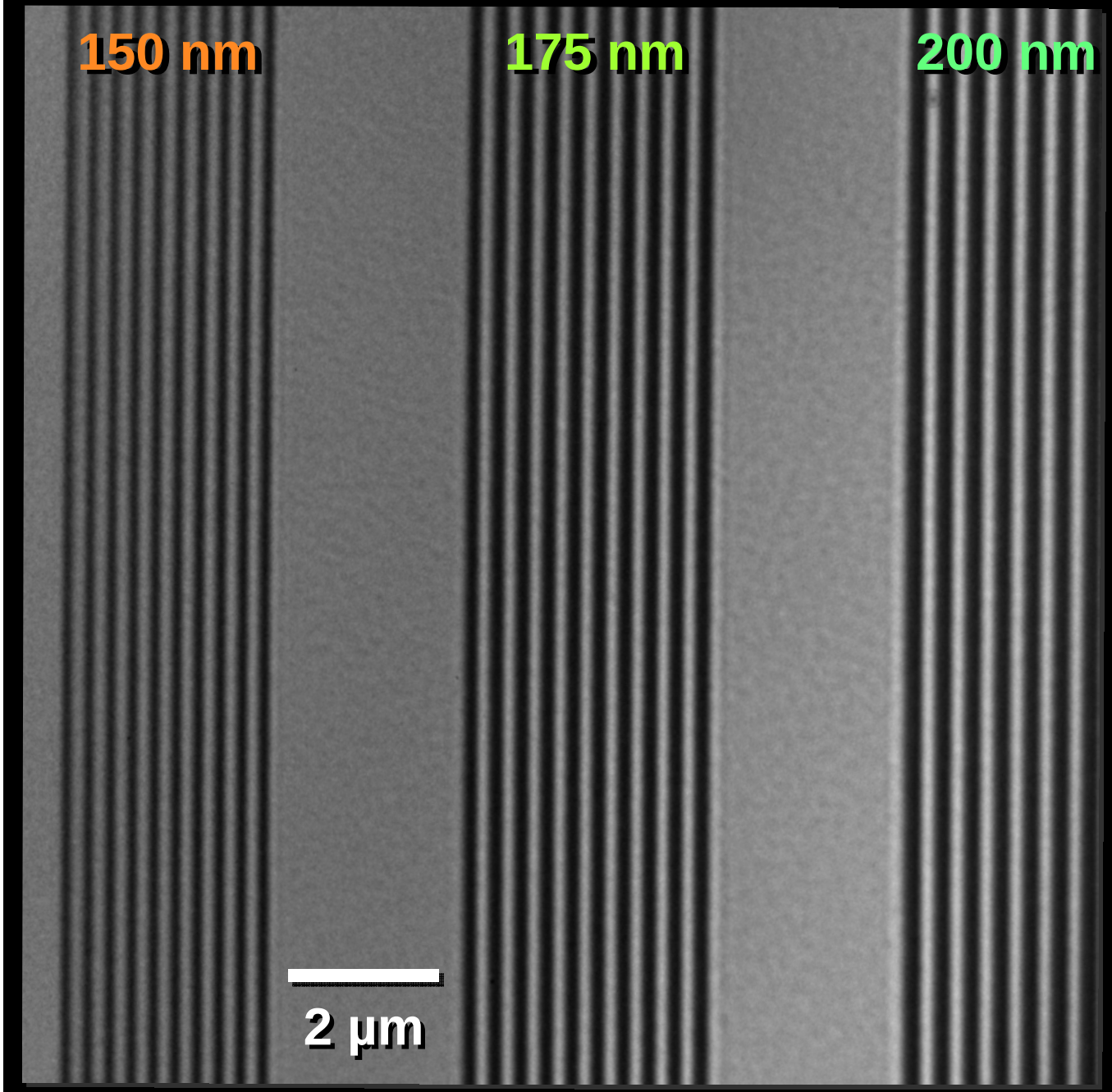
250 nm CD

1 µm

Liang *Intel*

Clifford *EIPBN 2009*

We assess line measurement limits vs. pitch



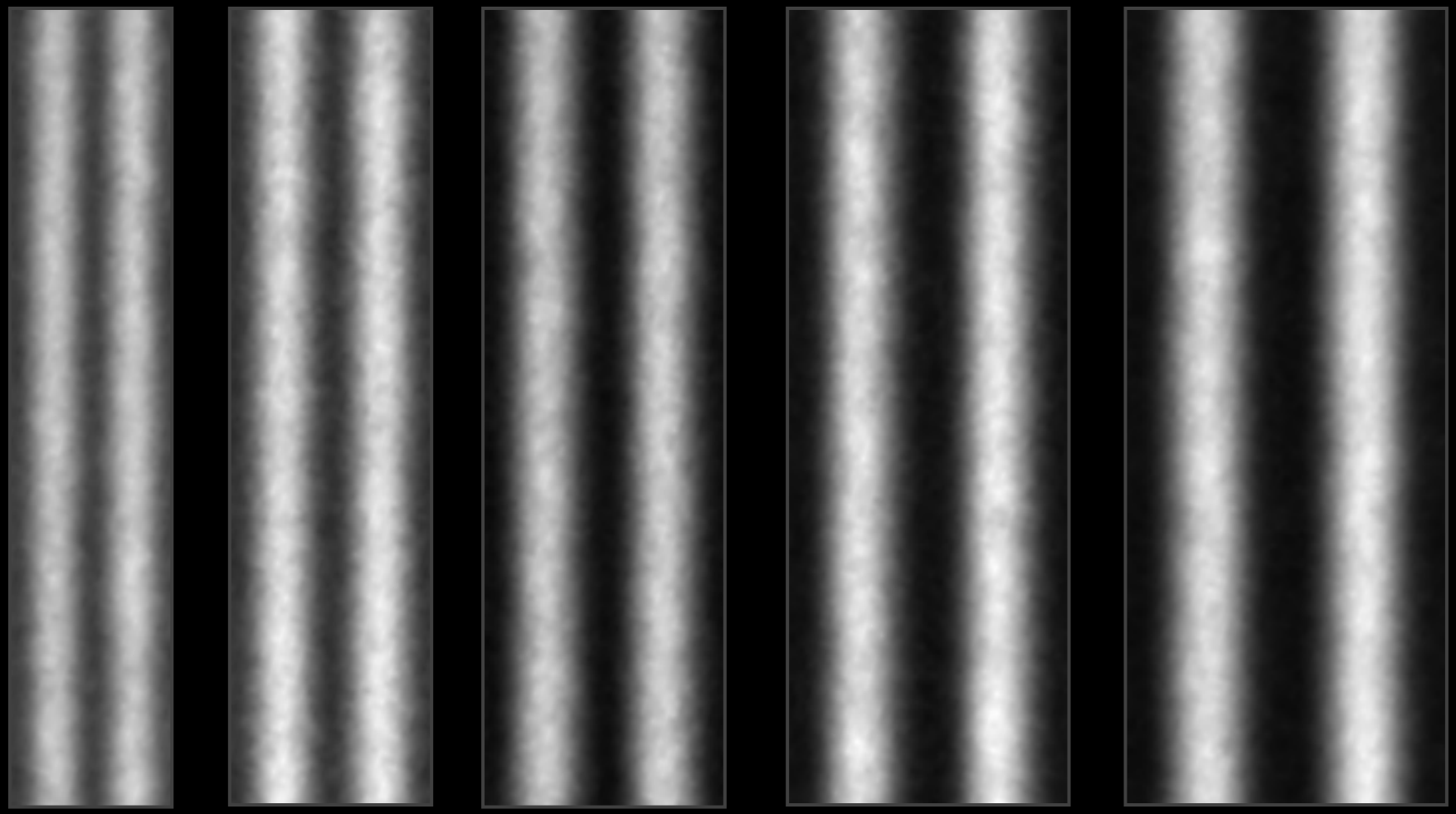
A different mask
with a dense-line pattern
and varying pitch.

Yan
Intel

Goldberg
EIPBN
2009

Five line sizes at best focus

We study each line size through focus. . .



