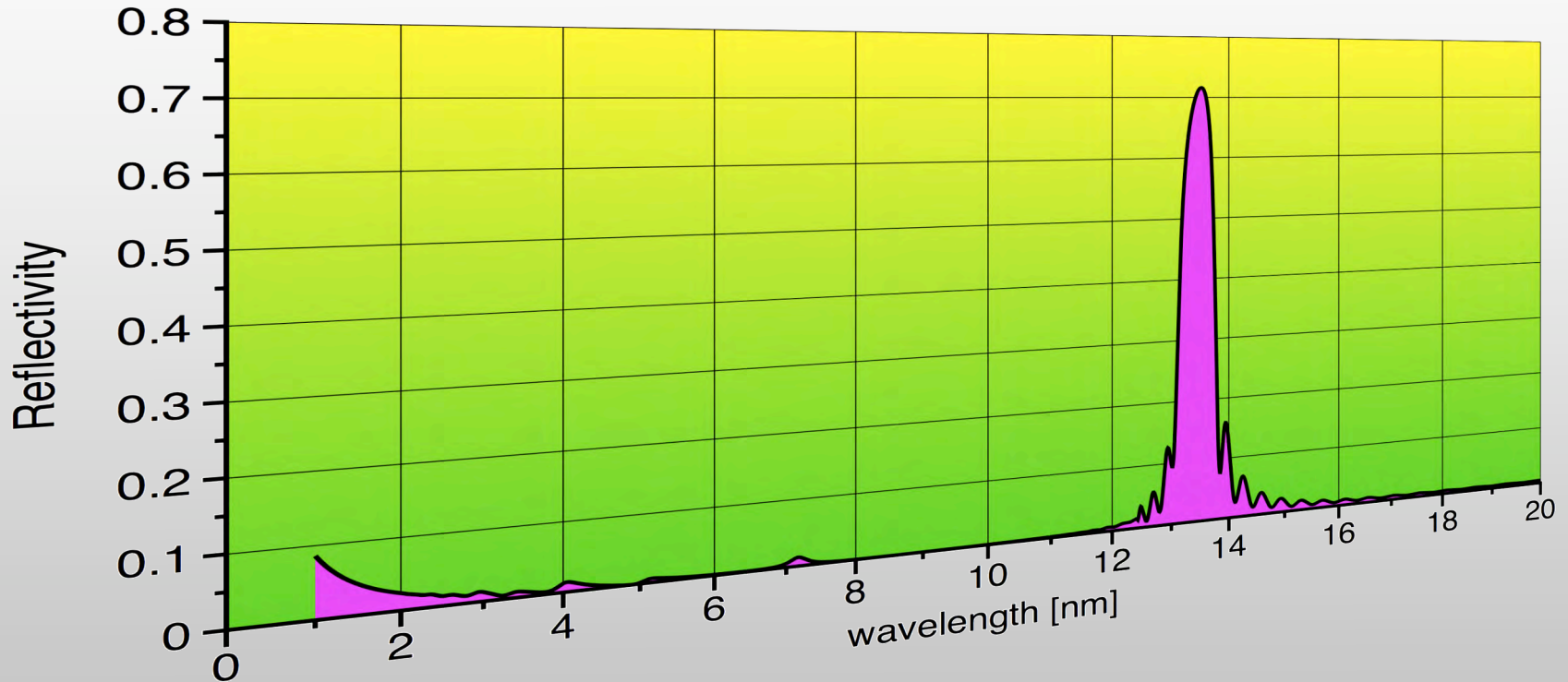


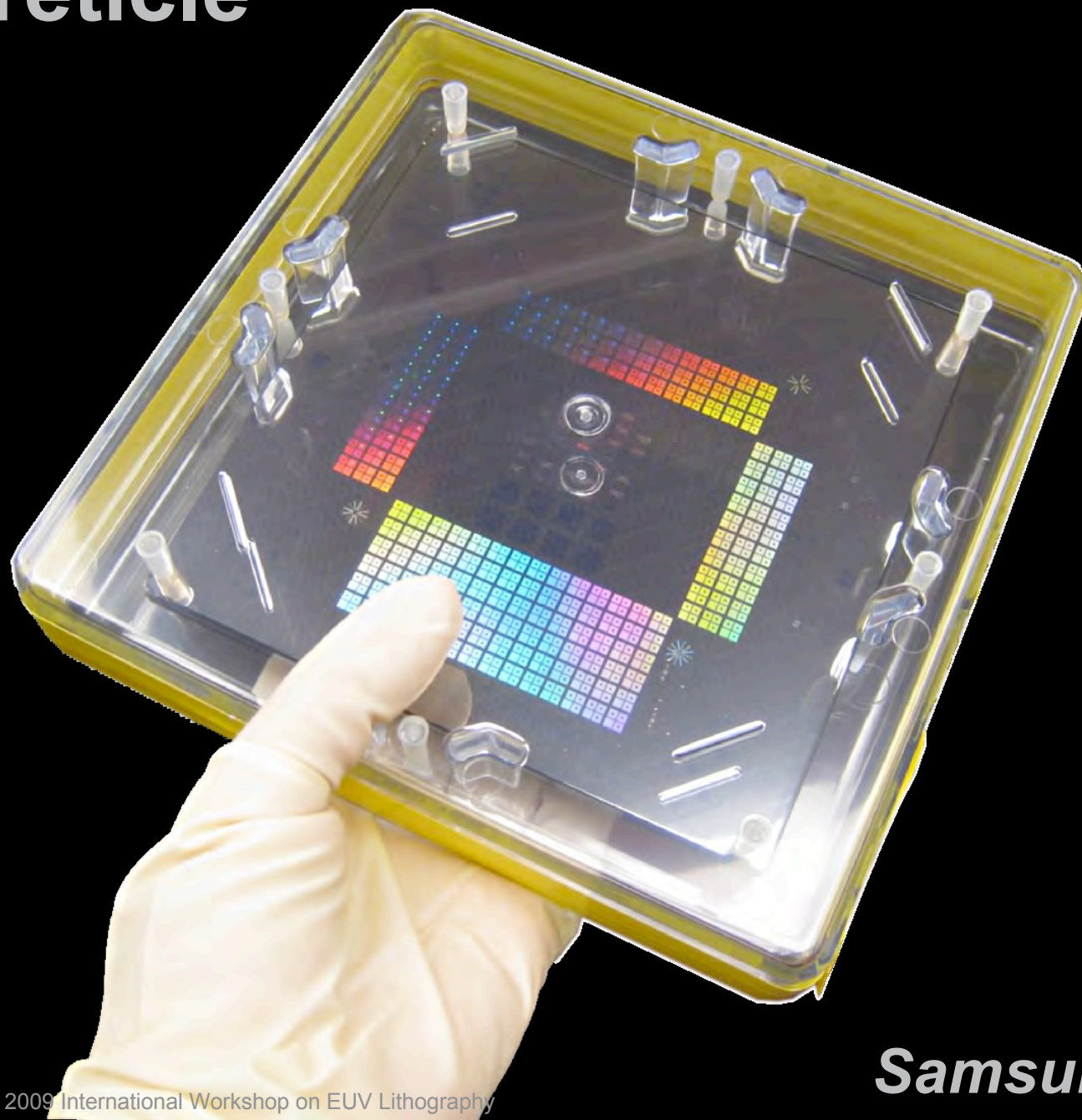
Wavelength-Specific Reflections

A Decade of EUV Mask Inspection Research



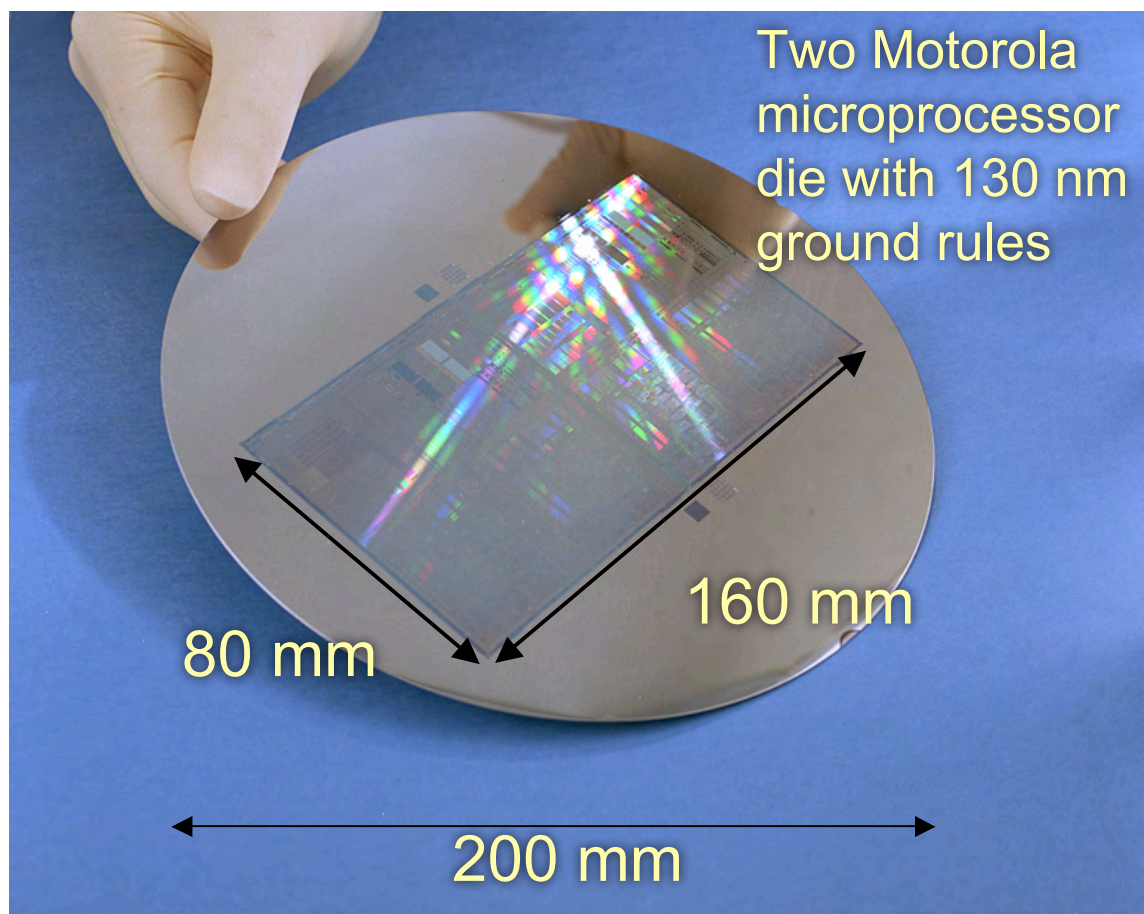
Kenneth Goldberg, Iacopo Mochi
Lawrence Berkeley National Laboratory

EUV reticle



Samsung 2007

Full field patterned EUVL mask

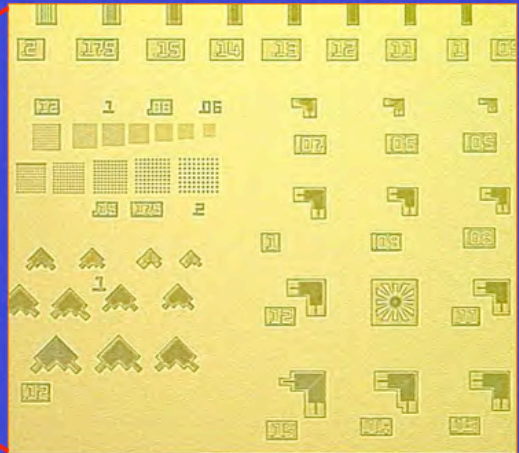
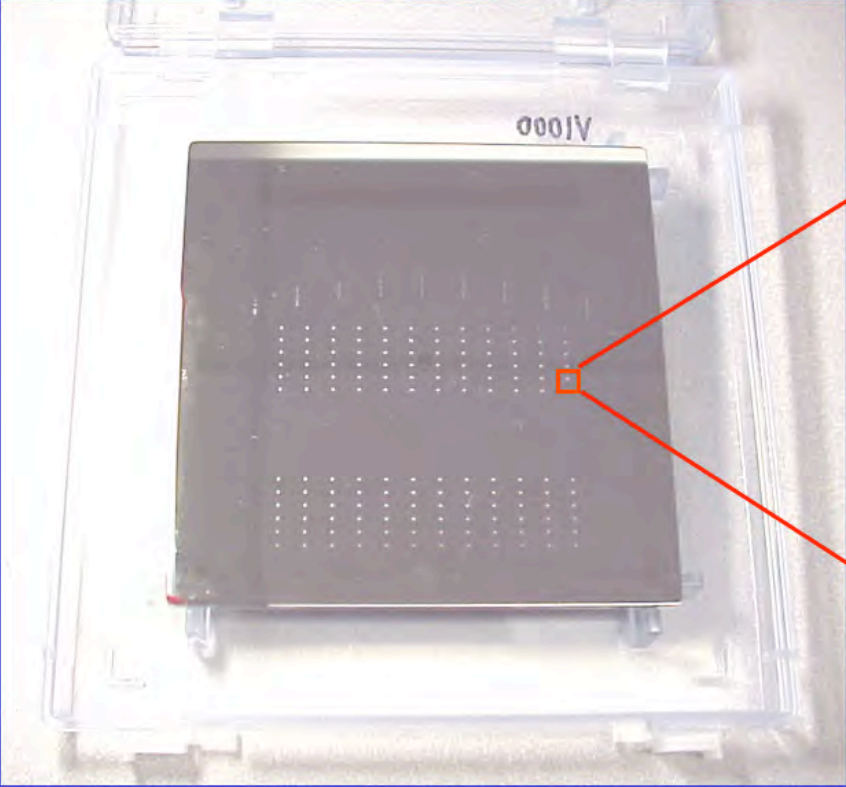


Absorber patterned on Mo/Si multilayers on a Si substrate



Full Field 6" EUV Mask with ETS Test Pattern

Fused silica substrate, Mo/Si multilayers, 30nm SiO₂, 70 nm Cr



1.1 mm x 1.1 mm test pattern cells

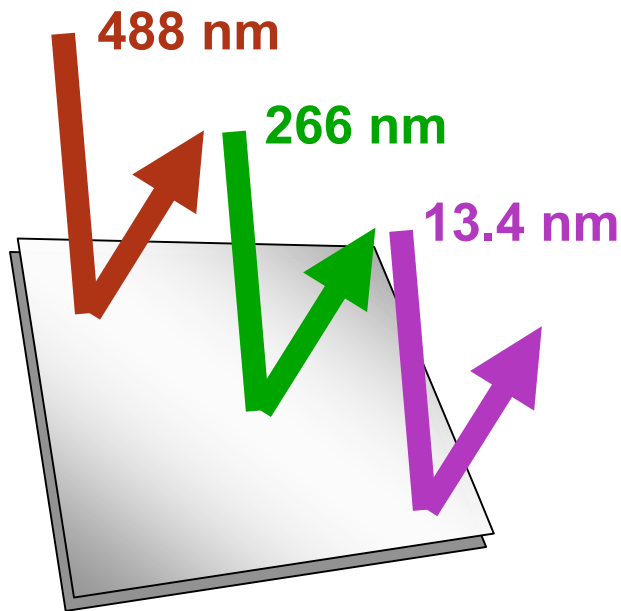
120 mm x 104 mm field size



16 Courtesy of Pei-Yang Yan and Guojing Zhang, Intel

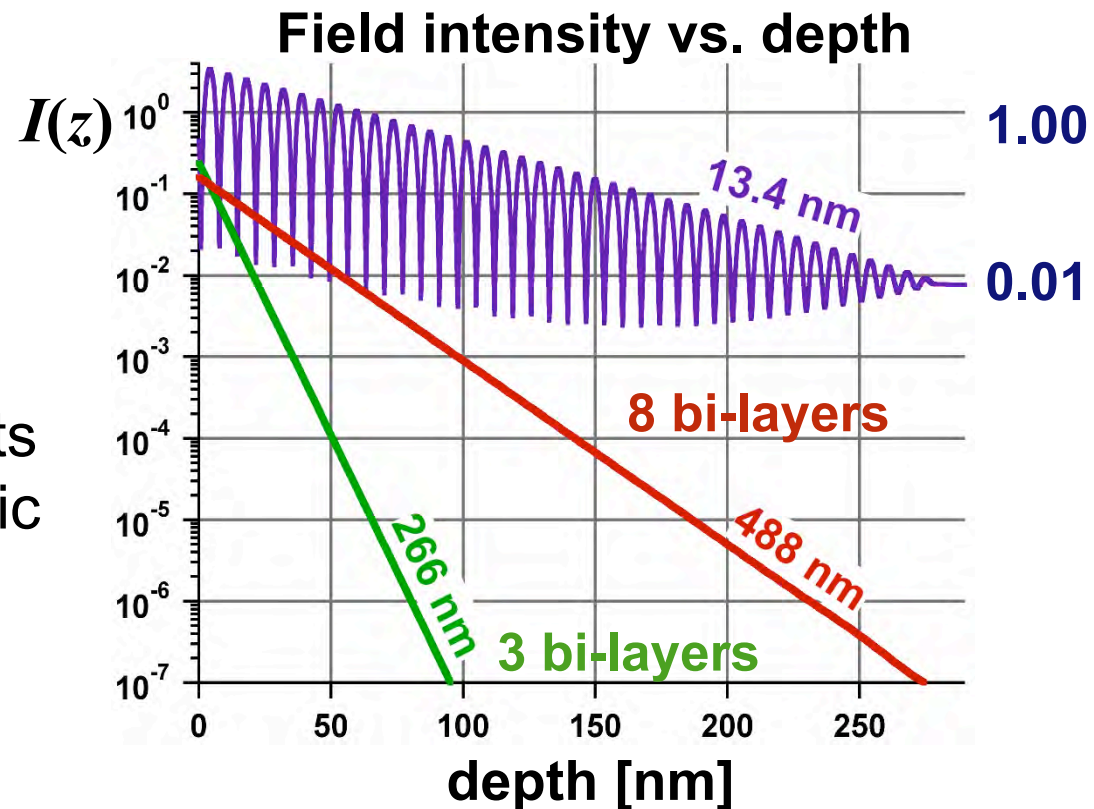


Defects: Can we find them all?



