Developing a New State of the Art EUV Mask Imaging Research Tool at Berkeley

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Lawrence Berkeley National Laboratory

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The SEMATECH Berkeley Actinic Inspection Tool (AIT)

λ: 13.2–13.6 nm

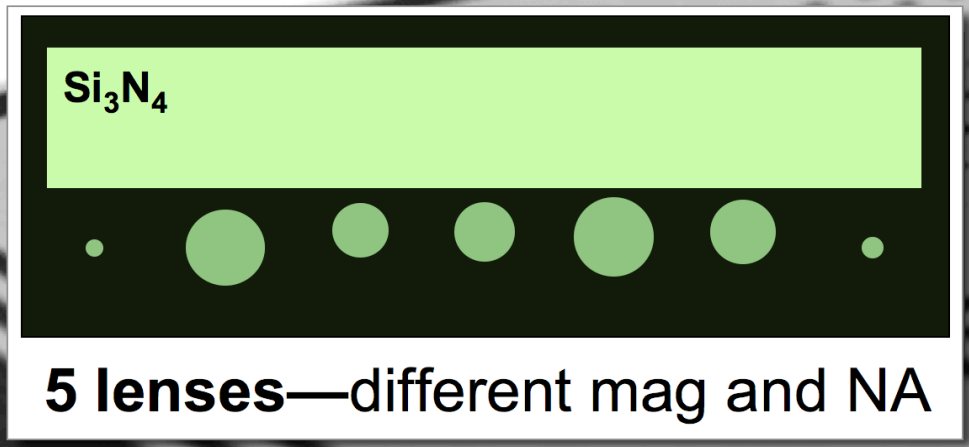
NA (4x): 0.25–0.35, ∠6°

Mag: ~900x

Synchrotron

all EUV

CCD



5 lenses—different mag and NA

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

Primary AIT users in 2010/11

CNSE
SUNY Albany

intel

GLOBALFOUNDRIES

SAMSUNG

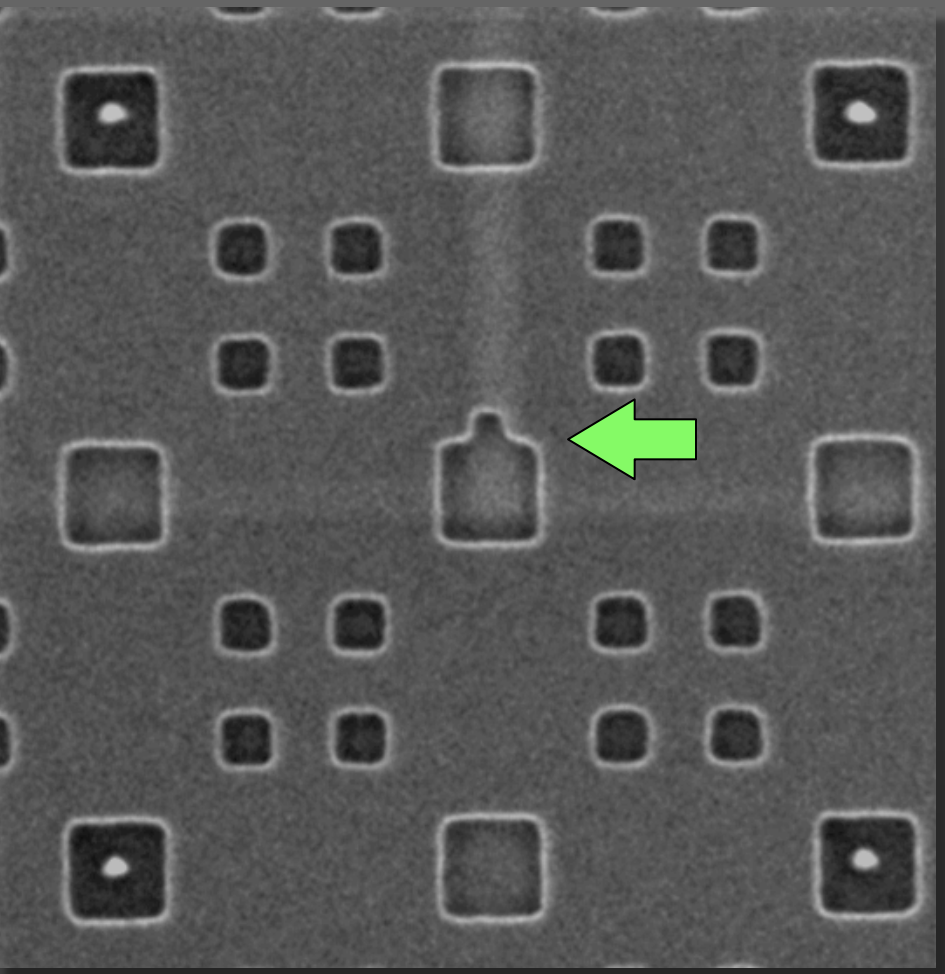
IBM

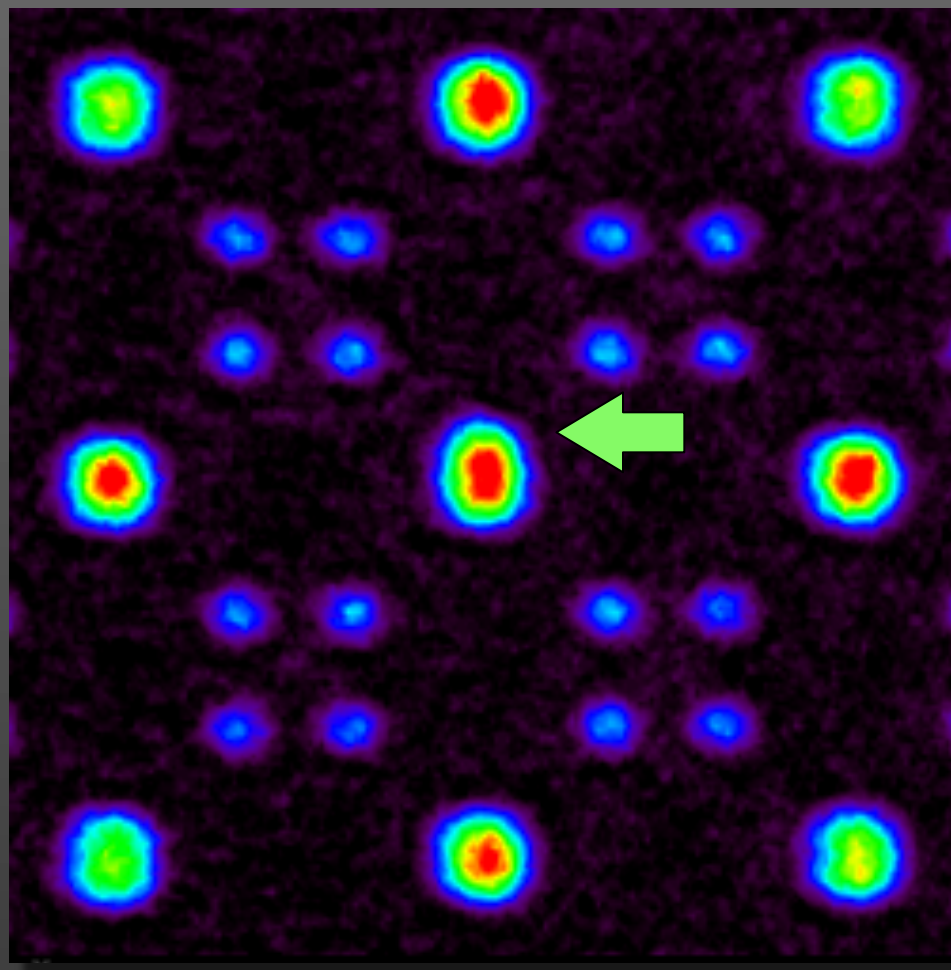
SEMATECH

CXRO
THE CENTER FOR X-RAY OPTICS

BERKELEY LAB
Lawrence Berkeley National Laboratory

IBM Programmed Pattern Defects





SEM

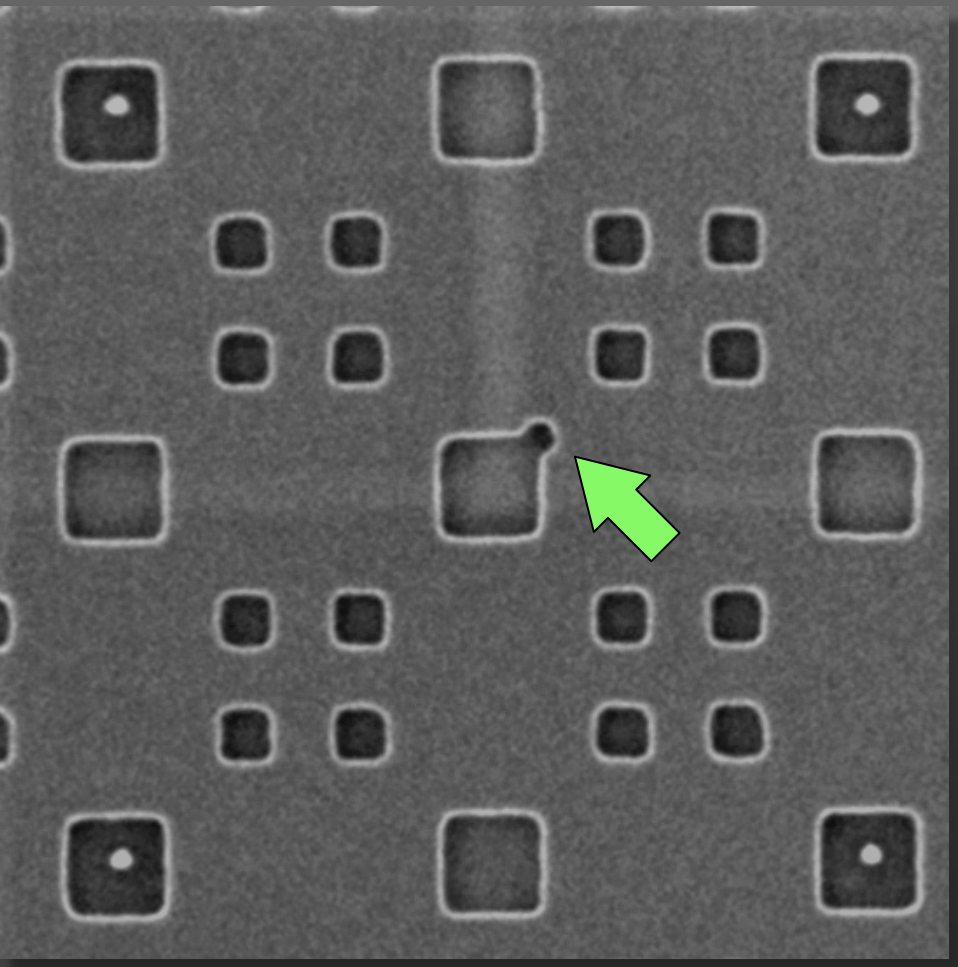
AIT (EUV)