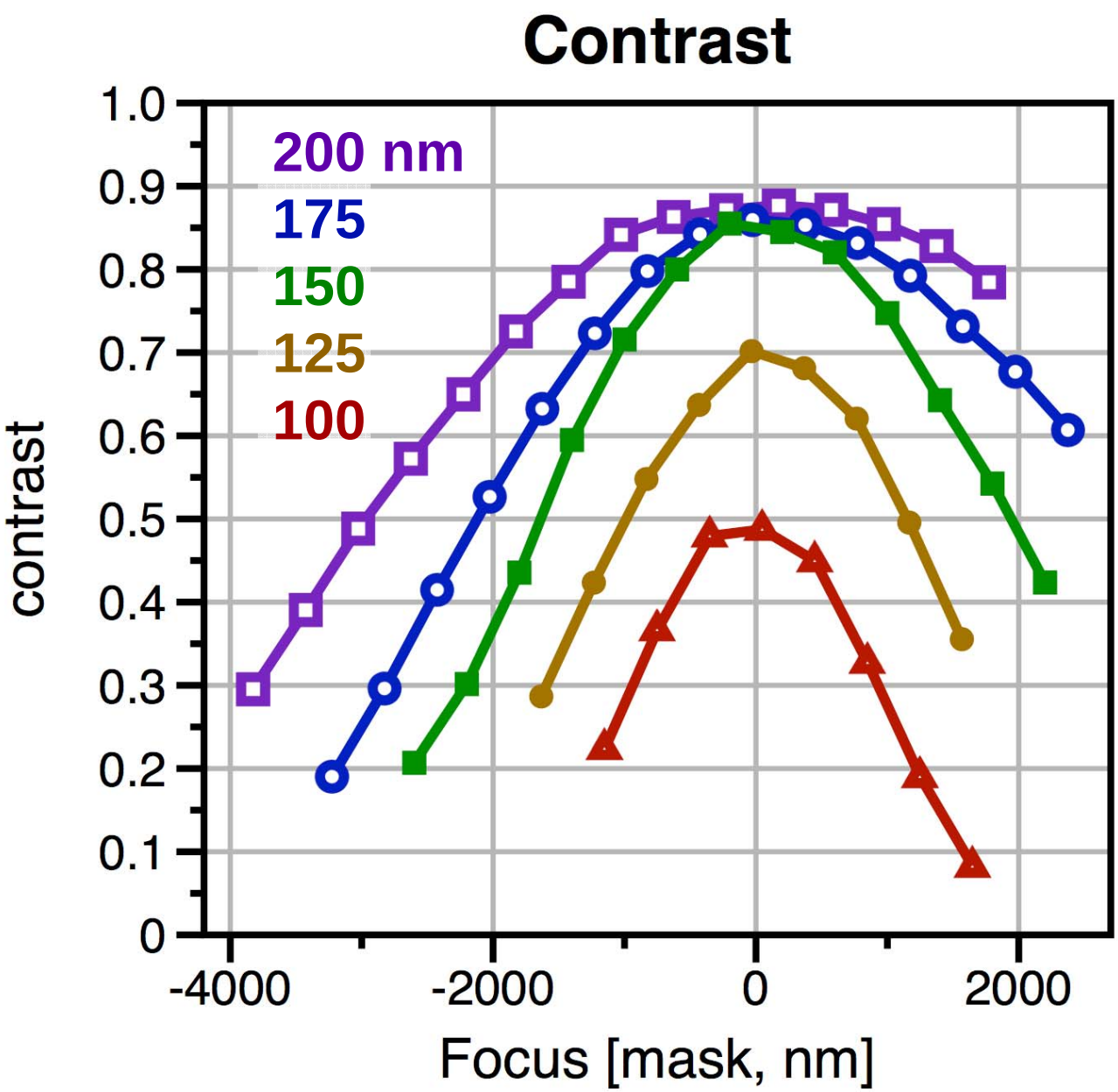
1 µm

100 nm | 125 nm | 150 nm | 175 nm | 200 nm

AIT (EUV) Images

Goldberg, *EIPBN 2009*

Measured contrast = mask contrast * AIT's CTF



Contrast curves for each pitch, through-focus

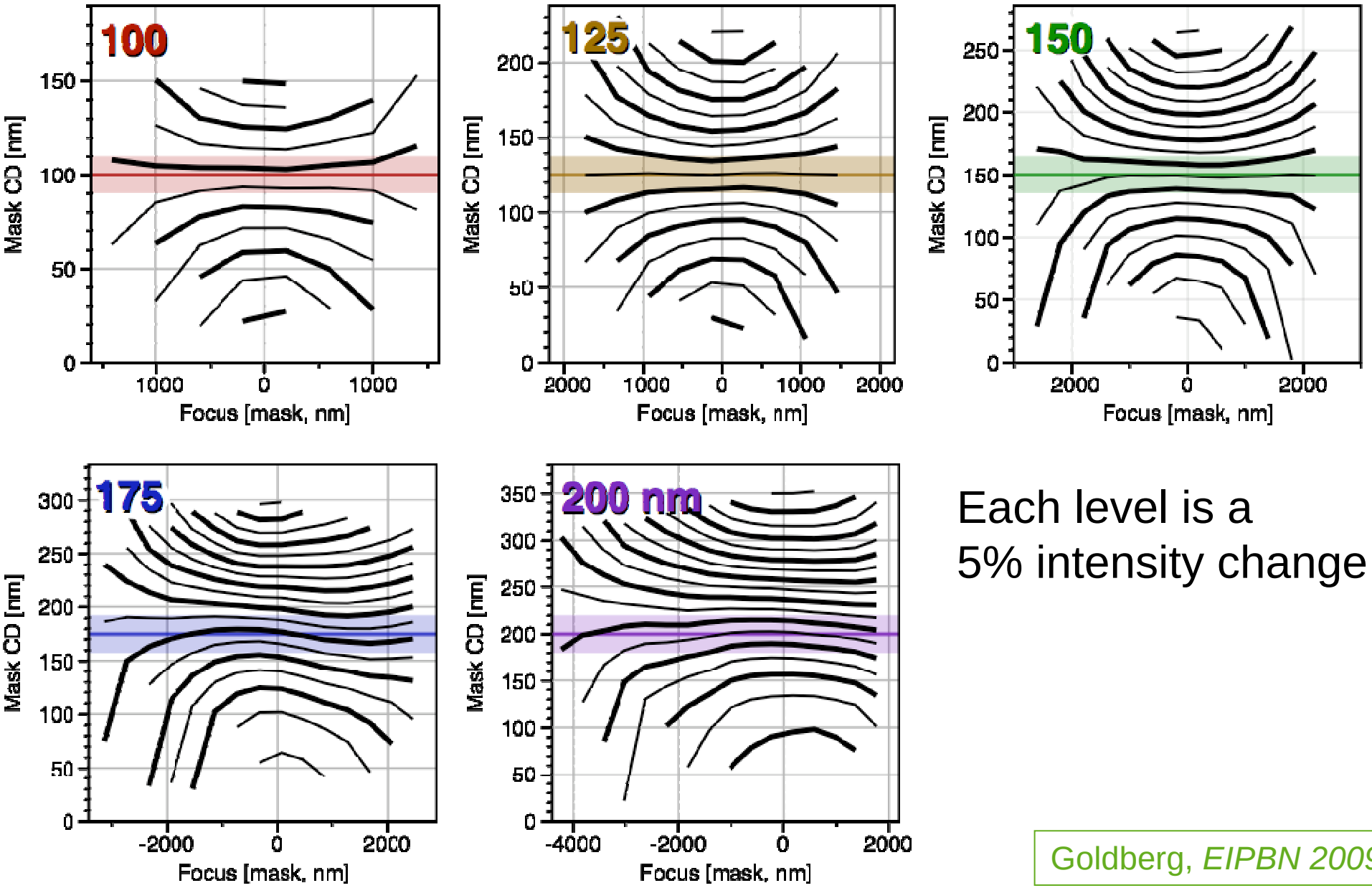
width

depth of focus

On this mask, contrast rolls-off below 150 nm

Goldberg, *EIPBN 2009*

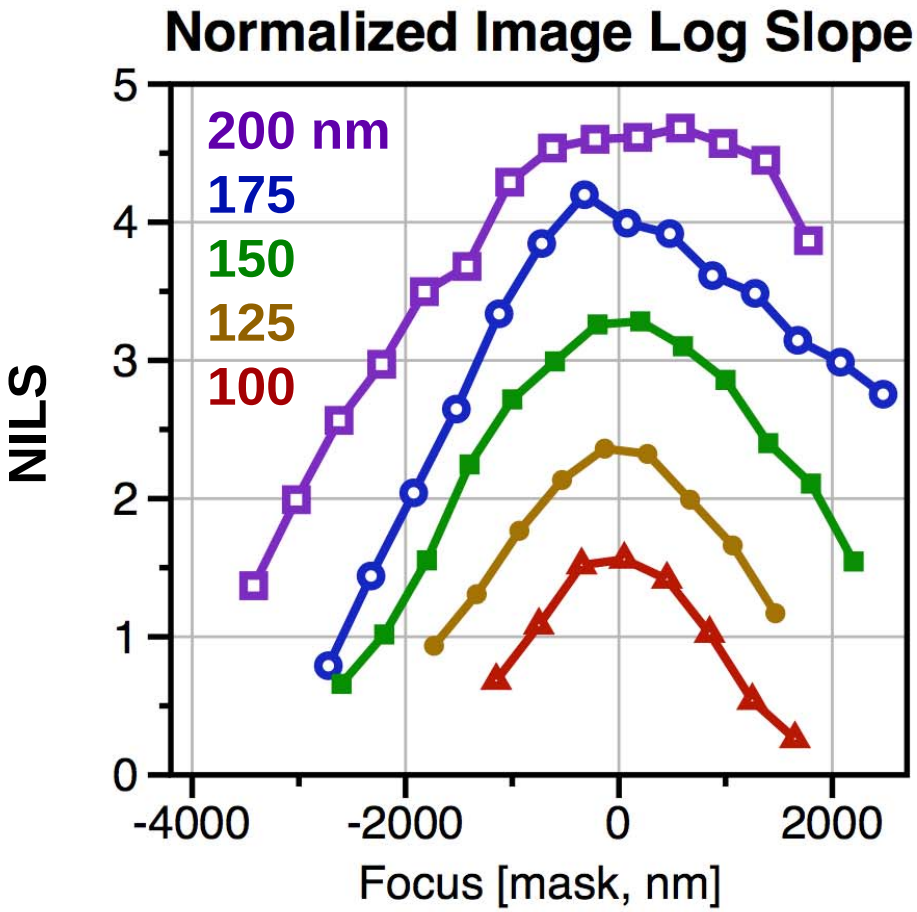
Bossung plots measured with the AIT
Linewidth through focus at different dose levels