EUV light penetrates deeply into the resonant ML structure. 488-nm and 266-nm light barely reaches below the surface.

Absorber pattern and defects also have different, λ -specific optical properties



Different types of defects pose a challenge



Non-Actinic Inspection

Surface
Particles

Phase
Defects

Pattern
Defects

Organic
Contamination

Incomplete
Repairs

less difficult

more difficult

Actinic Inspection

Surface
Particles

Phase
Defects

Pattern
Defects

Organic
Contamination

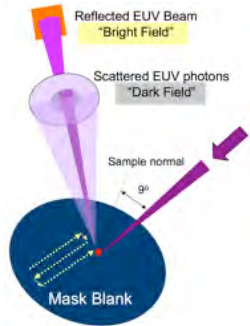
Incomplete
Repairs

direct image measurement means uniform difficulty

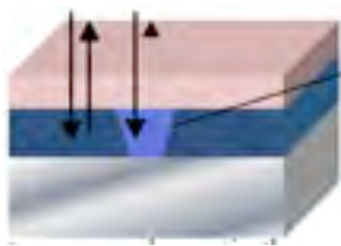
Visible-light inspection



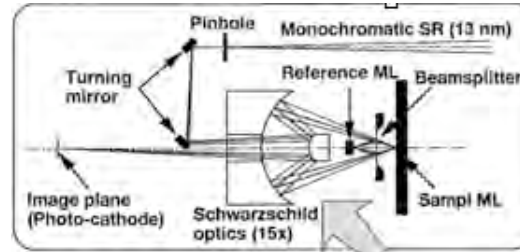
14+ years of EUV-wavelength ("actinic") mask inspection



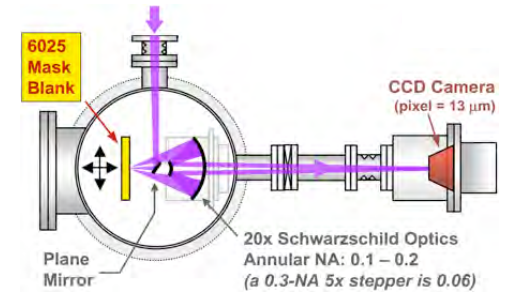
EUV LLC/LBNL



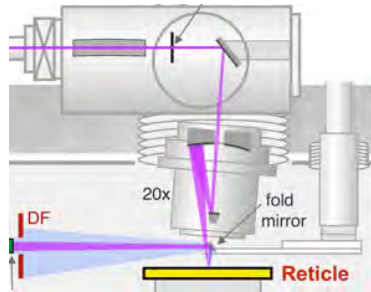
Lucent



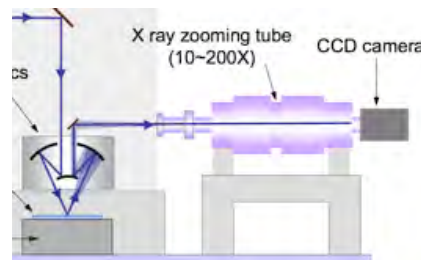
NTT



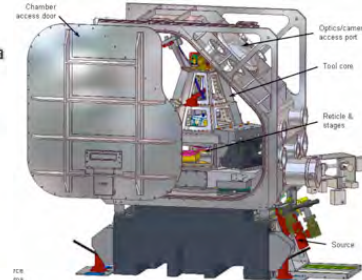
MIRAI



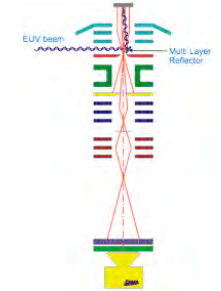
SEMATECH/LBNL



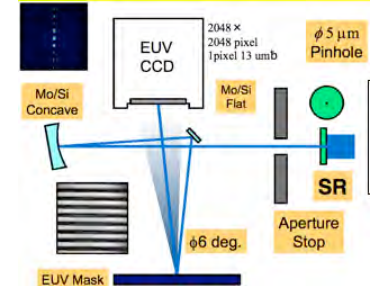
U. Hyogo



Exitech



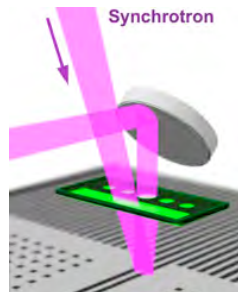
U. Bielefeld



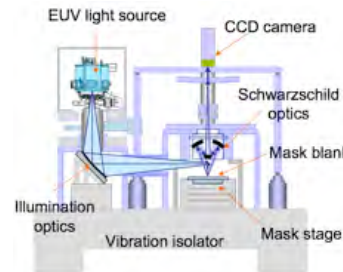
U. Hyogo



INVENT/CNSE

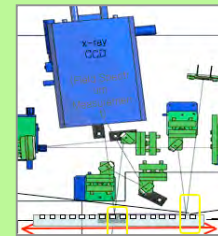


SEMATECH/LBNL

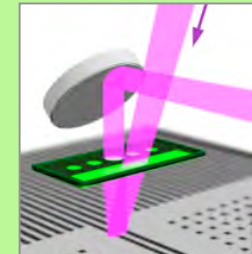
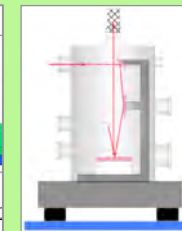


MIRAI/Selete

Future...



Hanyang U. / Pohang

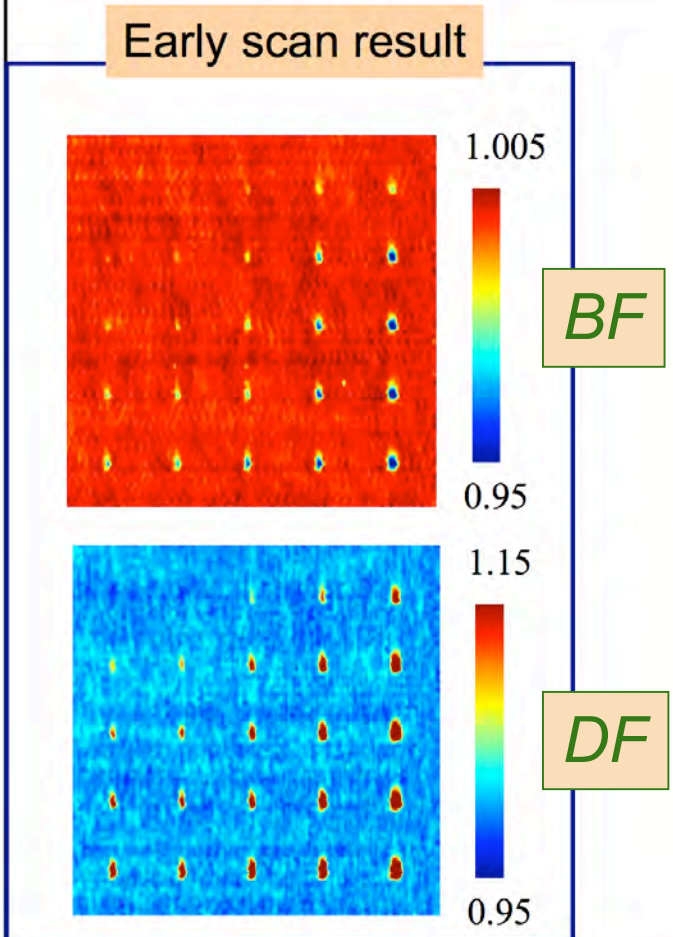
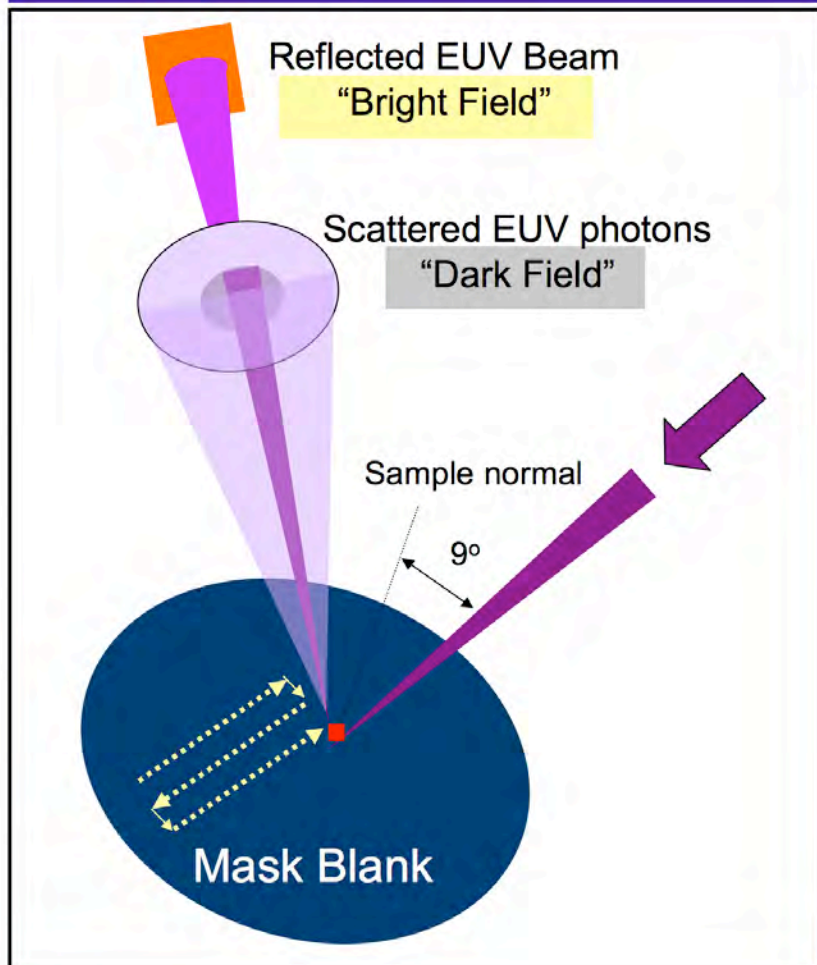


SEMATECH / LBNL

Bridge Tool

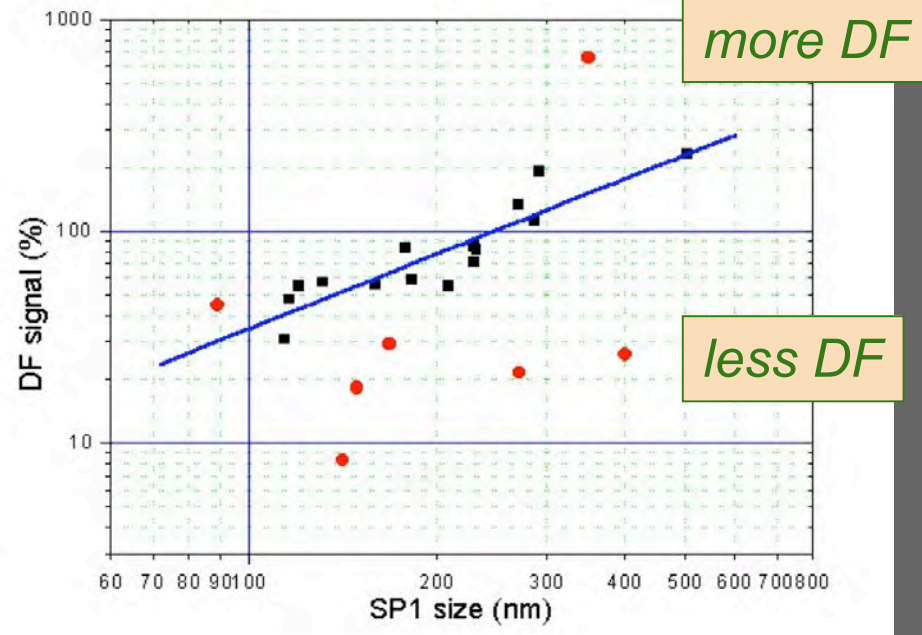
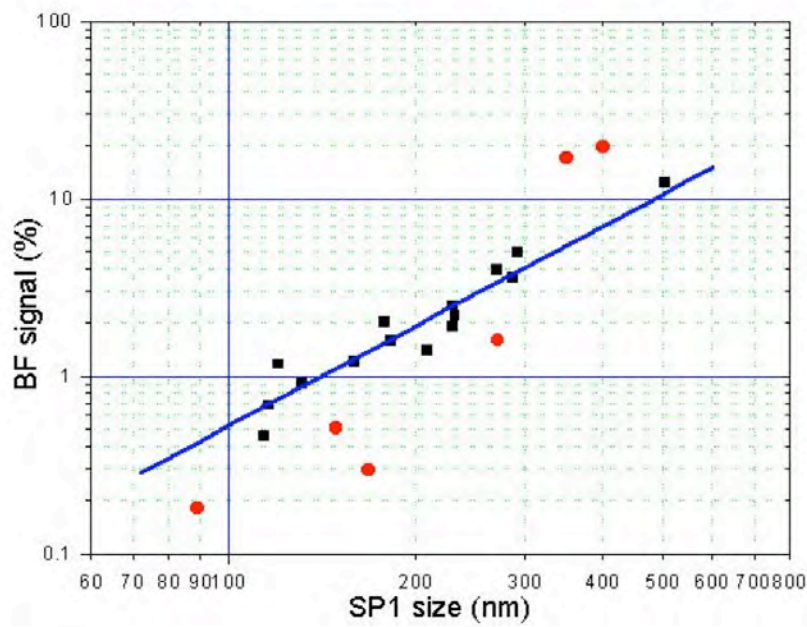
- **Dates are approximate.**
- **My sincere apologies to any actinic mask inspection / imaging project, or researchers, that I missed.**