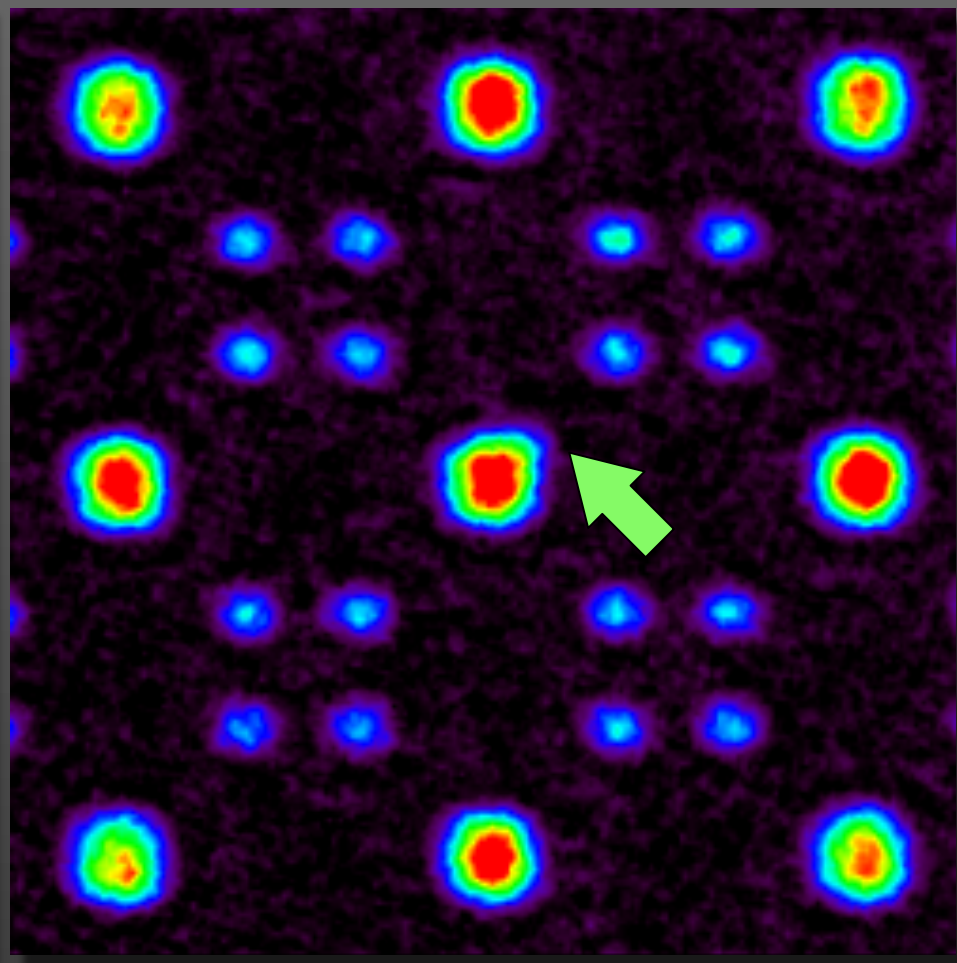
— 500 nm

Mask: SMOCOL2 / Gallagher, Badger, *unpublished 2011*

Defect A3-B30

IBM Programmed Pattern Defects





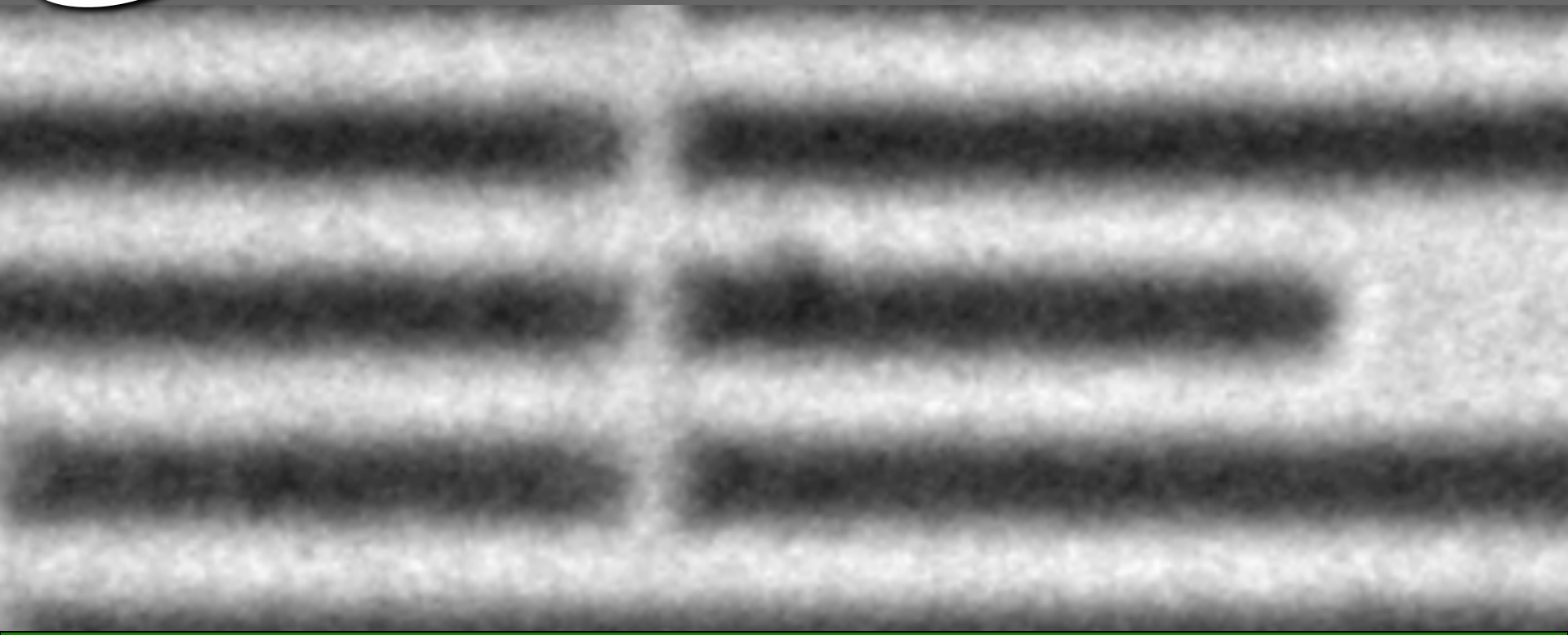
SEM ***AIT (EUV)***

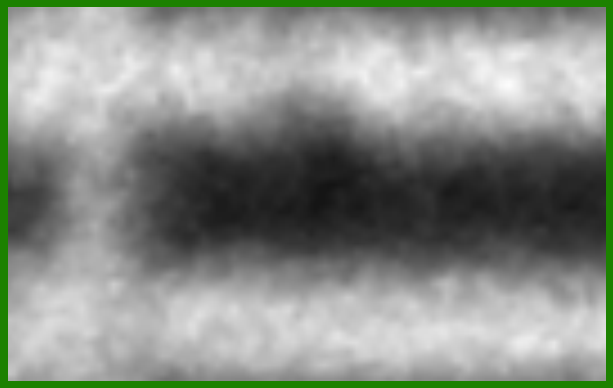
— 500 nm

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

Defect A3-D30

Native Pattern Amplitude Defect

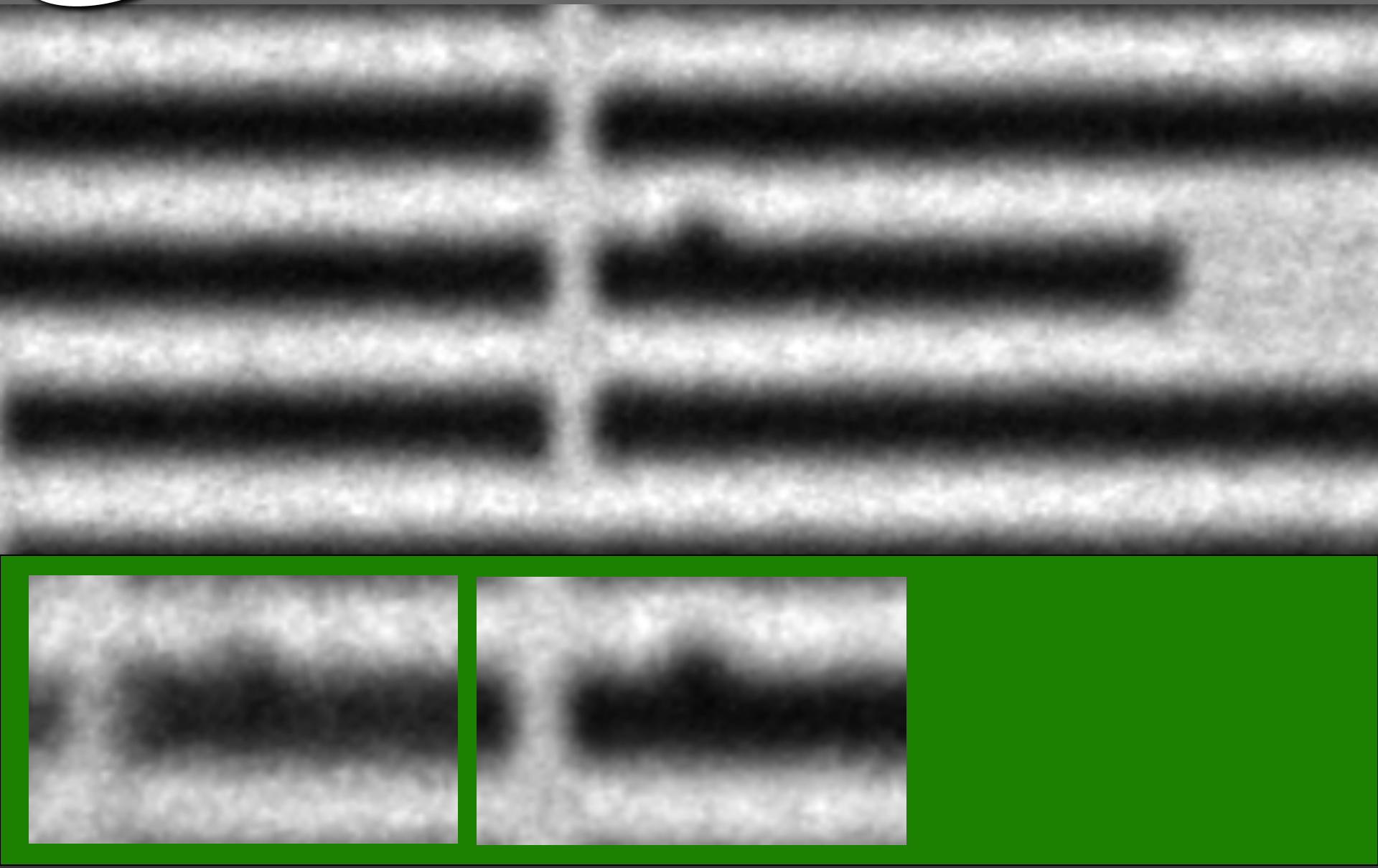




Mask: IMO182140 / Magana, *unpublished 2010*

500 nm

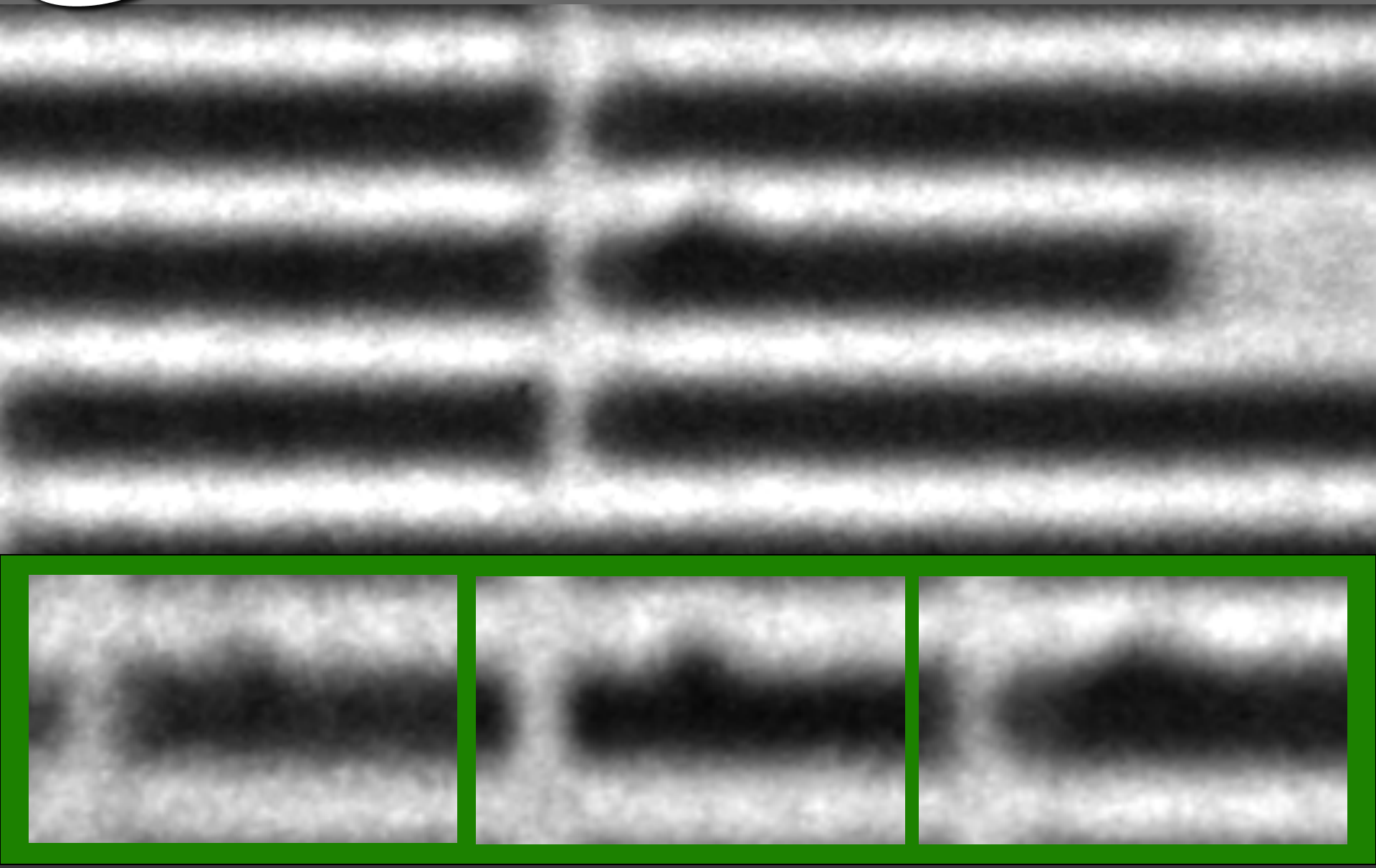
Native Pattern Amplitude Defect



Mask: IMO182140 / Magana, *unpublished 2010*

500 nm

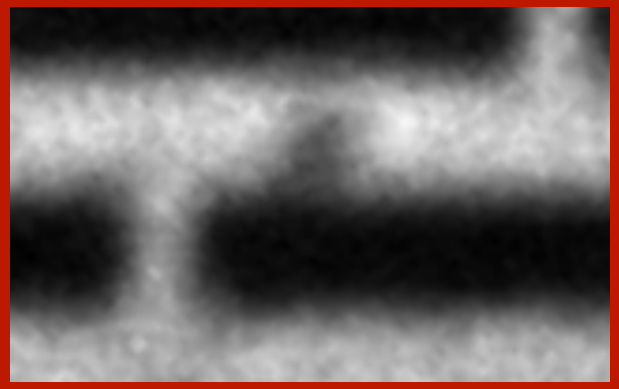
Native Pattern Amplitude Defect



Mask: IMO182140 / Magana, *unpublished 2010*

500 nm

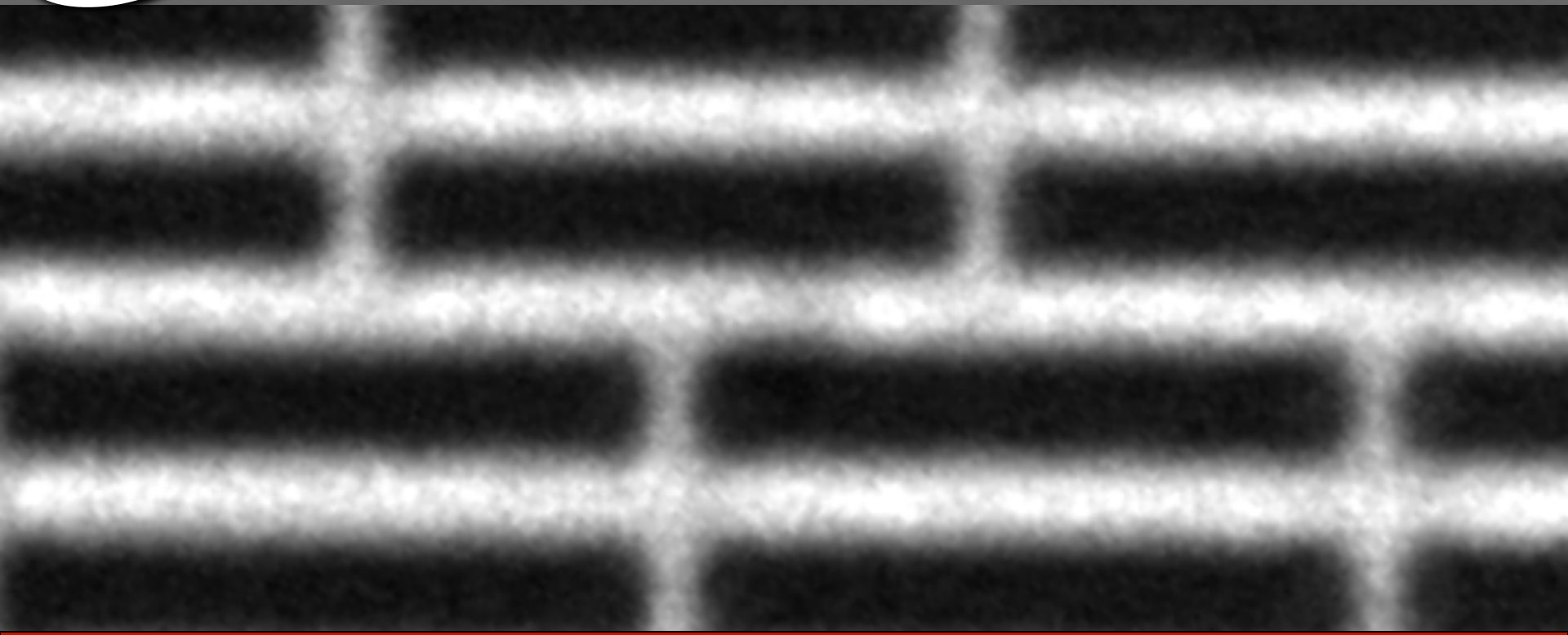
Native Pattern Phase Defect

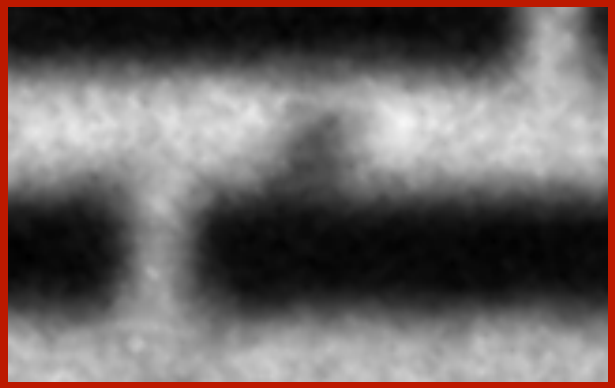


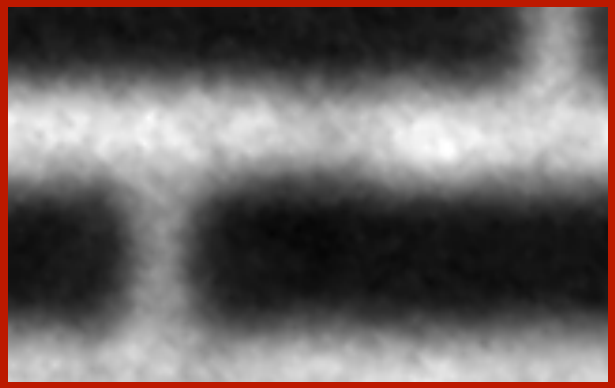
Mask: IMO182140 / Magana, *unpublished 2010*

500 nm

Native Pattern Phase Defect



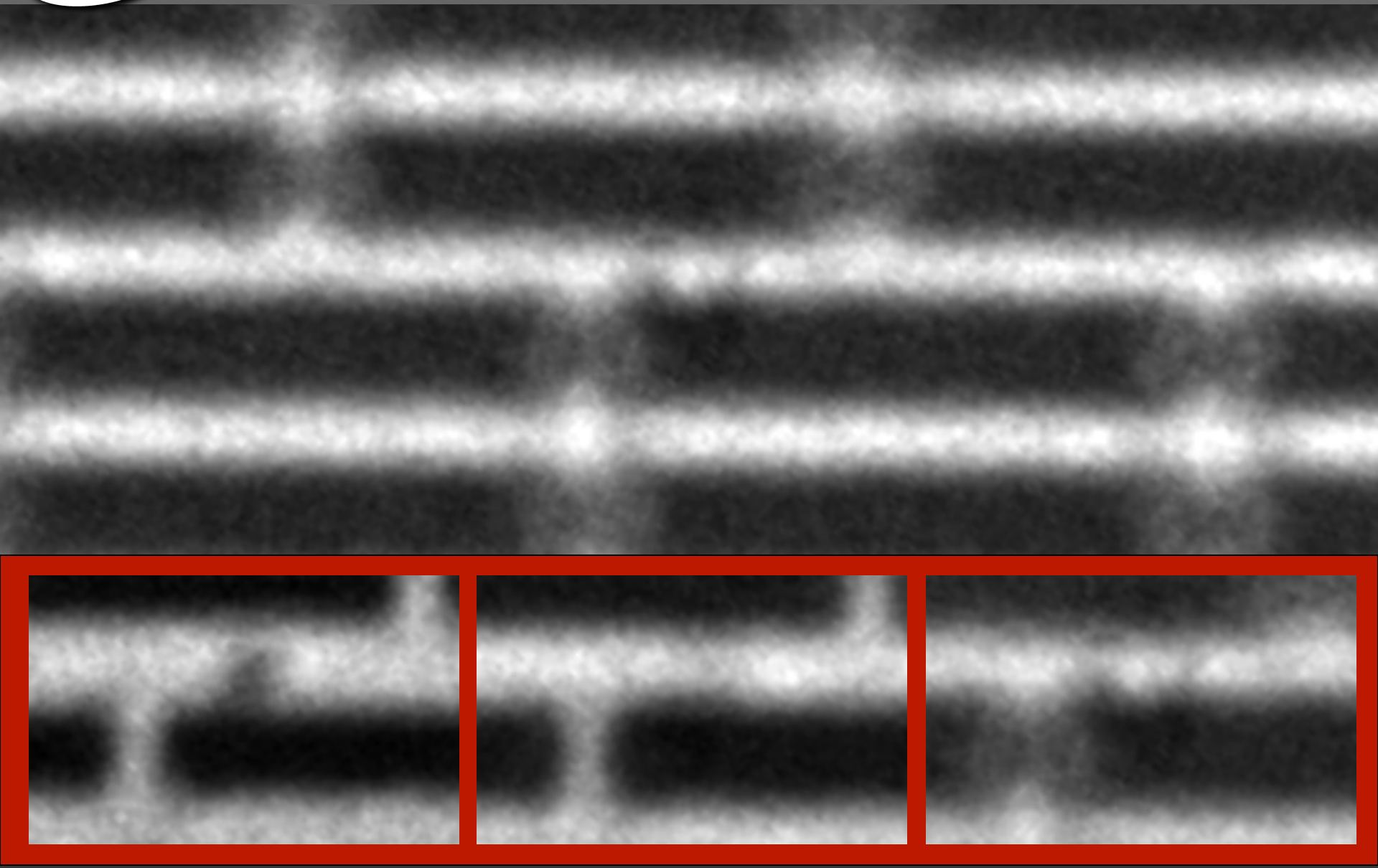




Mask: IMO182140 / Magana, *unpublished 2010*

500 nm

Native Pattern Phase Defect

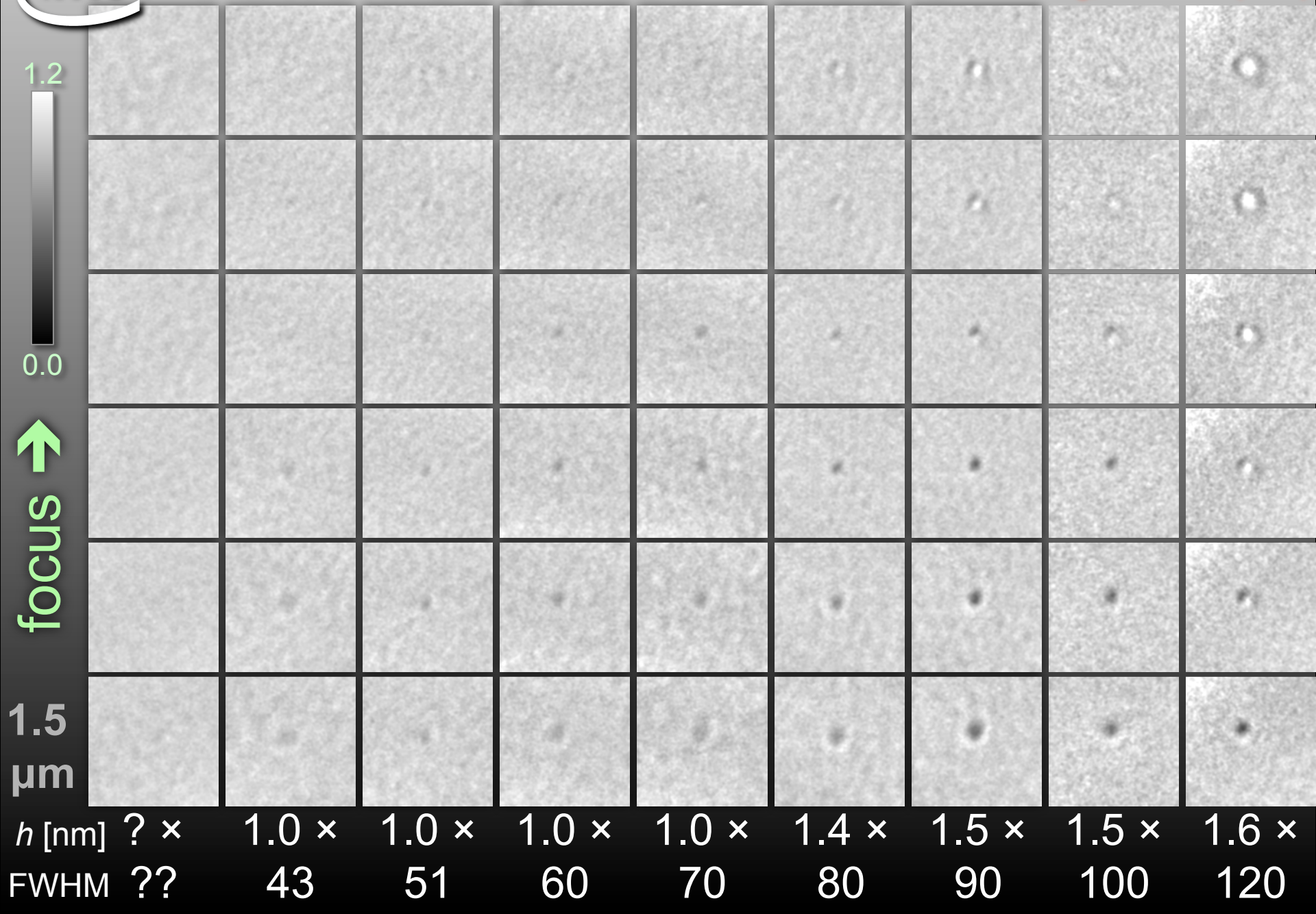


Mask: IMO182140 / Magana, *unpublished 2010*

500 nm

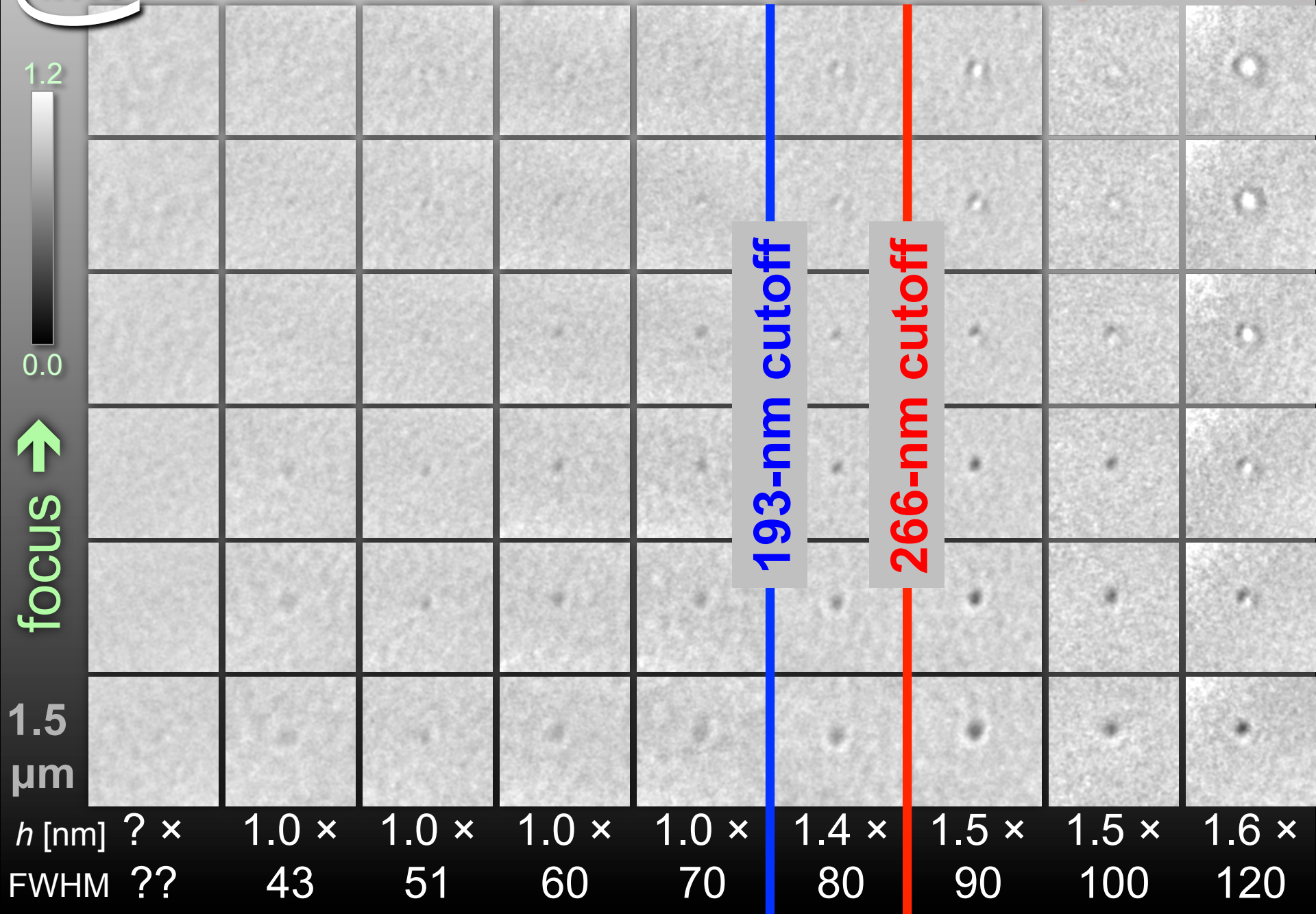
Patterned phase defects

Goldberg, *JVSTB* (2011)
Liang, *SPIE* **7823** (2010)

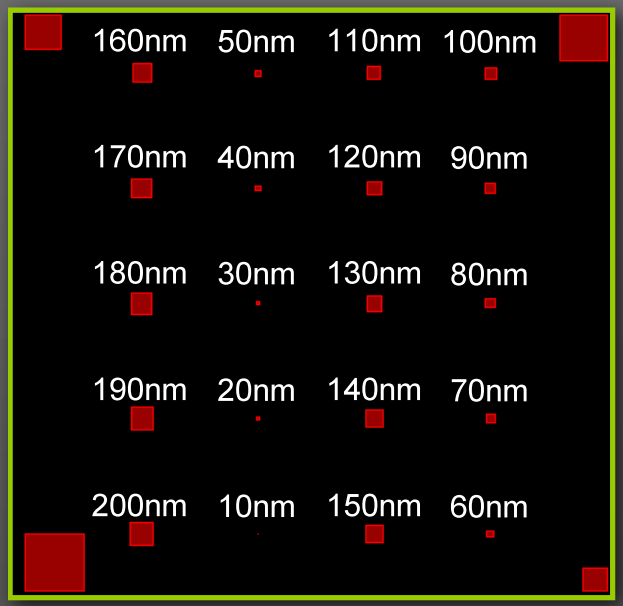


Patterned phase defects

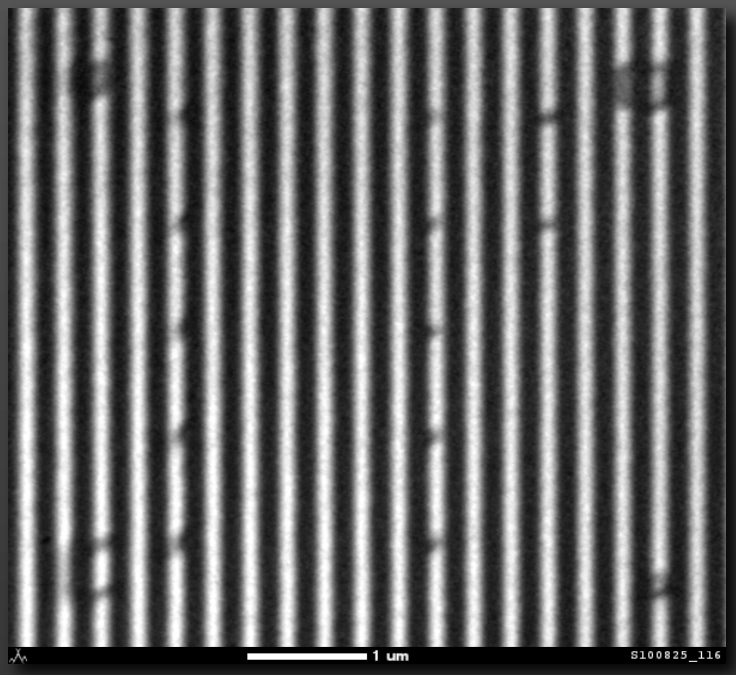
Goldberg, *JVSTB* (2011)
Liang, *SPIE* **7823** (2010)



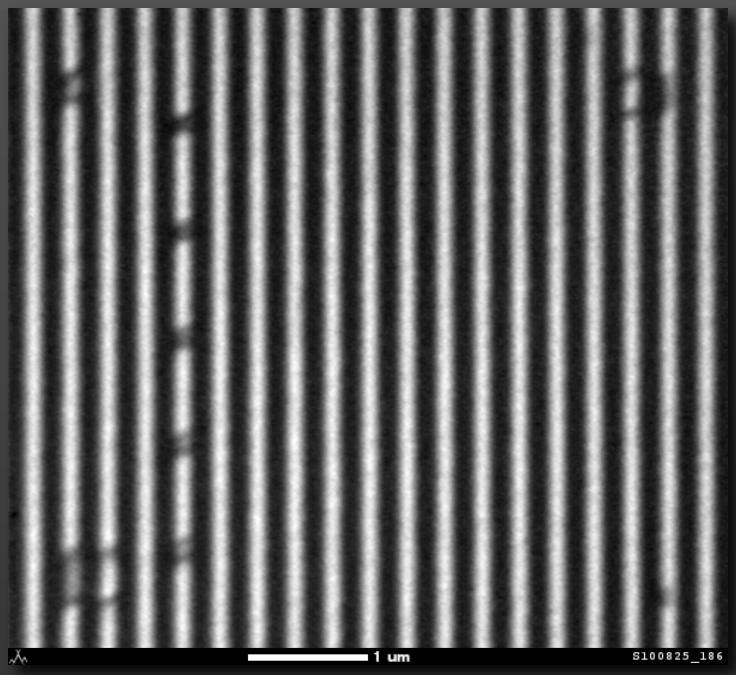
Buried phase defects



AIT Images

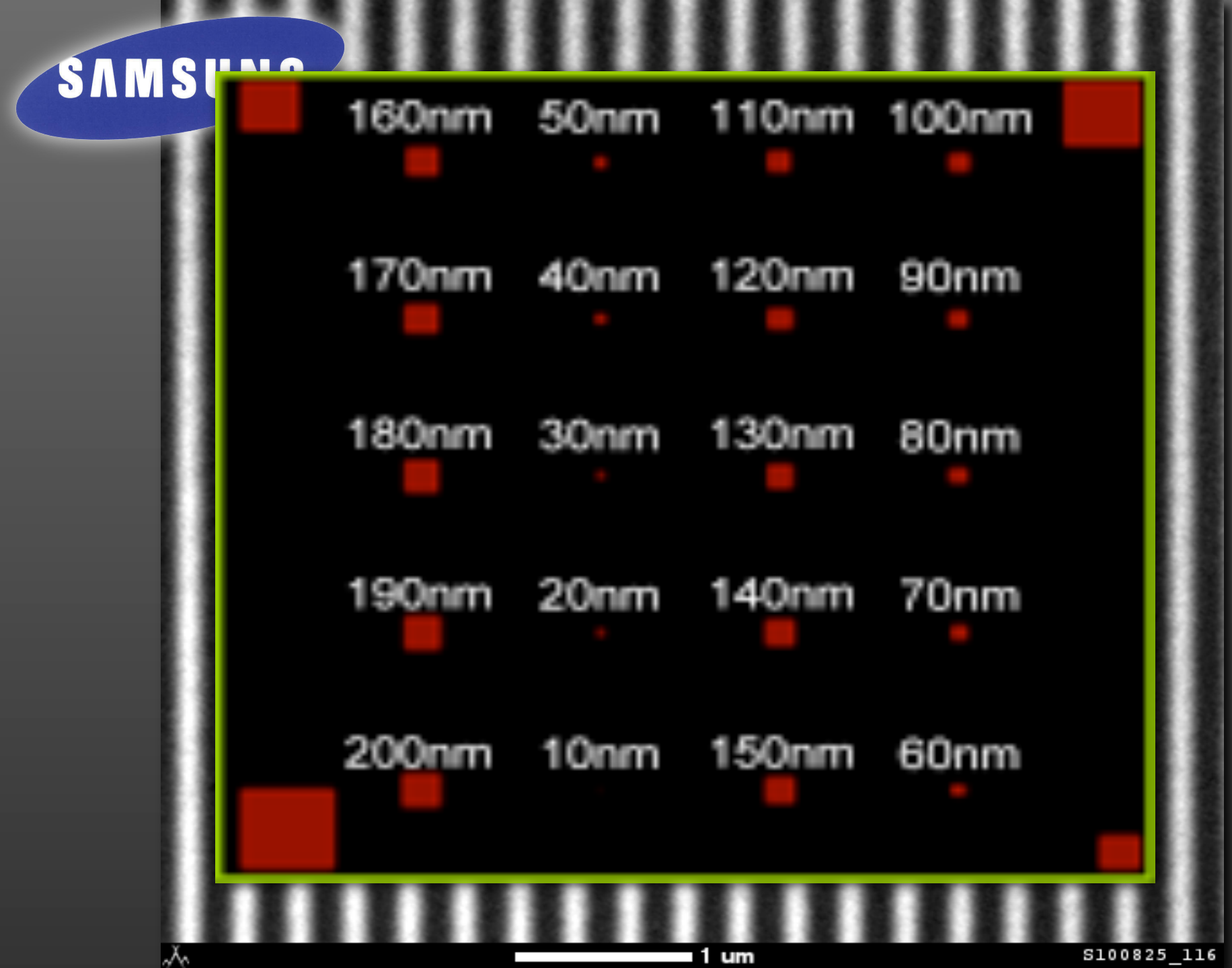


A pattern position shift. . .