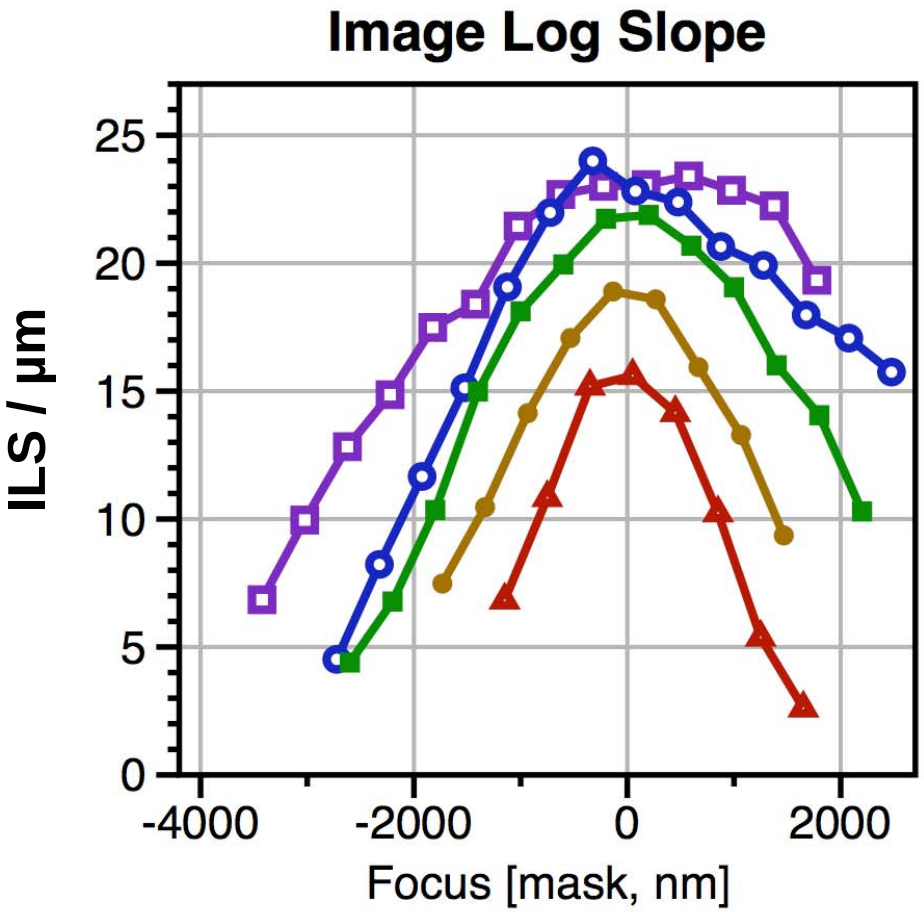


Each level is a
5% intensity change

Goldberg, *EIPBN 2009*

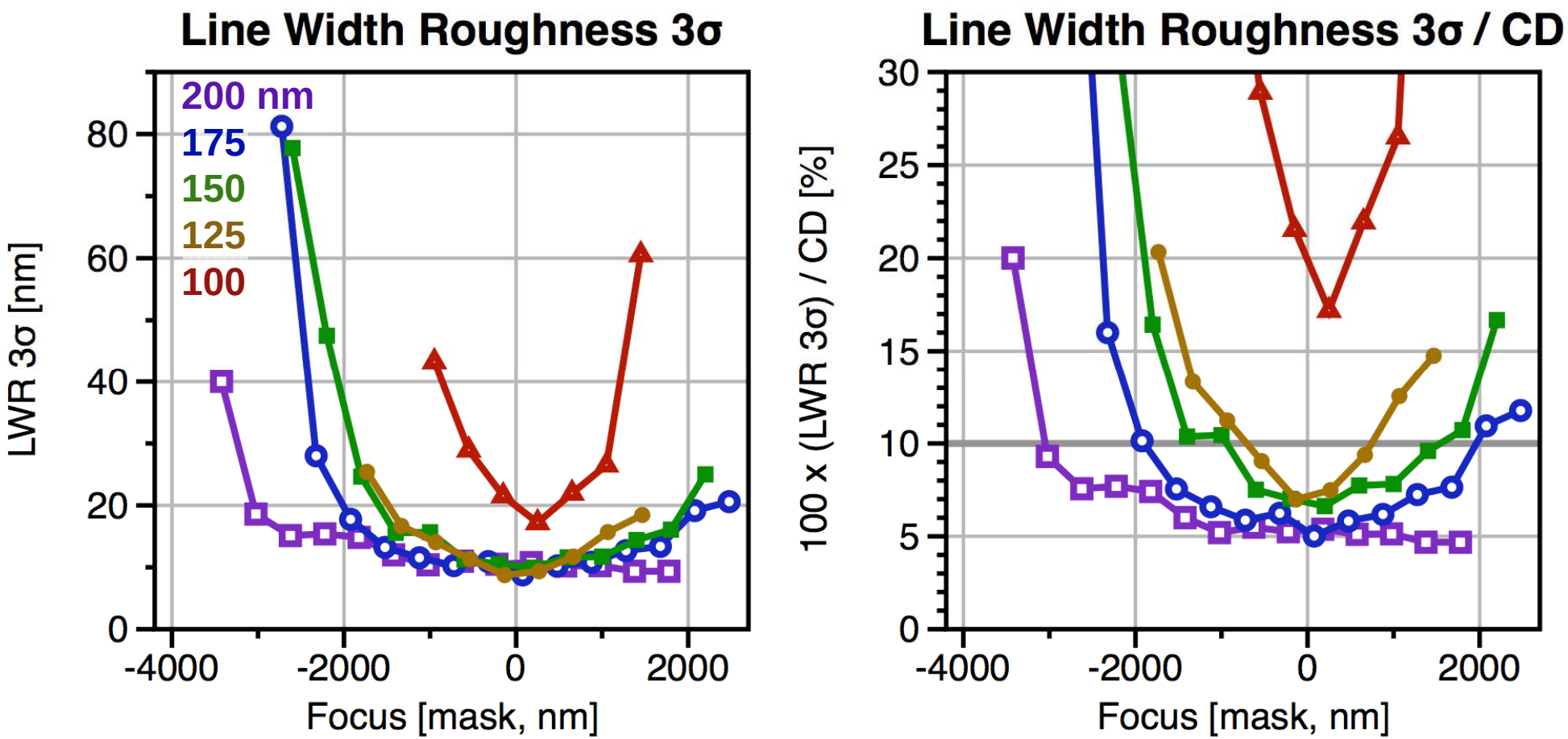
Intensity slope through-focus vs. pitch





Goldberg, *EIPBN 2009*

LWR 3σ through-focus vs. pitch

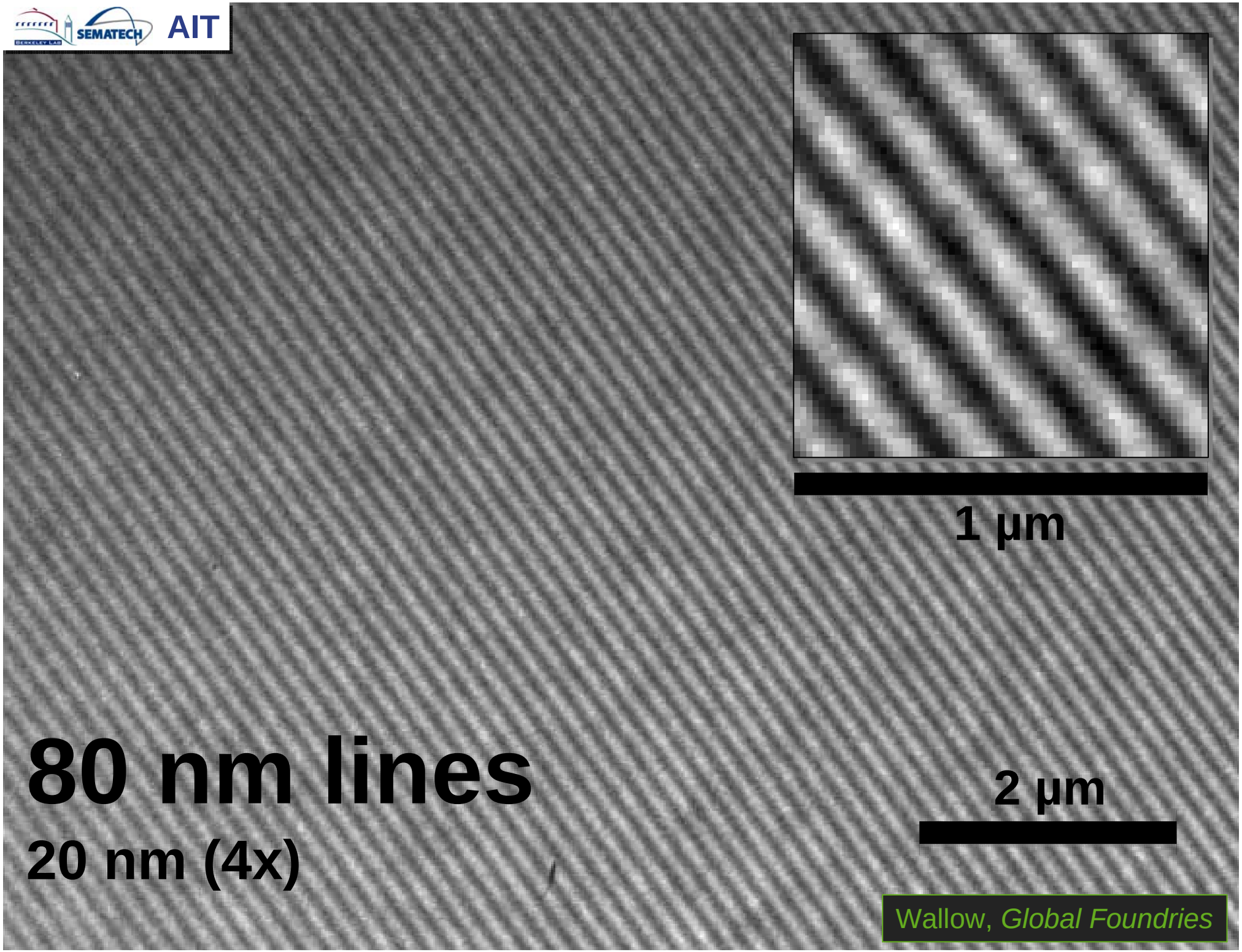


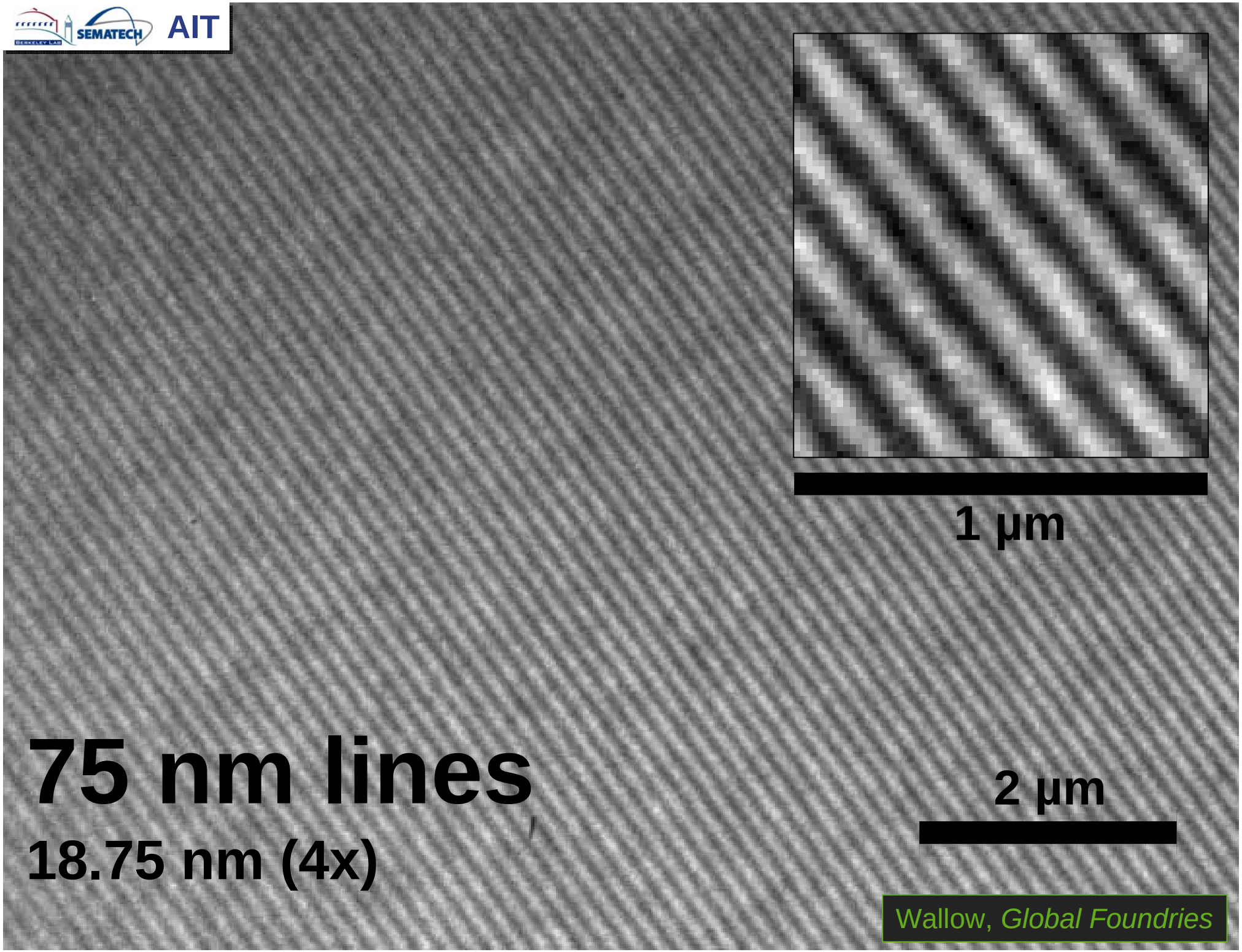
Minimum values are

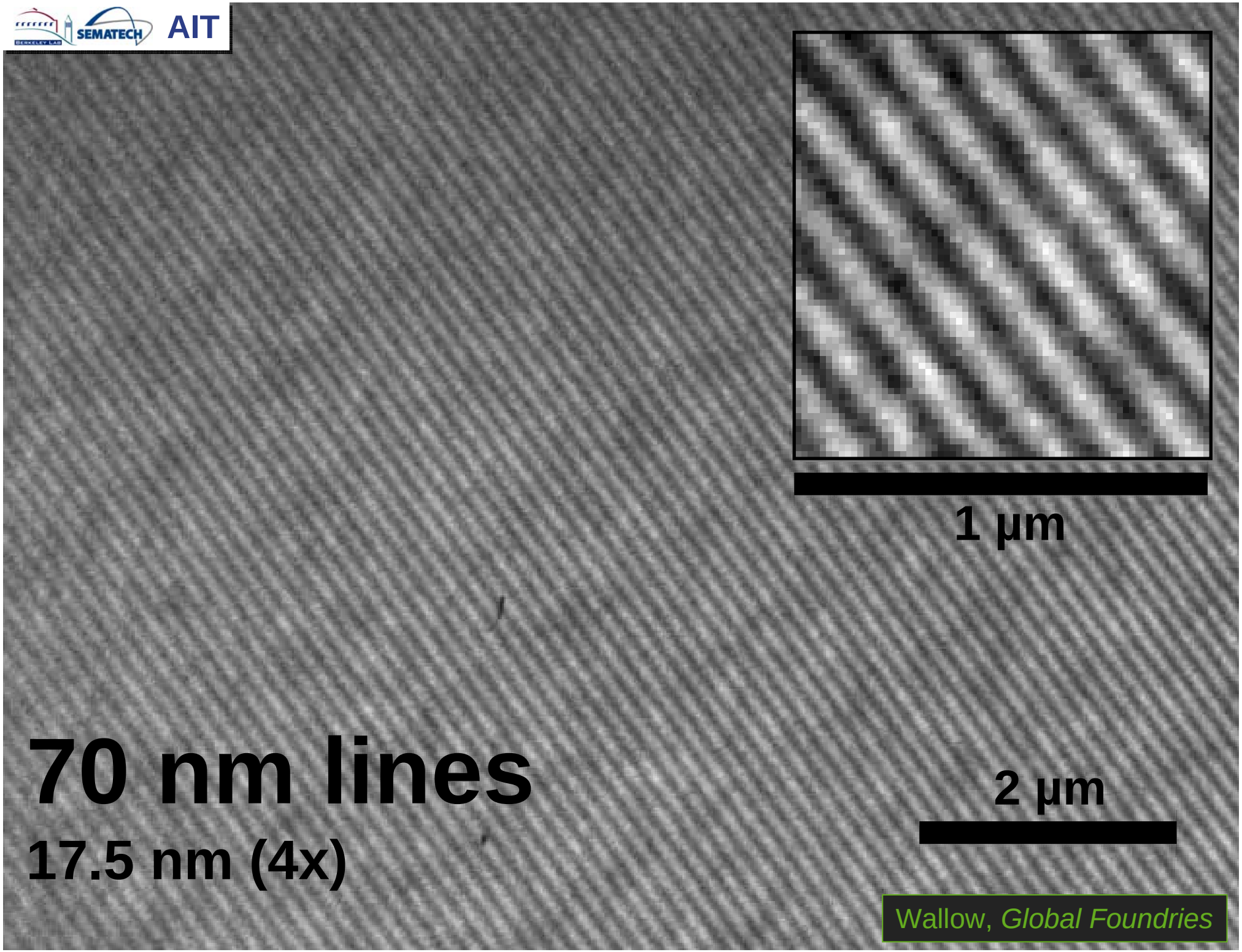
8–10 nm 3σ = 5–8% of CD

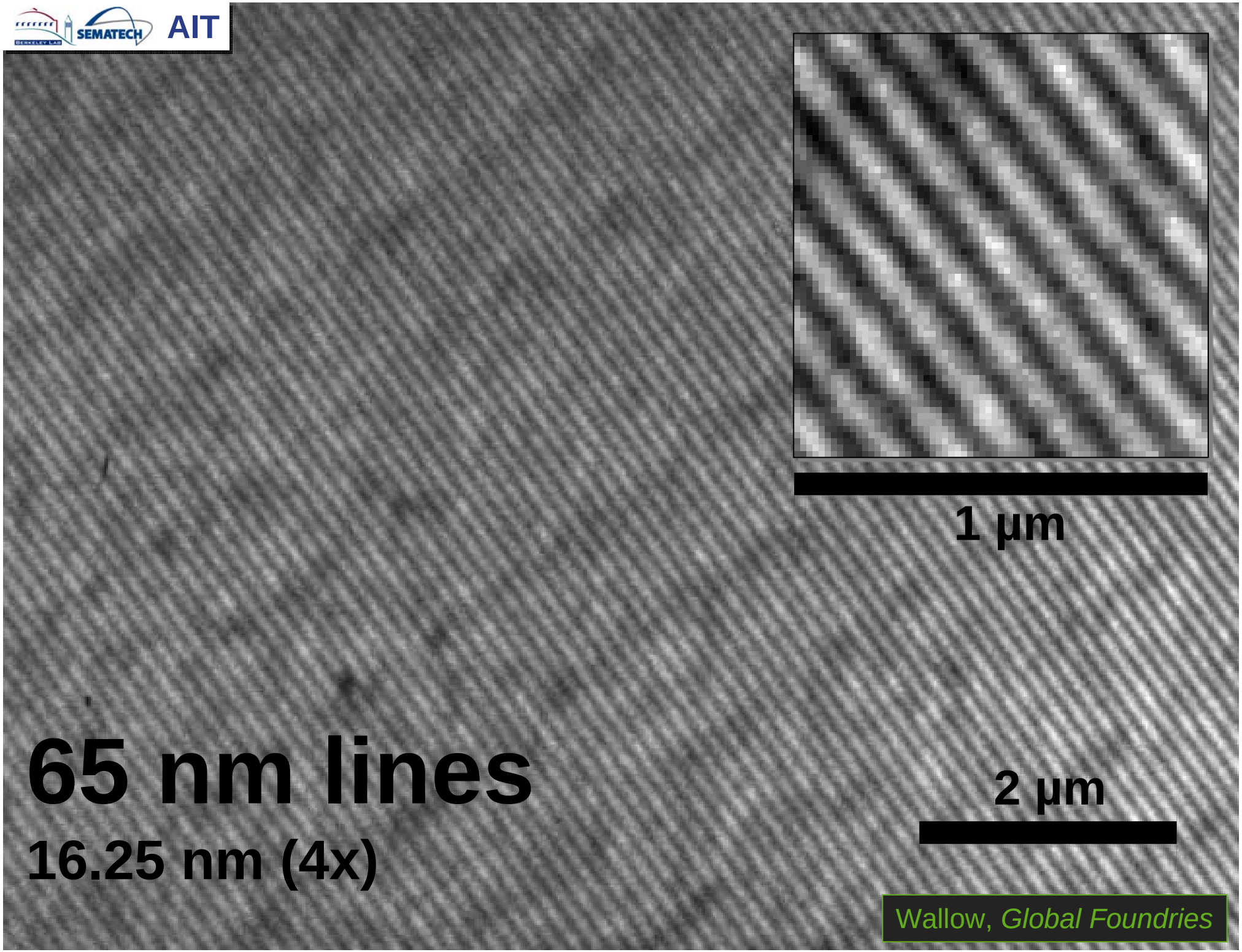
Flat bottom ⇒ inherent mask roughness.