EUV Scanner: The Concept



Seongtae Jeong

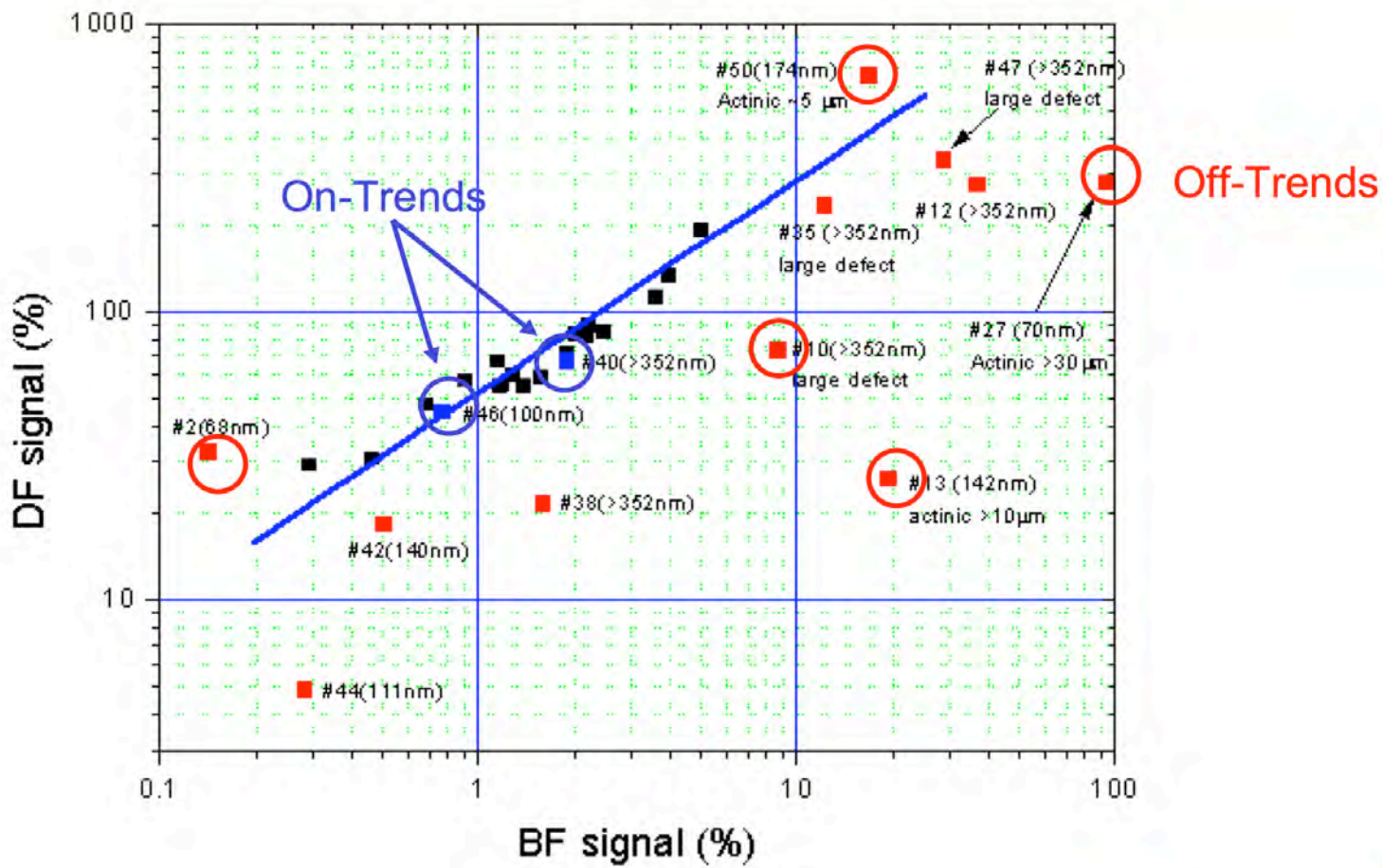
3



- Strong correlation between actinic and optical response
- Some of off-trend defects were analyzed in detail

First group to . . .

- Perform actinic inspection with sensitivity to sub-100-nm defects.
- Describe differences between BF and DF: investigate using multiple means.
- Find “actinic-only” defects.



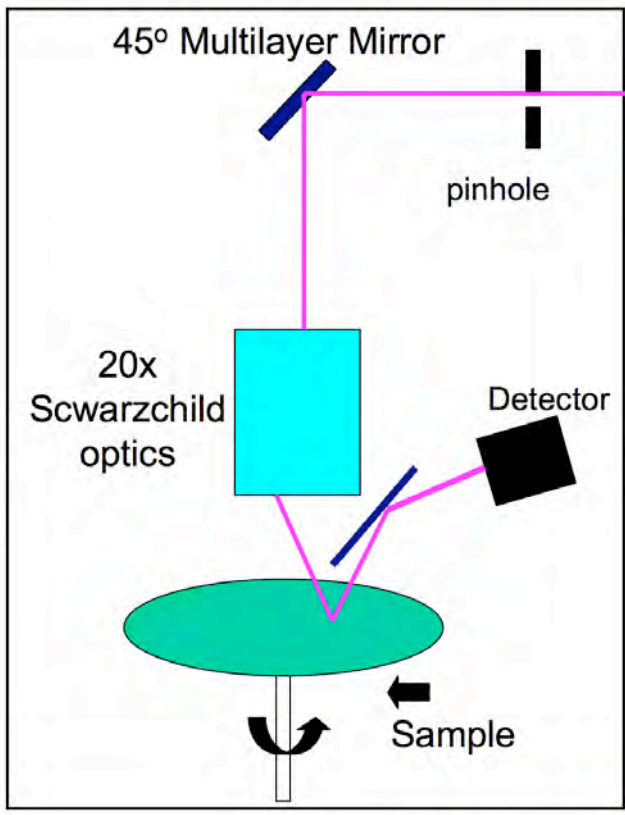
Jeffrey Bokor



05/14/01

Proposed high-speed tool

The scanning speed can be increased with flux increase and new focusing optics



- **Flux increase** :Utilize the full bandwidth of the synchrotron radiation
- Focusing optics: **20x Camera**
More photons into smaller spot.
- High speed stage and data acquisition
- Clean mask handling

Under 10 hrs per 100 cm² @ 100nm



Seongtae Jeong



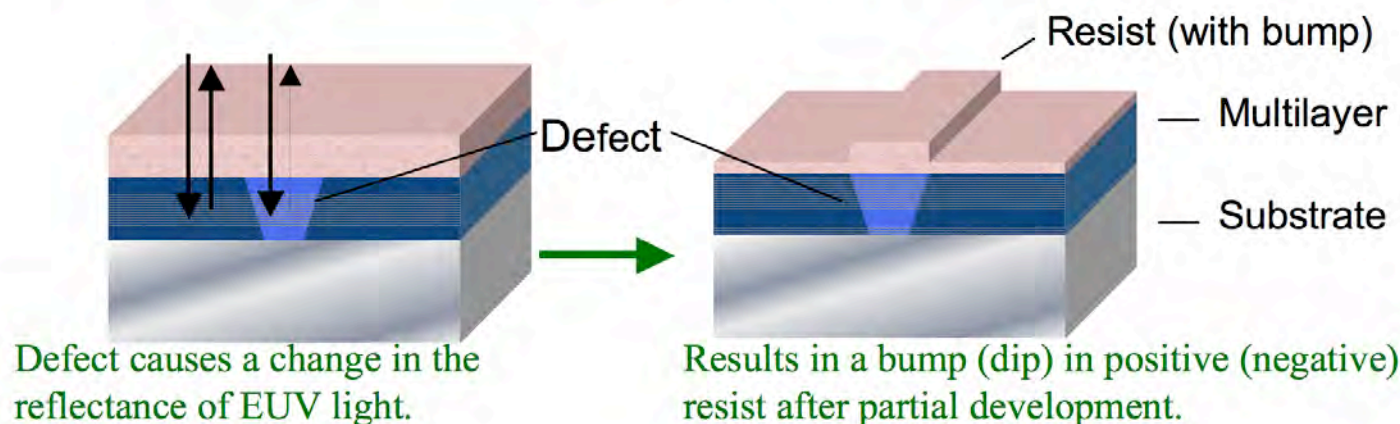
Concept

Lucent Technologies
Bell Labs Innovations



- Two step process

- Resist coated mask blank is flood exposed with EUV.

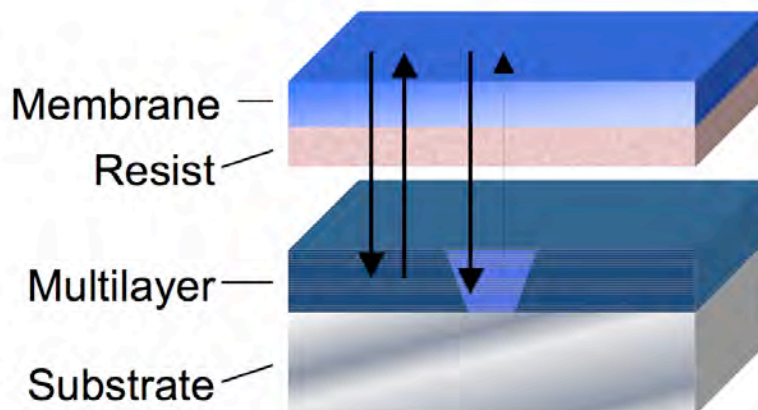


- Find bumps (defects) with optical inspection tool.

EIPBN 1999; Spector, *JVST B* 17(6), 1999.

Membrane Method

Lucent Technologies
Bell Labs Innovations



- **Alternative to direct application method**
 - **Apply resist to membrane instead of blank.**
 - Less likely to contaminate blank
 - May increase sensitivity to phase defects

EIPBN 1999;
Spector, *JVST B*
17(6), 1999.

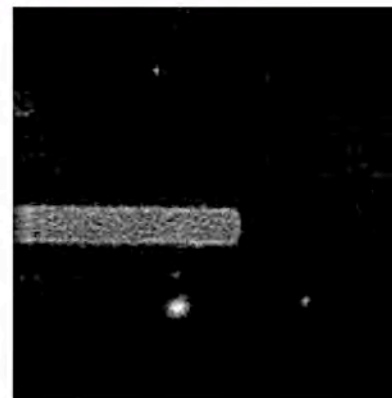
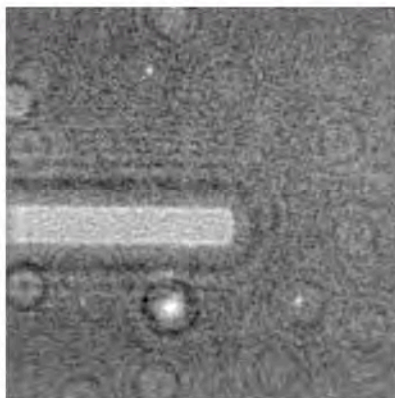
Reconstruction

Lucent Technologies
Bell Labs Innovations



- Can treat AFM image as a hologram to reconstruct image of mask
 - Very small features ($\sim 0.2 \mu\text{m}$) are now visible

Reconstruction
(fringes are
from virtual
image and dirt
on membrane).

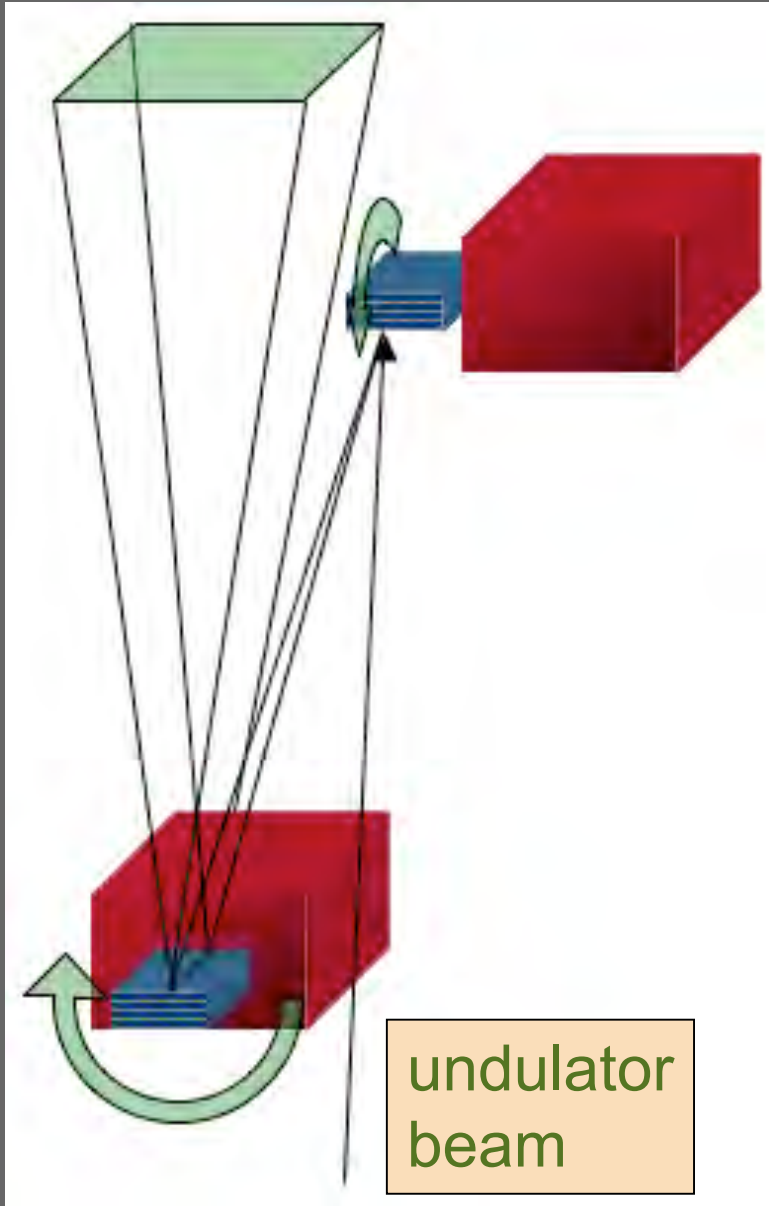


Same
reconstruction
with threshold
set to remove
excess fringes.



AFM image of
defect mask

Spector, *JVST B*
17(6), 1999.