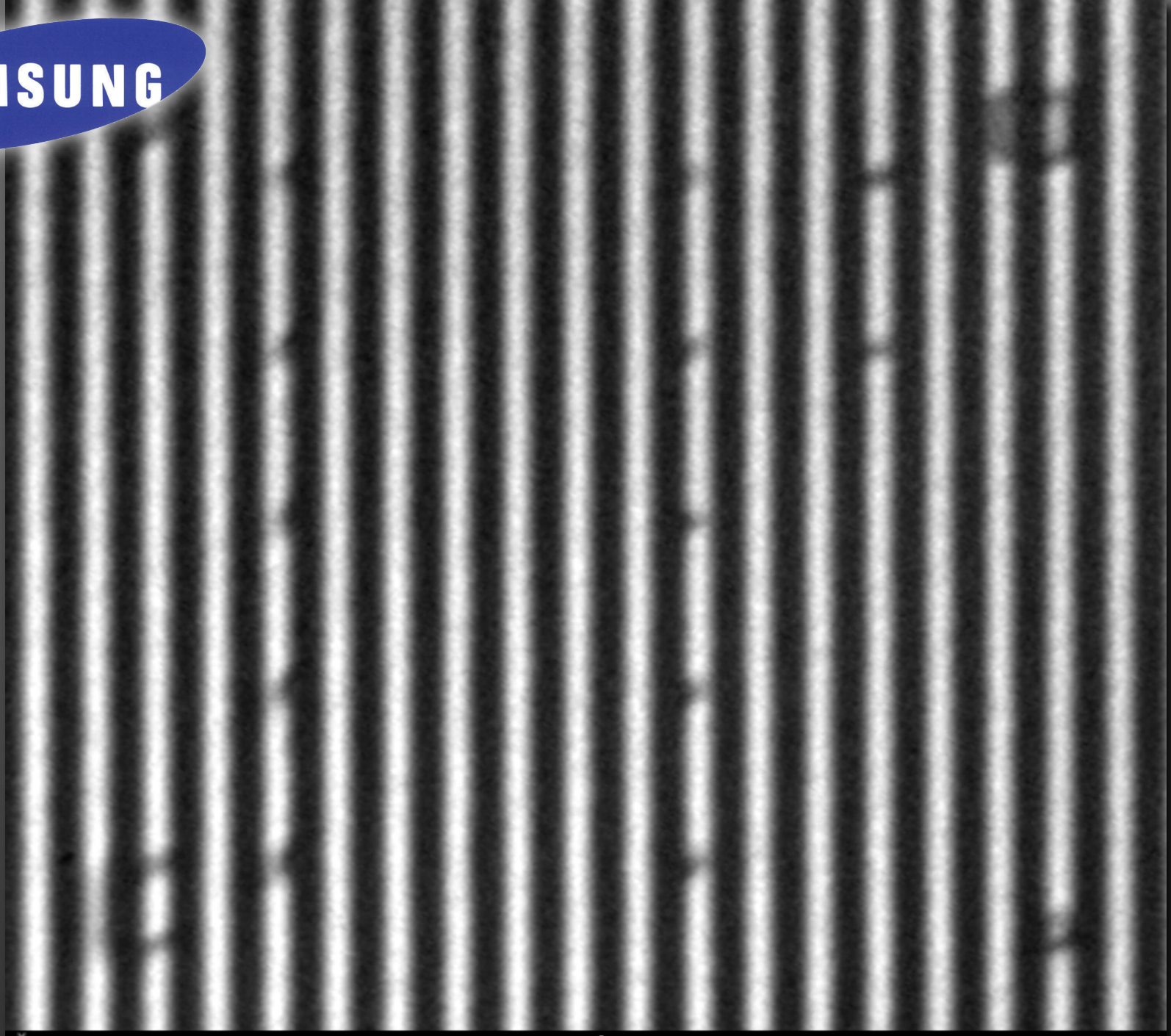


covers the defects

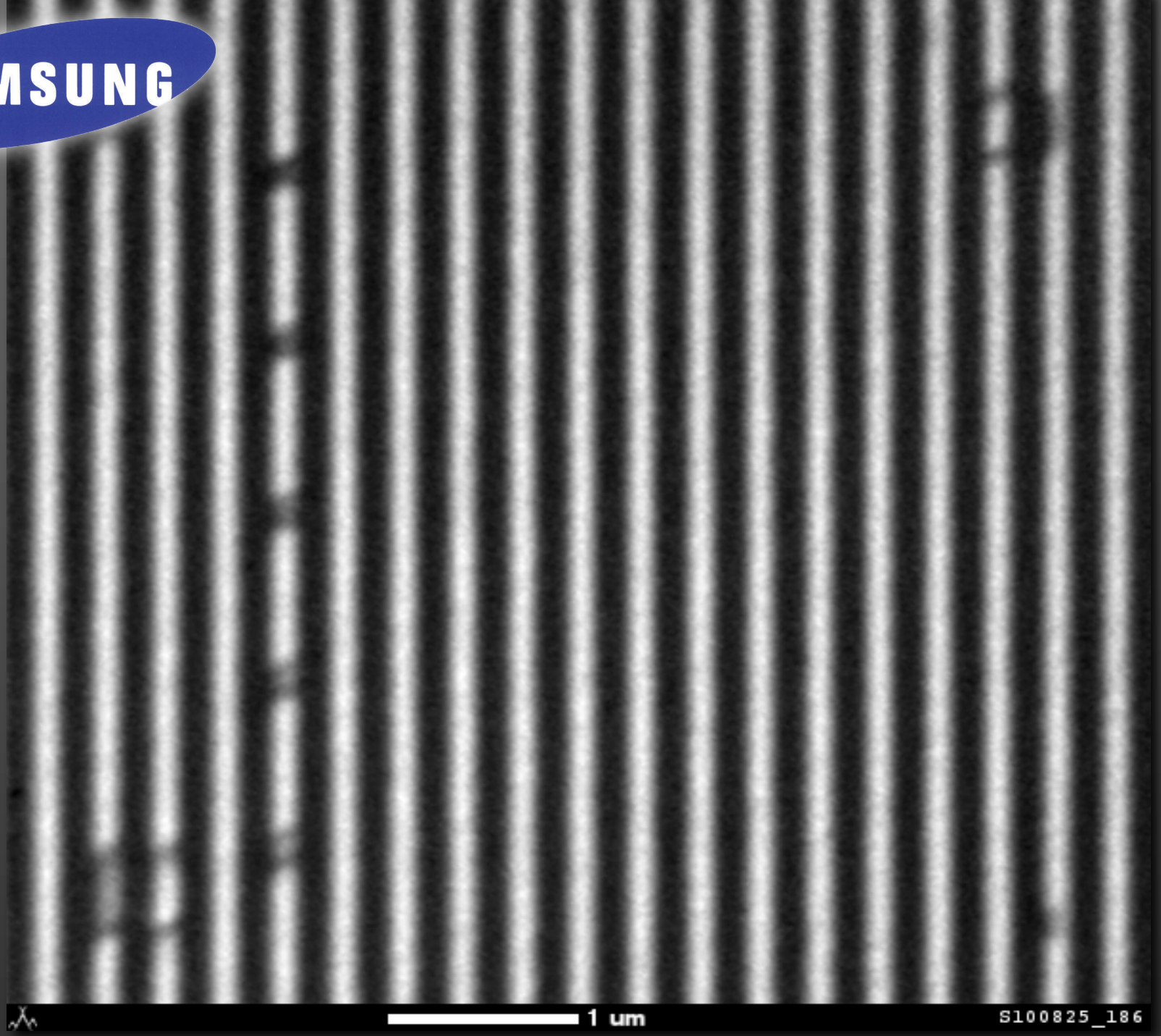
S. Huh, SPIE 2011



S. Huh, SPIE 2011

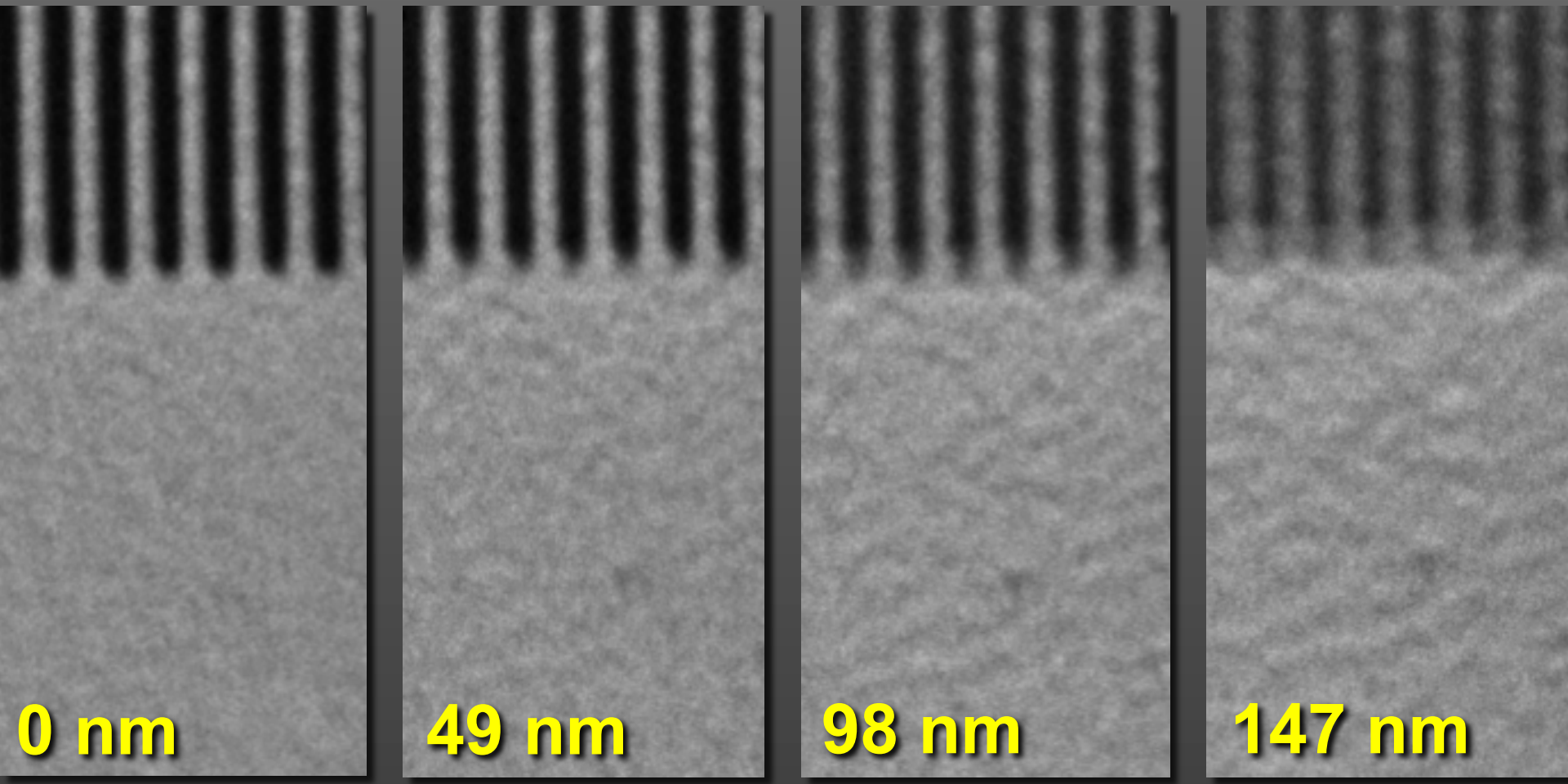


S. Huh, SPIE 2011



S. Huh, SPIE 2011

Speckle from ML phase roughness

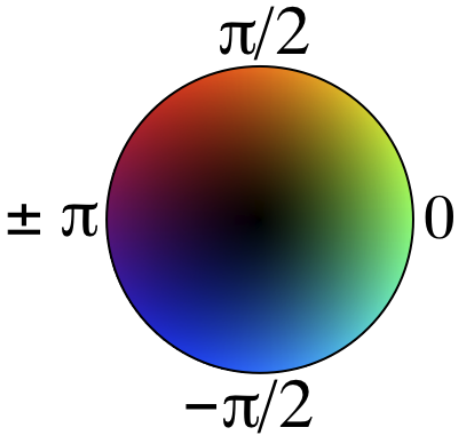


Goldberg, Mochi, Naulleau, George (2008), *unpublished*

CXRO GLOBALFOUNDRIES

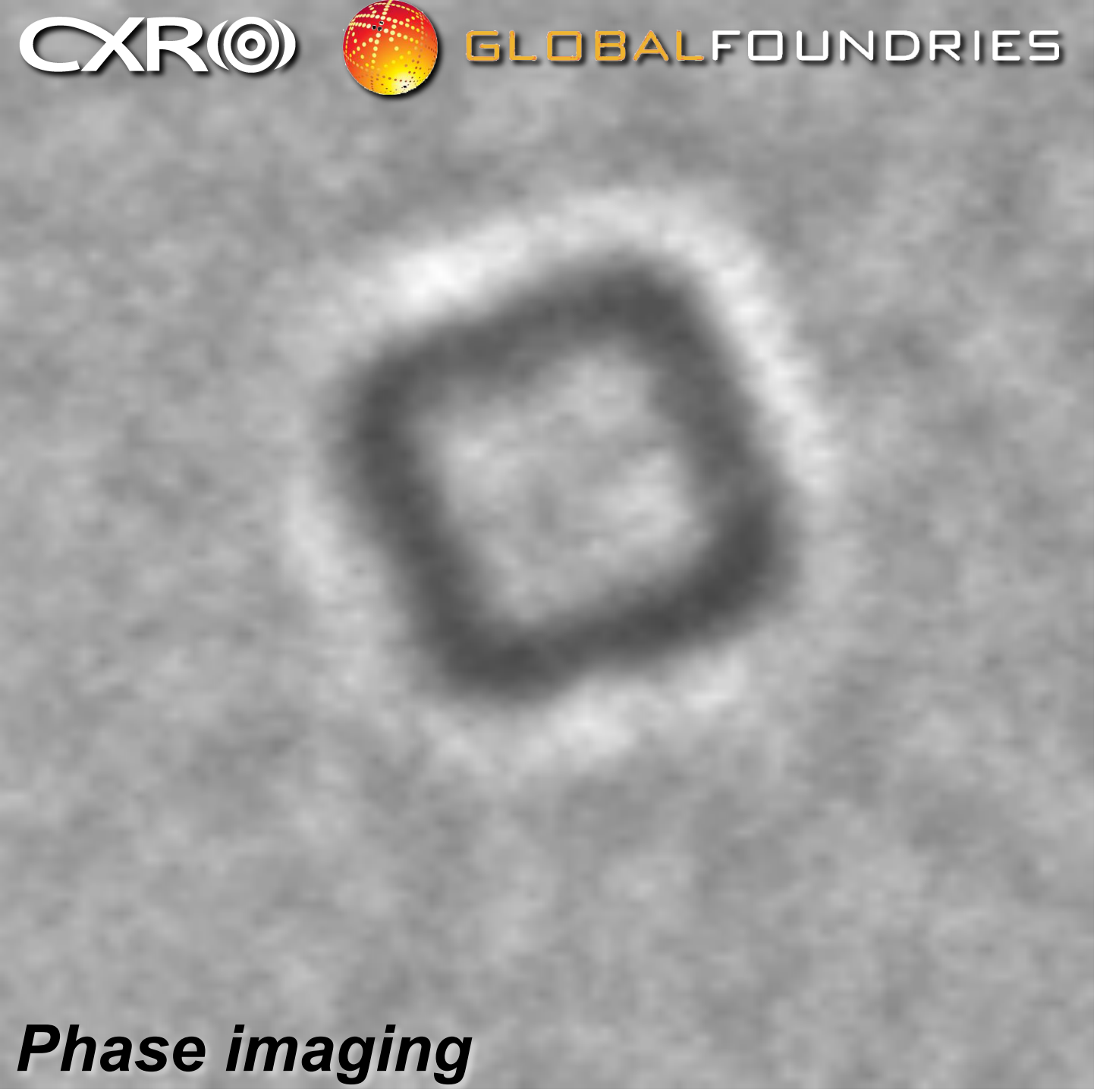
See Poster:

I. Mochi
7969-67



0.5 μm

Phase imaging



Phase imaging

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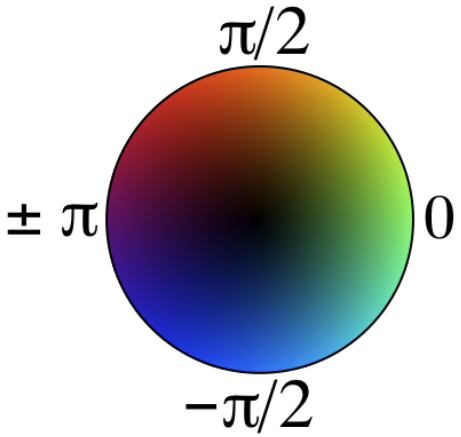
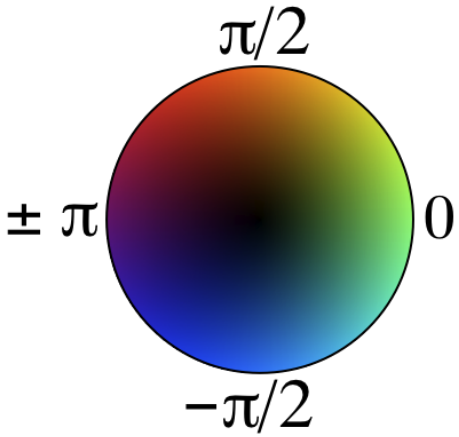


0.5 *μ*m

CXRO GLOBALFOUNDRIES

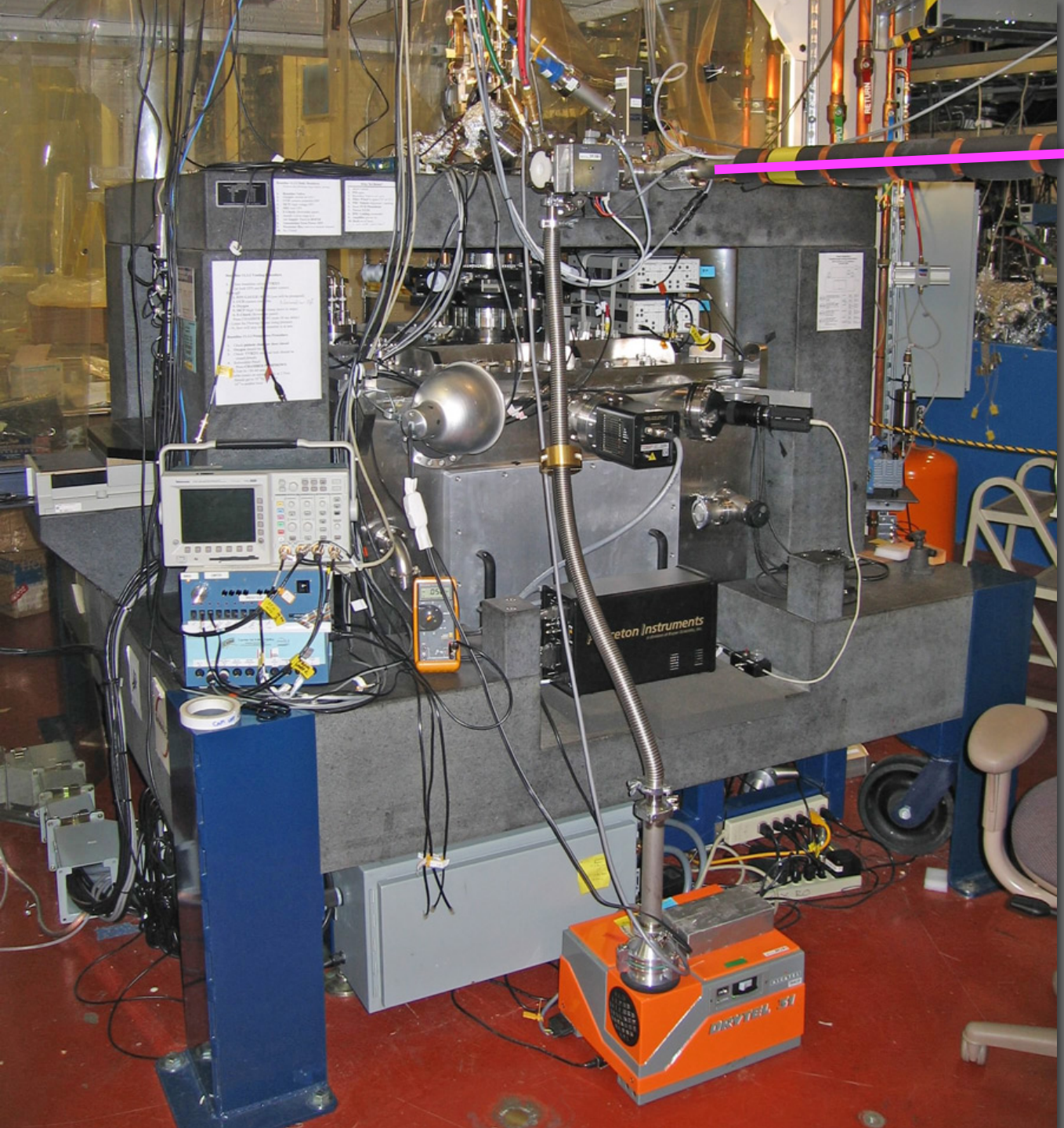
See Poster:

I. Mochi
7969-67



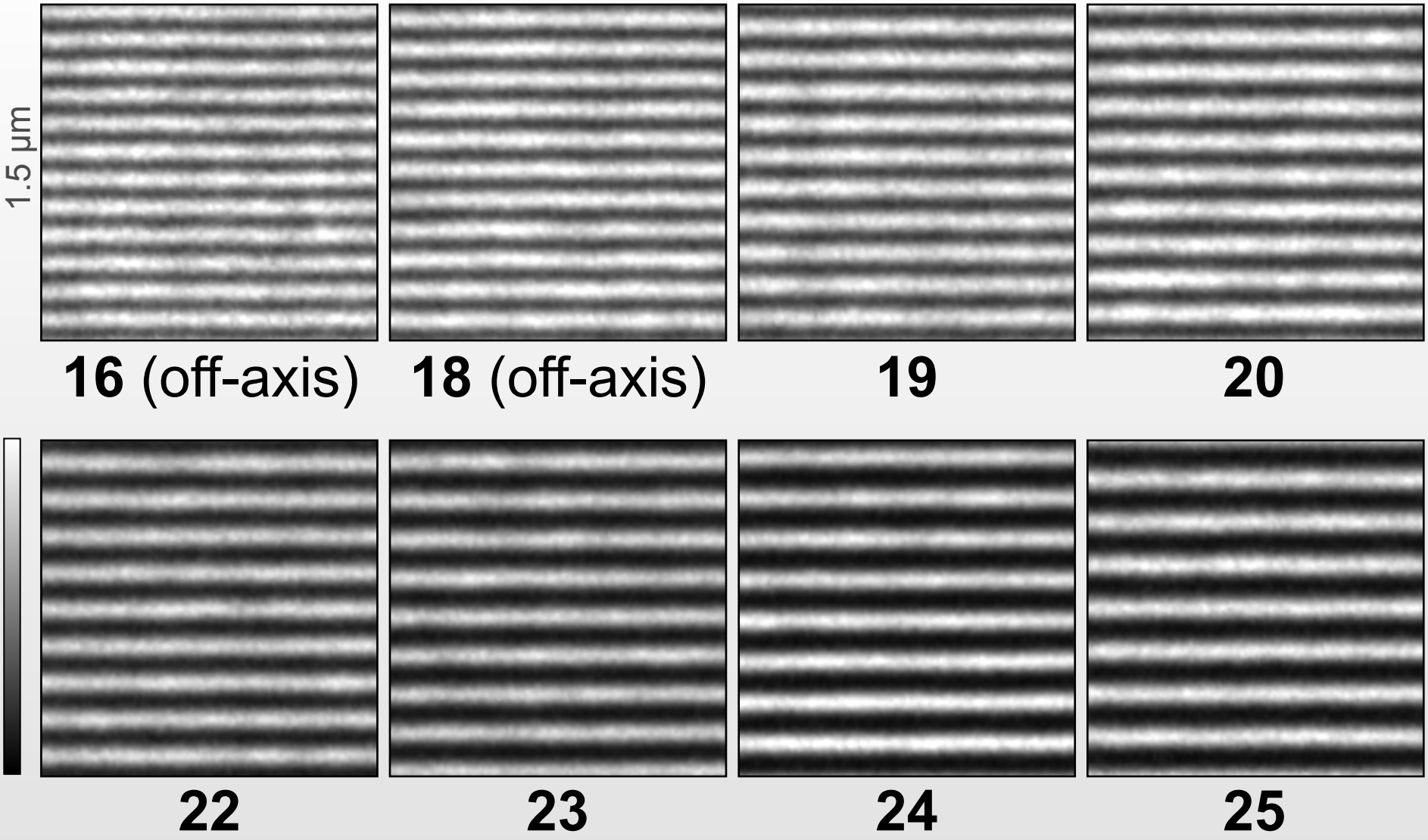
0.5 μm

Phase imaging



The AIT

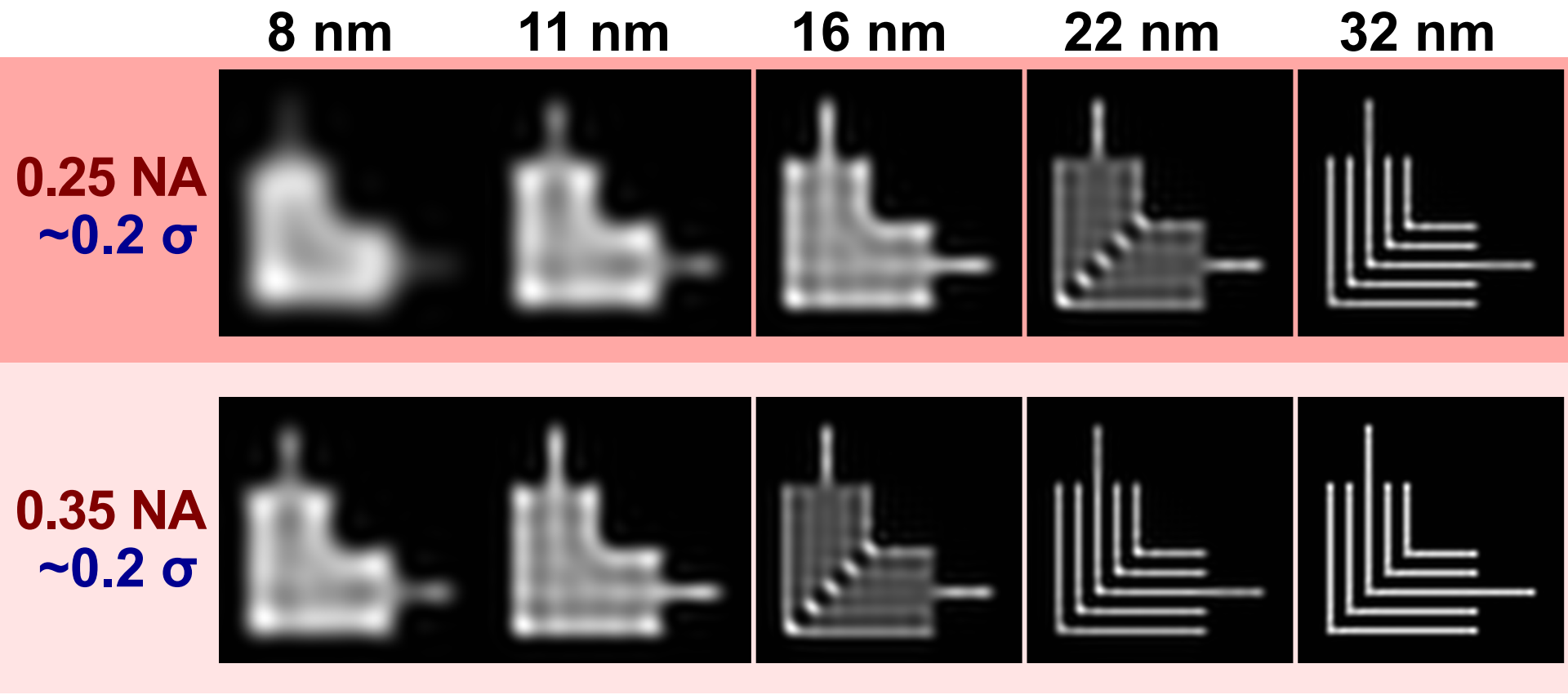
The AIT's line contrast reaches down to 16 nm