Goldberg, *EIPBN 2009*


AIT
1 µm
80 nm lines
20 nm (4x)
2 µm
Wallow, *Global Foundries*


AIT
1 µm
75 nm lines
18.75 nm (4x)
2 µm
Wallow, *Global Foundries*

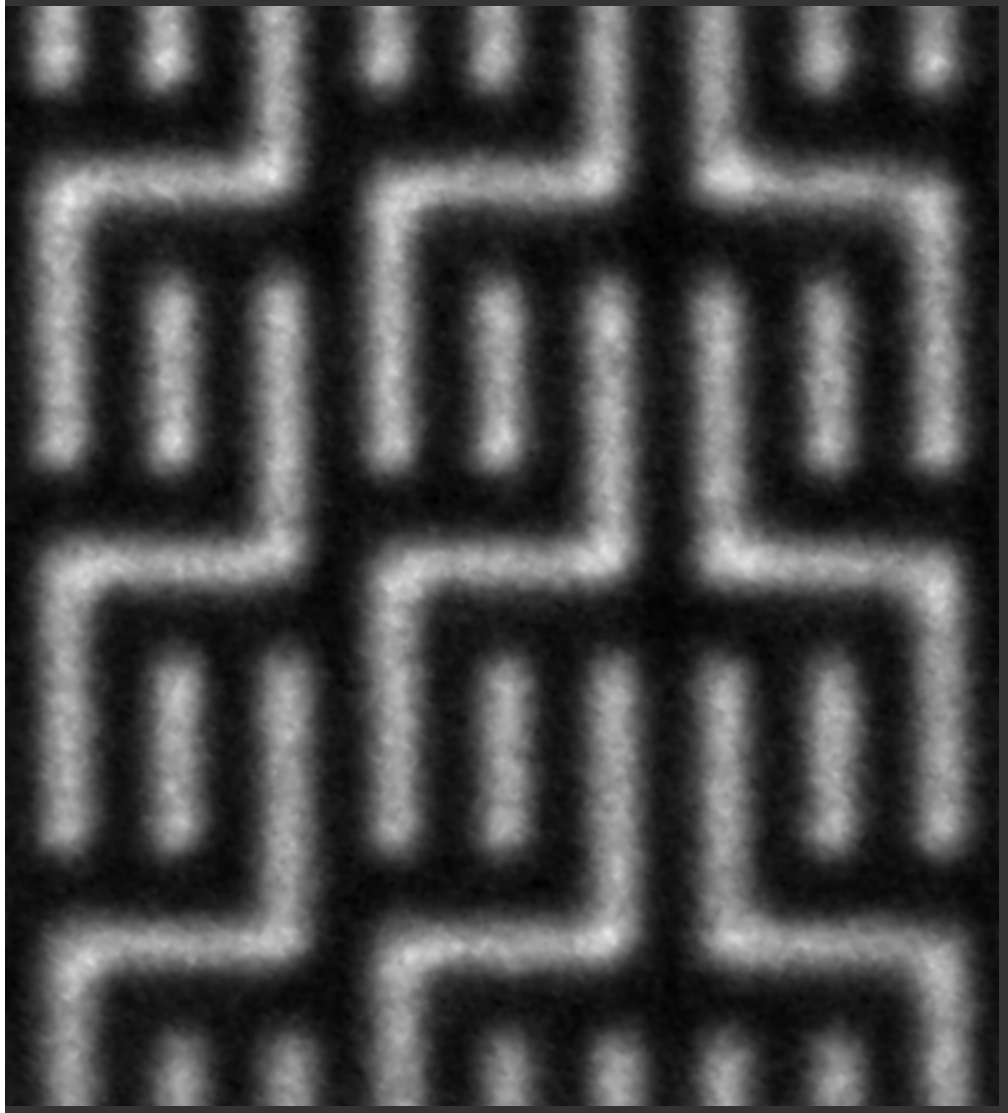

AIT
1 µm
70 nm lines
17.5 nm (4x)
2 µm
Wallow, *Global Foundries*

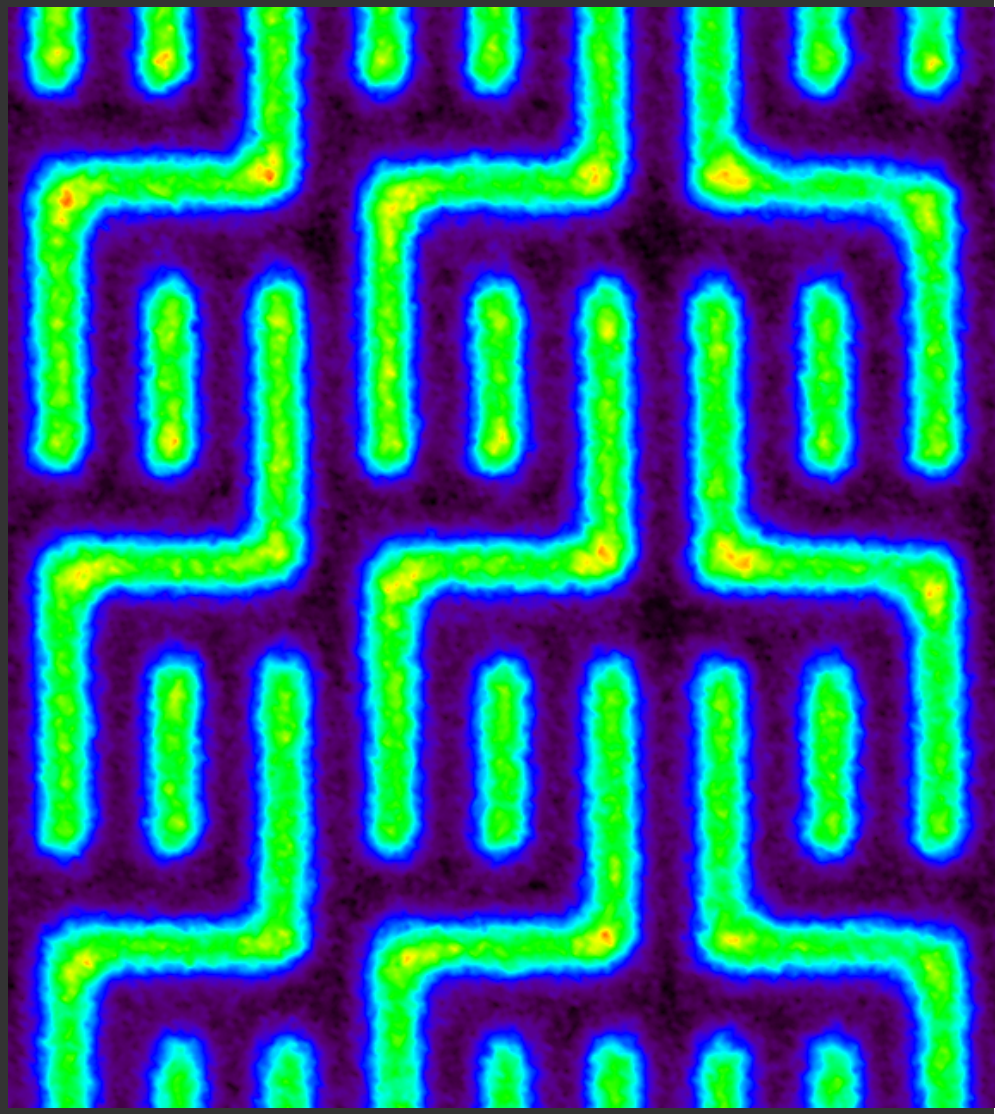

AIT
1 µm
65 nm lines
16.25 nm (4x)
2 µm
Wallow, *Global Foundries*

Using the AIT to explore OPC

32 nm hp

Normal: No OPC





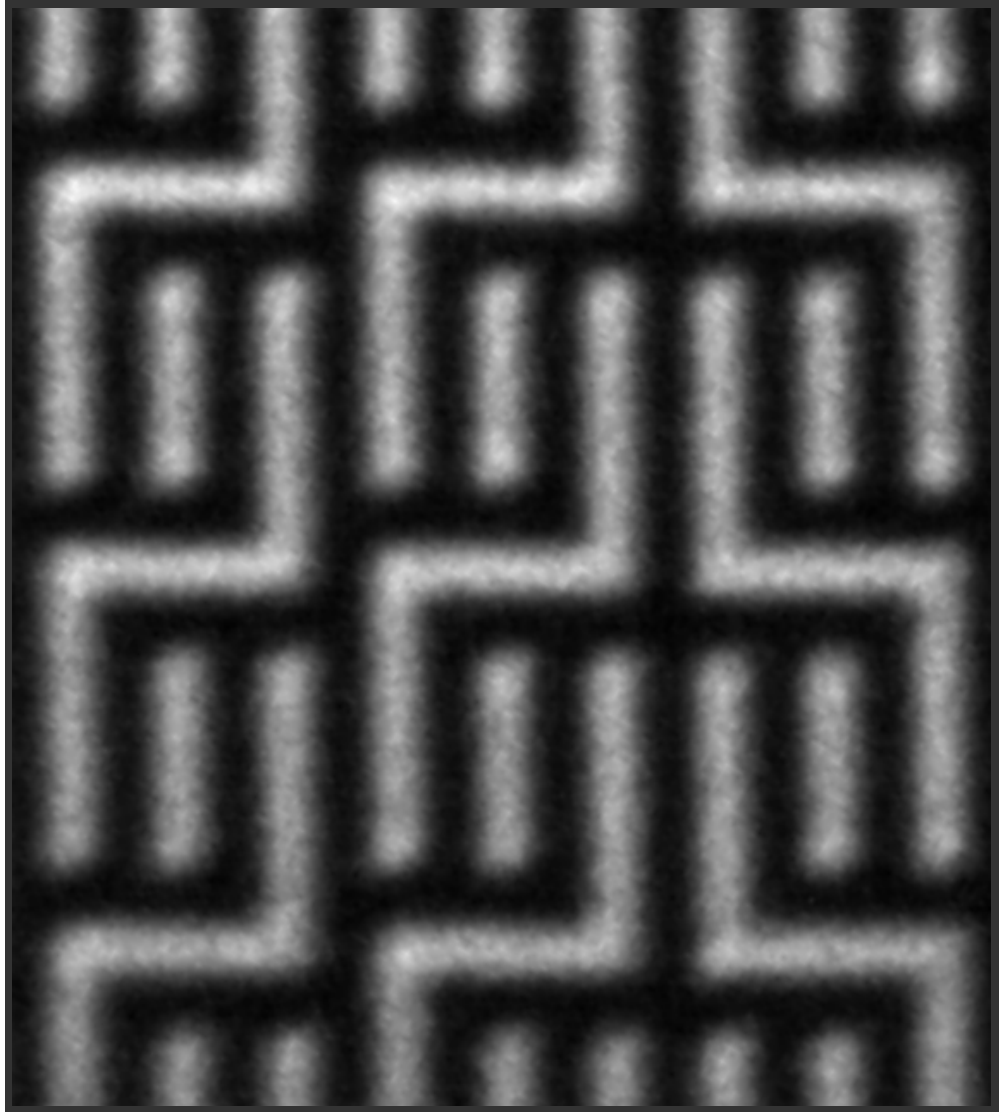
500 nm

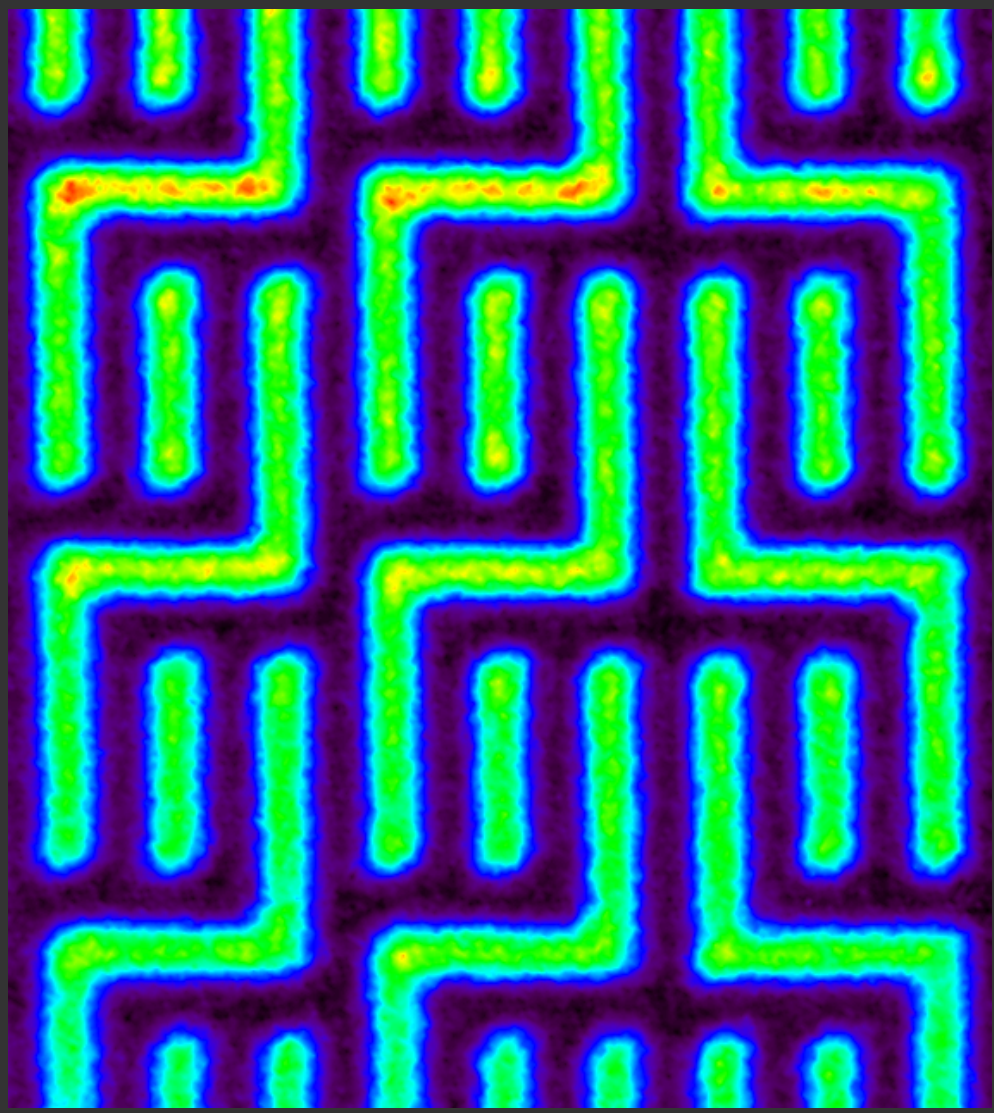
Wallow, *Global Foundries*

Using the AIT to explore OPC

32 nm hp

Full OPC



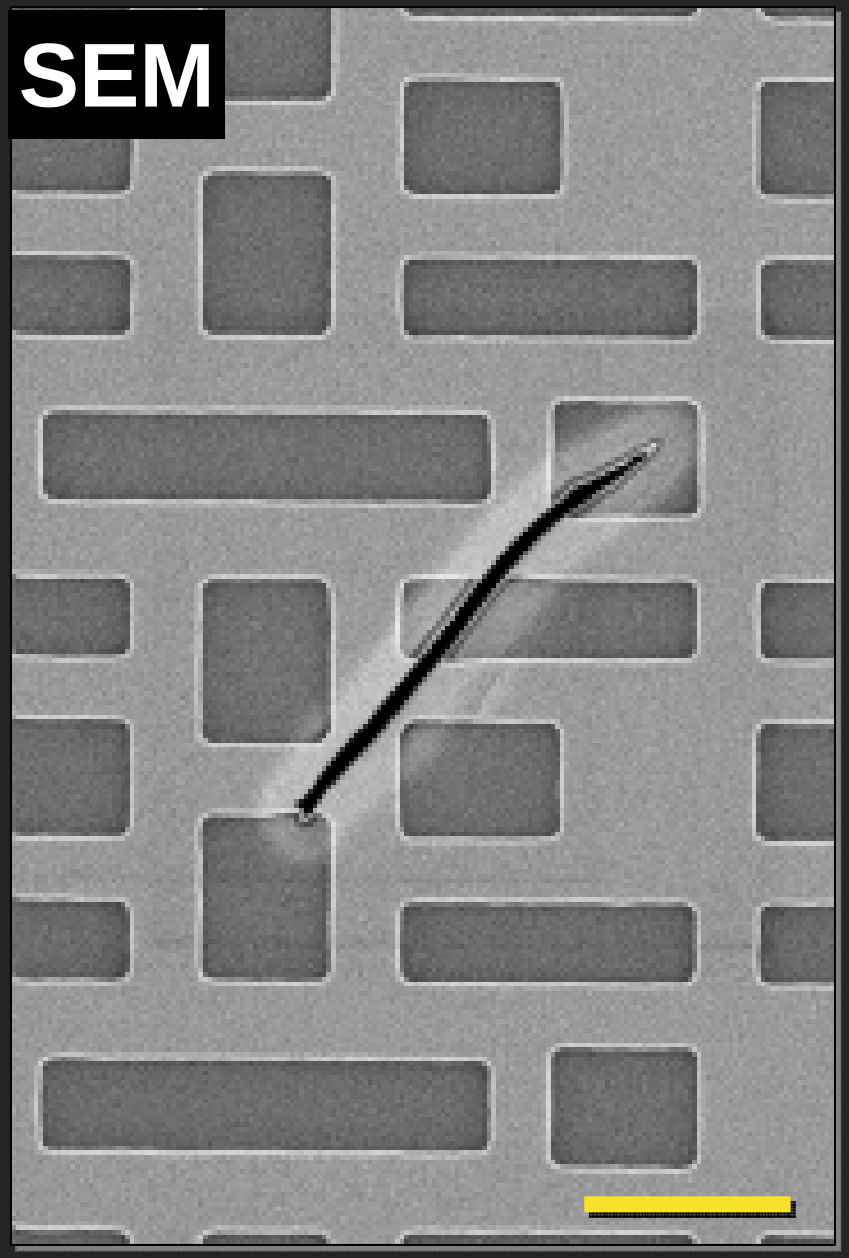


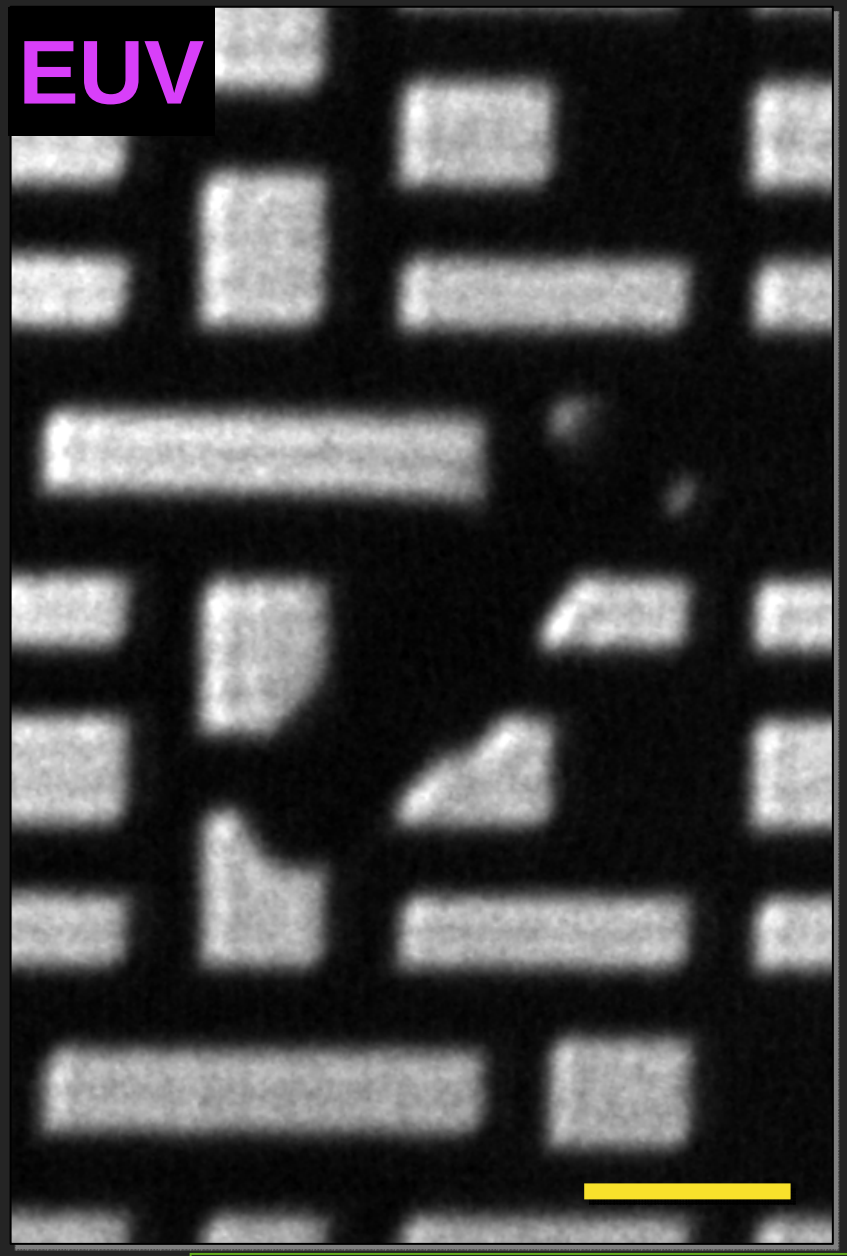
500 nm

Wallow, *Global Foundries*

Native defects on a full-field mask (1)