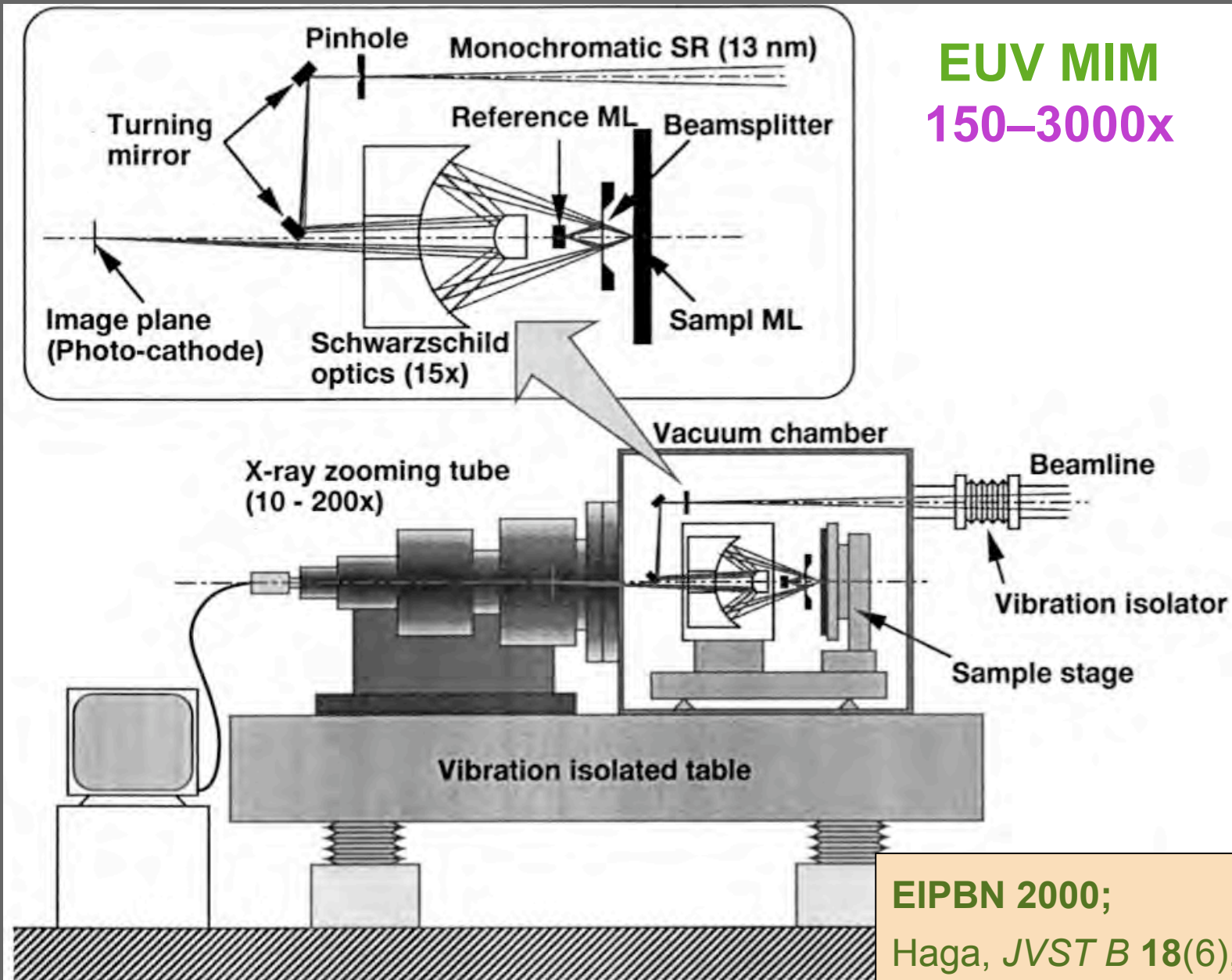


**Q: First group to propose a uniformity scanner for EUV??
1.5-inch square area**

EIPBN 1999; Spector, *JVST B* 17(6), 1999.

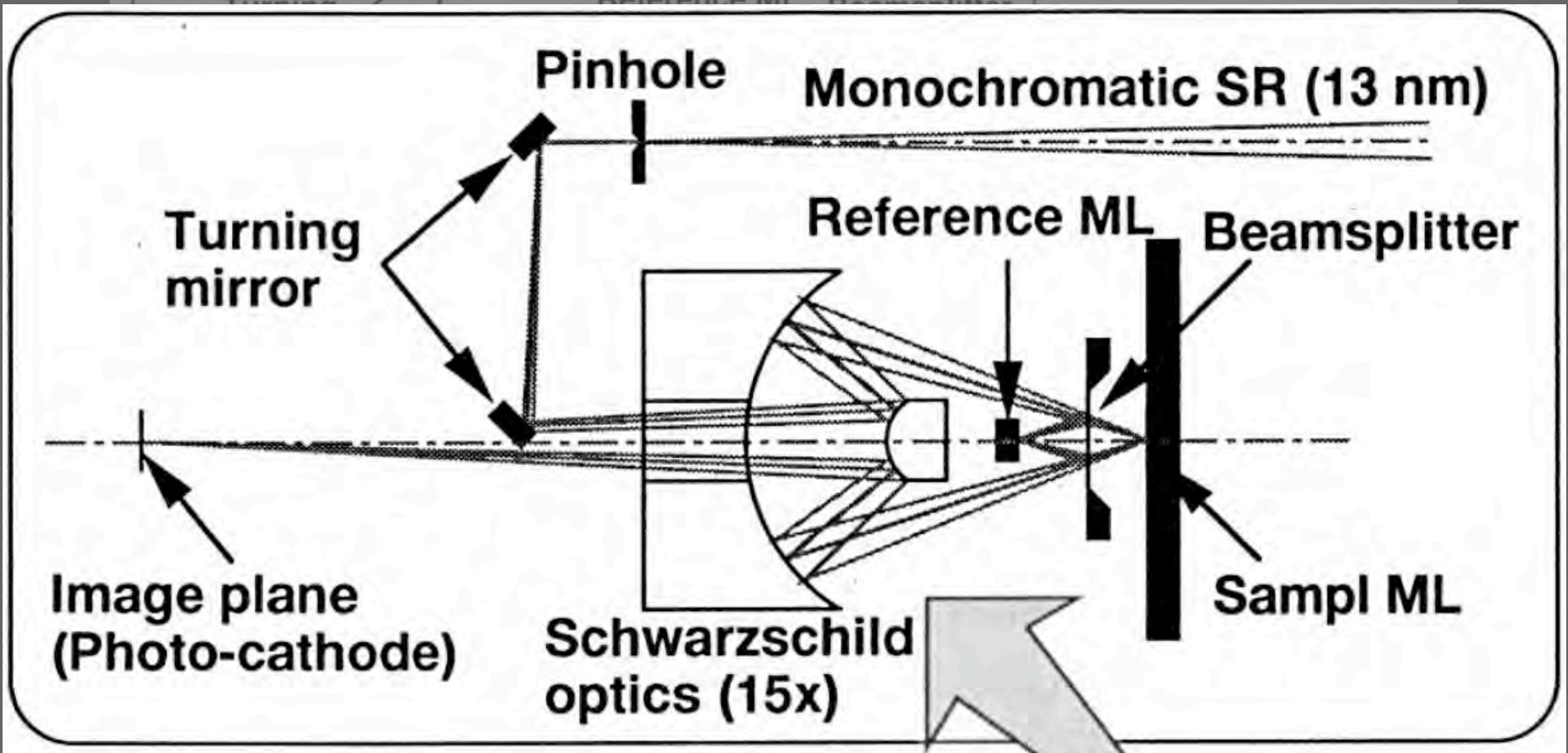
(1995) 2000 NTT Mirau Inspection Microscope (Haga, et al.)

EUV MIM
150–3000x



EIPBN 2000;
Haga, *JVST B* 18(6), 2000.

(1995) 2000 NTT Mirau Inspection Microscope (Haga, et al.)

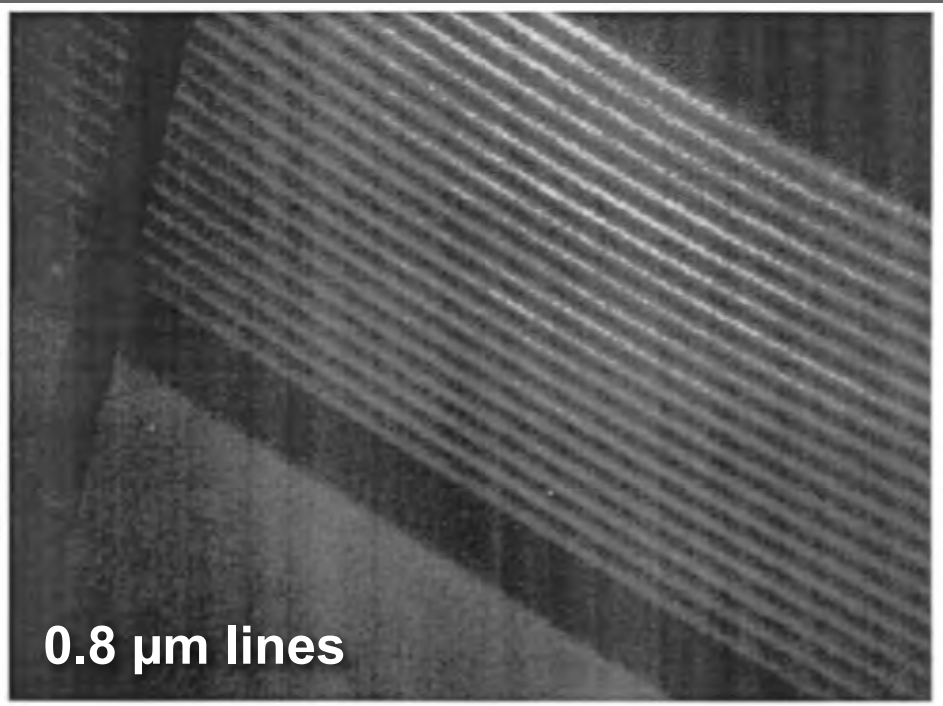


EIPBN 2000;
Haga, *JVST B* 18(6), 2000.

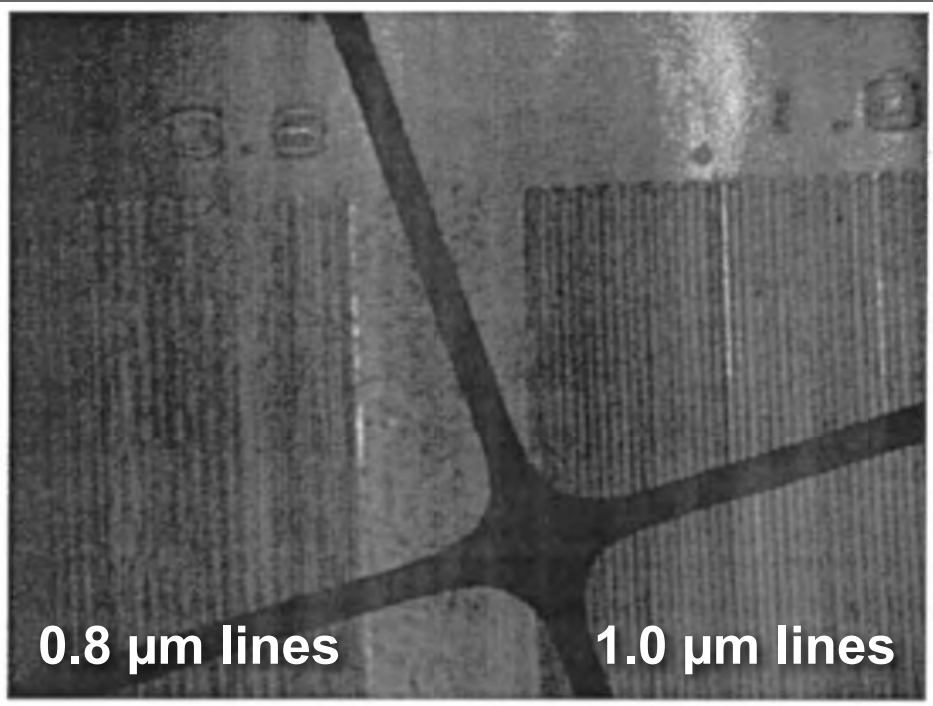
(1995) 2000 NTT Mirau Inspection Microscope (Haga, et al.)

absorber mask

phase-shift mask

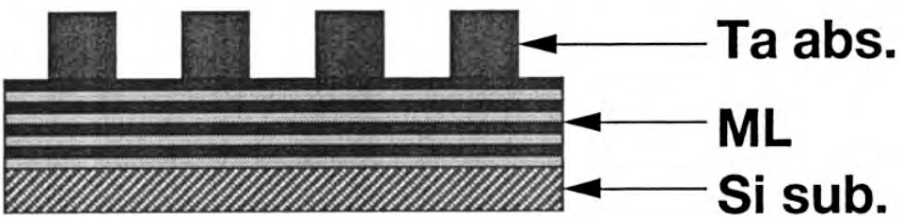


0.8 μm lines



0.8 μm lines

1.0 μm lines



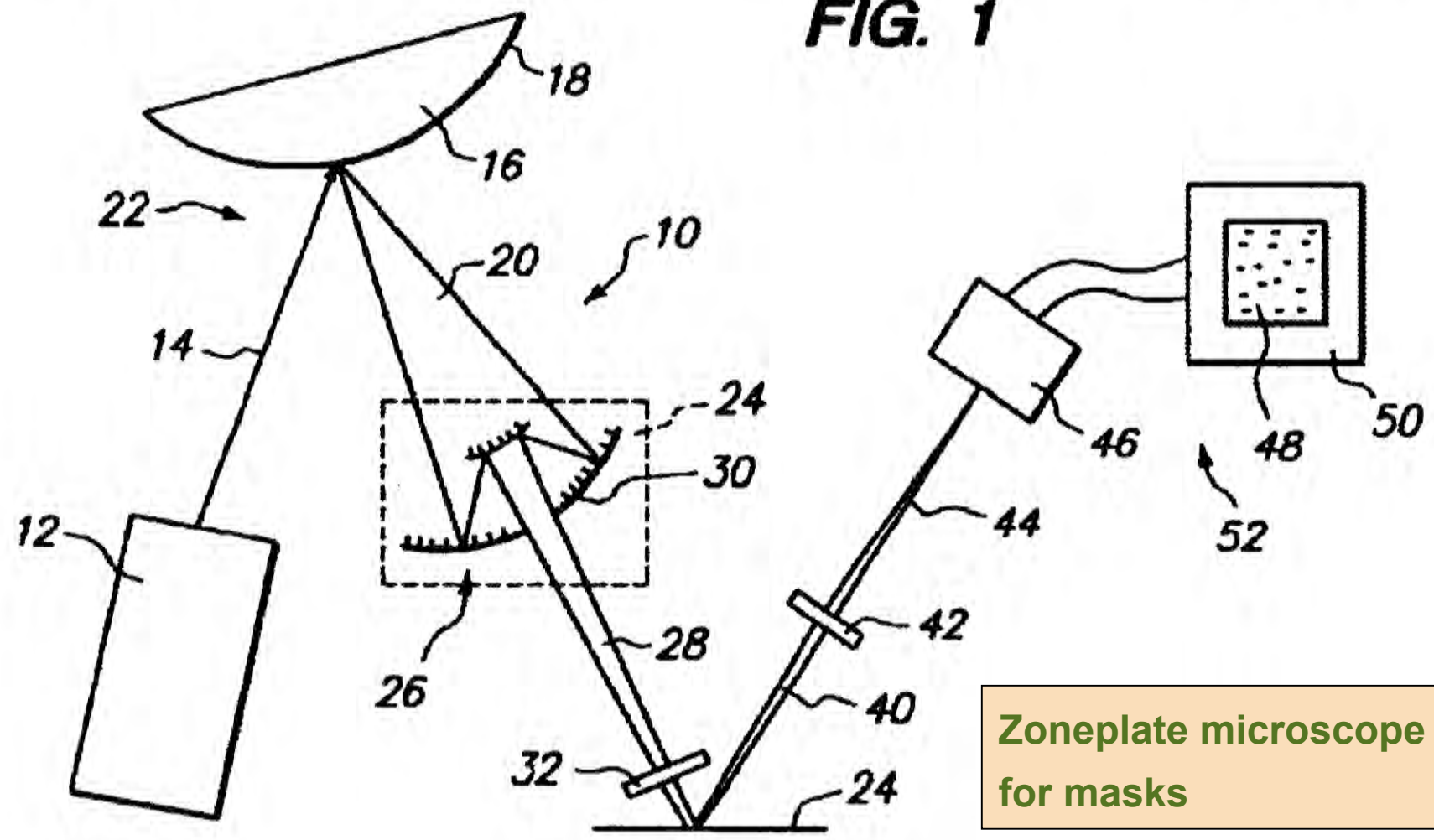
EIPBN 2000;
Haga, *JVST B* 18(6), 2000.