wafer CD @ 0.35 4×NA

GLOBALFOUNDRIES

AIT: Calculated performance



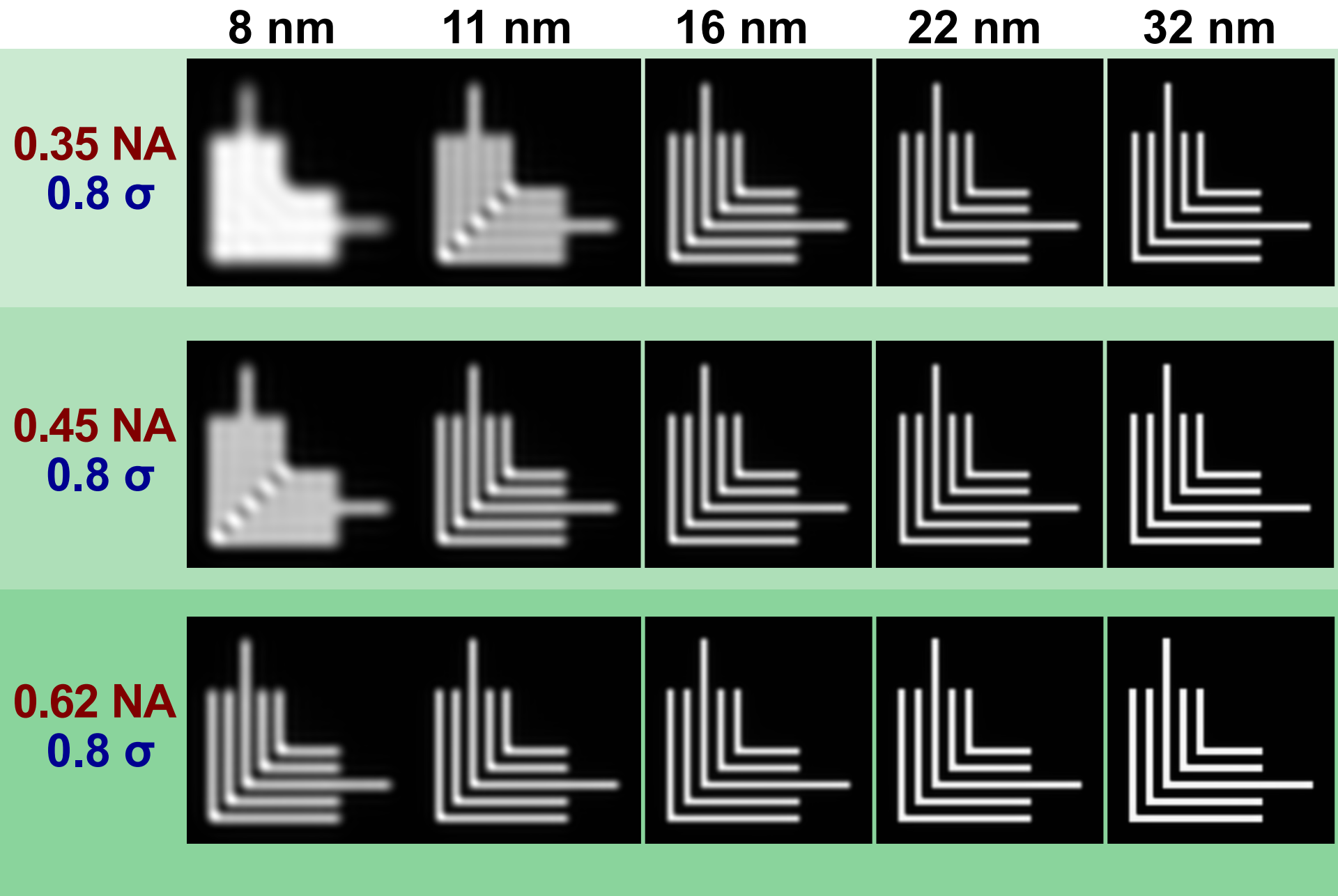
AIT Limit

The AIT is 7 years old.

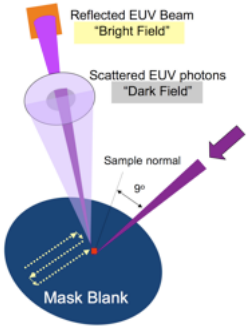
That's 65 in *litho* years.

Photo: Stefan Tell

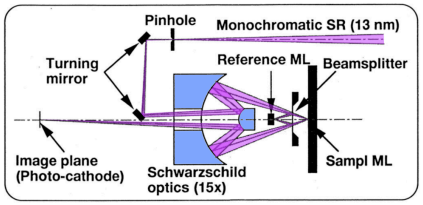
Higher resolution needs high NA and σ control



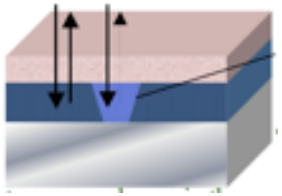
13+ years of actinic mask inspection/imaging



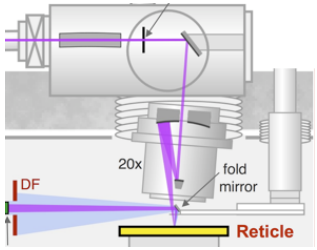
EUV LLC/LBNL



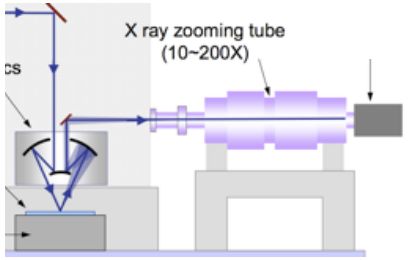
NTT



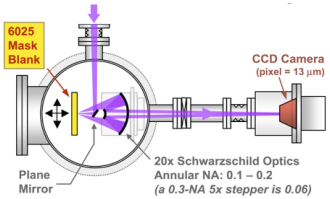
Lucent



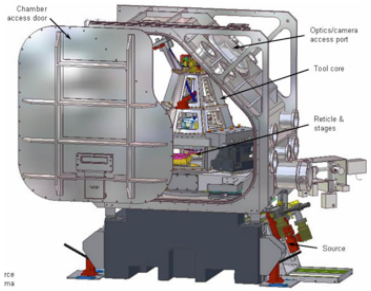
SEMATECH/LBNL



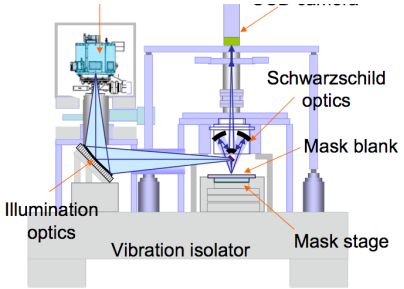
U. Hyogo



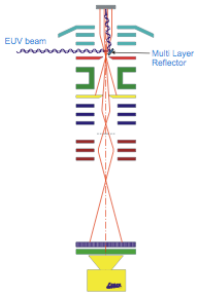
MIRAI



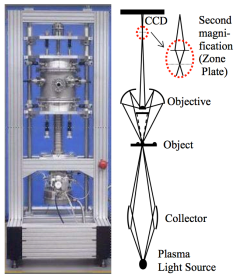
Exitech



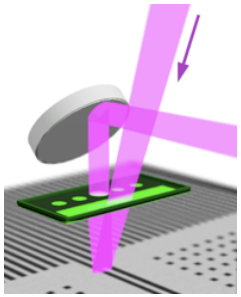
MIRAI II/Selete



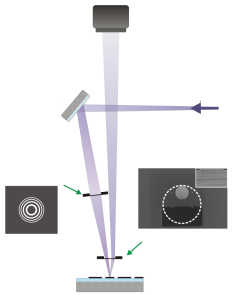
U. Bielefeld



Fraunhofer Institute

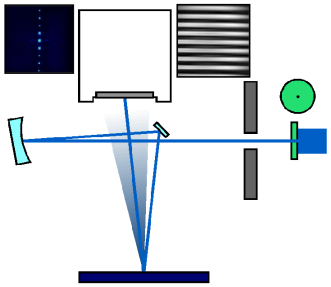


SEMATECH/LBNL

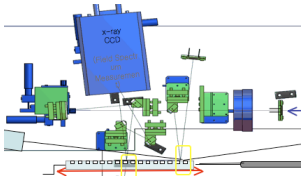


Colorado State

INVENT/CNSE



U. Hyogo



Hanyang

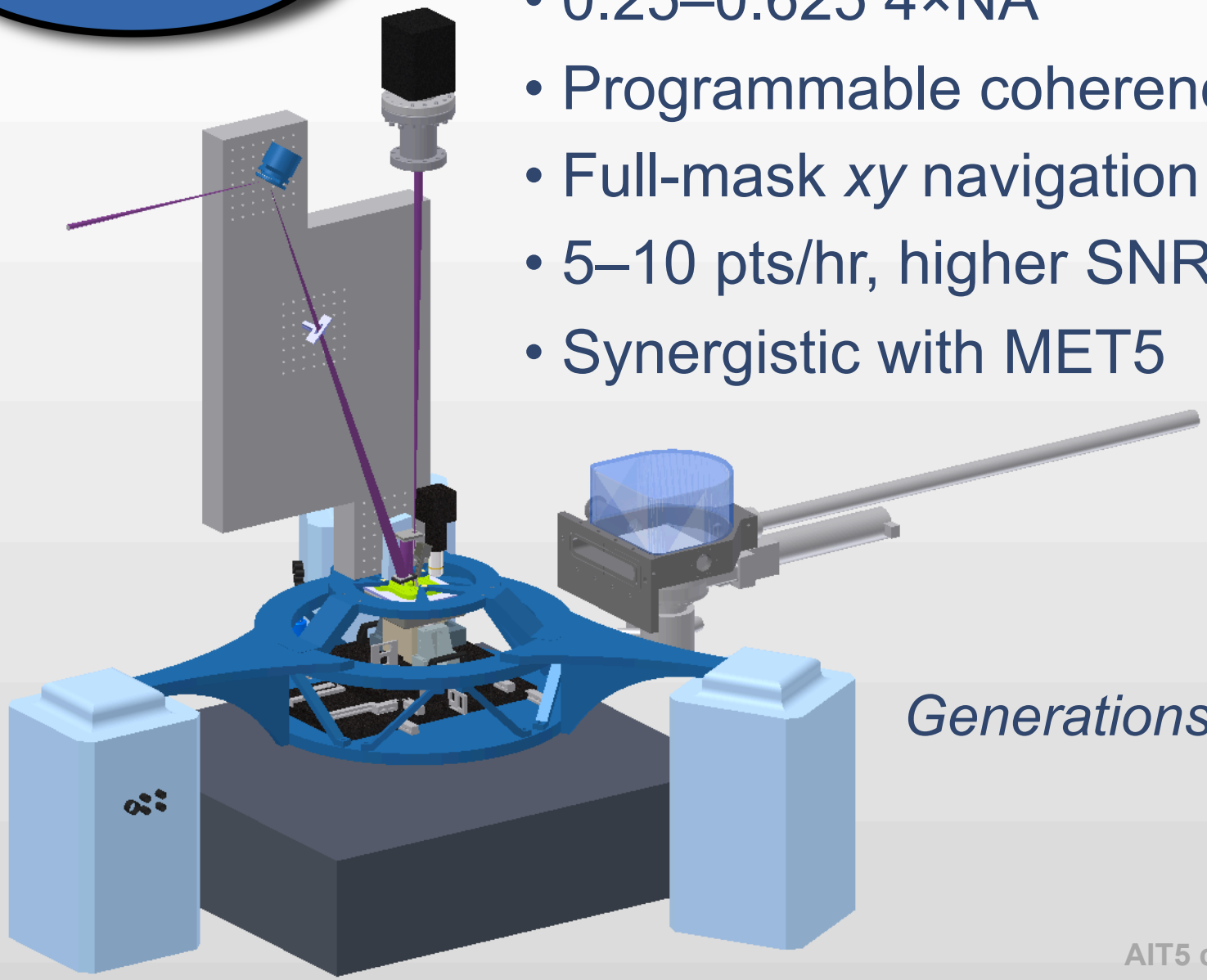
Zeiss

future

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

AIT5

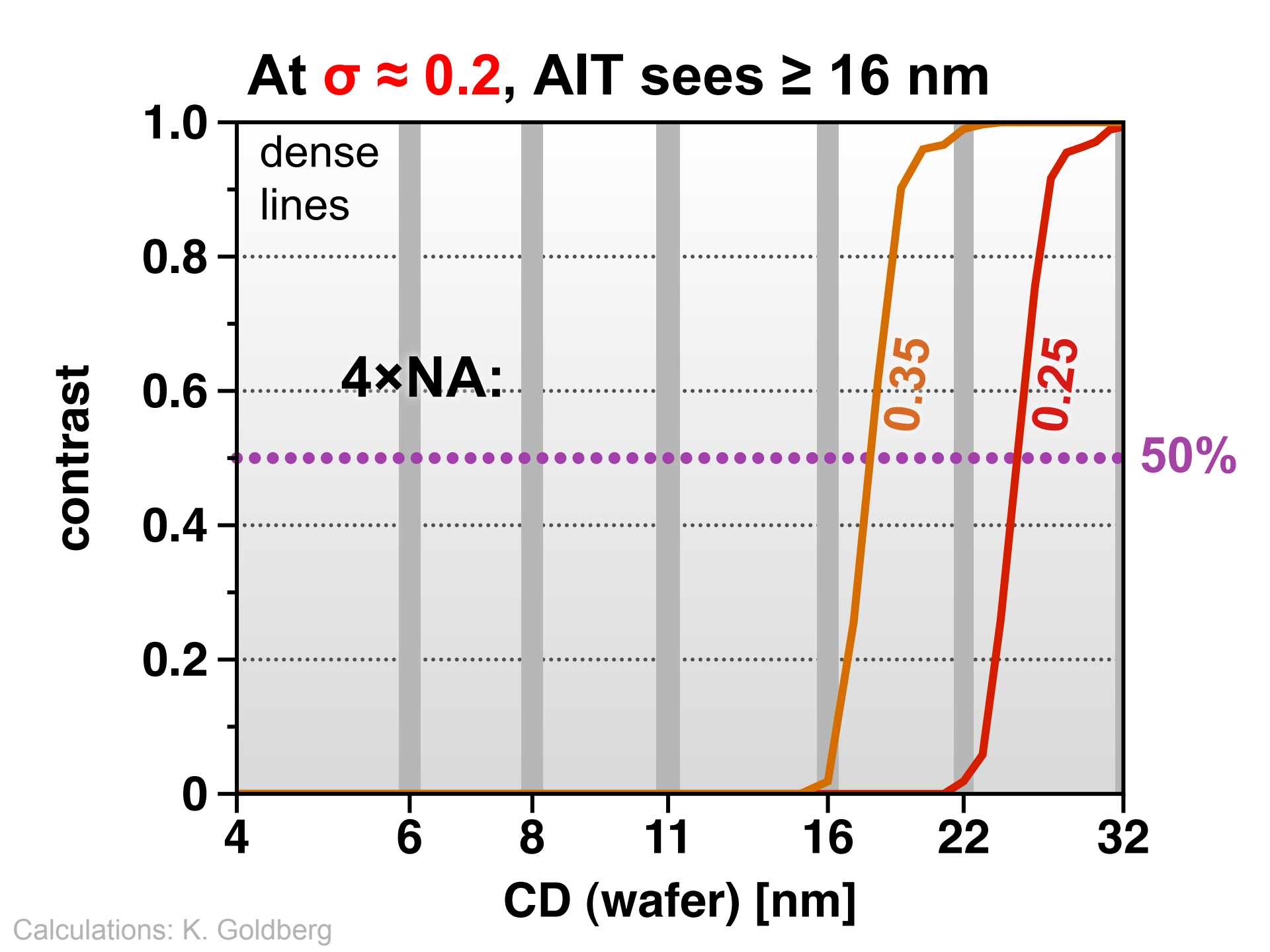
- Zoneplate-lens imaging
- 0.25–0.625 4×NA
- Programmable coherence, σ
- Full-mask *xy* navigation
- 5–10 pts/hr, higher SNR
- Synergistic with MET5