SEM image





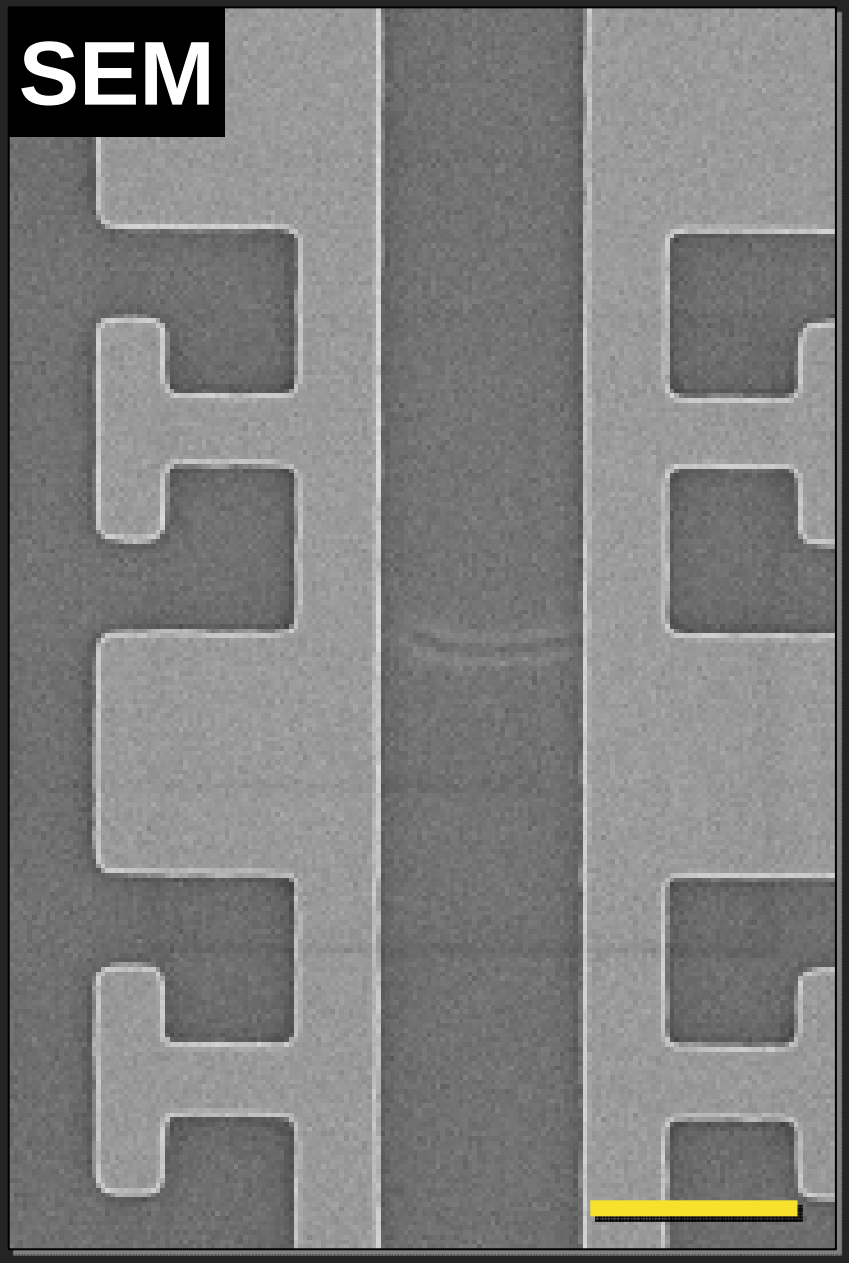
AIT (EUV) image

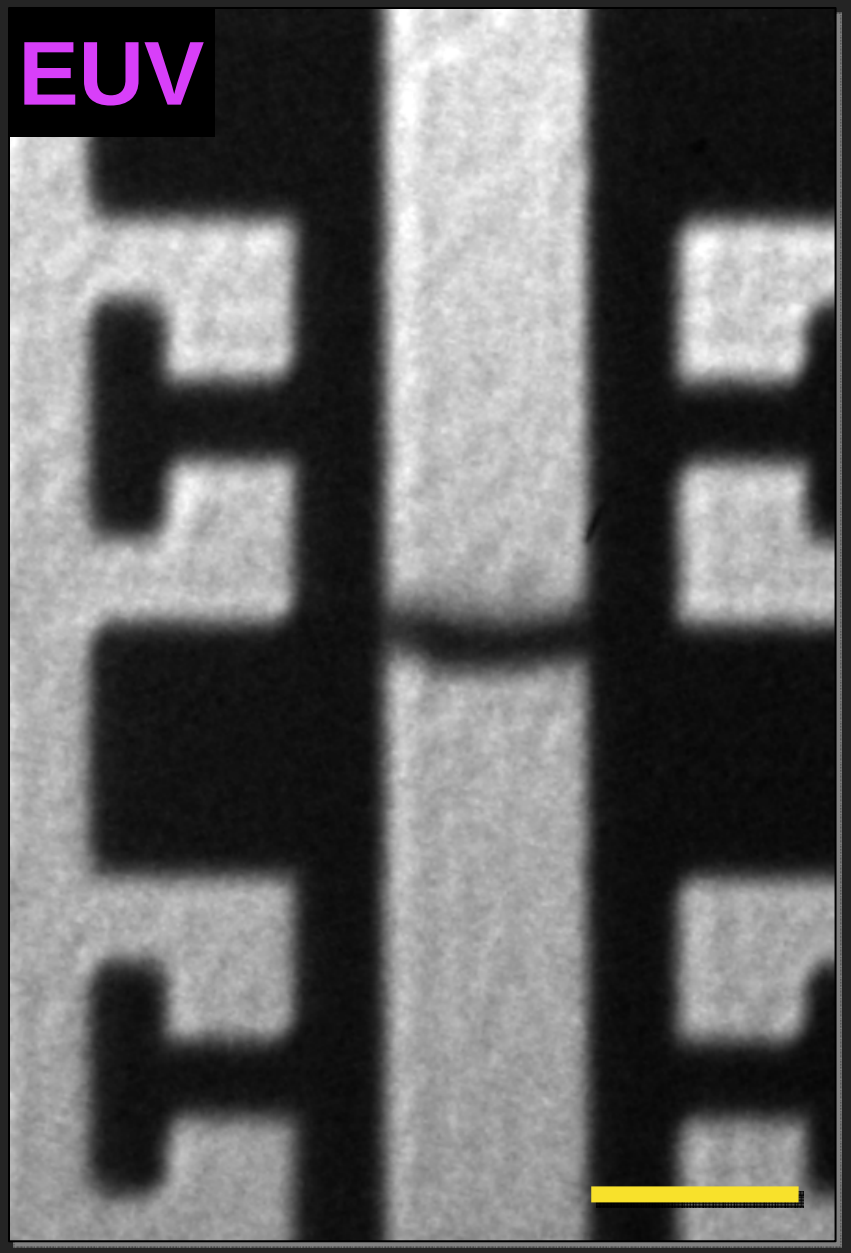
1 µm

LaFontaine, *GlobalFoundries, AMTC*

Native defects on a full-field mask (2)

SEM image



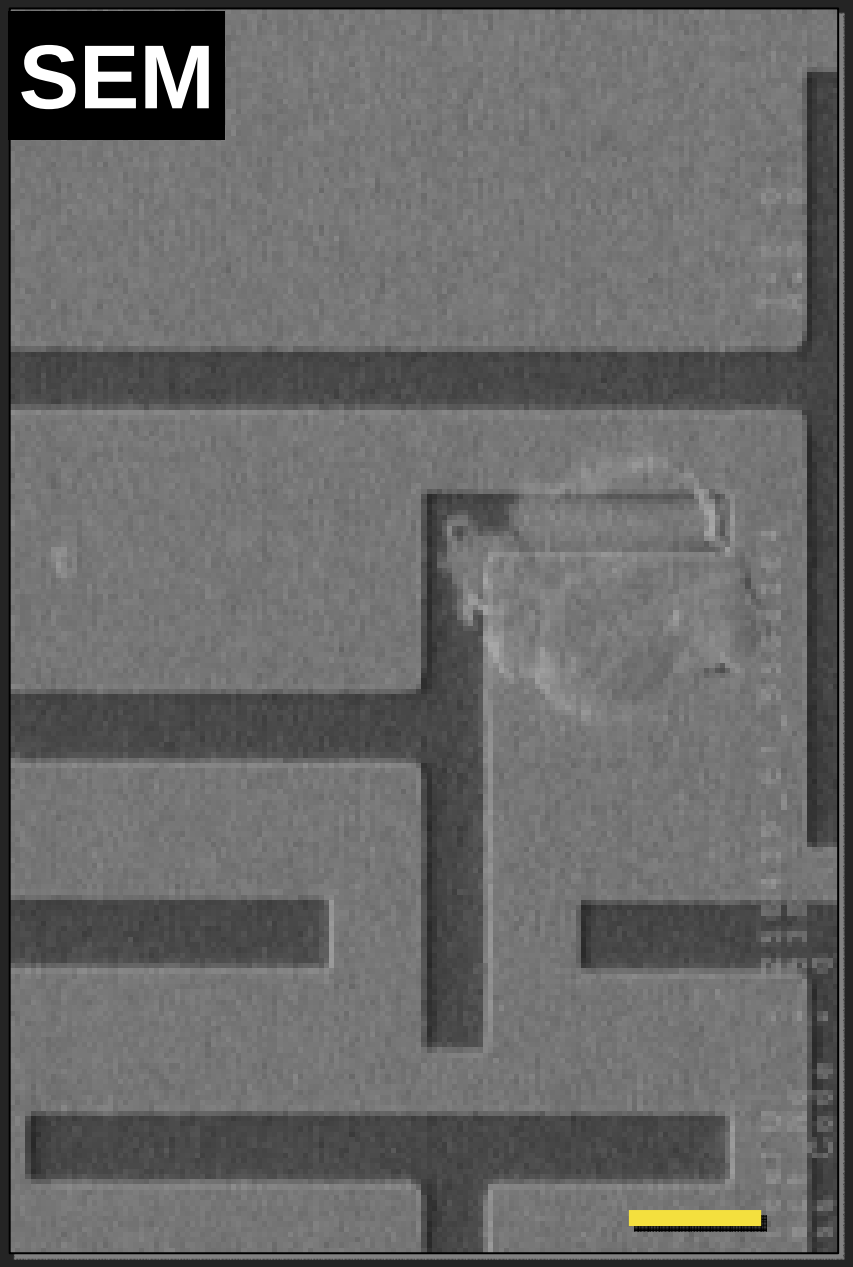


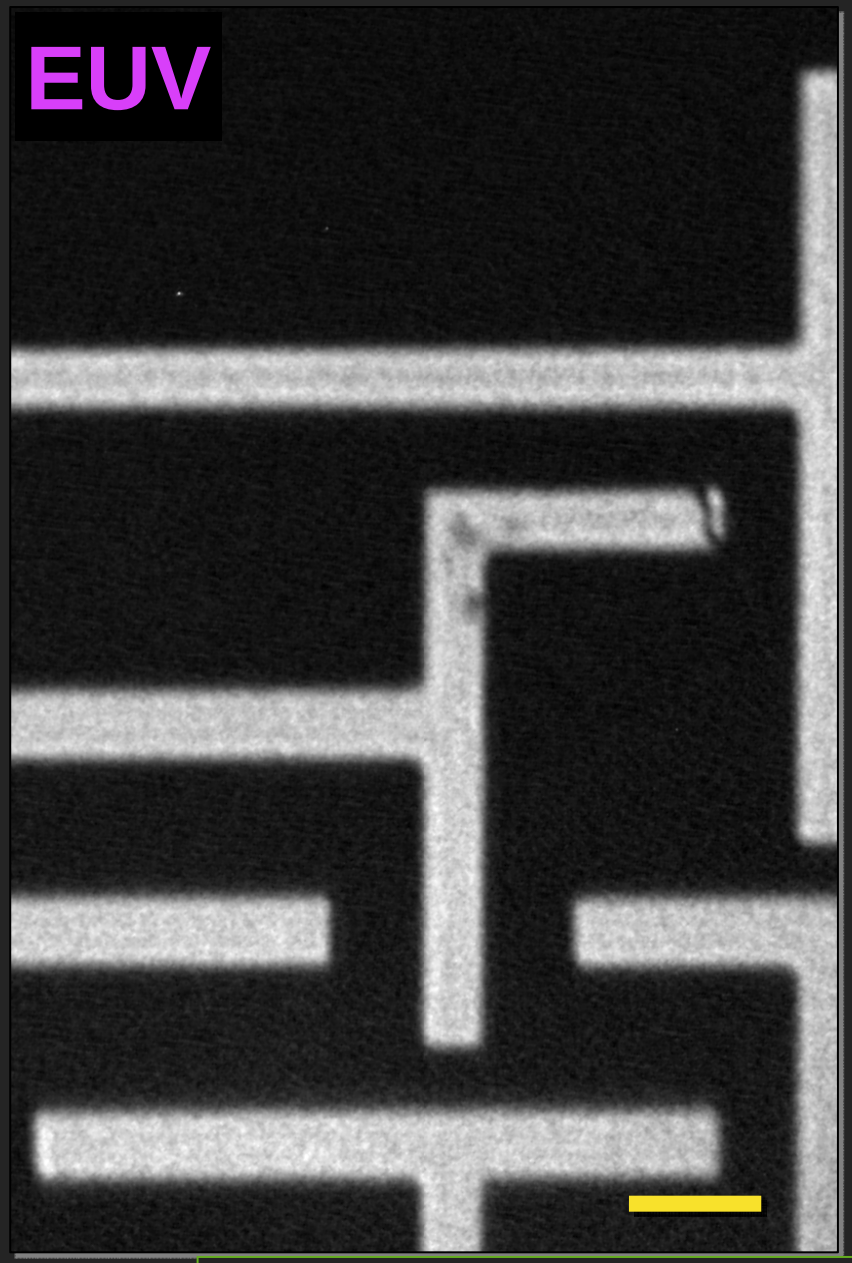
AIT (EUV) image

LaFontaine, *GlobalFoundries, AMTC*

Native defects on a full-field mask (3)