U.S. Patent

May 18, 2004

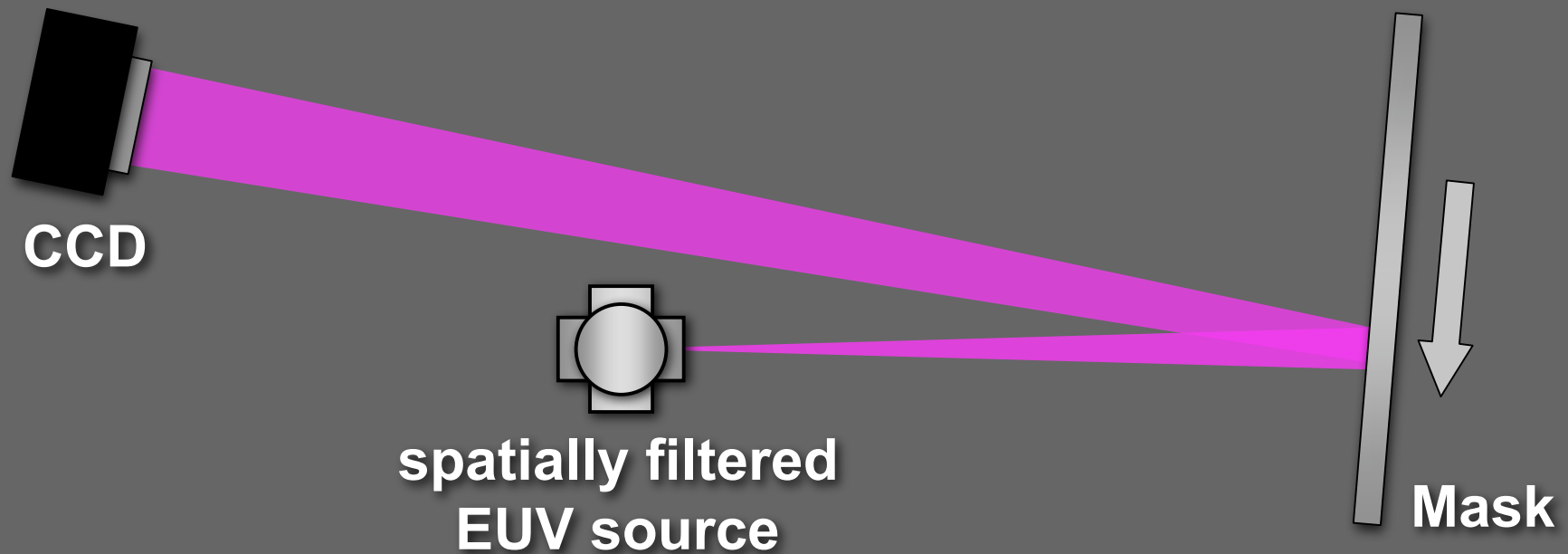
US 6,738,135 B1

FIG. 1



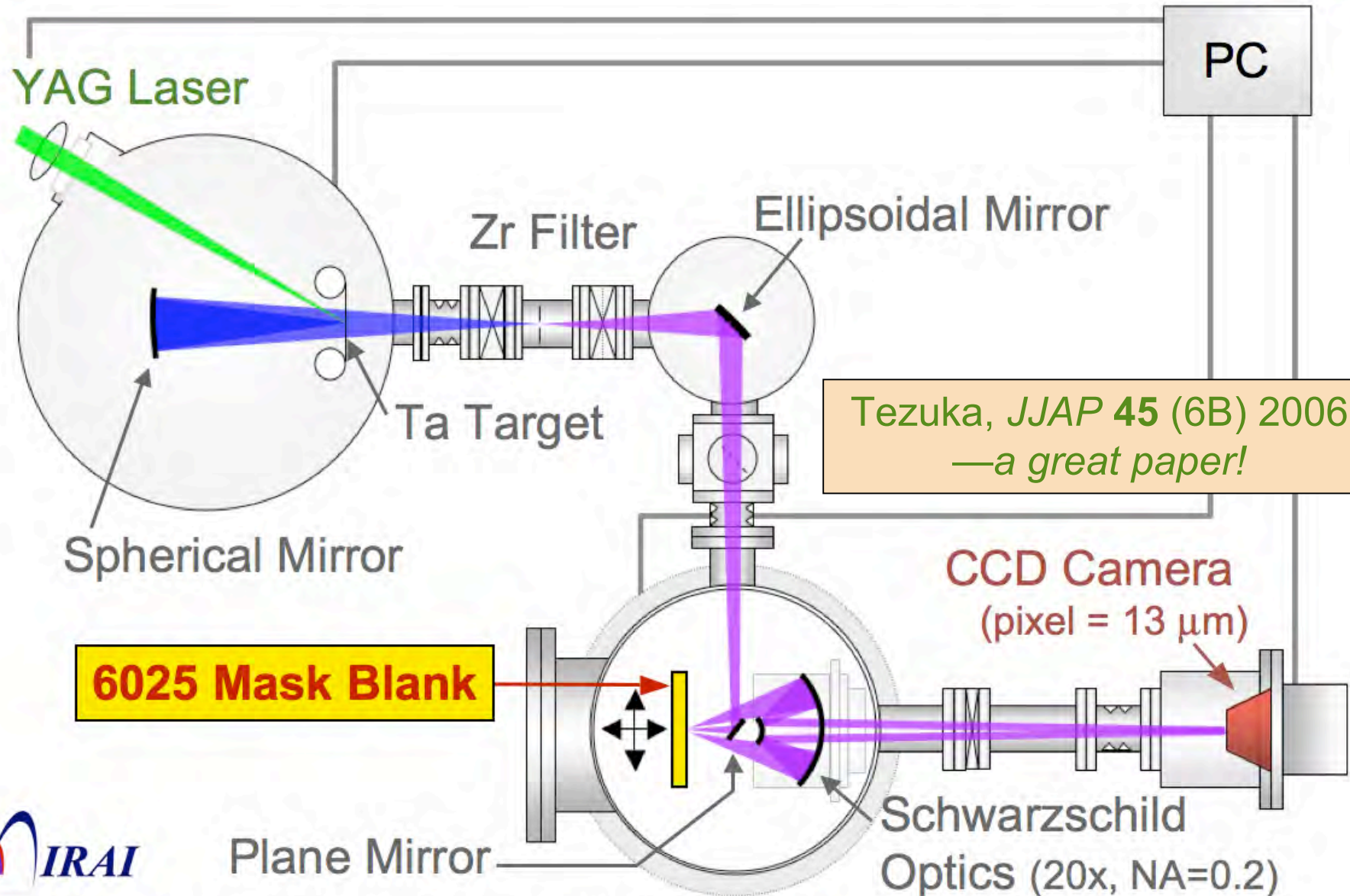
Zoneplate microscope for masks

US 6,963,395



- a cheap, low-resolution, point-projection microscope for mask-blank inspection
- very high efficiency
- finds ML-coating errors, and large particles
- sees diffraction/shadow from any large-scale defect

2006 MIRAI Tool



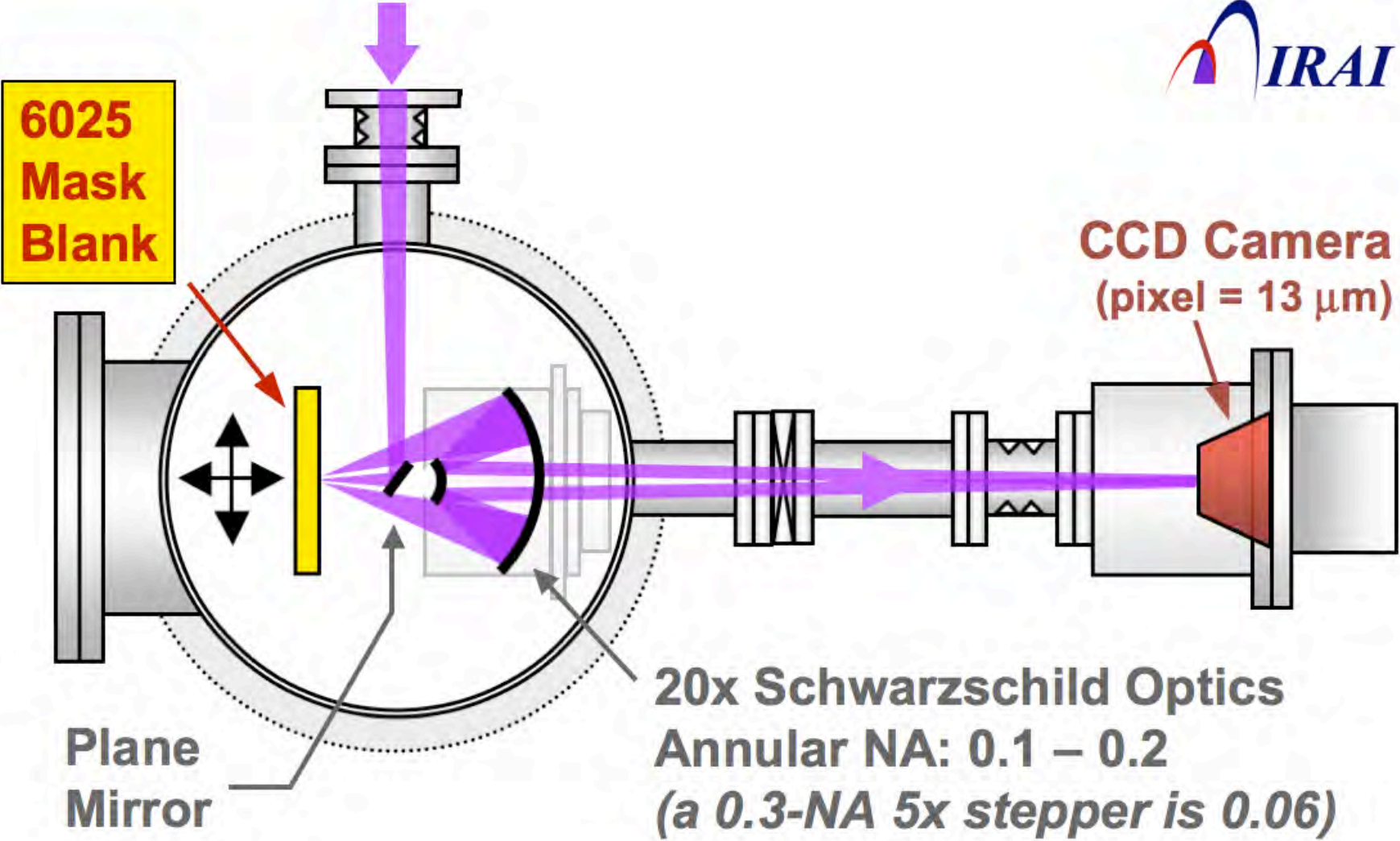
Tezuka, *JJAP* 45 (6B) 2006
—a great paper!

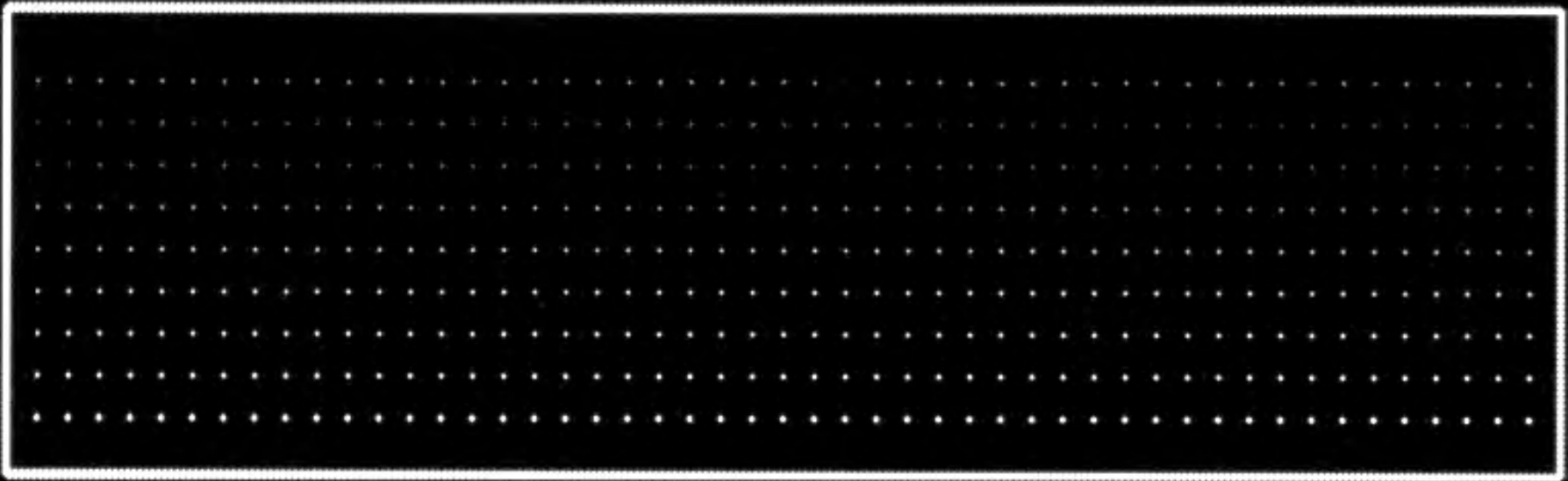
6025 Mask Blank



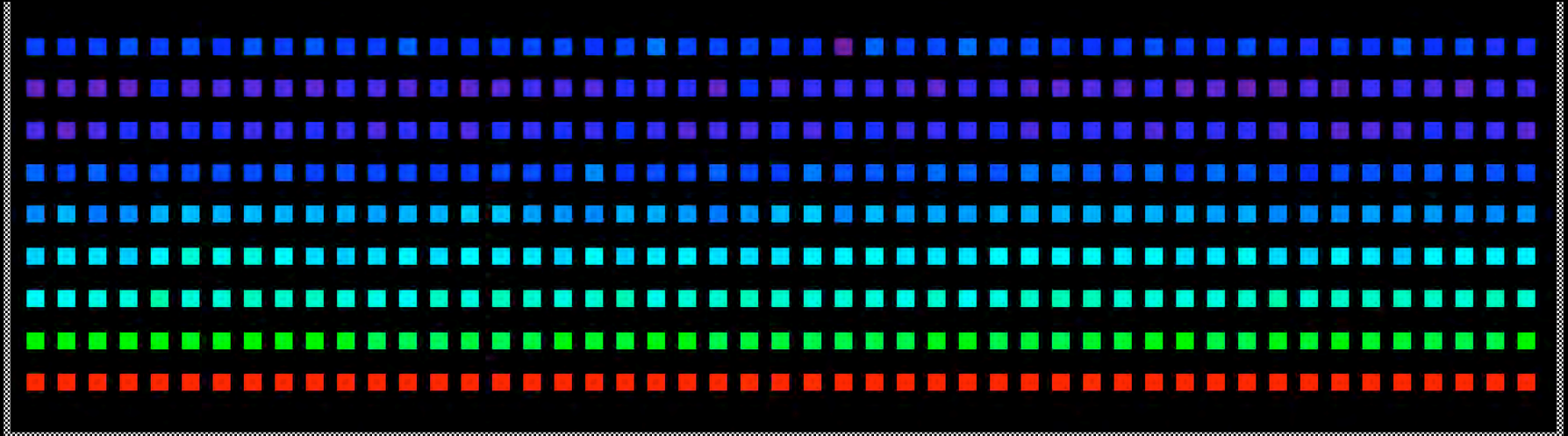
Plane Mirror

Schwarzschild Optics (20x, NA=0.2)