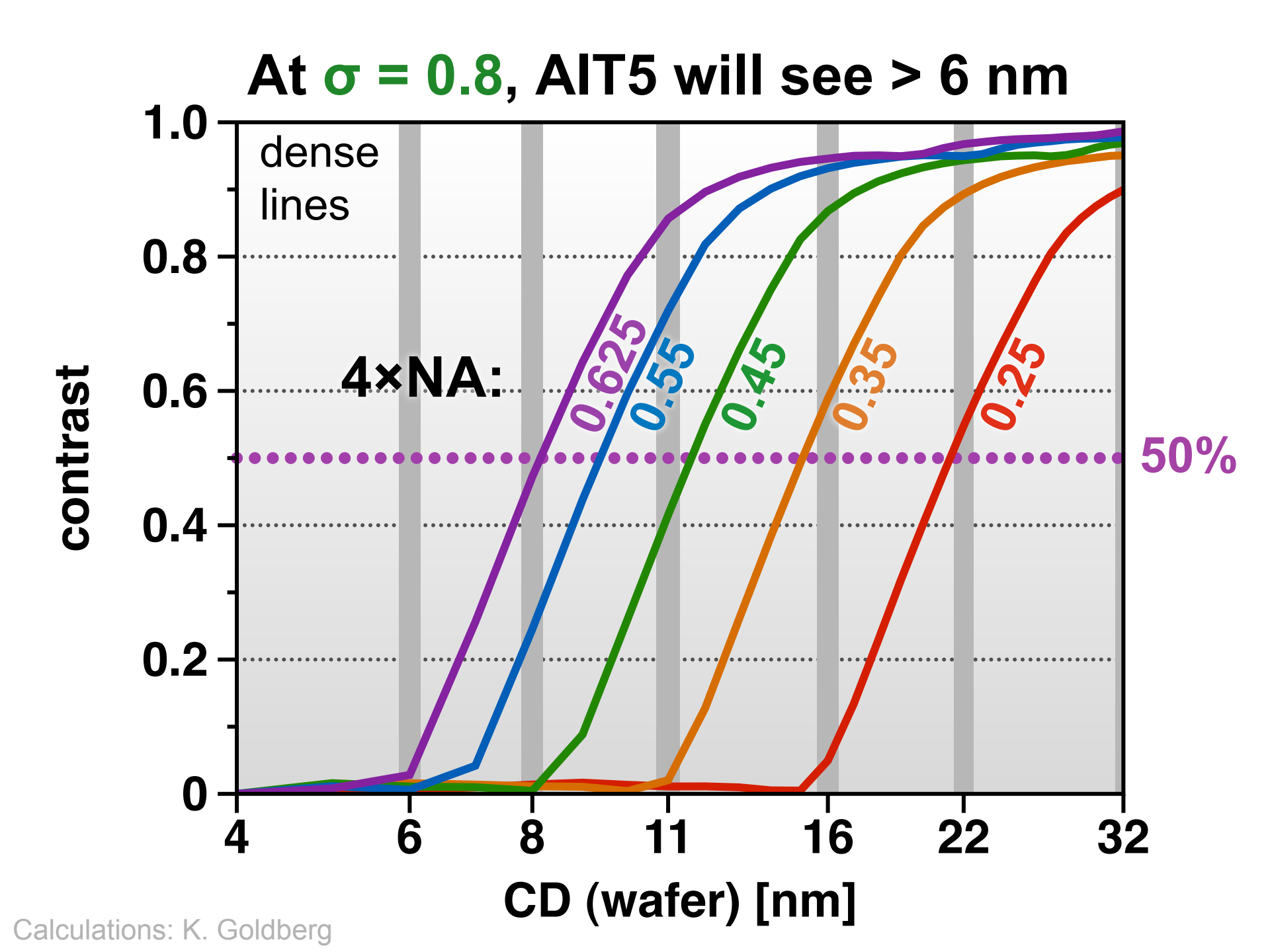
Generations Ahead

CXRO

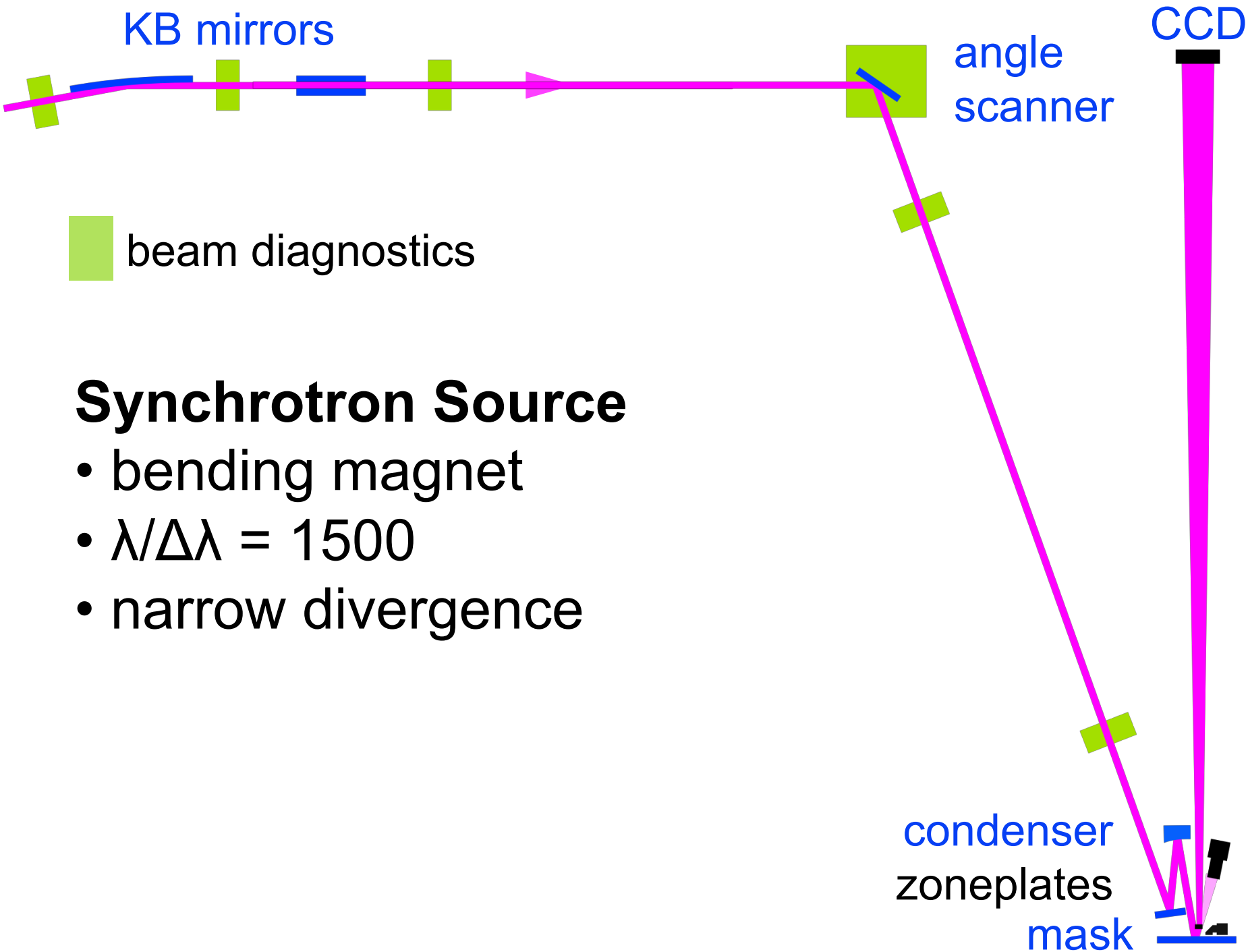
AIT5 concept drawing



Calculations: K. Goldberg



Calculations: K. Goldberg

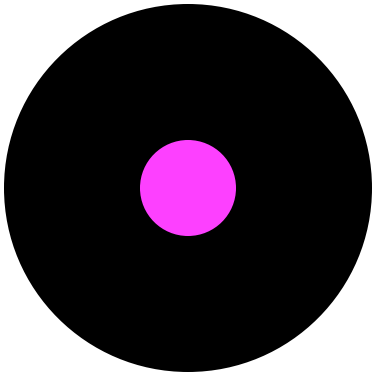


Synchrotron Source

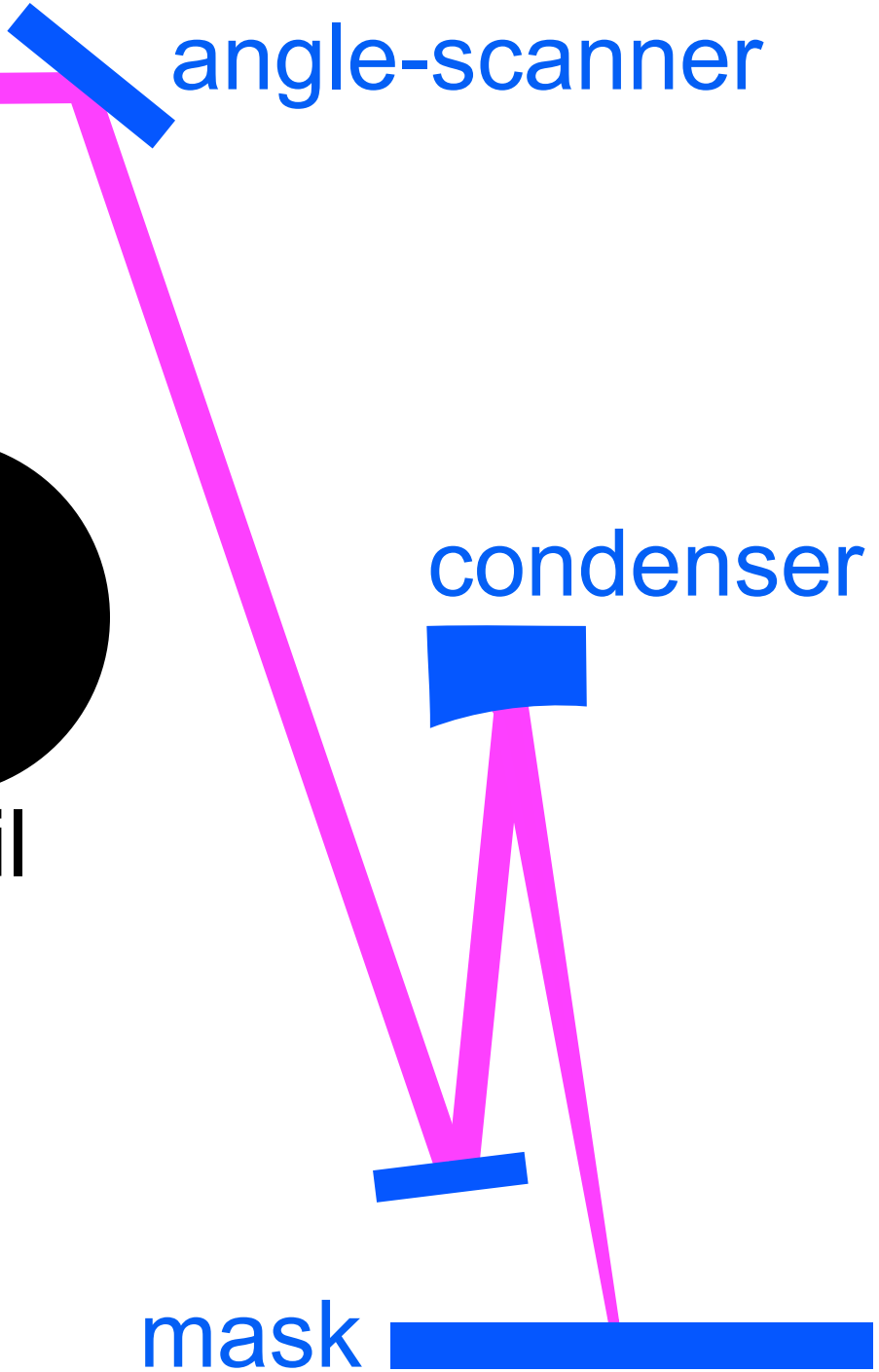
- bending magnet
- $\lambda/\Delta\lambda = 1500$
- narrow divergence

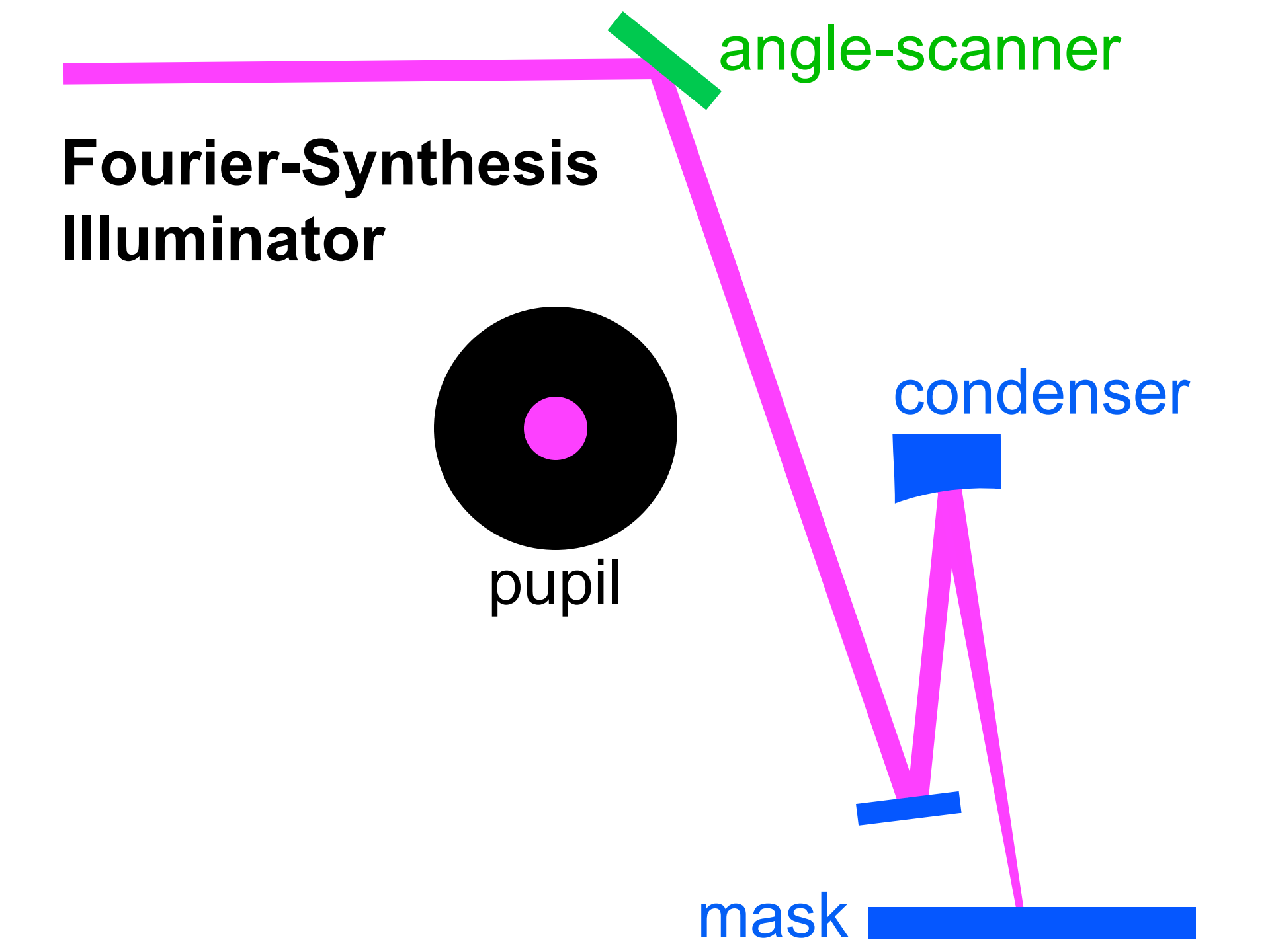
Fourier-Synthesis Illuminator

Naulleau

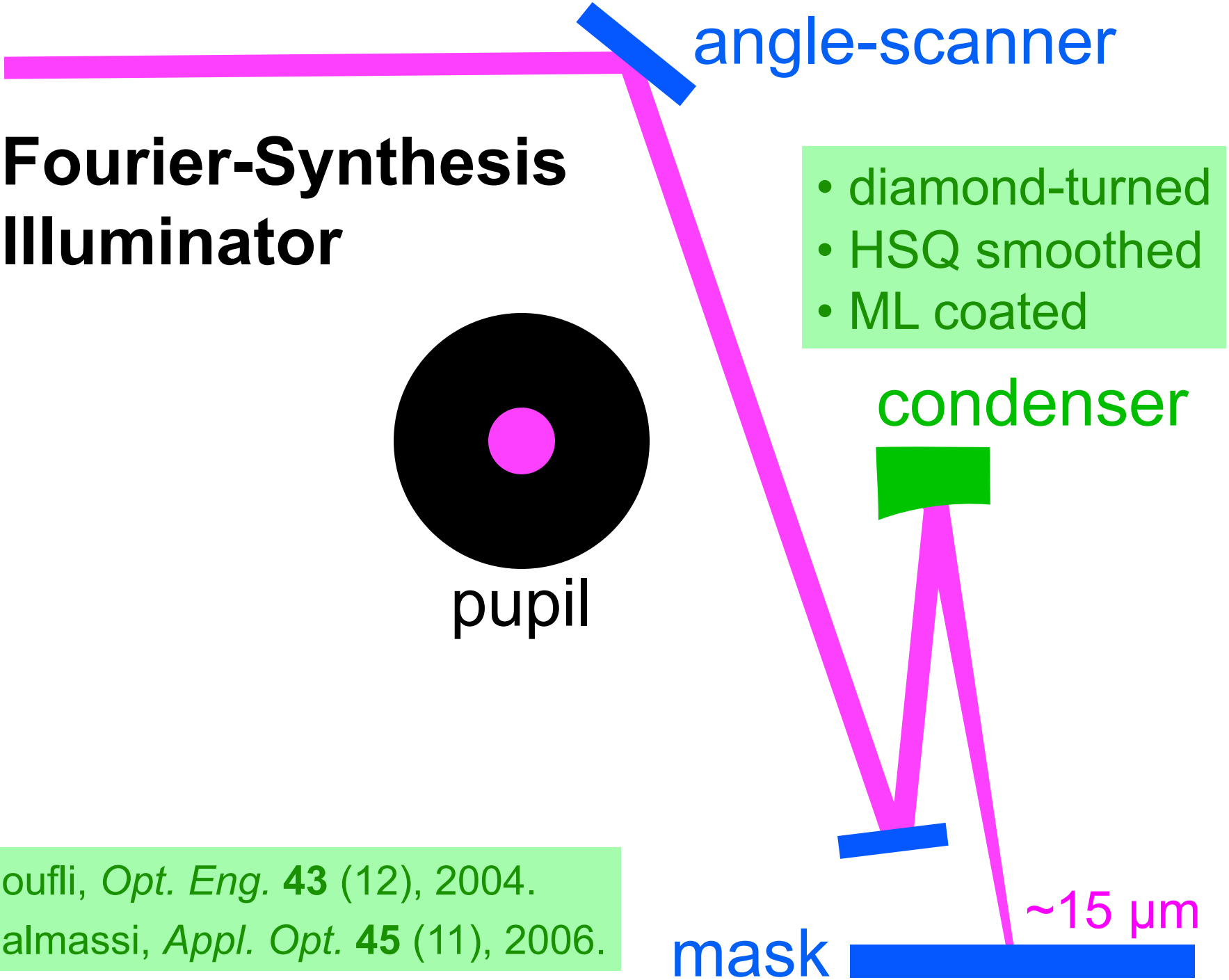


pupil

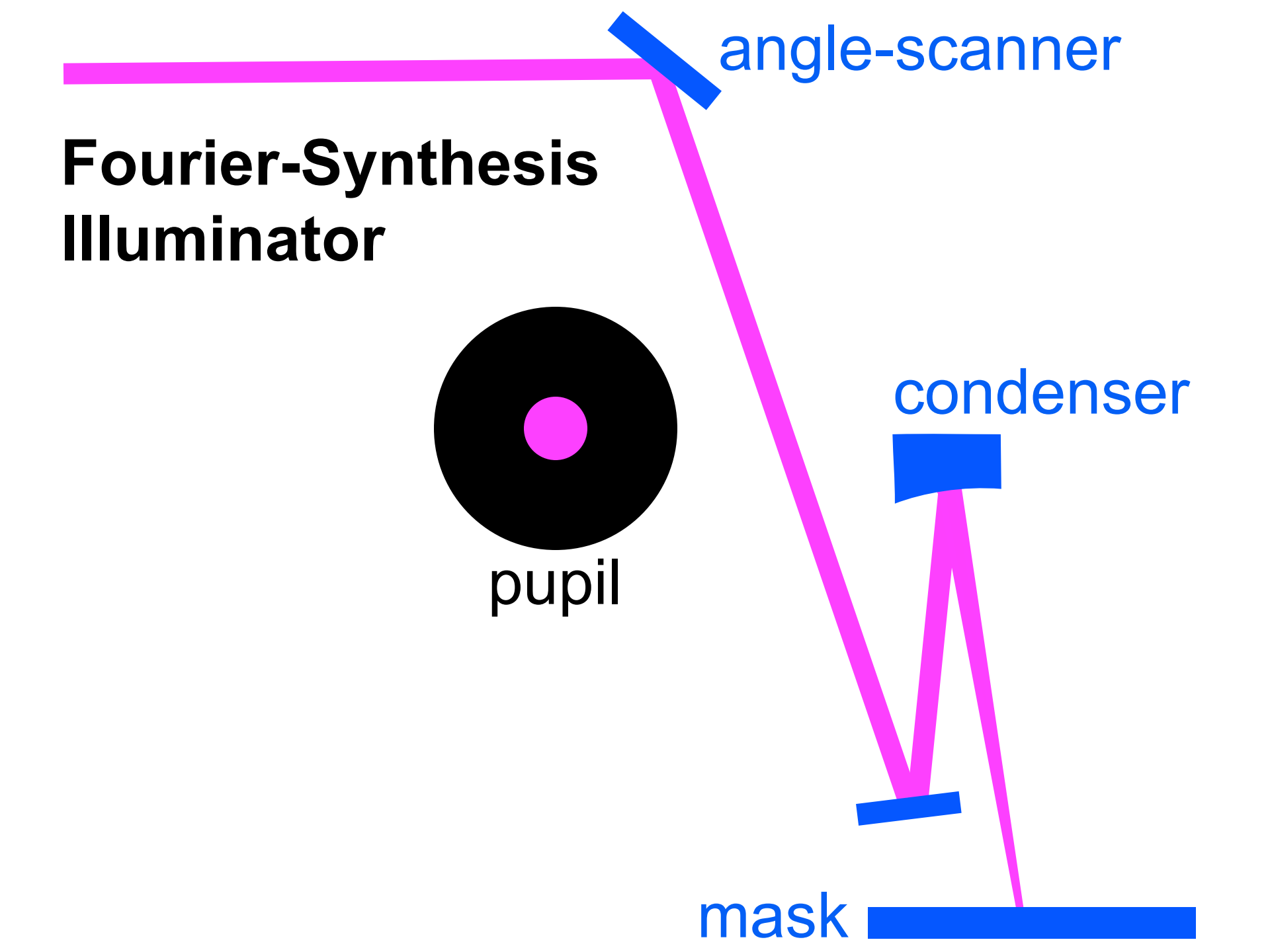


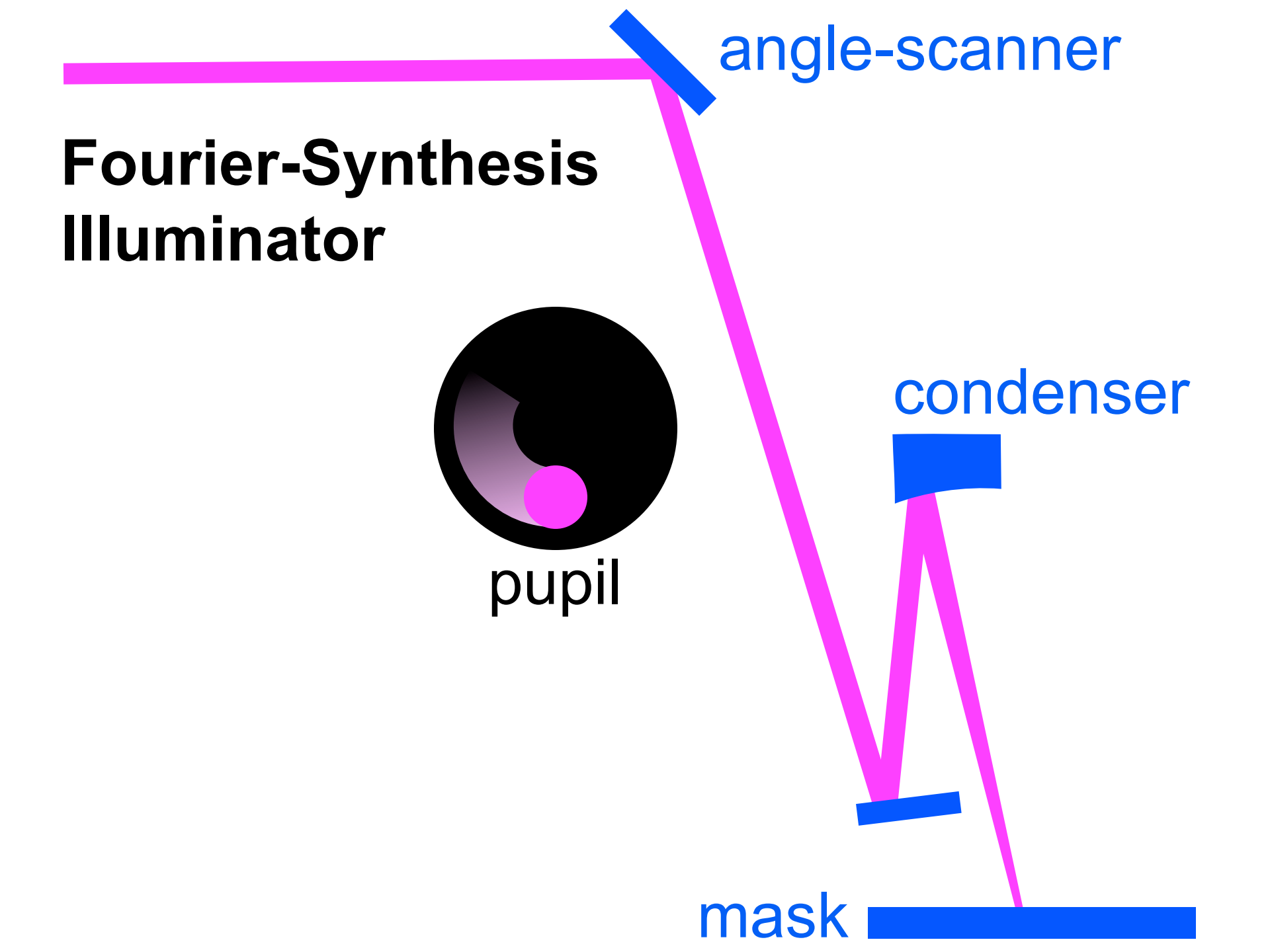

angle-scanner
Fourier-Synthesis
Illuminator
pupil
condenser
mask

Fourier-Synthesis Illuminator



Soufli, *Opt. Eng.* **43** (12), 2004.
Salmassi, *Appl. Opt.* **45** (11), 2006.