SEM image





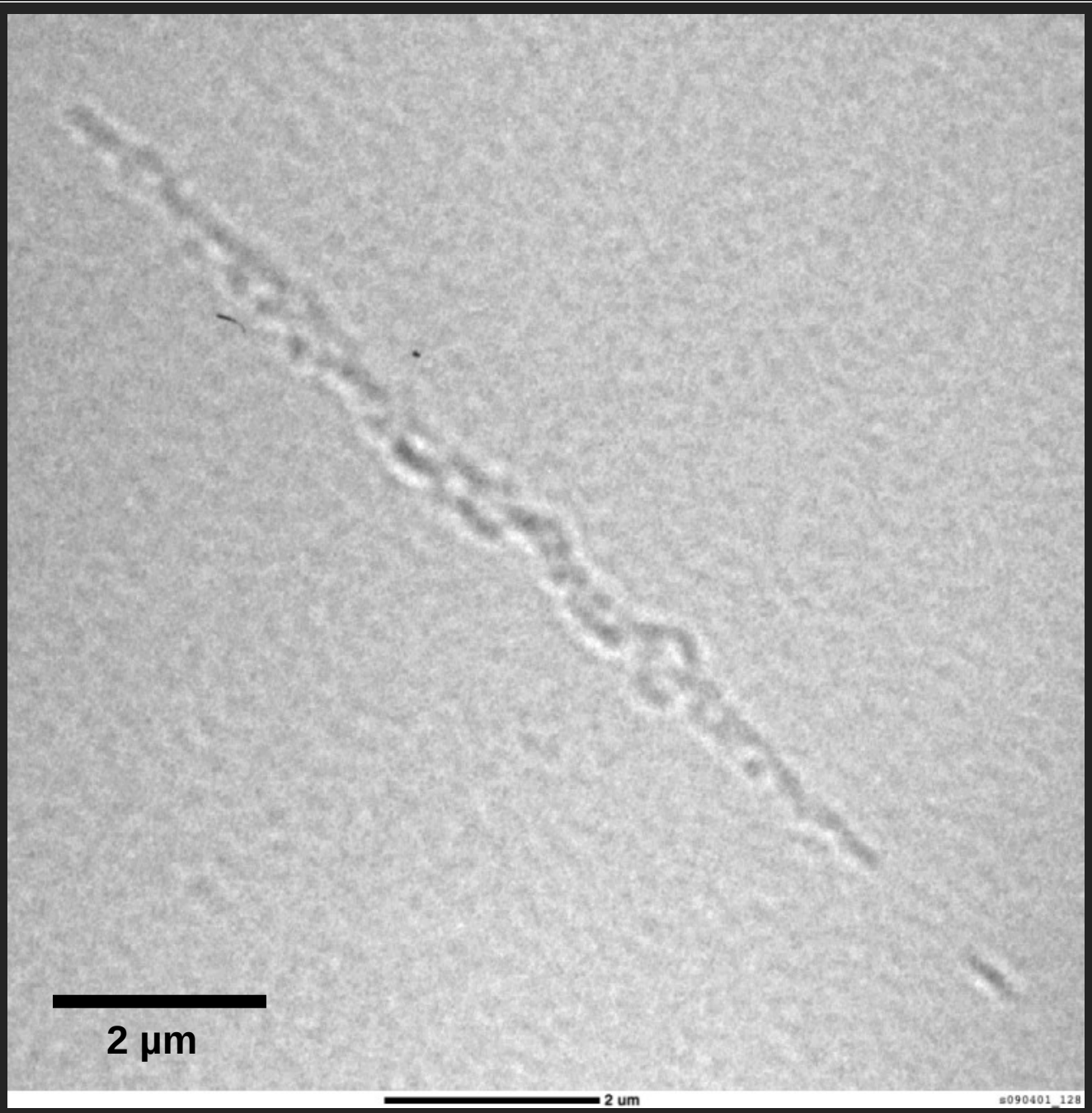
AIT (EUV) image

1 µm

LaFontaine, *GlobalFoundries, AMTC*

A “1 pixel” defect found in the Lasertec M7360

AIT (EUV) Image



Lasertec M7360 calls this a **“1 pixel defect”**

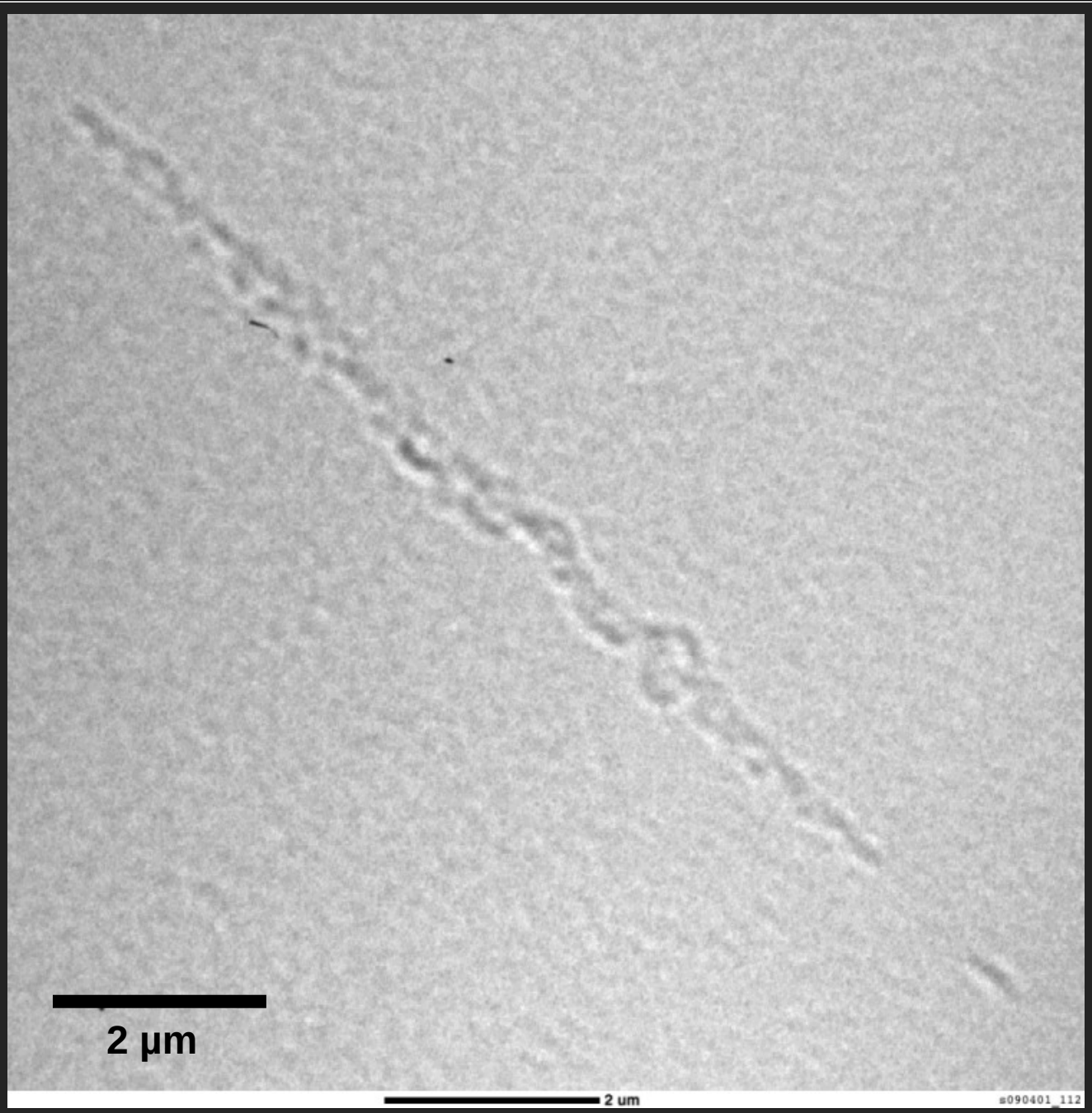
Phase-scratch **disappears in focus**

through-focus series

Huh, SEMATECH

A “1 pixel” defect found in the Lasertec M7360

AIT (EUV) Image



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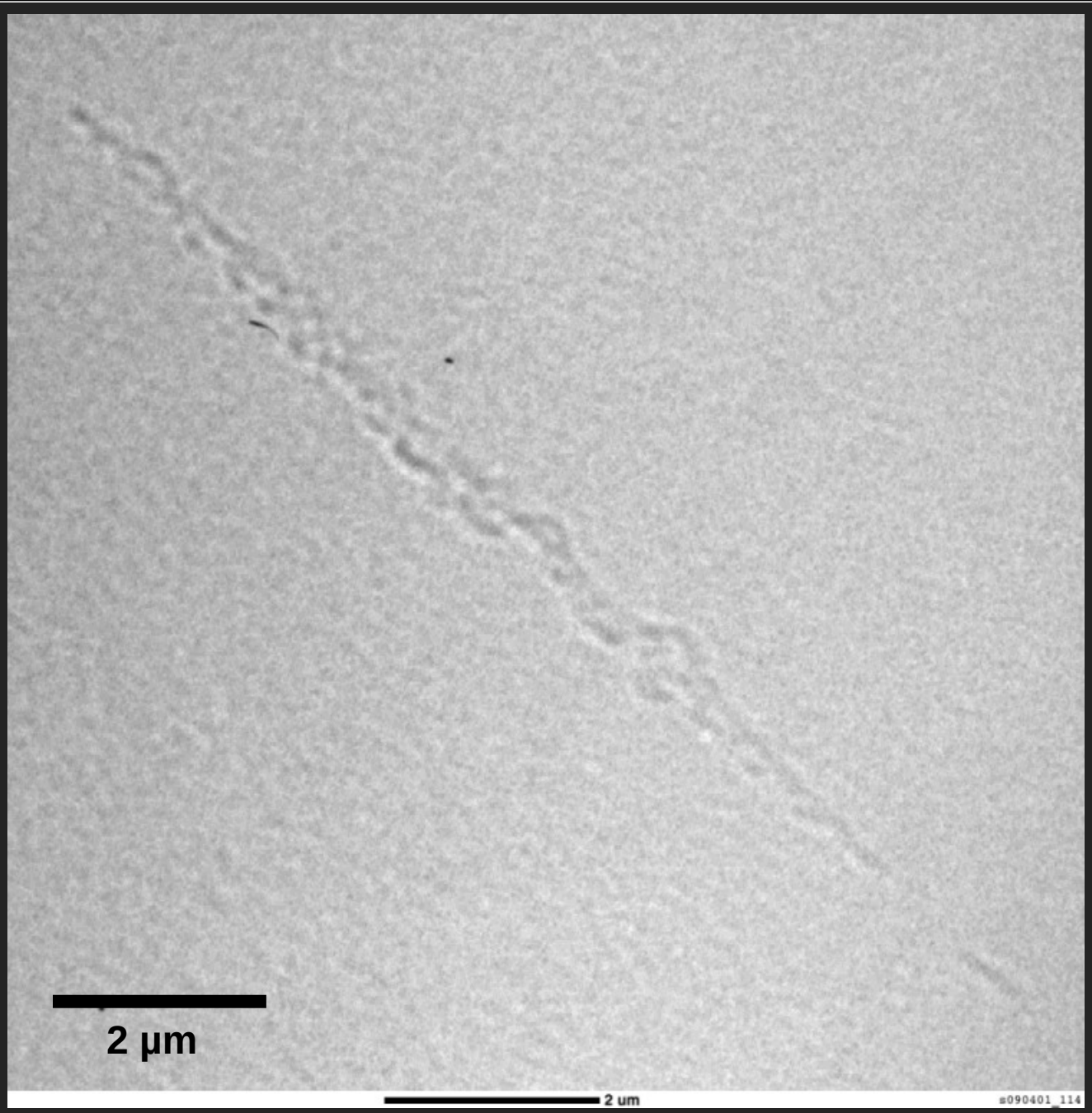

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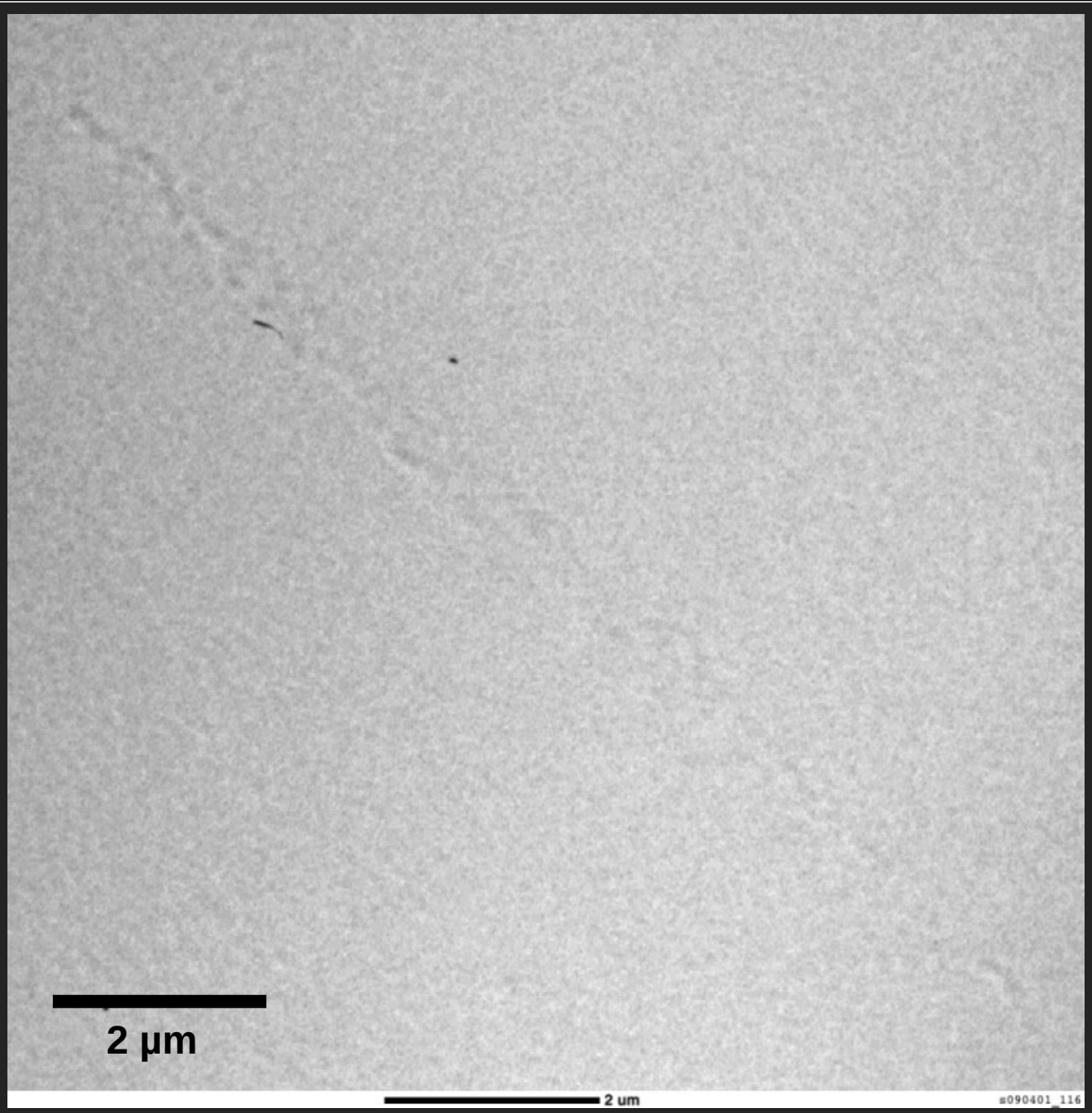