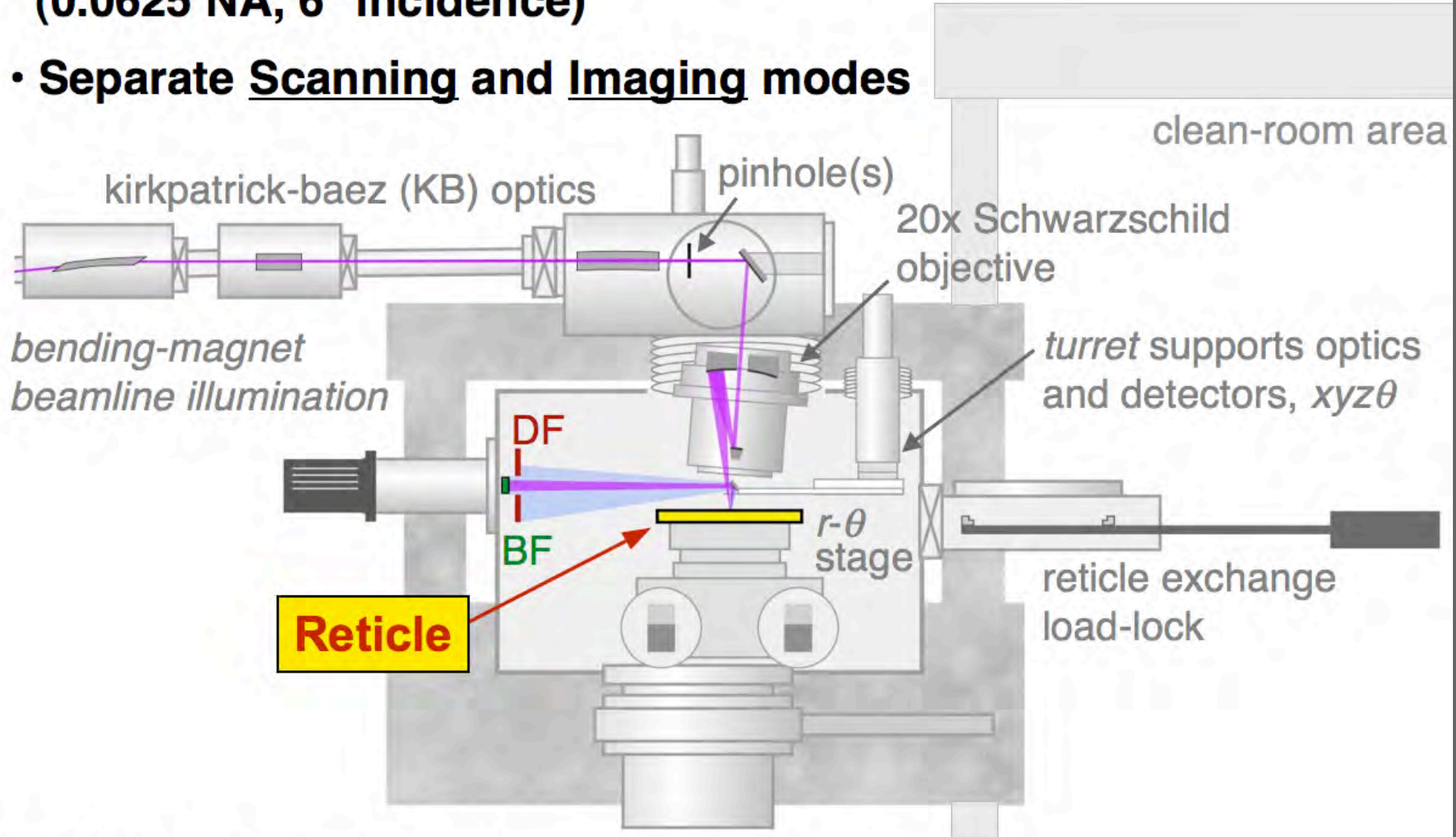
150 μm



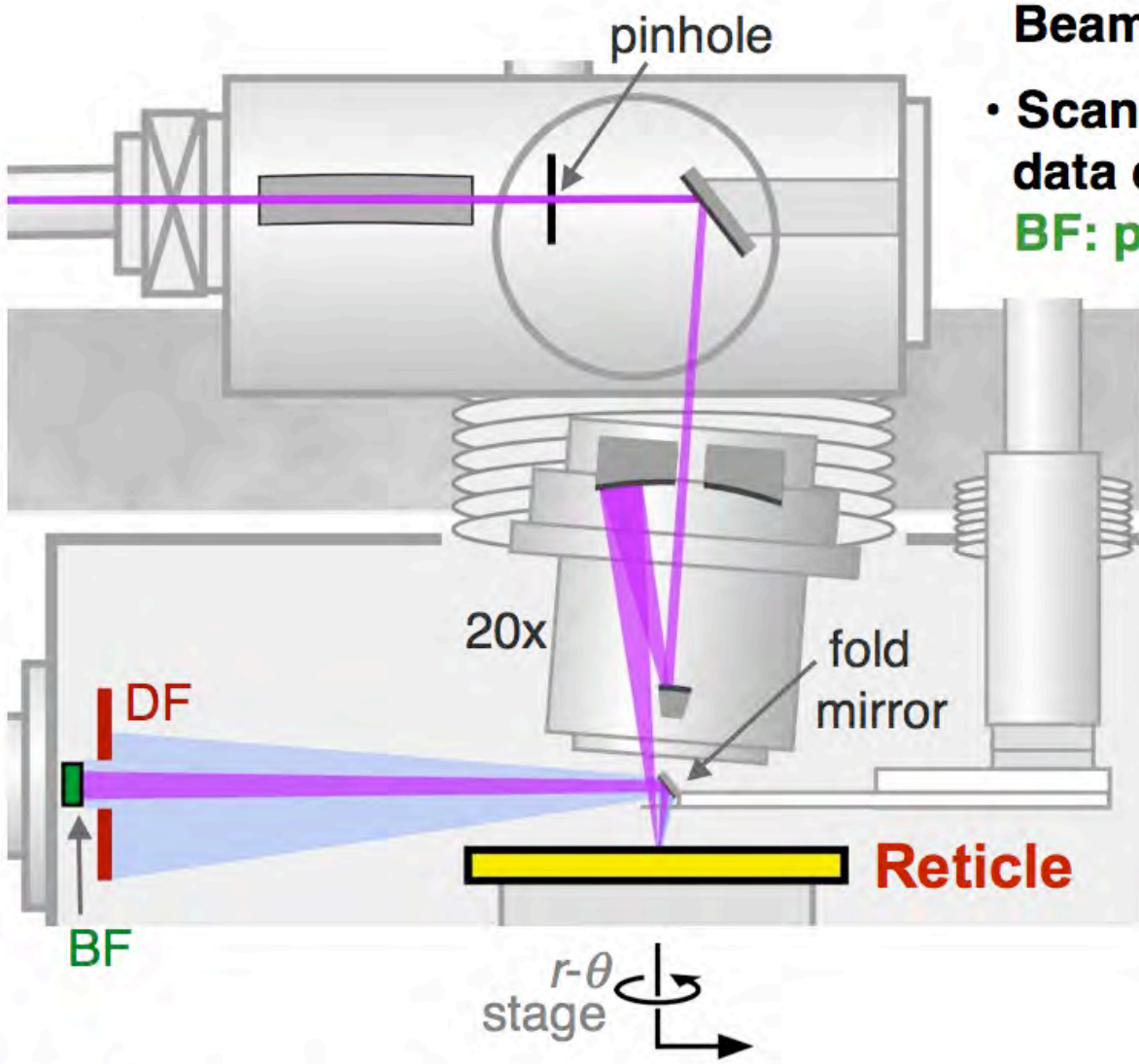
Hoya mask with bump-type buried phase-defects

2006 SEMATECH / LBNL Defect-Inspection Tool

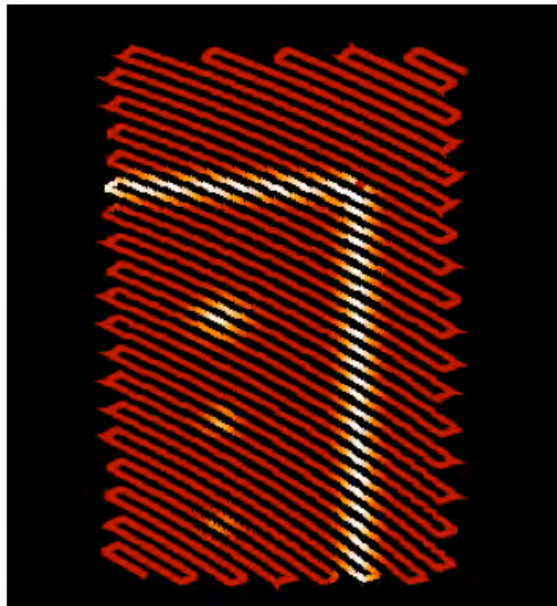
- Off-axis illumination emulates a 0.25-NA stepper (0.0625 NA, 6° incidence)
- Separate Scanning and Imaging modes



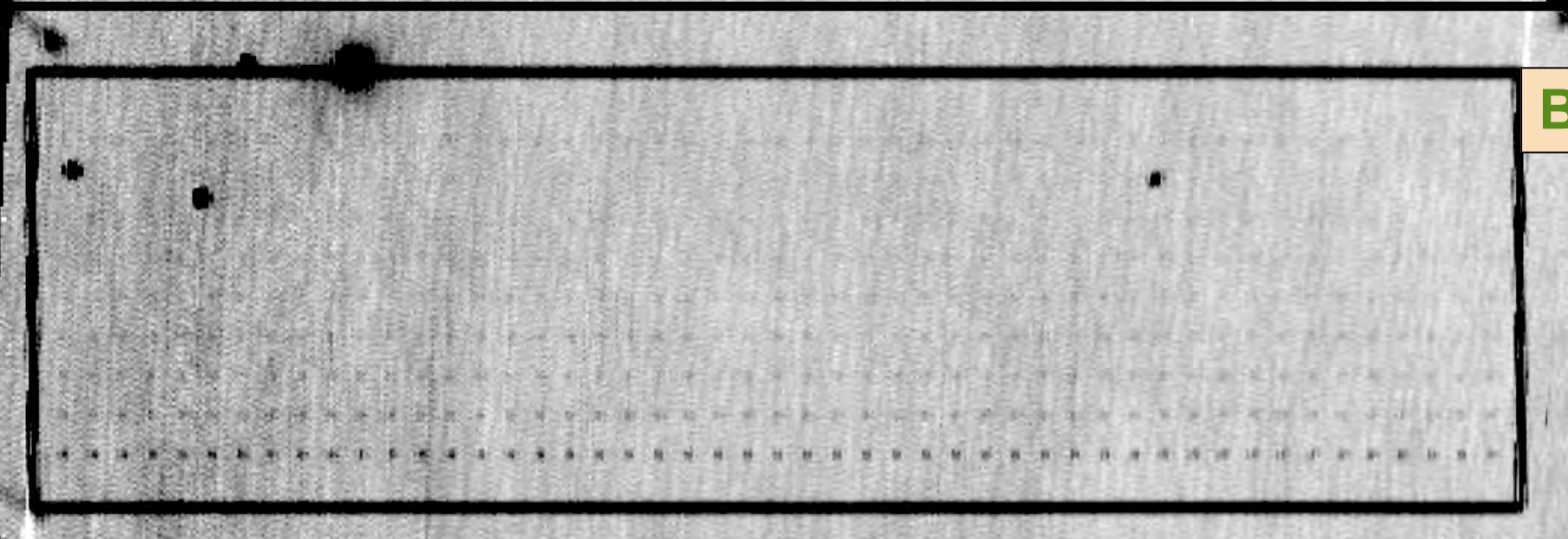
2006 SEMATECH / LBNL Defect-Inspection Tool



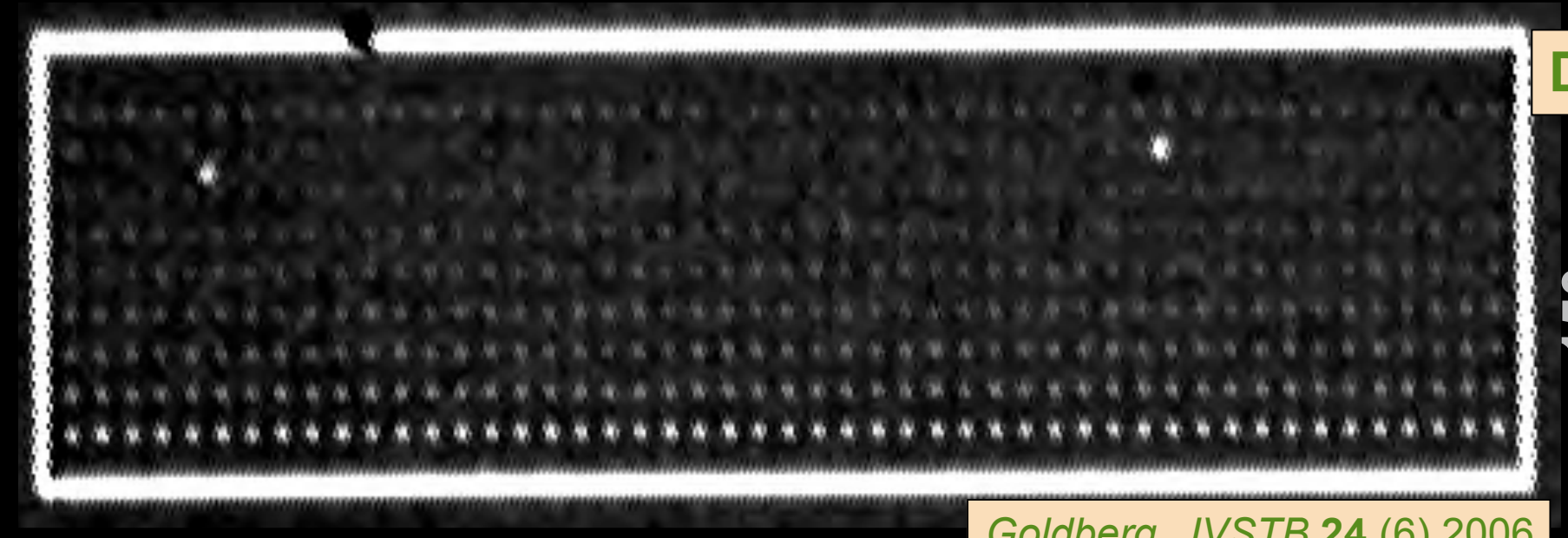
- Pinhole is re-imaged onto mask. Beam footprint is $\sim 1\text{-}\mu\text{m}$.
- Scanning-mode data collection at 10-100 kHz.
BF: photo-diode • DF: MCP