angle-scanner
Fourier-Synthesis
Illuminator
pupil
condenser
mask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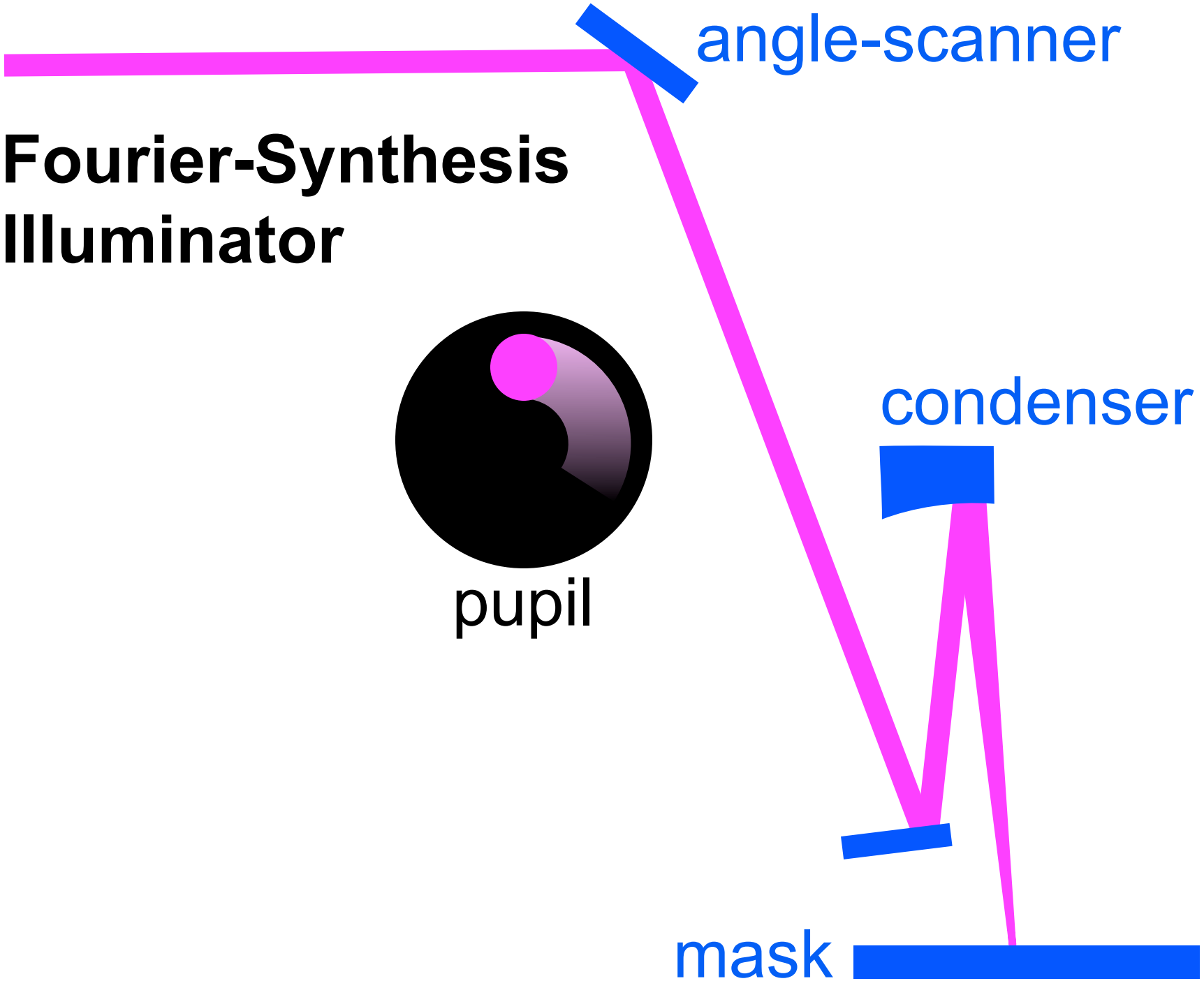
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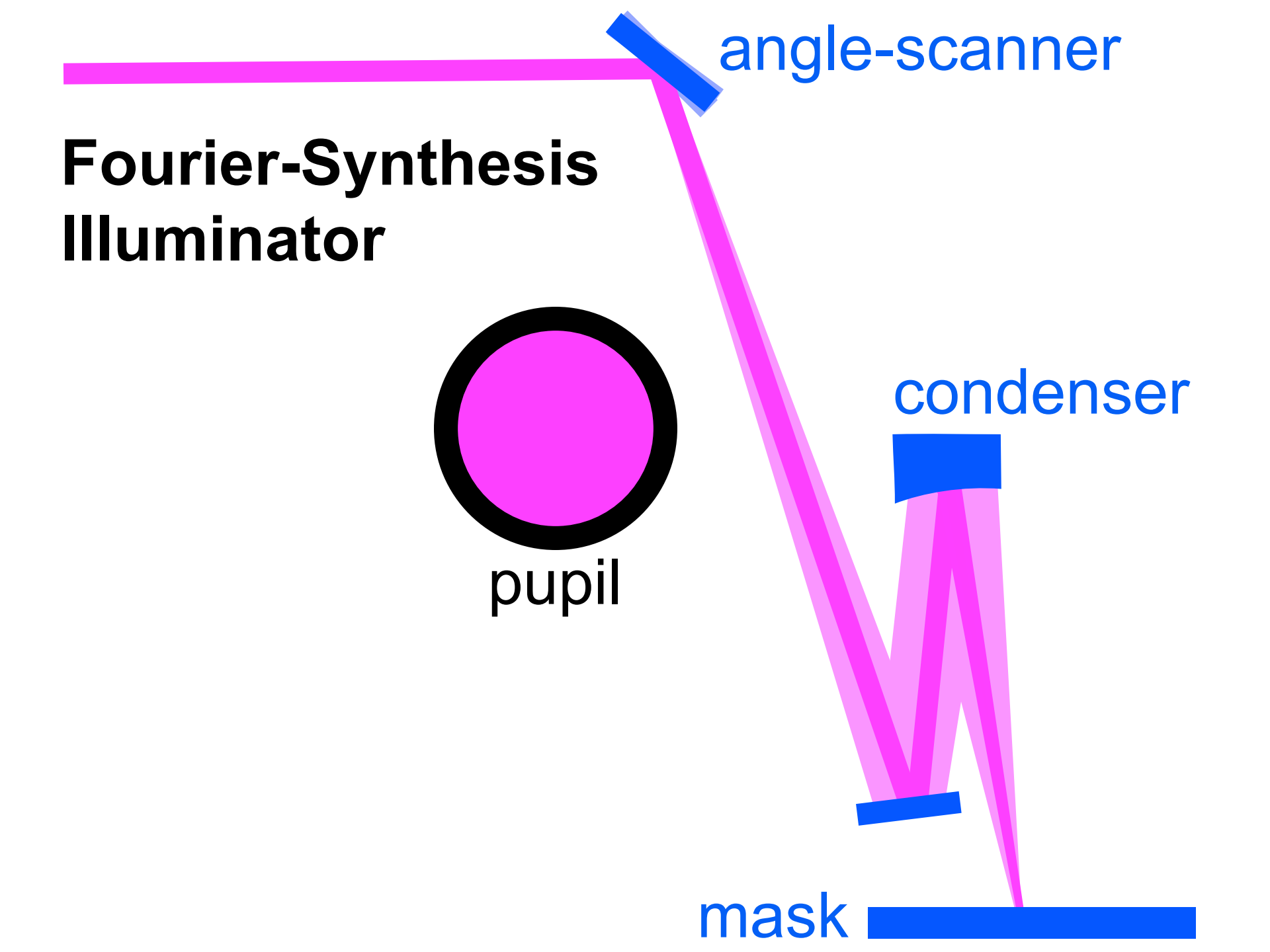
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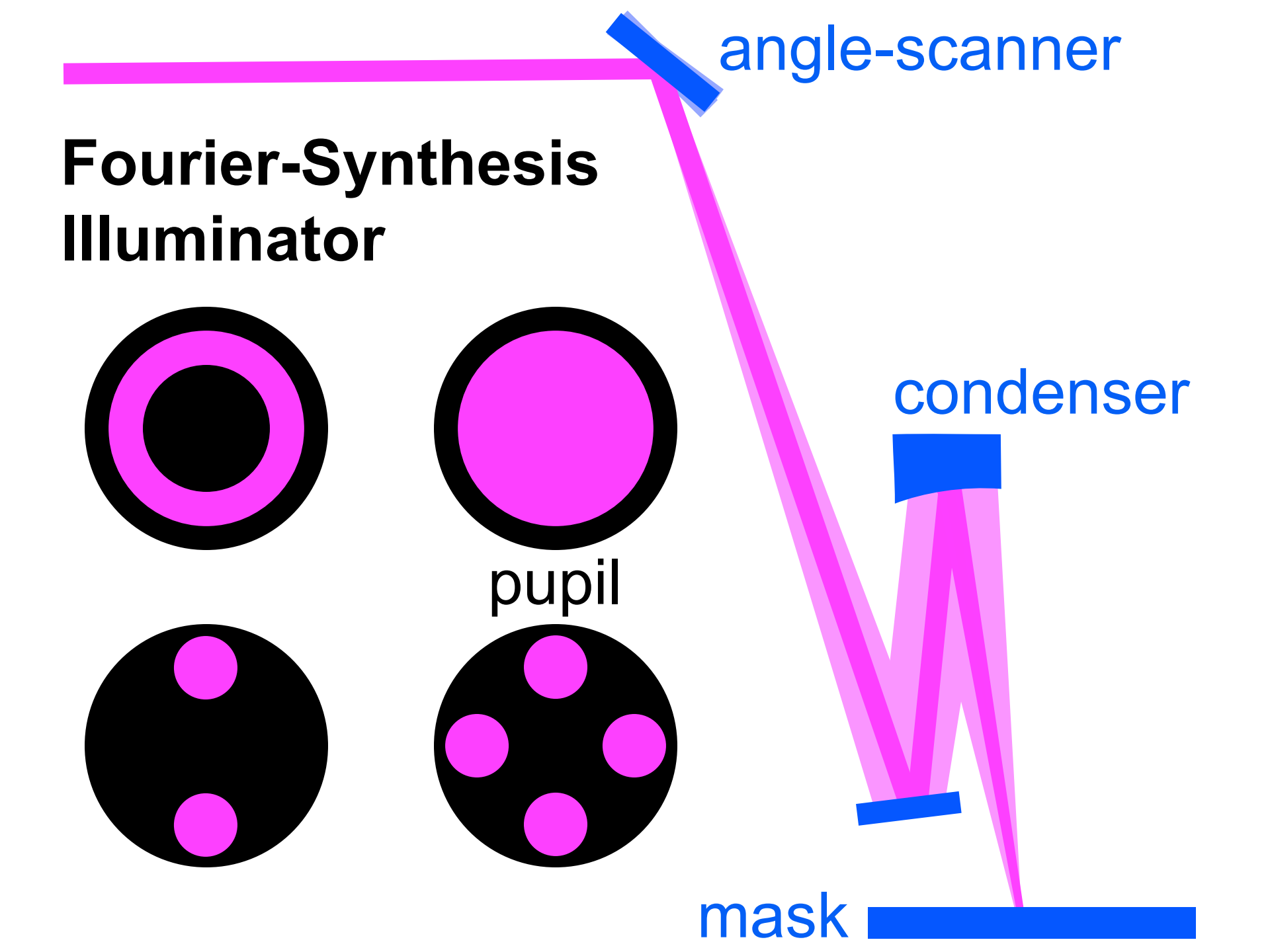
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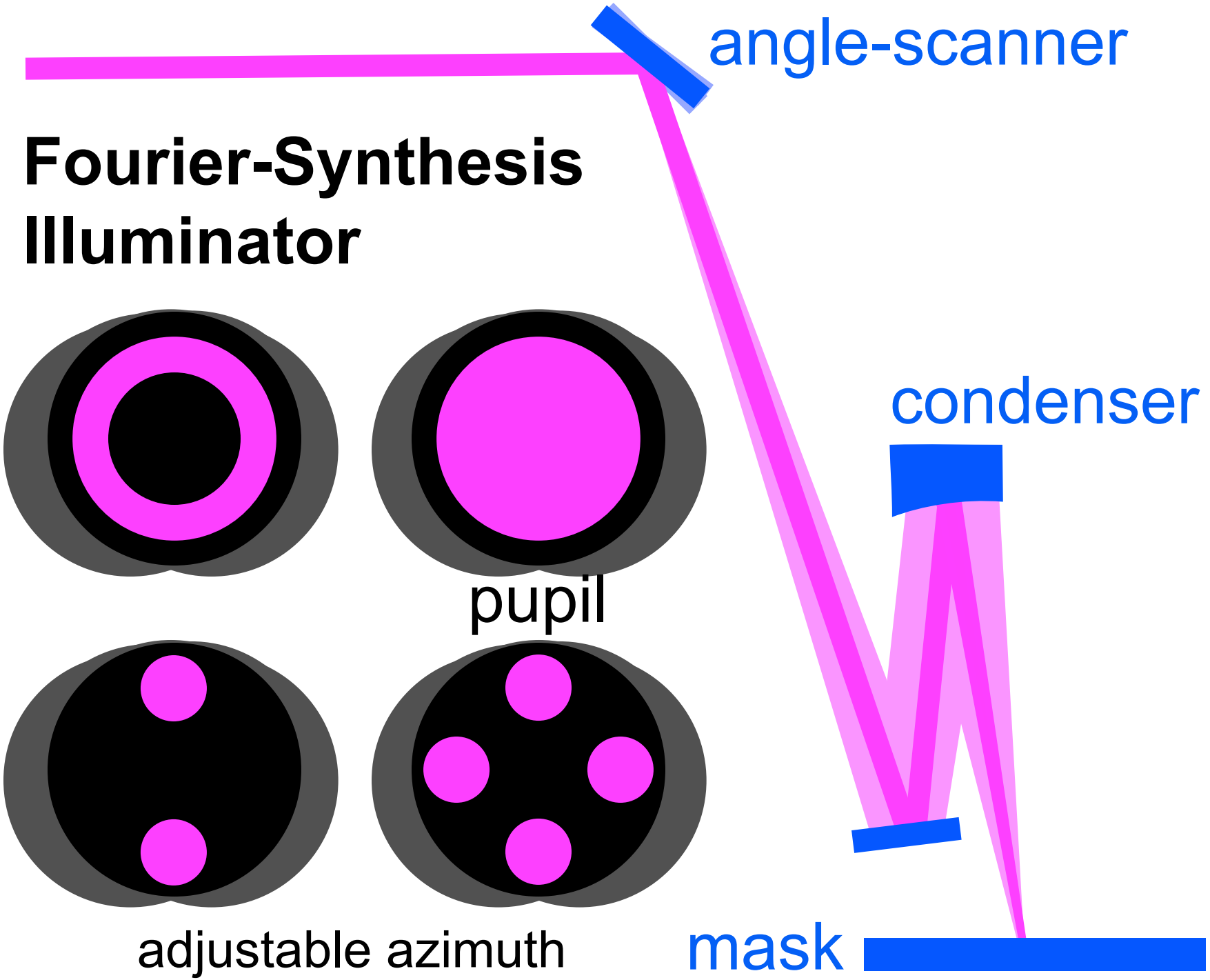
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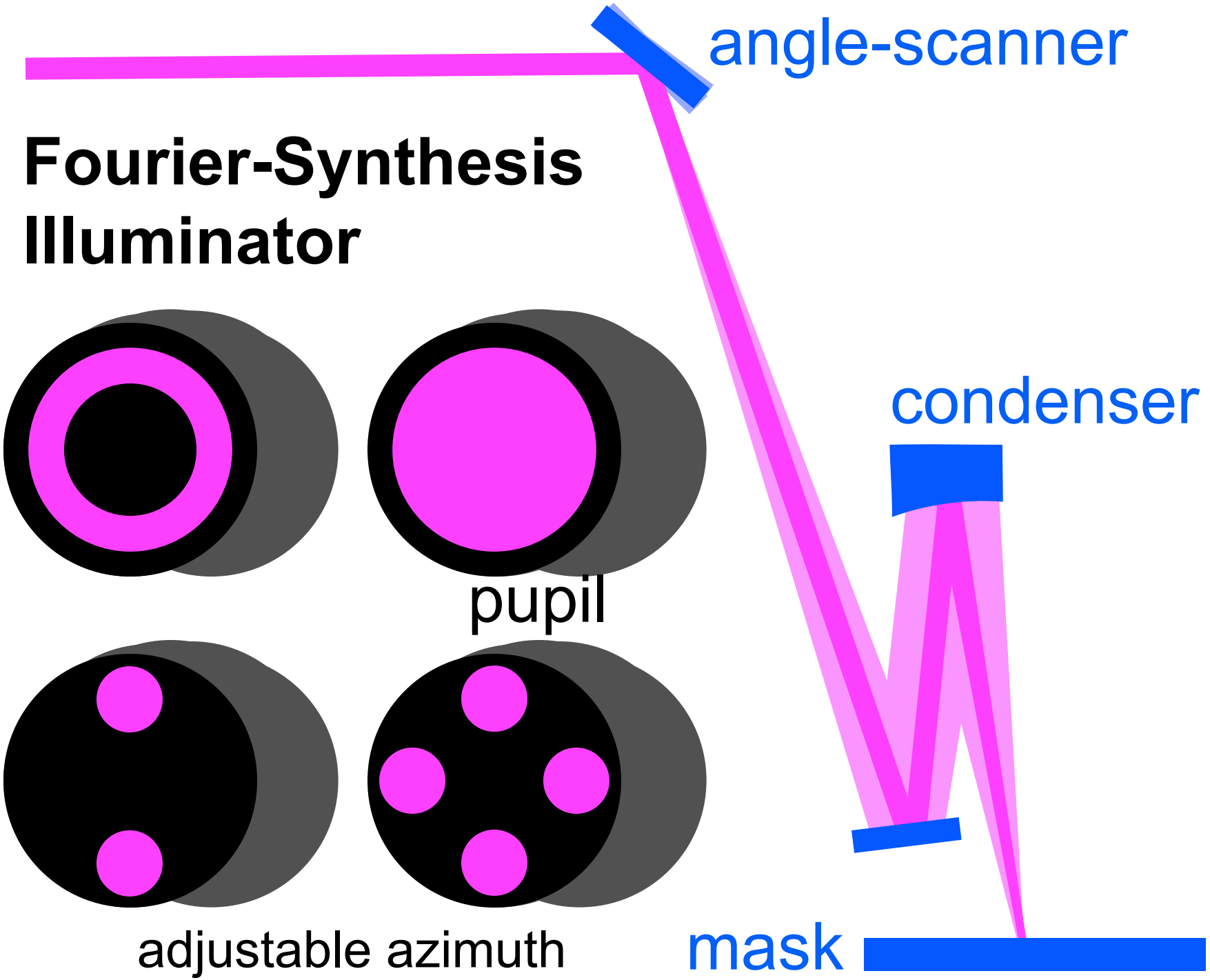
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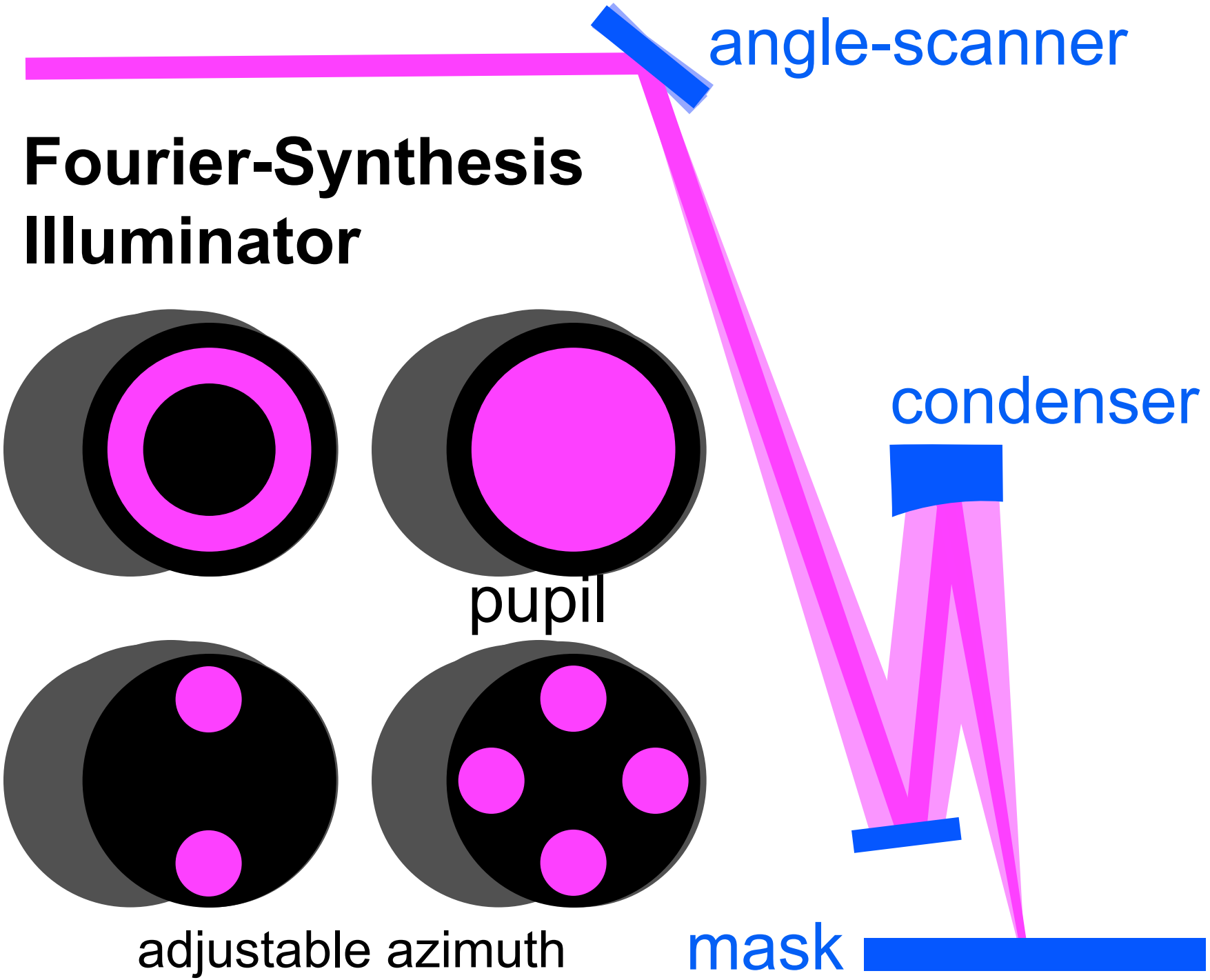
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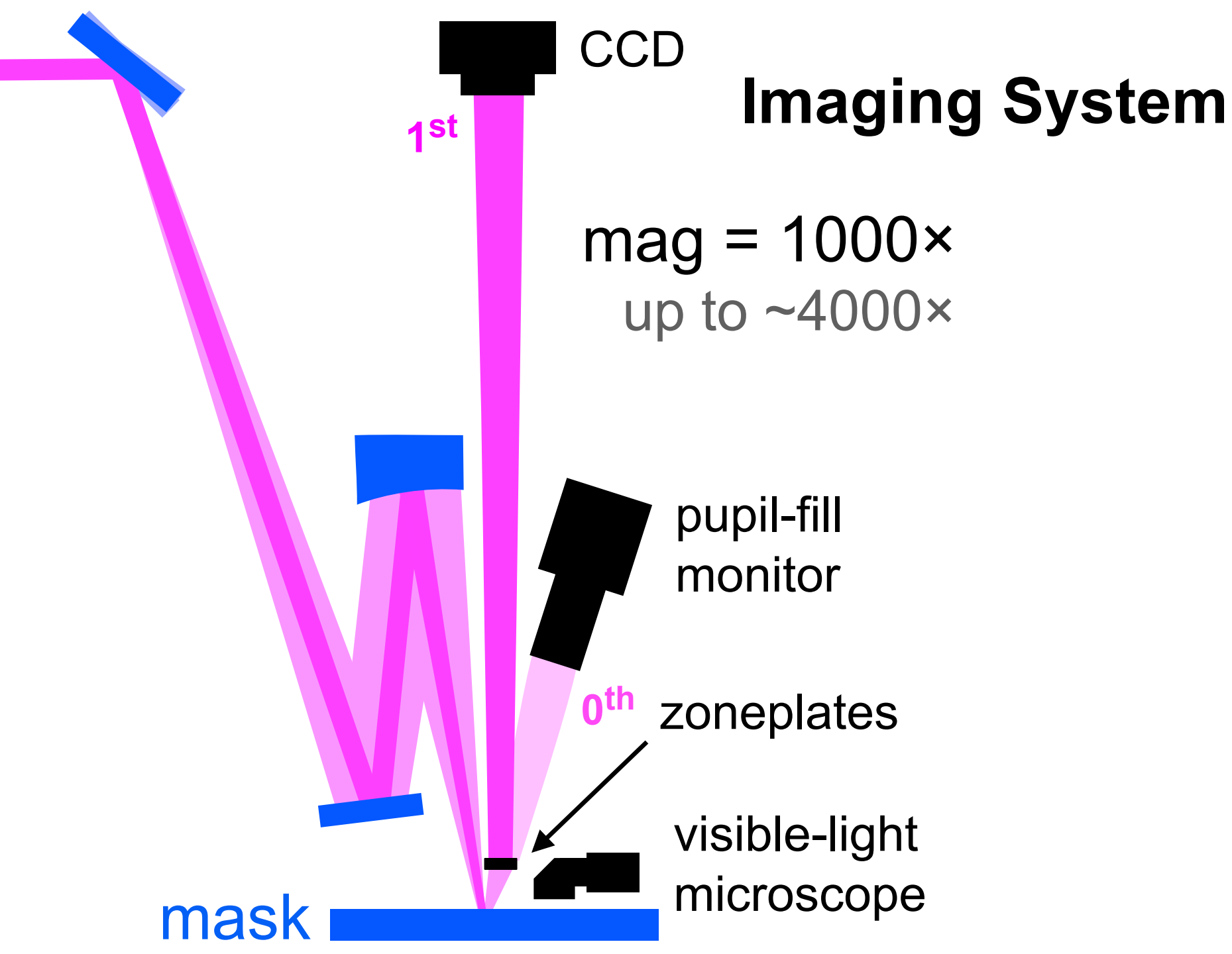
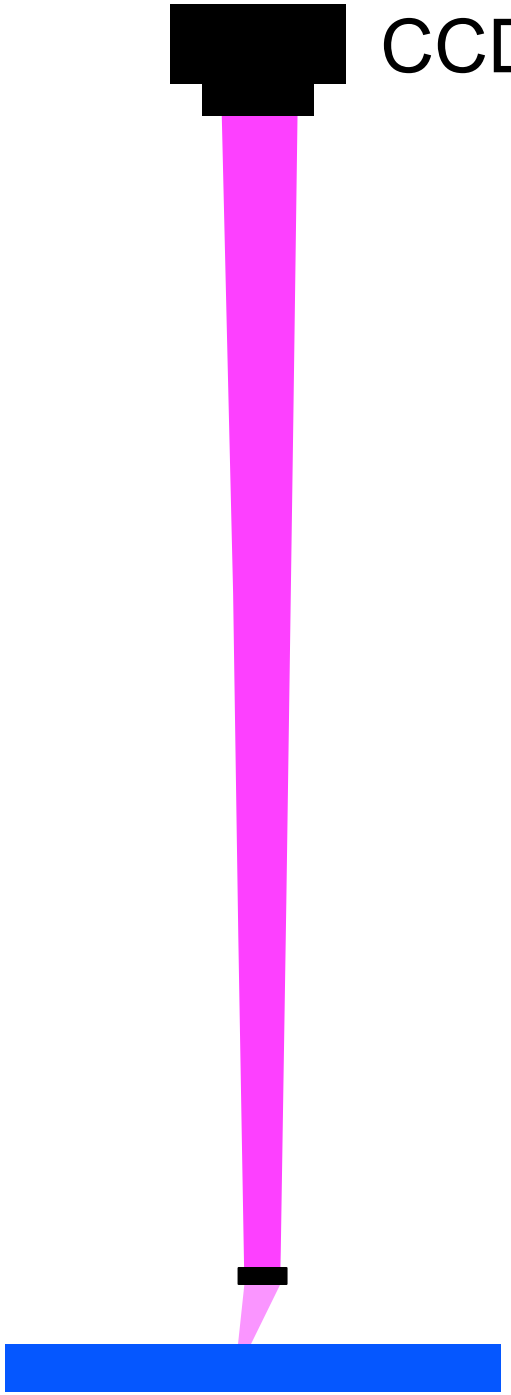