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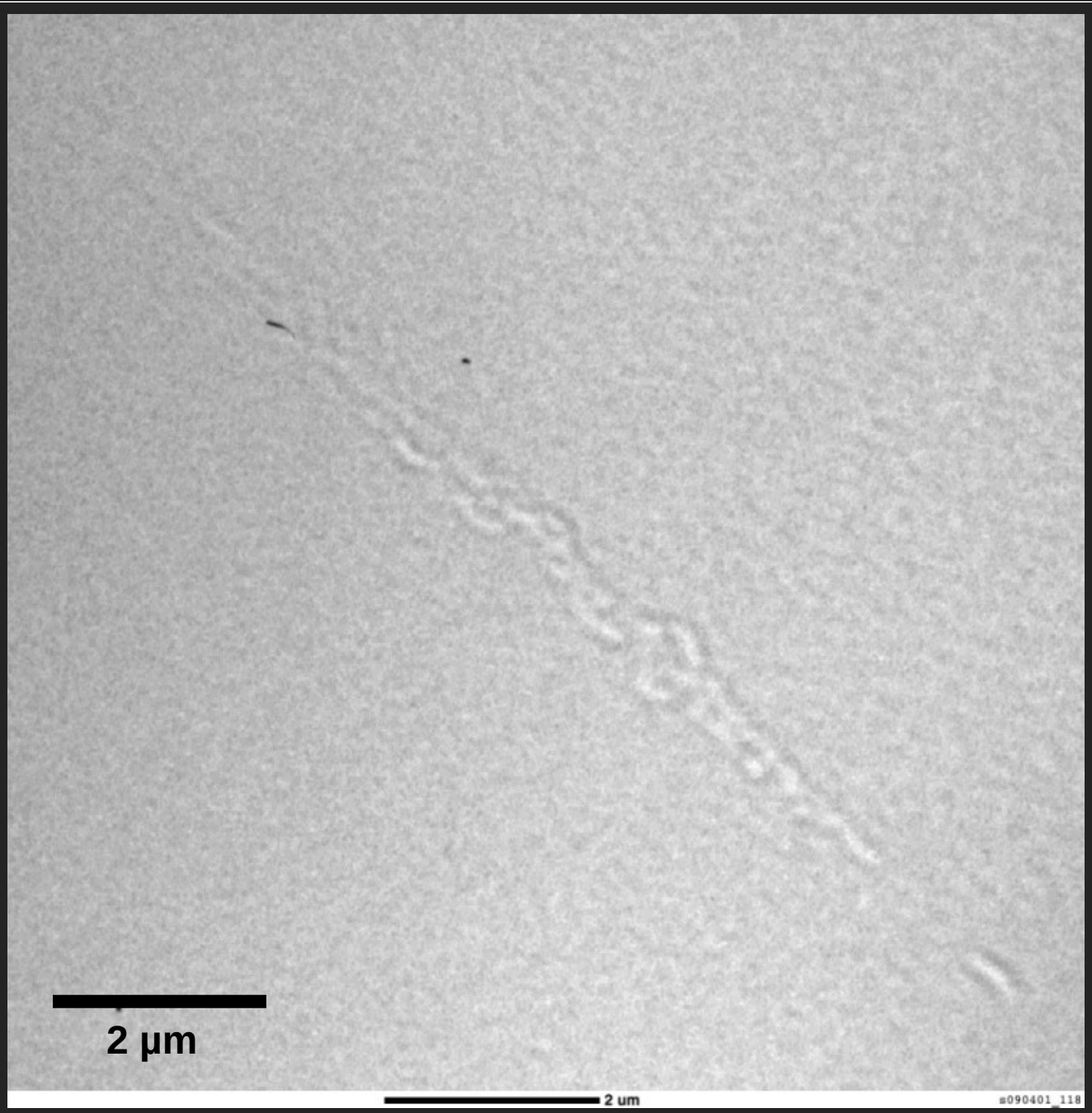

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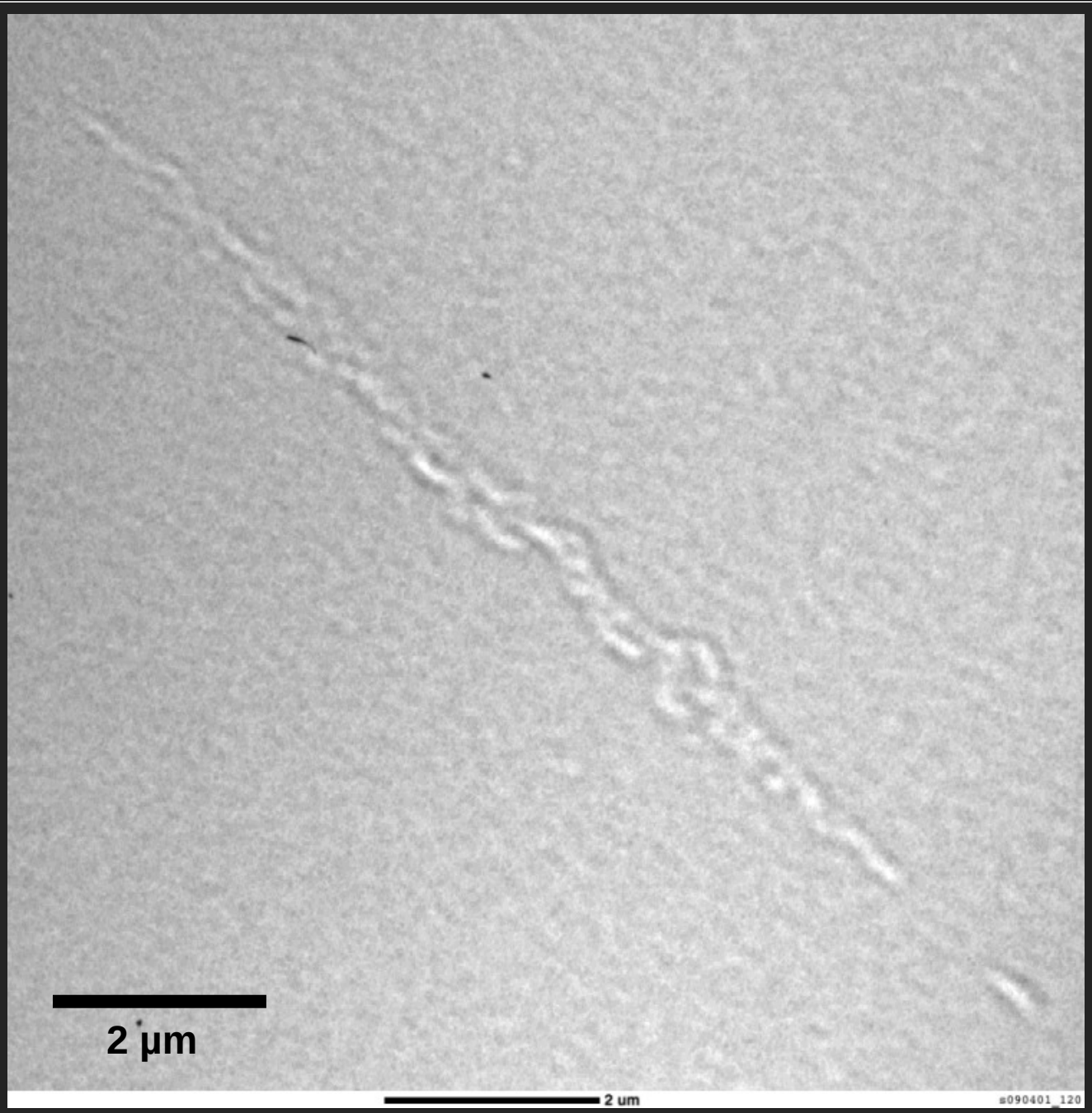

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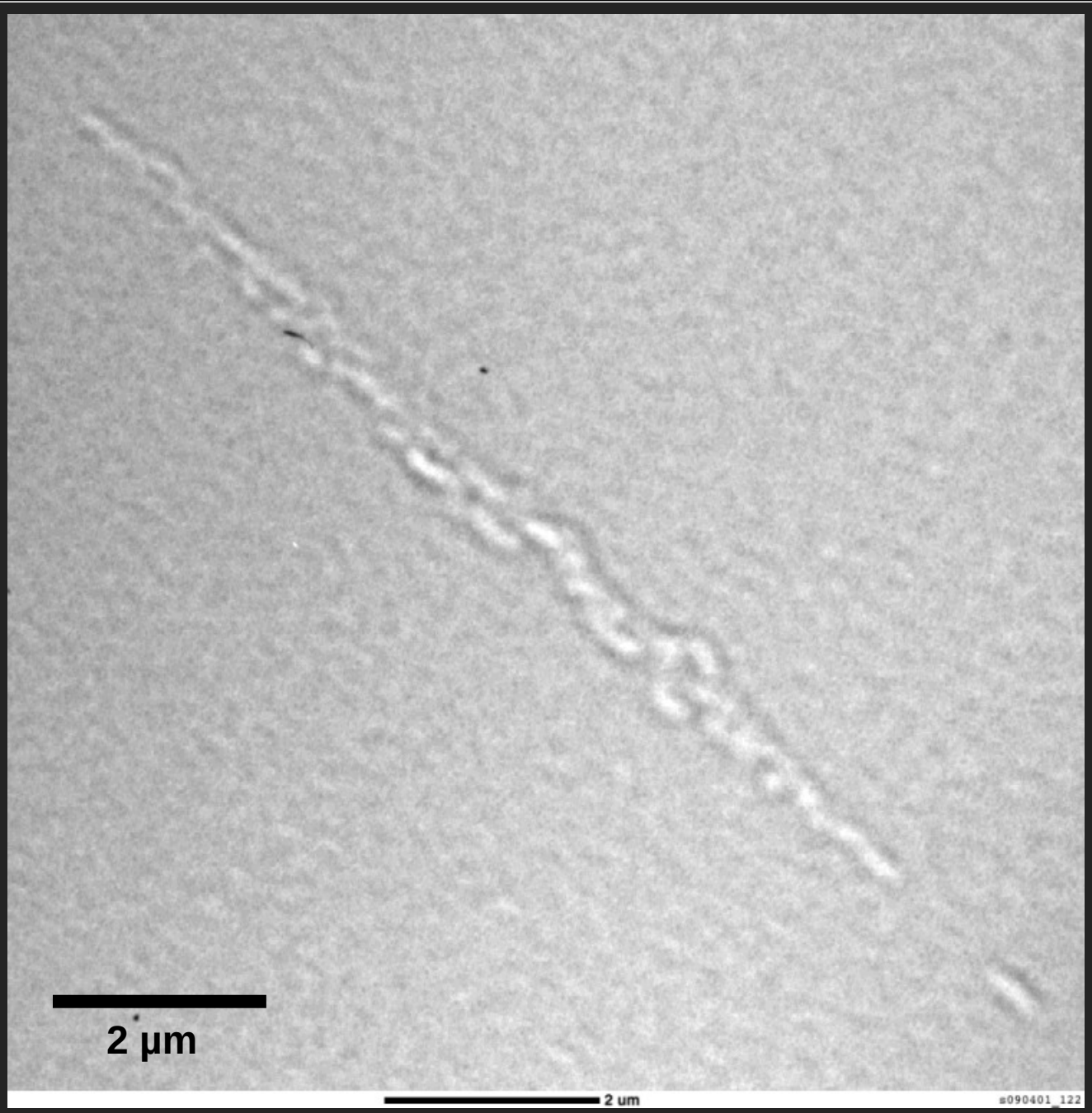
AIT (EUV) Image