Reconstruction from scanning data



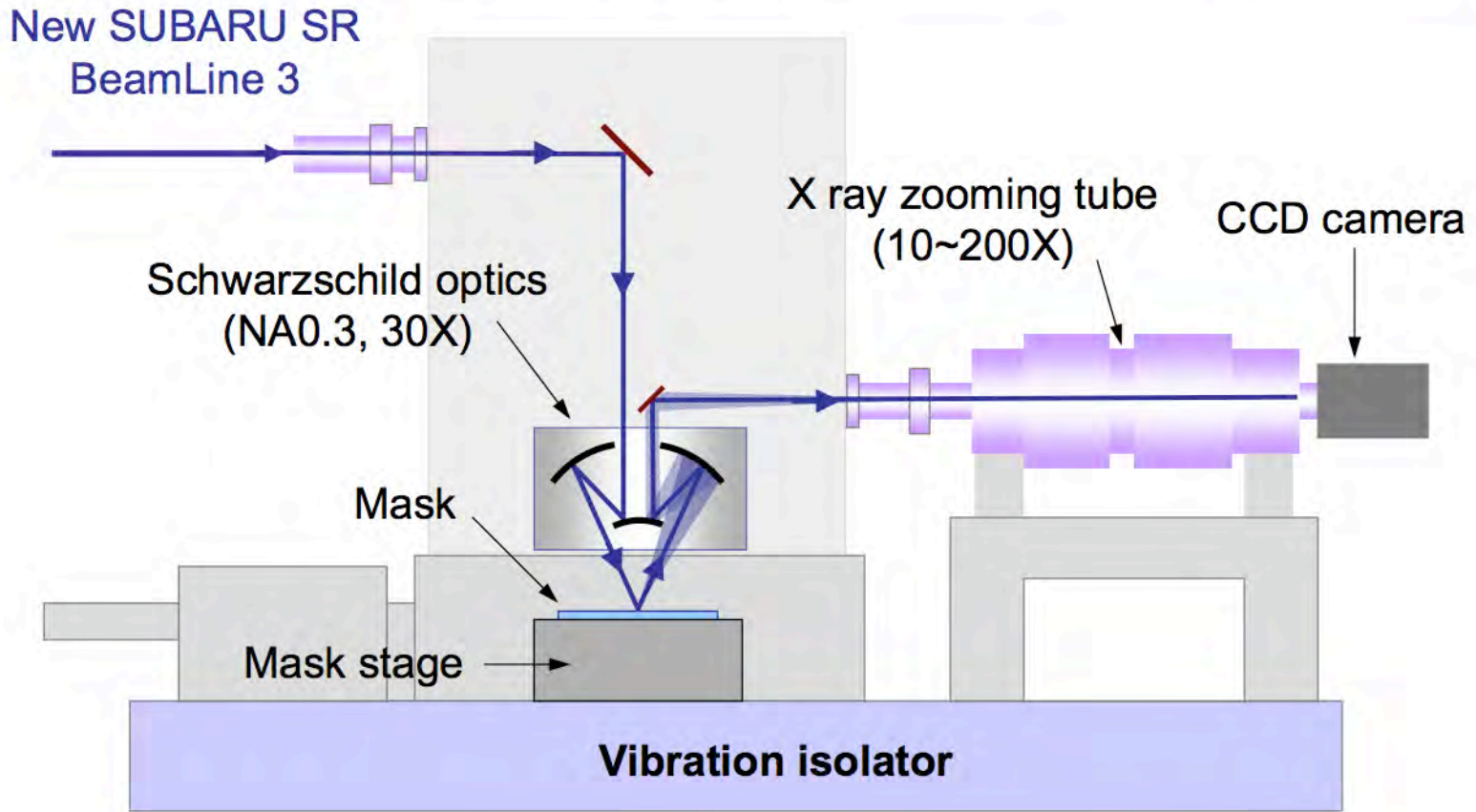
BF



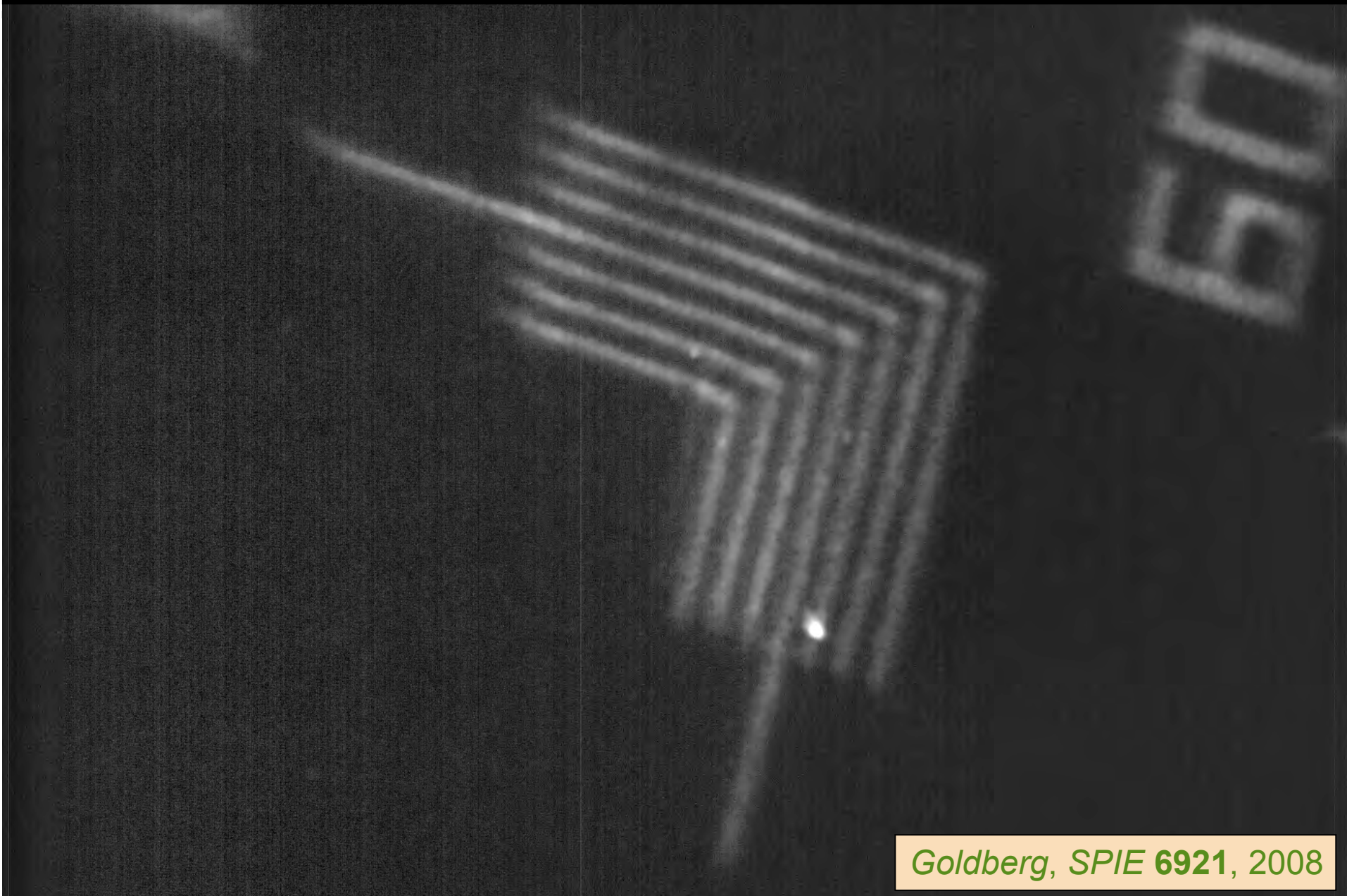
DF

150 μm

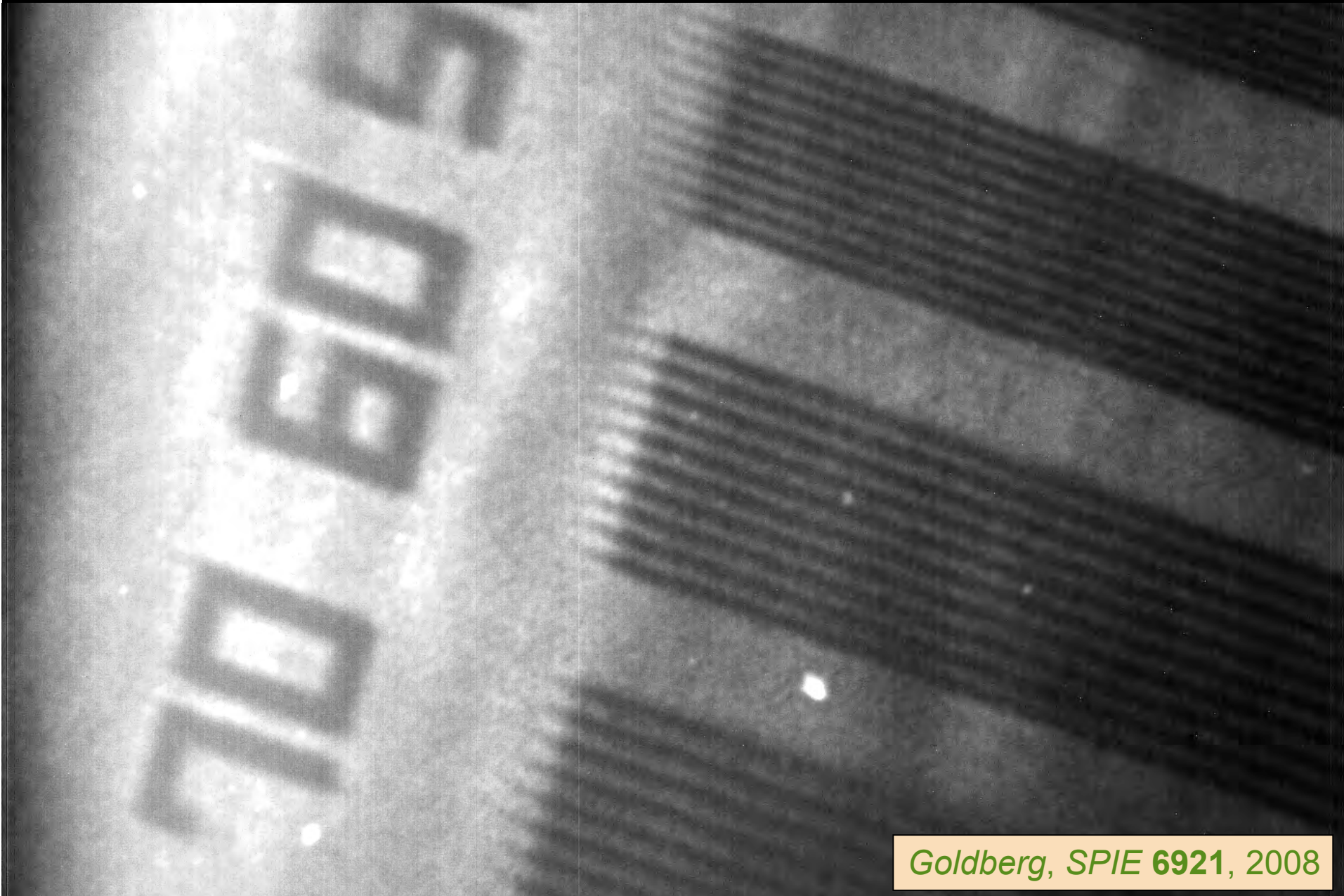
Goldberg, JVSTB 24 (6) 2006



University of Hyogo

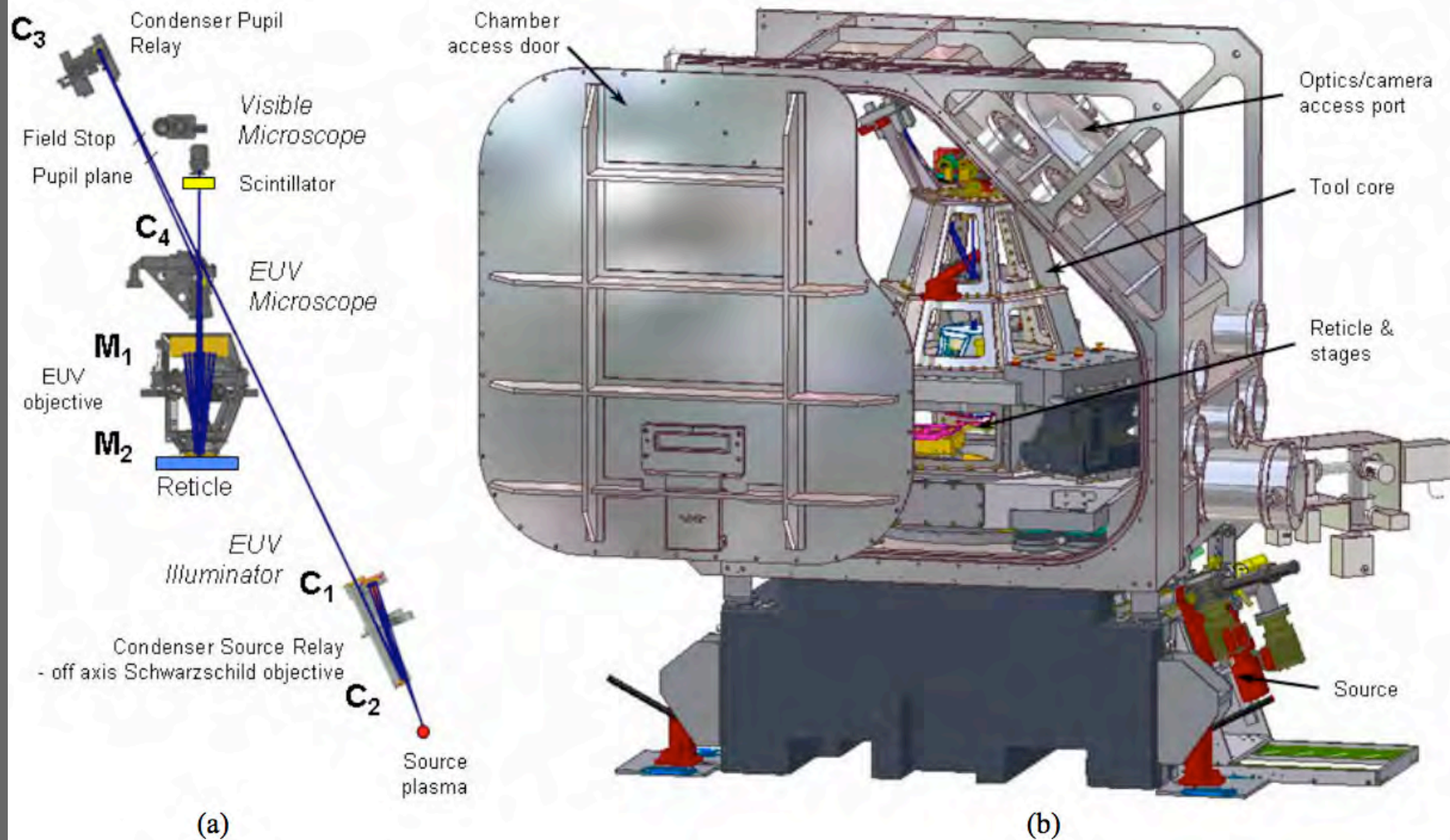


Goldberg, SPIE 6921, 2008



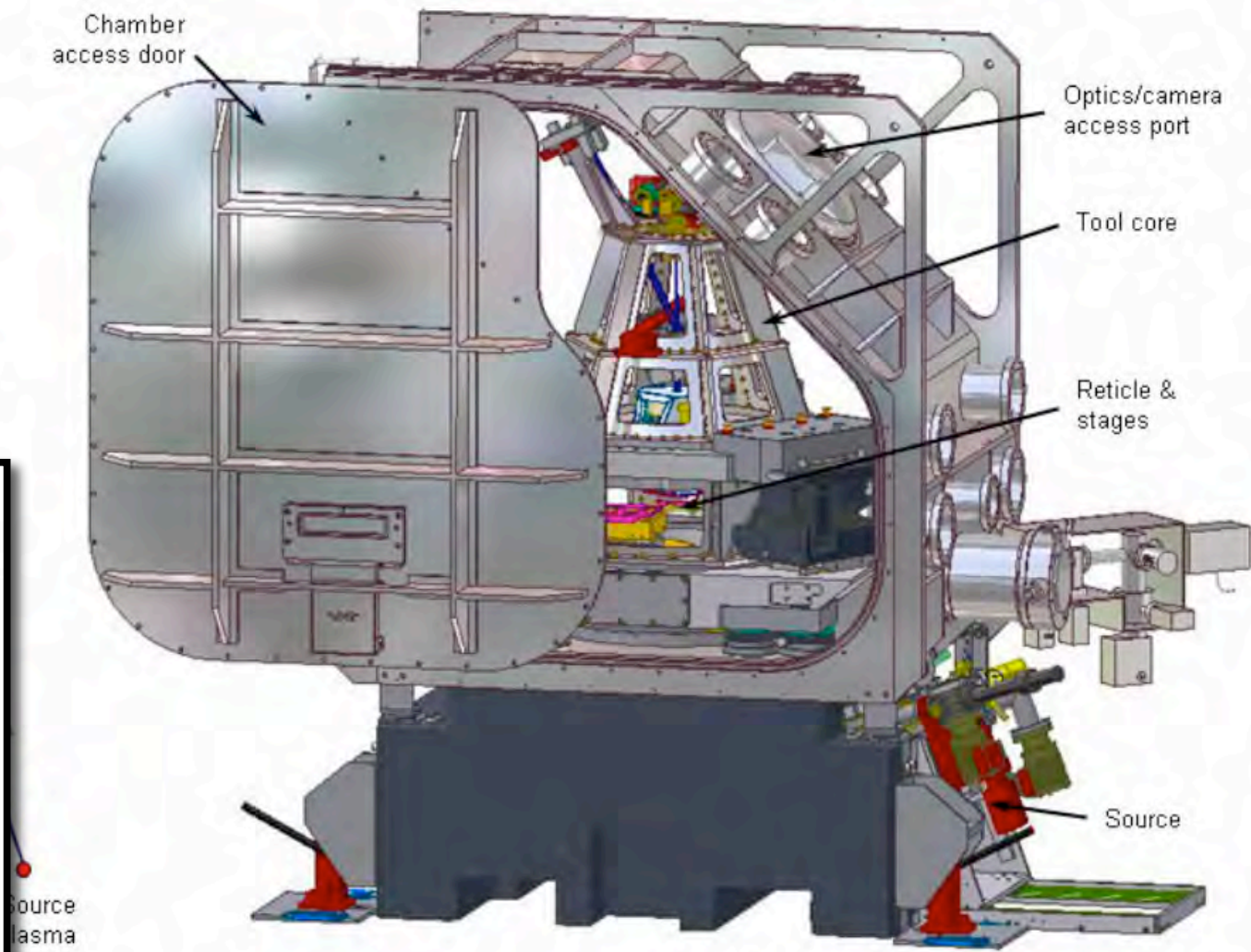
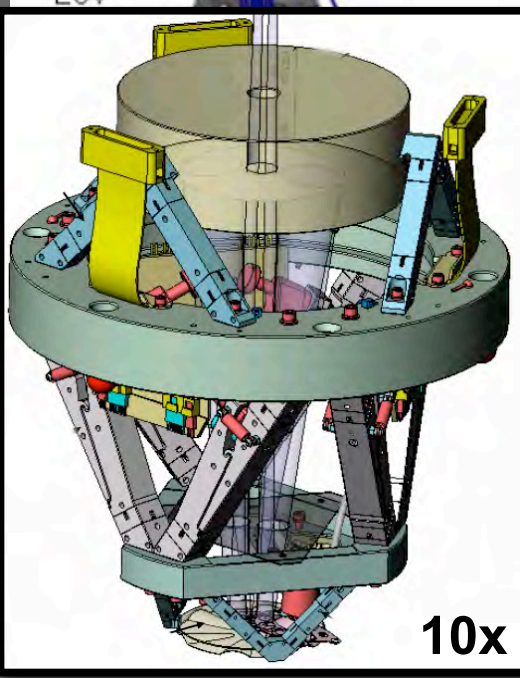
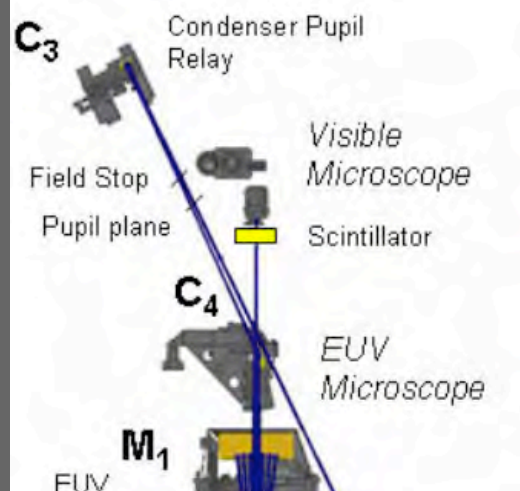
Goldberg, SPIE 6921, 2008