Imaging System

AIT5

SEMATECH & LBNL

CCD

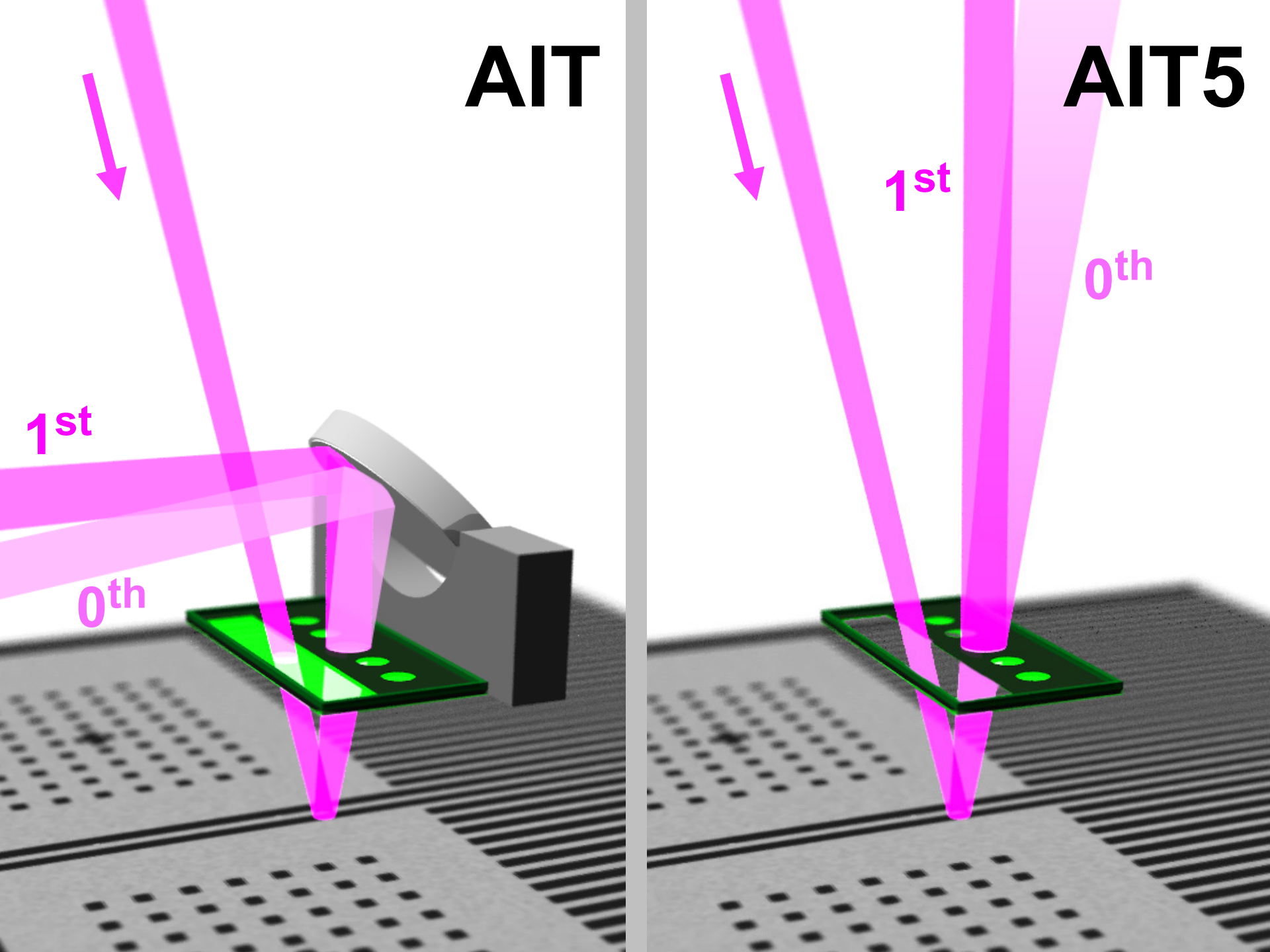


AIMS™EUV

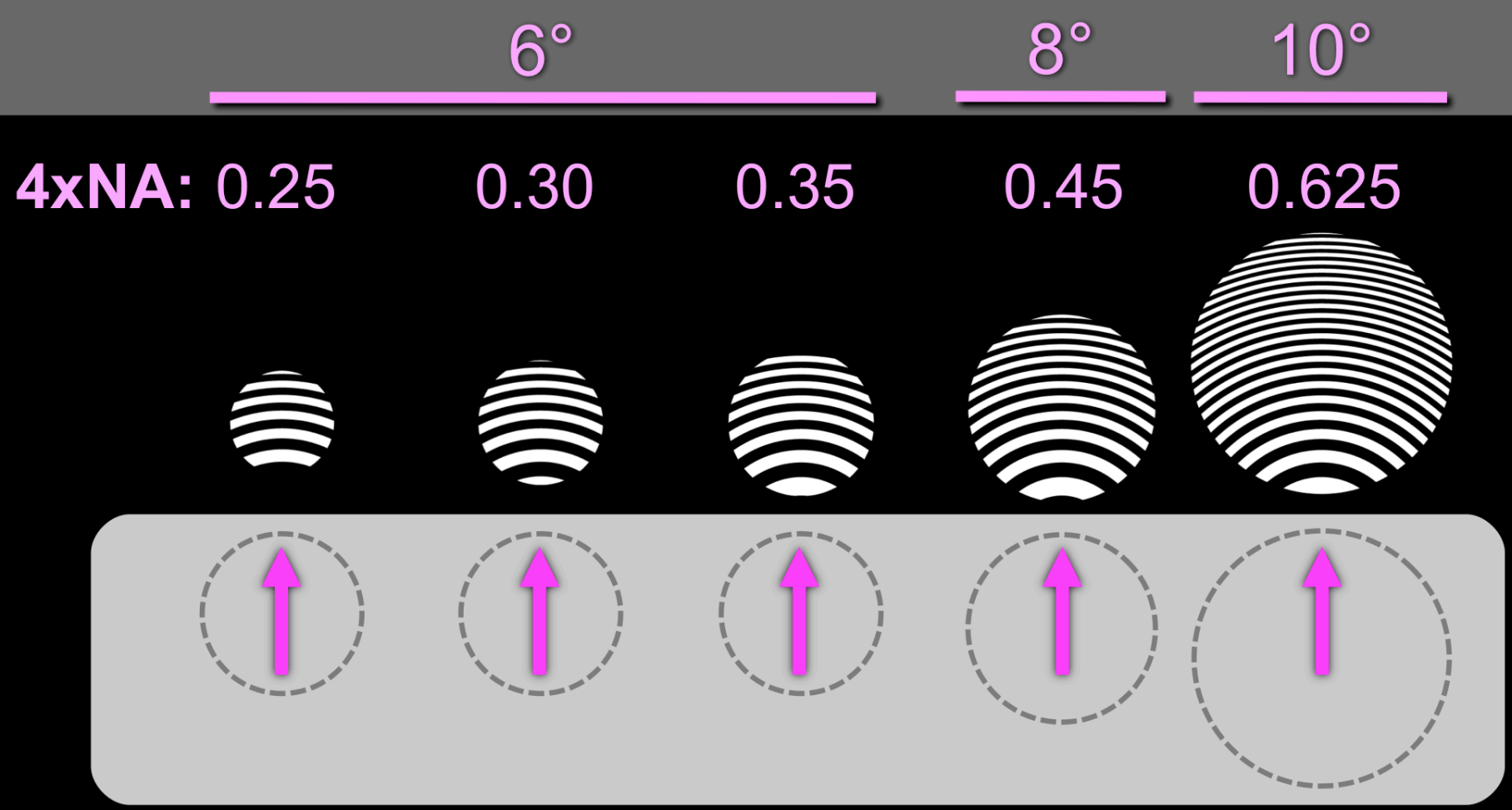
Zeiss

Goldberg, *SPIE* **7969** (2011)

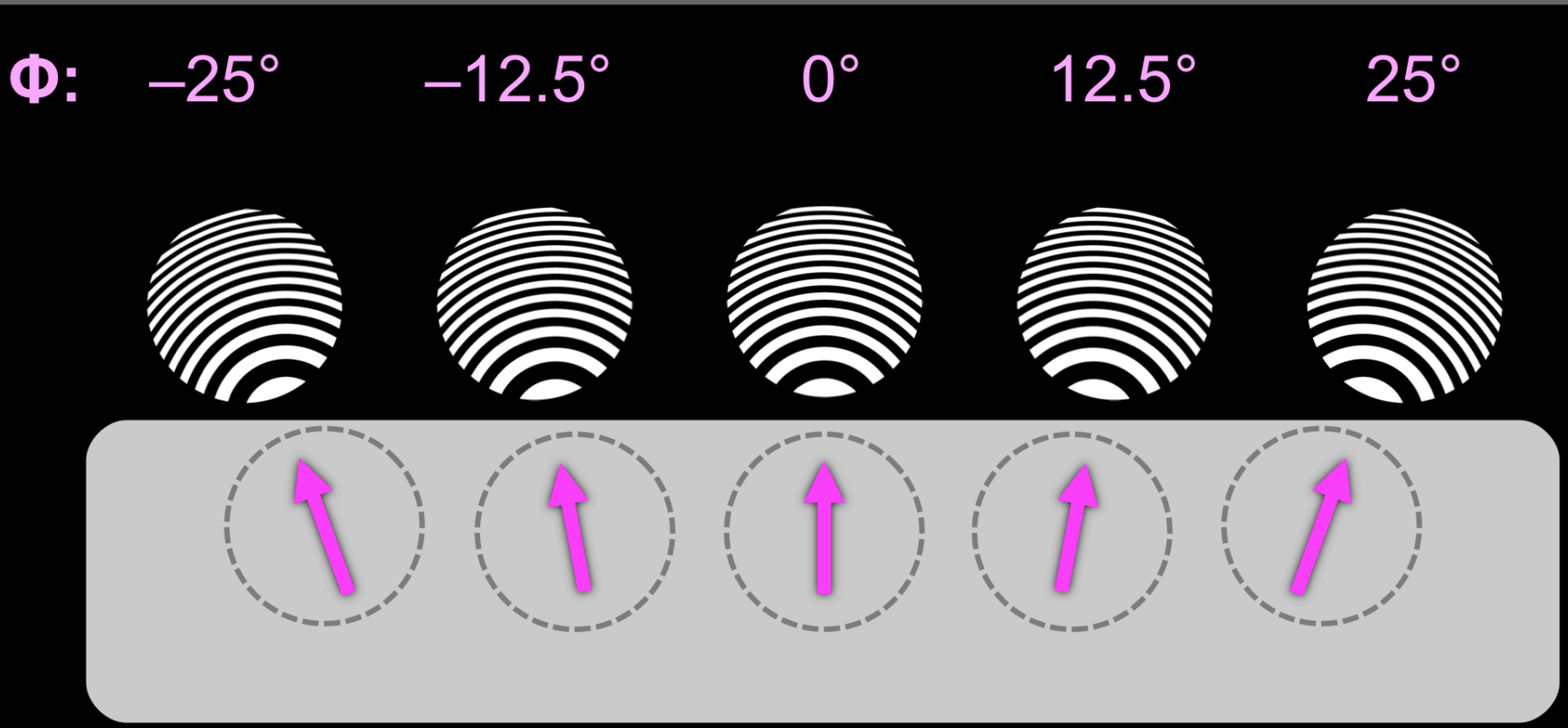
Feldmann, *SPIE* **7636** (2010)


AIT
1st
0th
AIT5
1st
0th

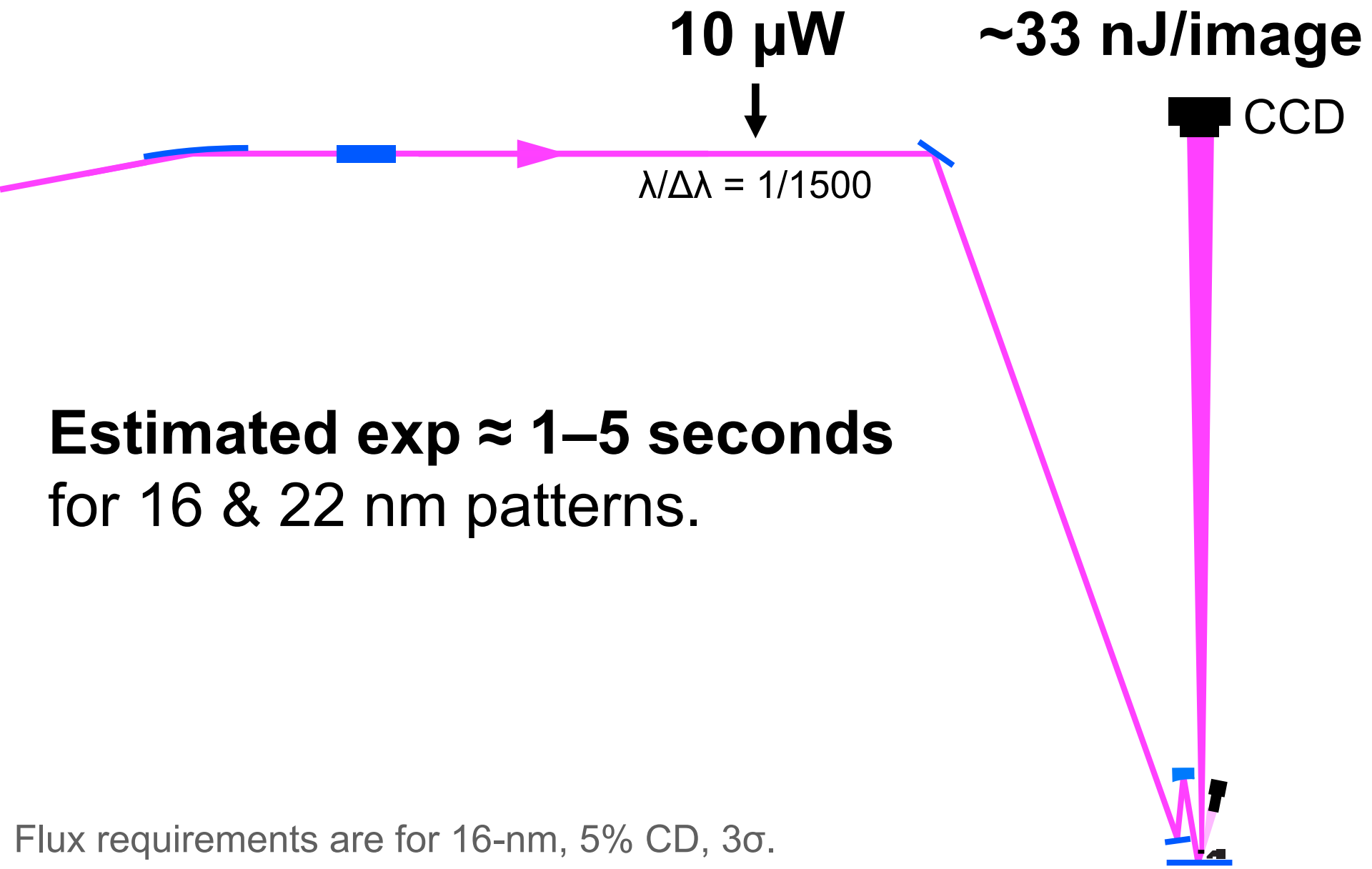
Zoneplate objective lenses arrayed by NA



Zoneplate objective lenses arrayed by azimuthal angle



What about *power*?



Estimated exp ≈ 1–5 seconds
for 16 & 22 nm patterns.

Flux requirements are for 16-nm, 5% CD, 3σ.
Wintz, *SPIE* **7636** (2010).

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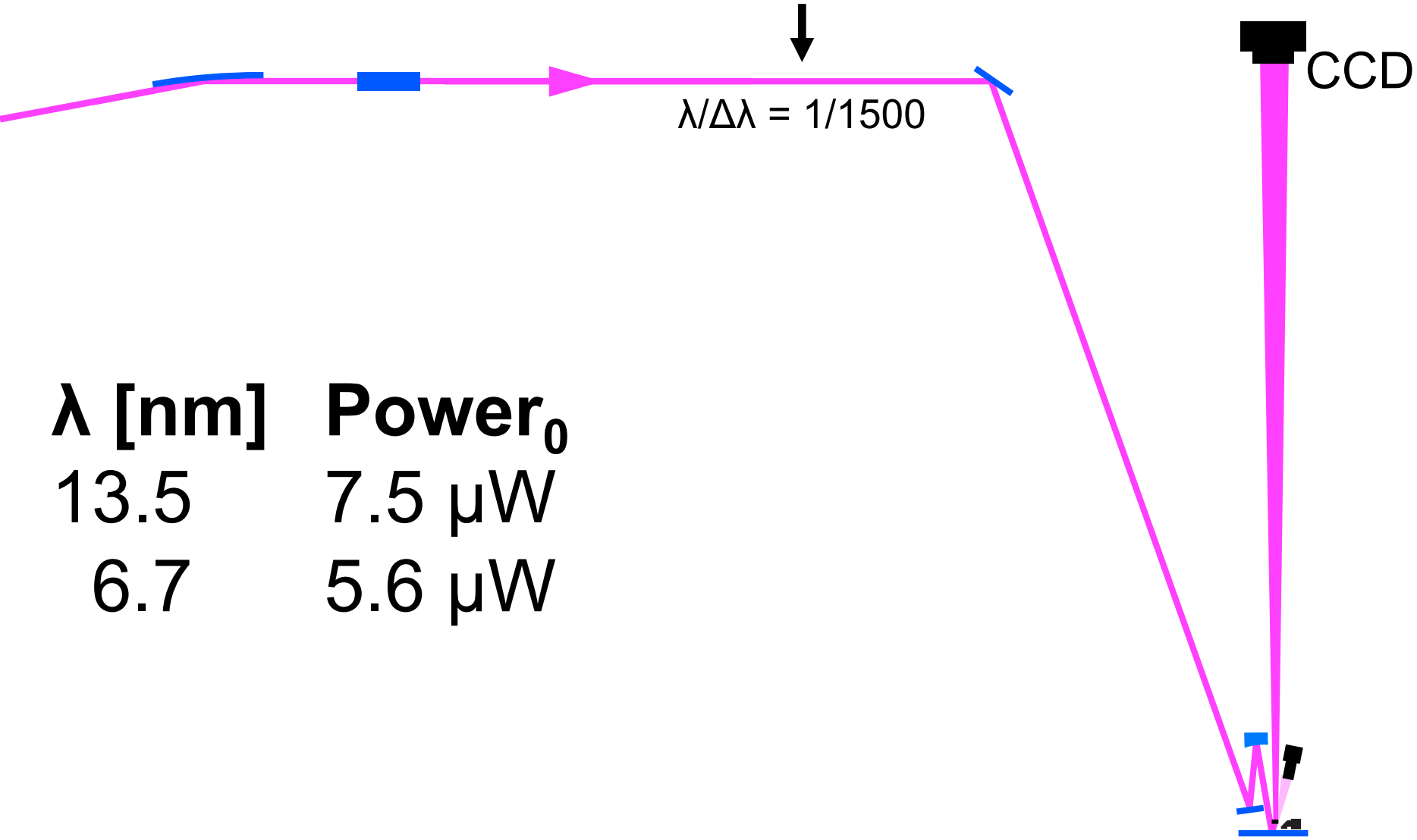
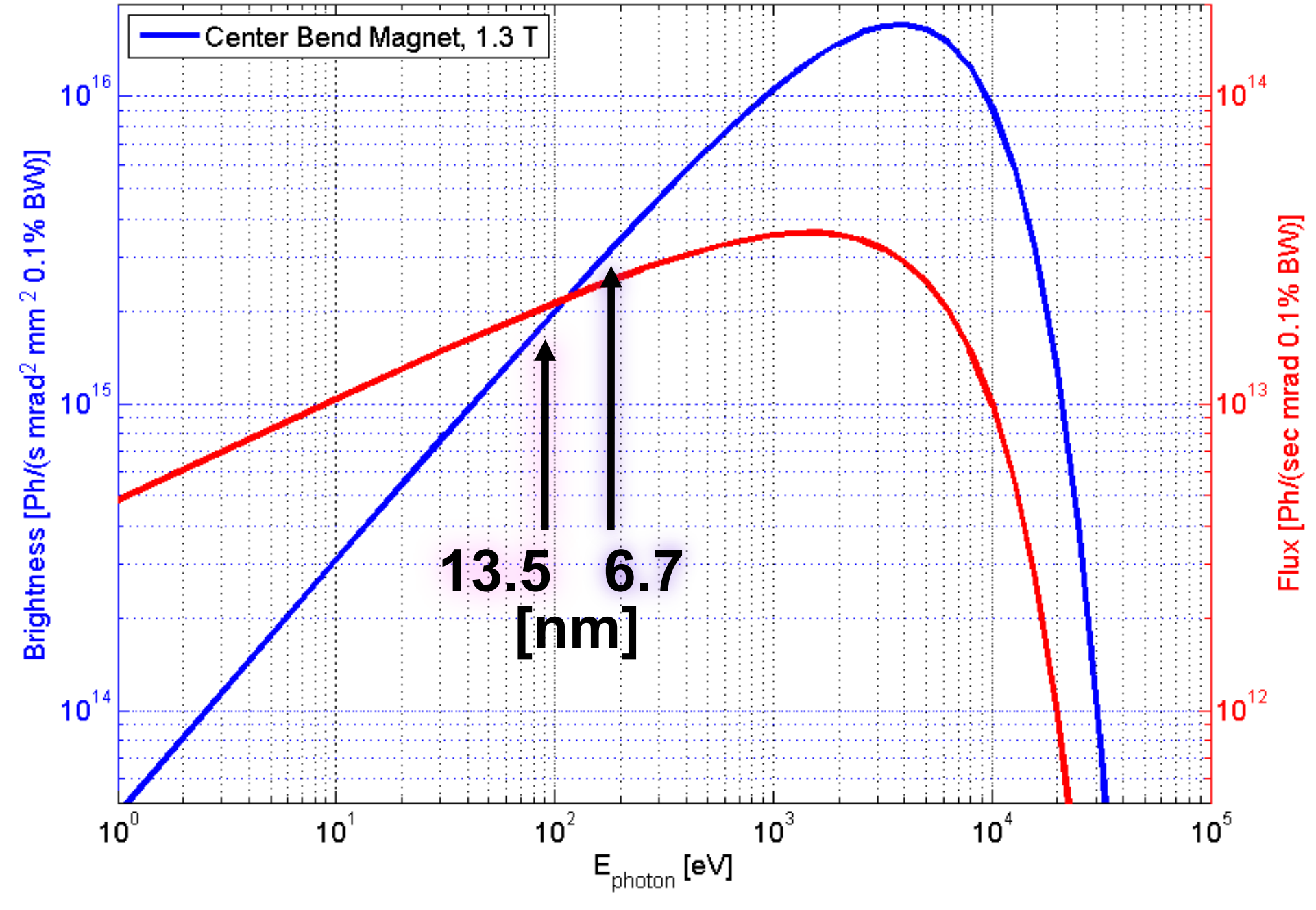
AIT *6.7*?