Lasertec M7360 calls this a **“1 pixel defect”**

Phase-scratch **disappears in focus**

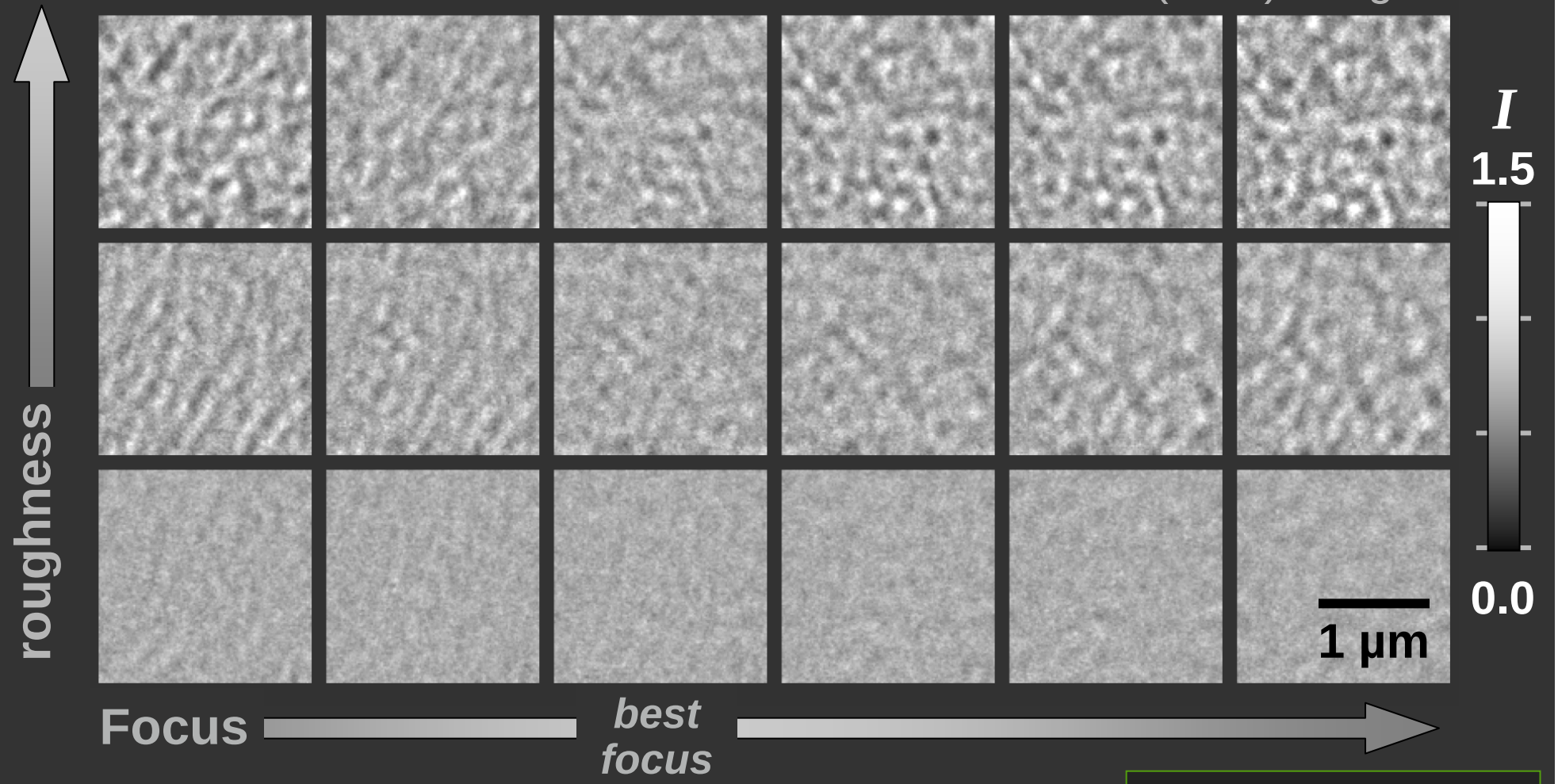
through-focus series

Huh, SEMATECH

Measuring the buried substrate roughness that increases LER

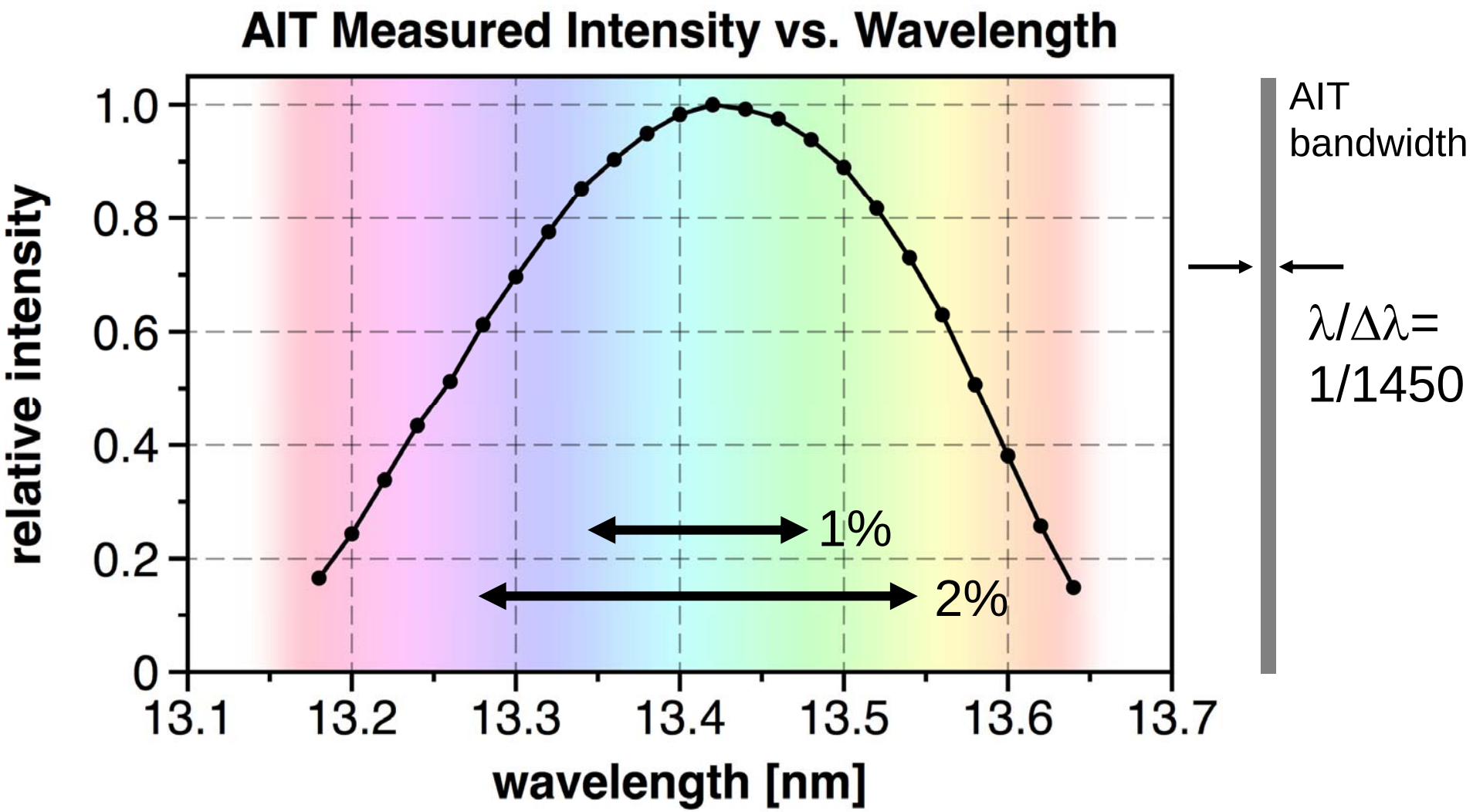
Intensity contrast in bright regions increases with roughness

AIT (EUV) images



P. Naulleau, S. George

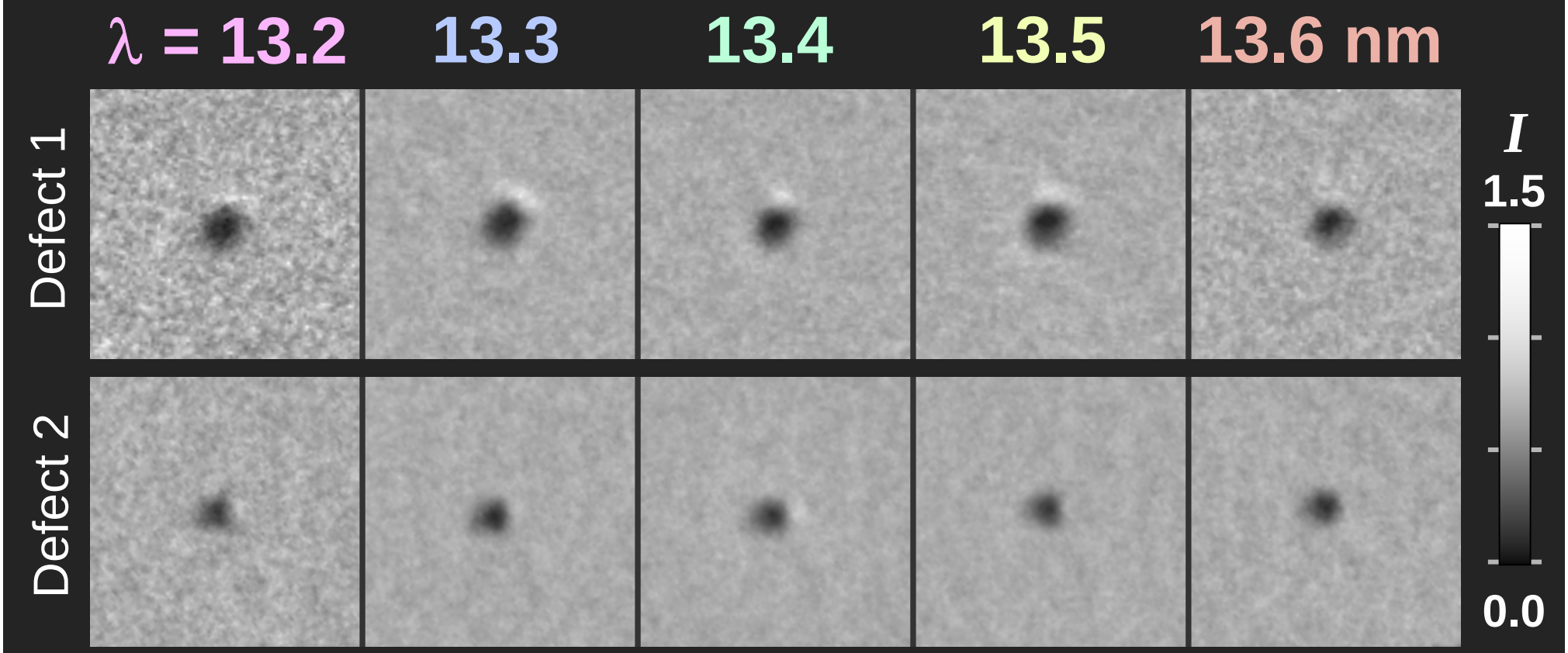
AIT: Tunable λ measurements from 13.2–13.6 nm



- Narrow-band illumination is required for zoneplates.
- The AIT can operate across a range of wavelengths to **synthesize broad-spectrum EUV illumination.**

Huh, *SEMATECH*

Native phase defects show little λ dependence



AIT (EUV) Images

Images at peak ΔI

Huh, SEMATECH

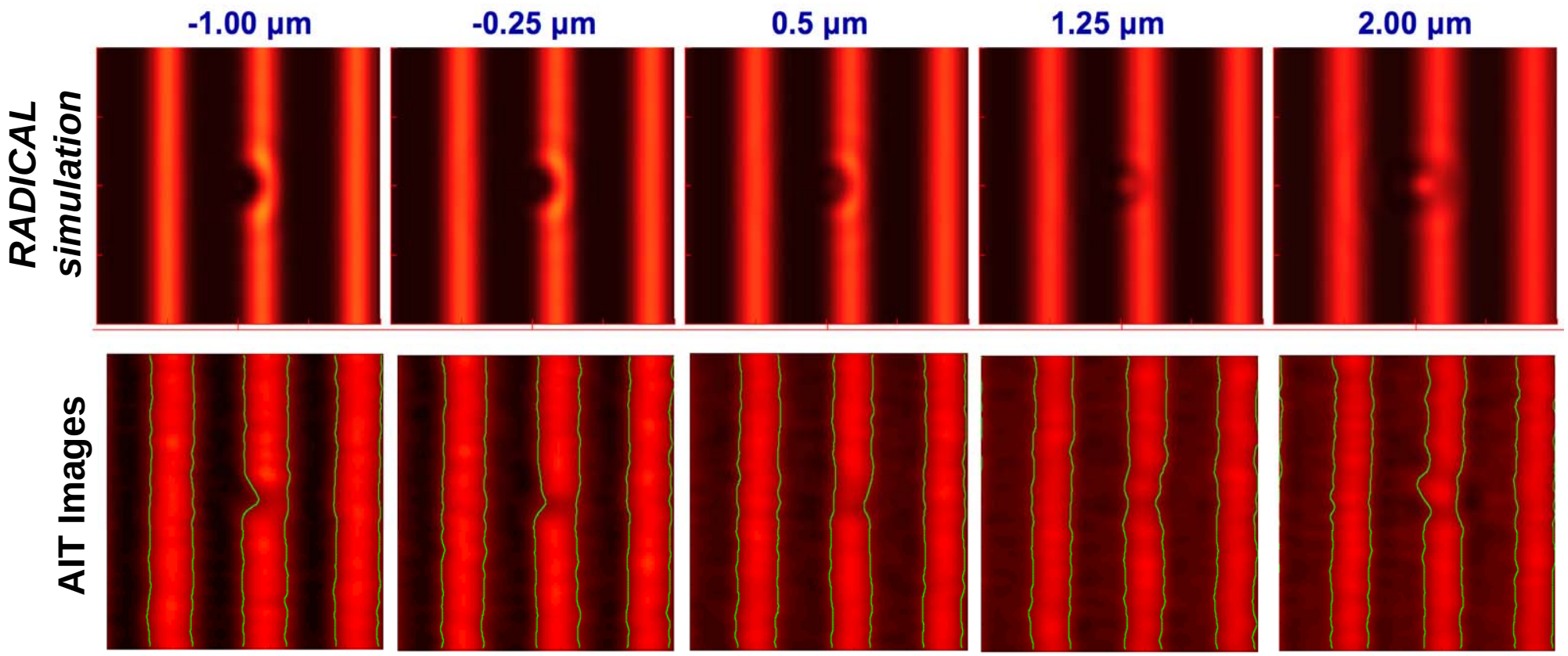
Comparison of RADICAL (simulation) to AIT images through focus

Surface Defect height: 5.3nm

1 Rayleigh Unit : $\lambda / 2NA^2 = 1.2\mu m$

AIT Images

RADICAL Images (Simulation)



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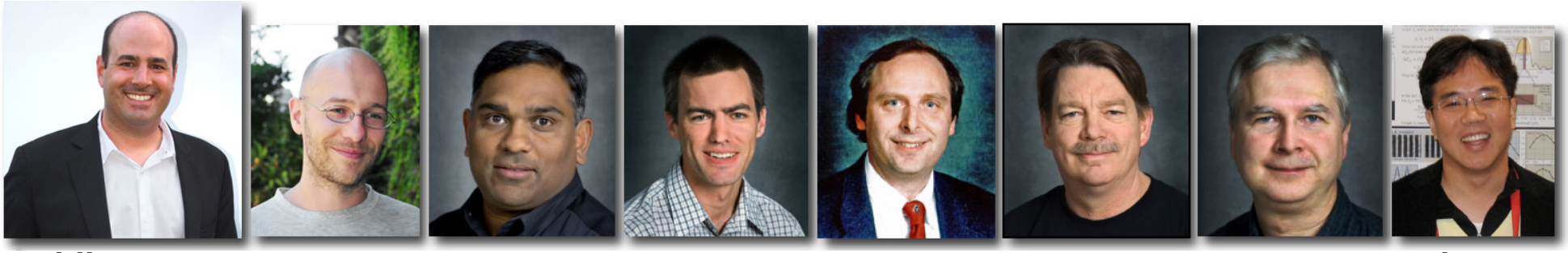
The AIT is used in every aspect of mask research



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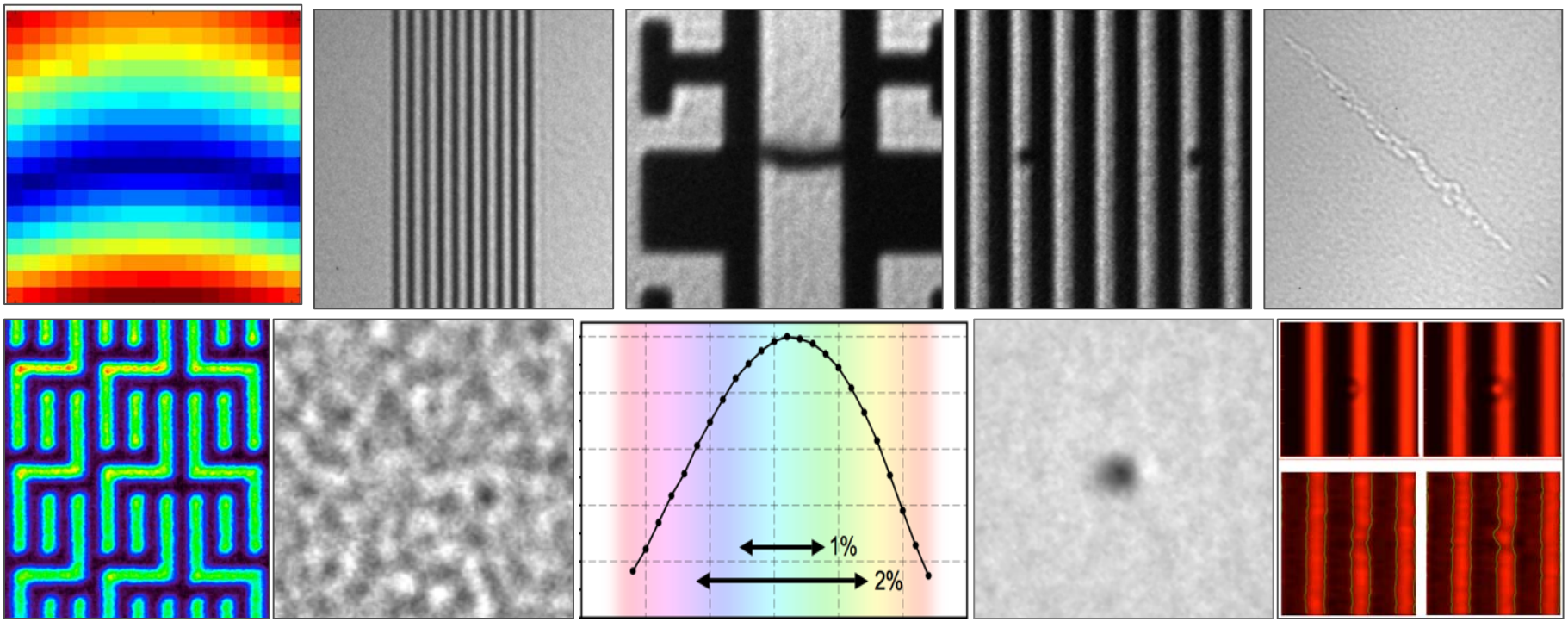
AIT 2009 Highlights



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