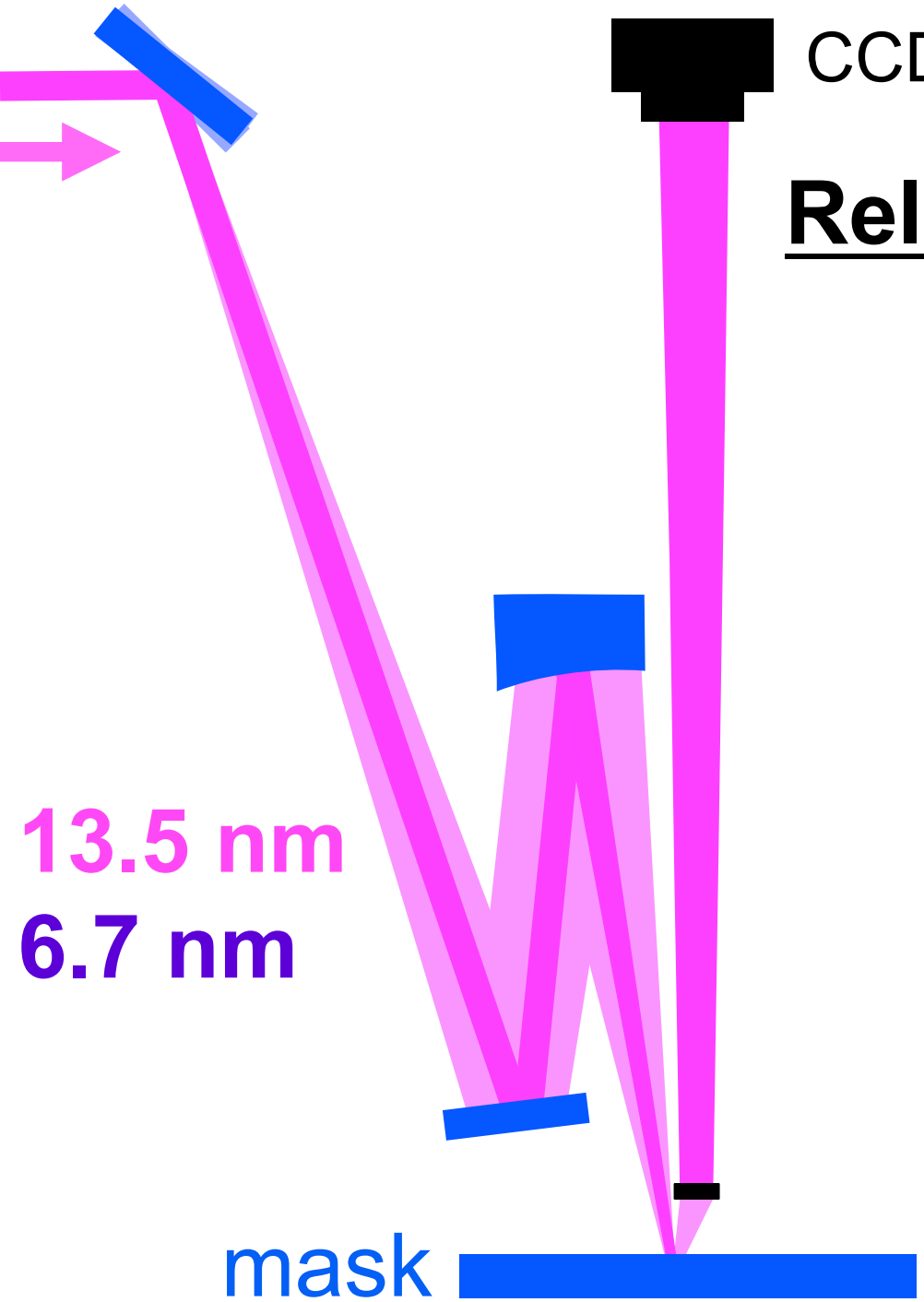
Beamline Power @ ALS



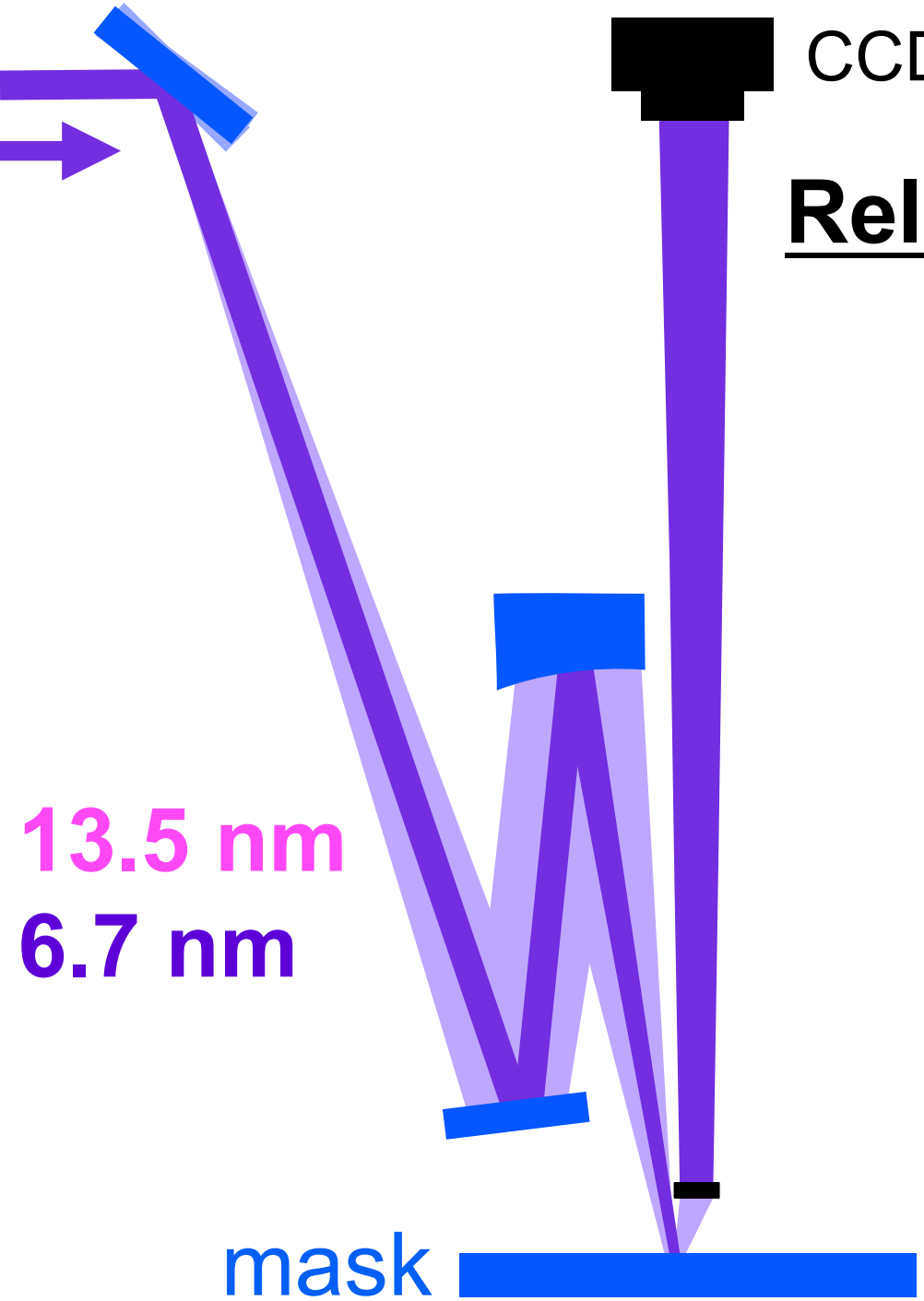
λ [nm]	$Power_0$
13.5	7.5 μW
6.7	5.6 μW

Advanced Light Source (ALS) @ LBNL

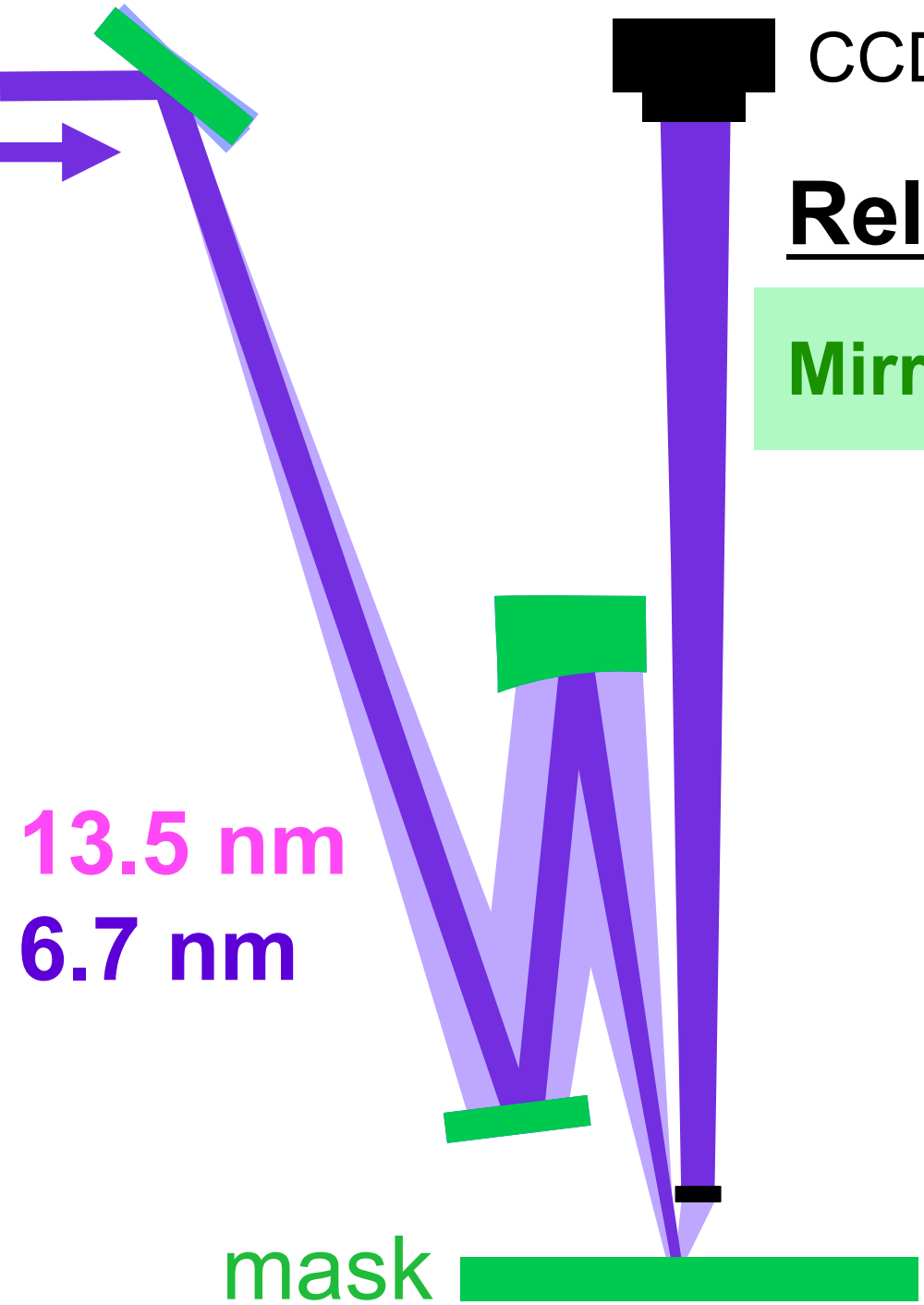




Relative Performance

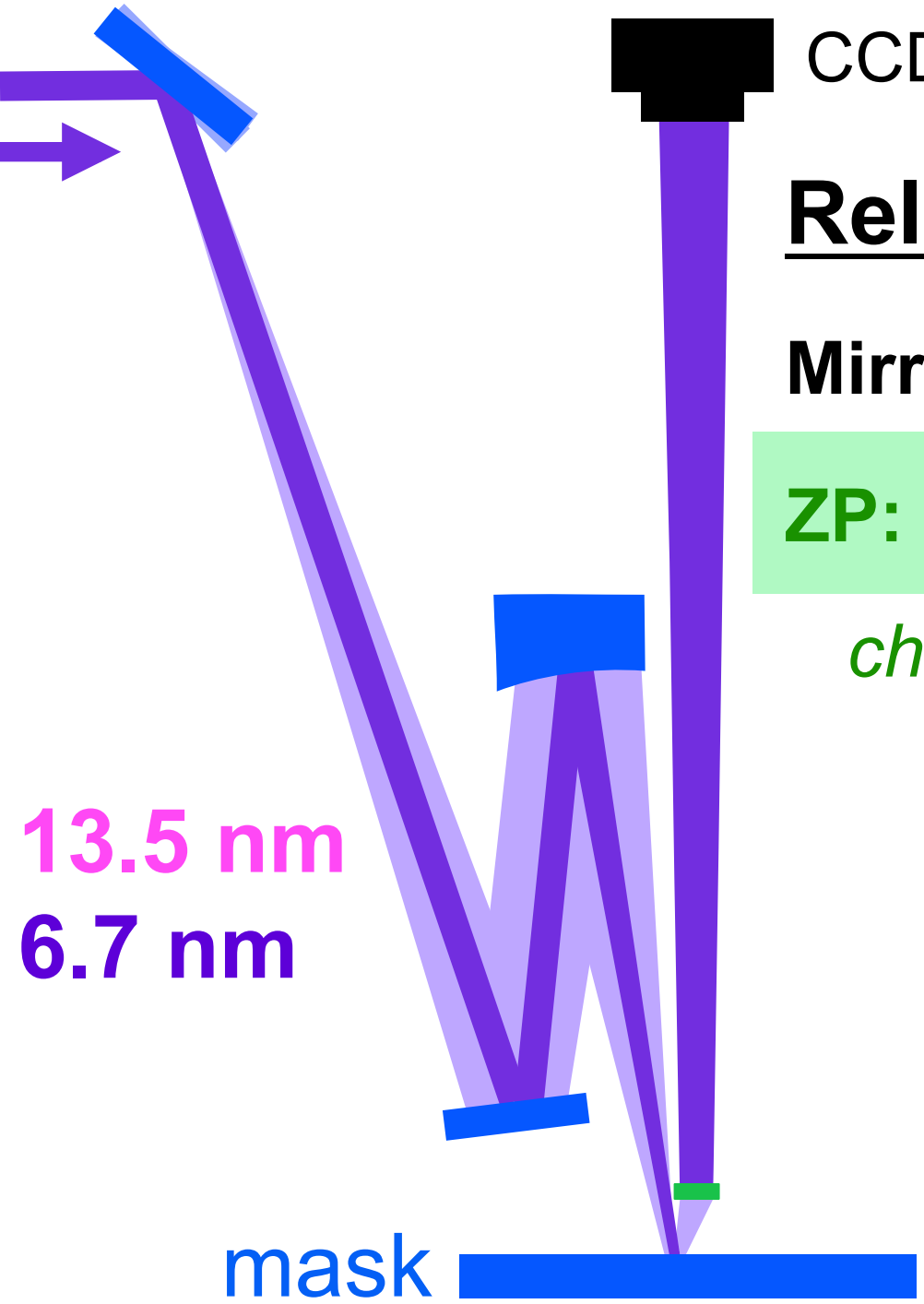


Relative Performance



Relative Performance

Mirrors: $(0.45 / 0.65)^4 \approx$ **0.25**

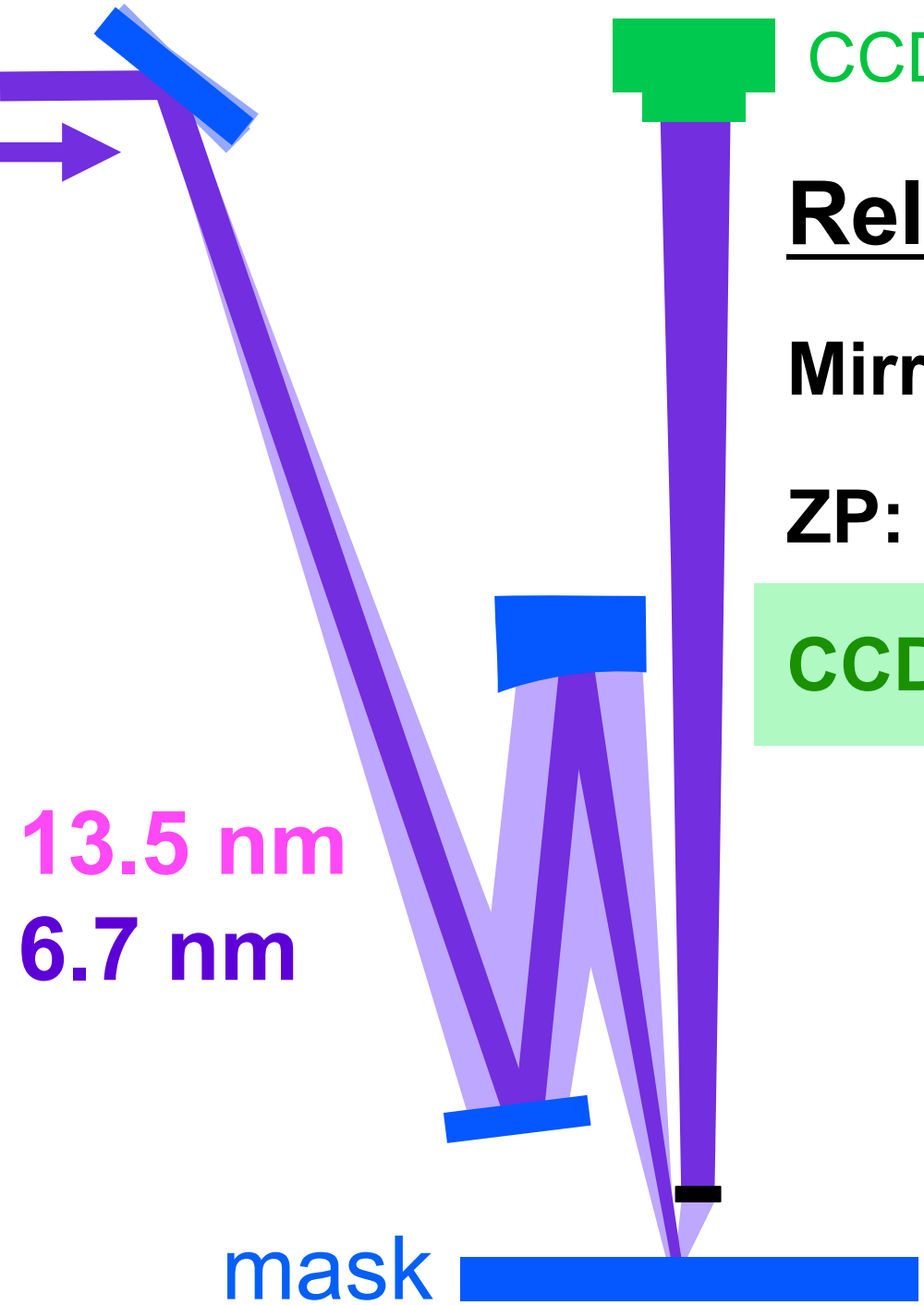


Relative Performance

Mirrors: $(0.45 / 0.65)^4 \approx \mathbf{0.25}$

ZP: ≈ **0.5** (bandwidth / 2)*

challenging at high-NA



Relative Performance

Mirrors: $(0.45 / 0.65)^4 \approx$ **0.25**

ZP: ≈ **0.5** (bandwidth / 2)

CCD: ≈ **0.8** (detection)

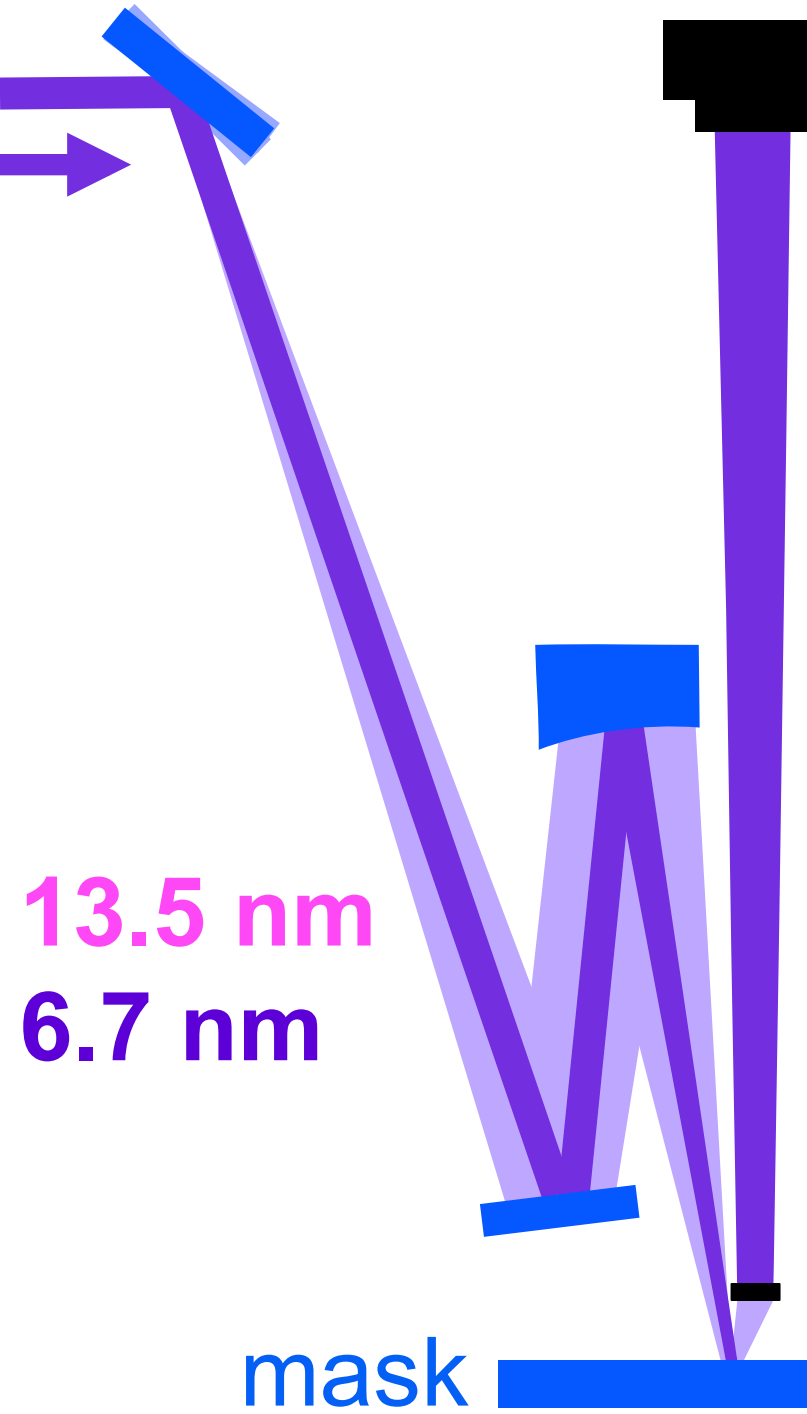
Relative Performance

Mirrors: $(0.45 / 0.65)^4 \approx$ **0.25**

ZP: ≈ **0.5** (bandwidth / 2)

CCD: ≈ **0.8** (detection)

Beamline: ≈ **5.6** (power)



Relative Performance

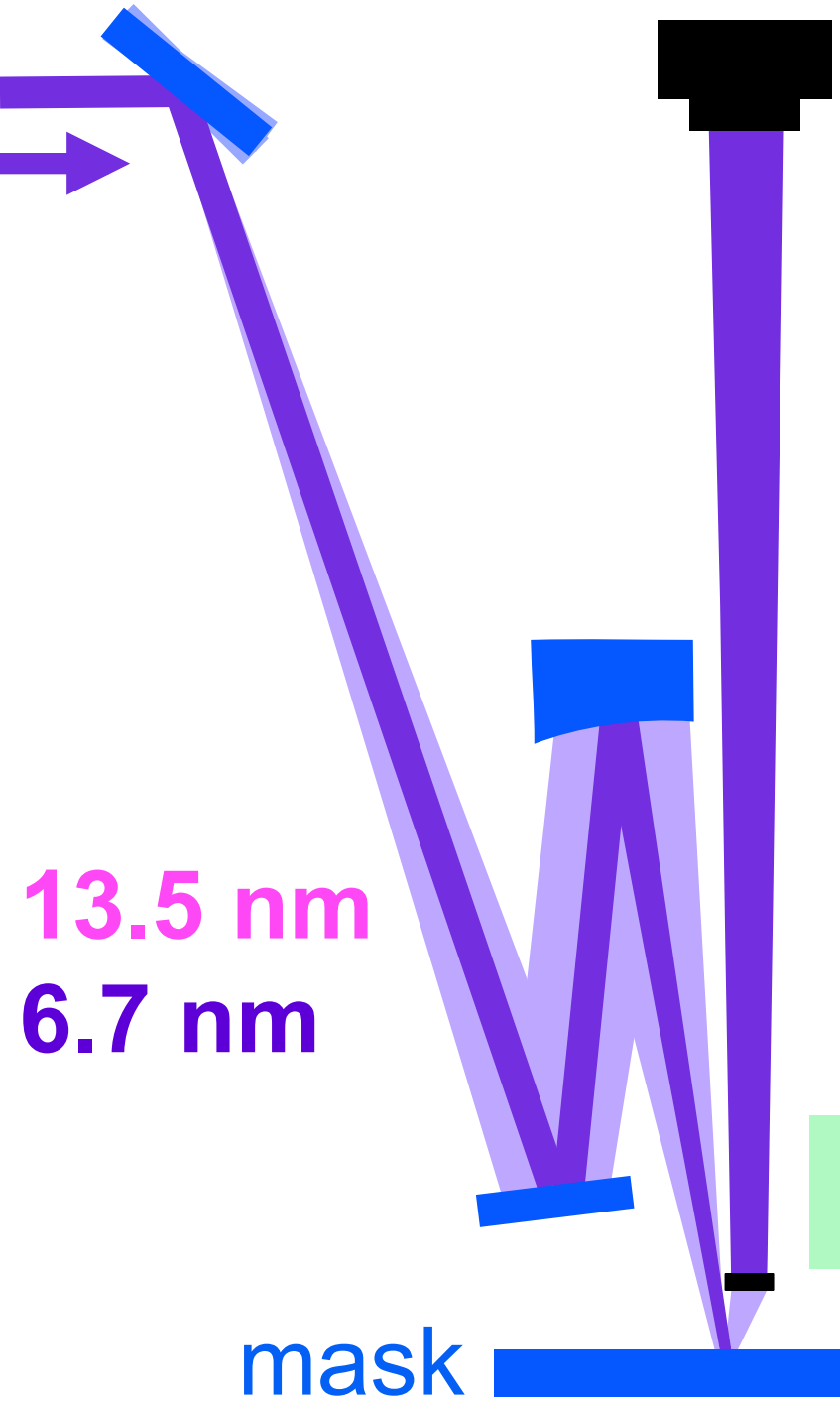
Mirrors: $(0.45 / 0.65)^4 \approx$ **0.25**

ZP: ≈ **0.5** (bandwidth / 2)

CCD: ≈ **0.8** (detection)

Beamline: ≈ **5.6** (power)

Total: ≈ **1/2** power ≈ **1/4** ph



Relative Performance

Mirrors: $(0.45 / 0.65)^4 \approx$ **0.25**

ZP: ≈ **0.5** (bandwidth / 2)

CCD: ≈ **0.8** (detection)

Beamline: ≈ **5.6** (power)

Total: ≈ **1/2** power ≈ **1/4** ph

It will work at 6.7 nm!

AIT

> 16 nm

low σ

∠6°

AIT5

> 6 nm

any σ

up to ∠10°

AIT5

> 6 nm

any σ

up to ∠10°

AIT6.7

> ? nm

any σ

up to ∠10°

The AIT team

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THE CENTER FOR X-RAY OPTICS

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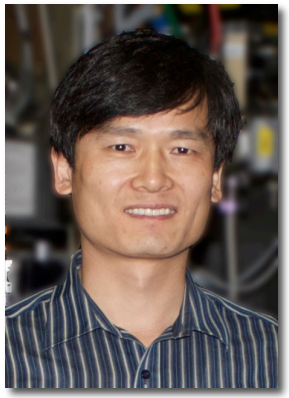
Graduate Student

Nathan Smith
Engineering Associate

Seno Rekawa
Chief Engineer

Ken Goldberg
Principal Investigator

SEMATECH



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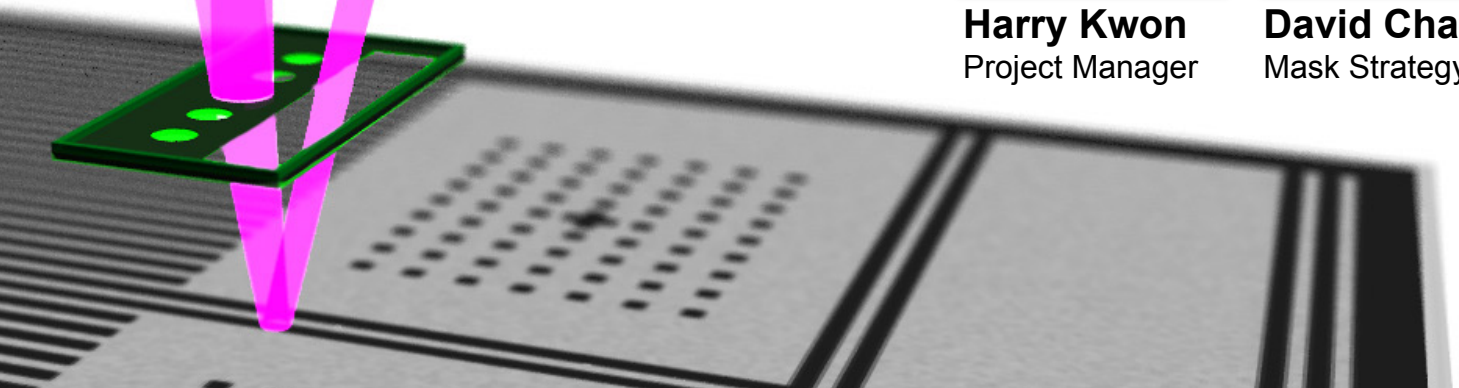
Project Manager

David Chan
Mask Strategy

Bryan Rice
Director of Lithography



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