2005 Exitech RIM-13, Reticle Imaging actinic Microscope



Booth, SPIE 5751, 2005

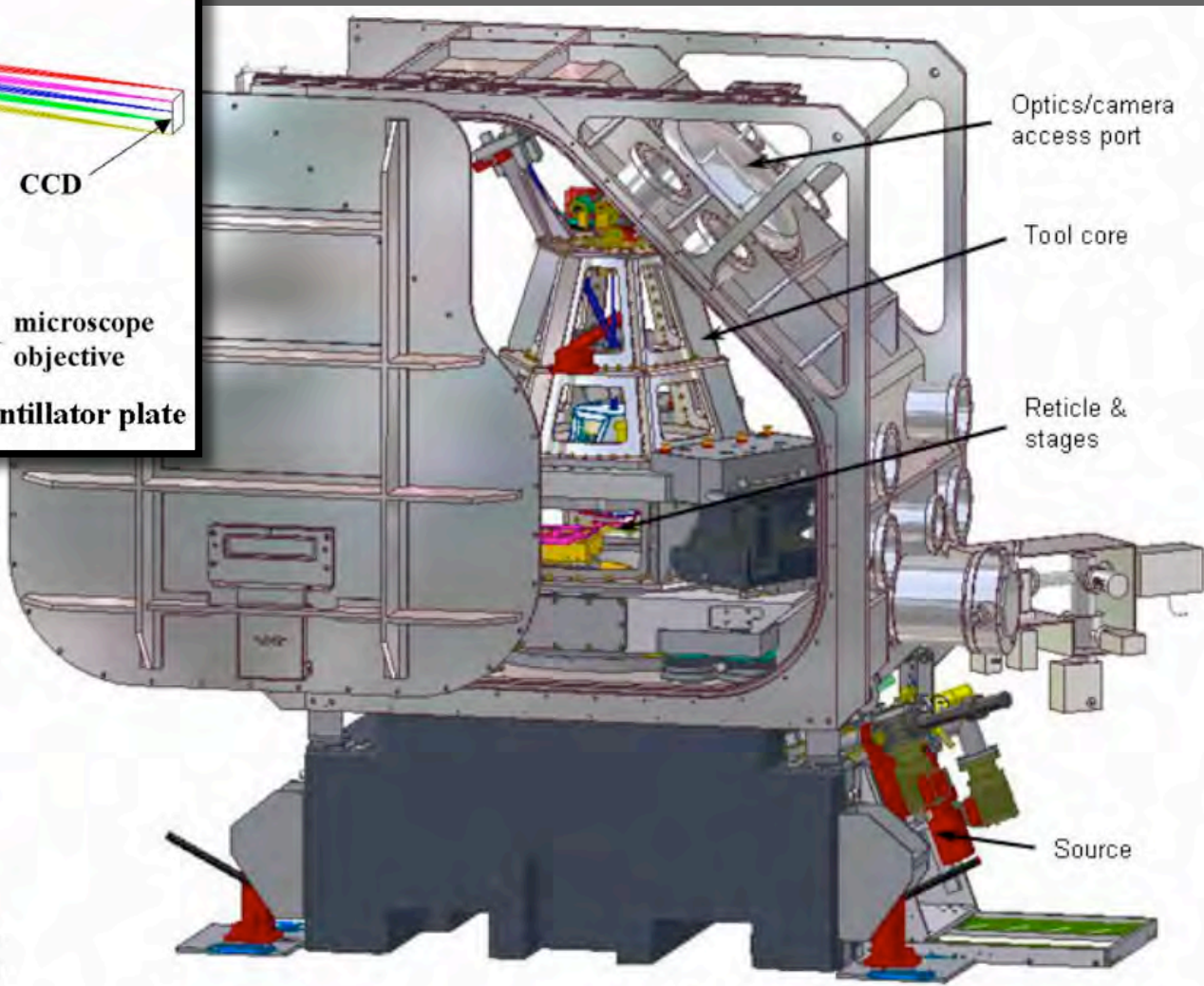
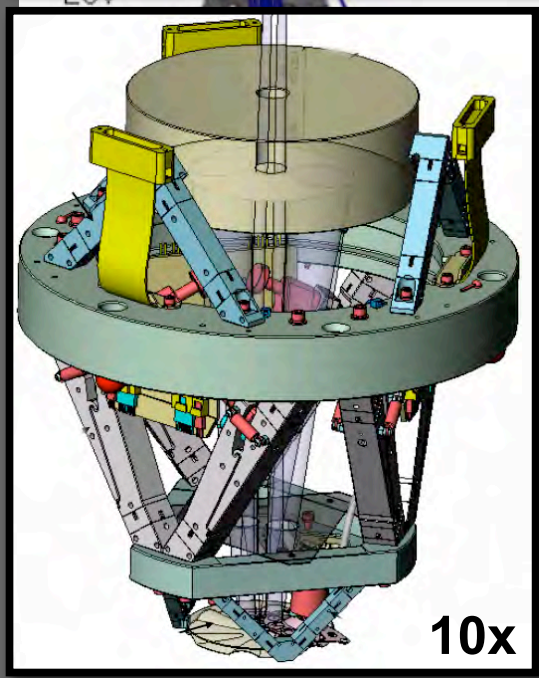
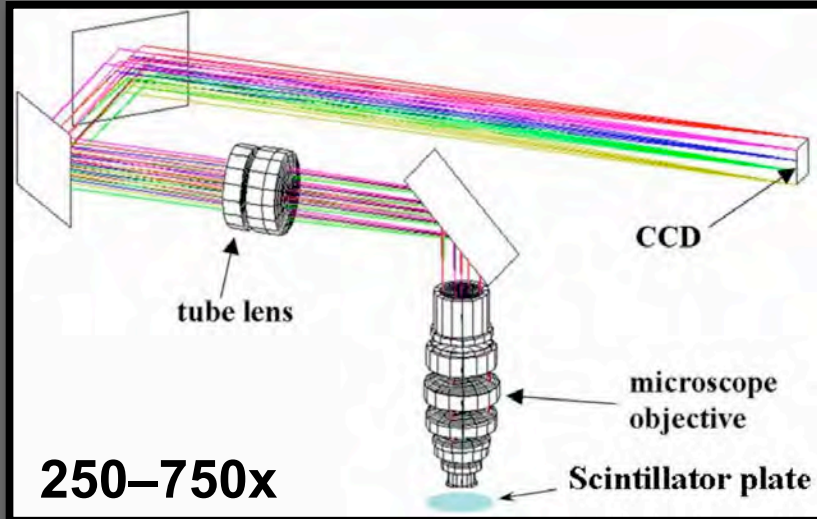
2005 Exitech RIM-13, Reticle Imaging actinic Microscope



(b)

Booth, SPIE 5751, 2005

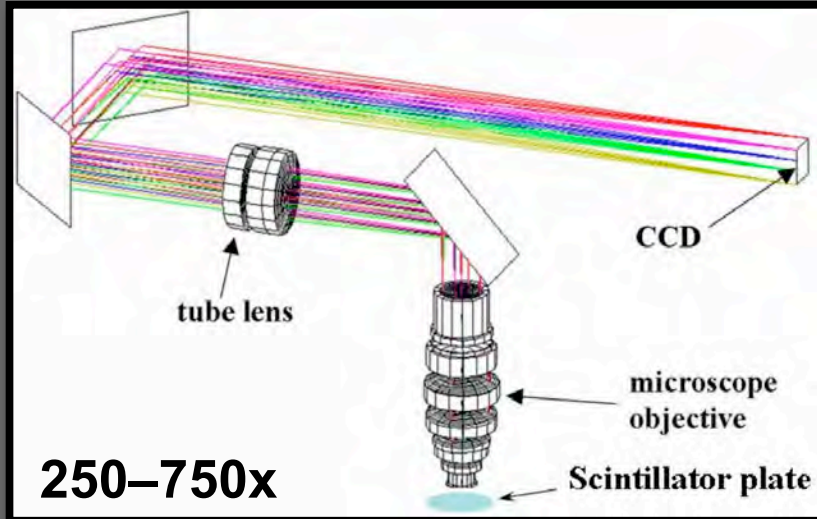
2005 Exitech RIM-13, Reticle Imaging actinic Microscope



(b)

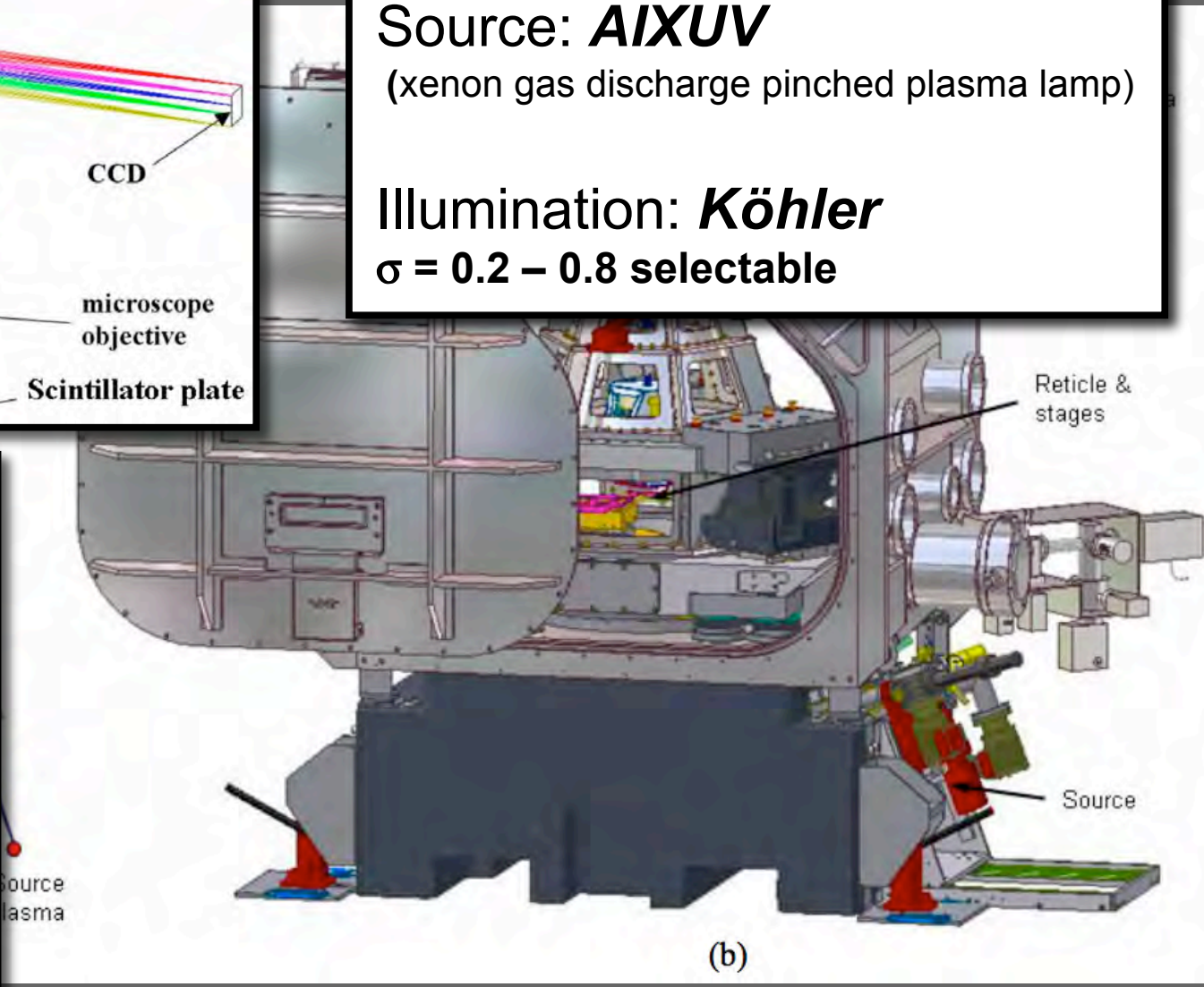
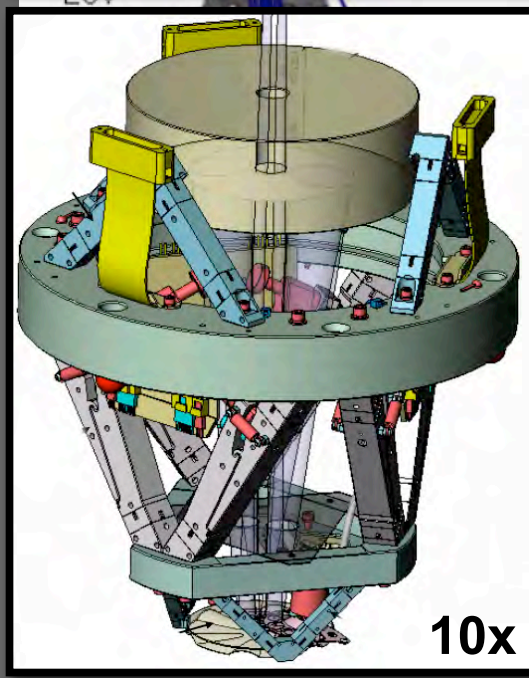
Booth, SPIE 5751, 2005

2005 Exitech RIM-13, Reticle Imaging actinic Microscope



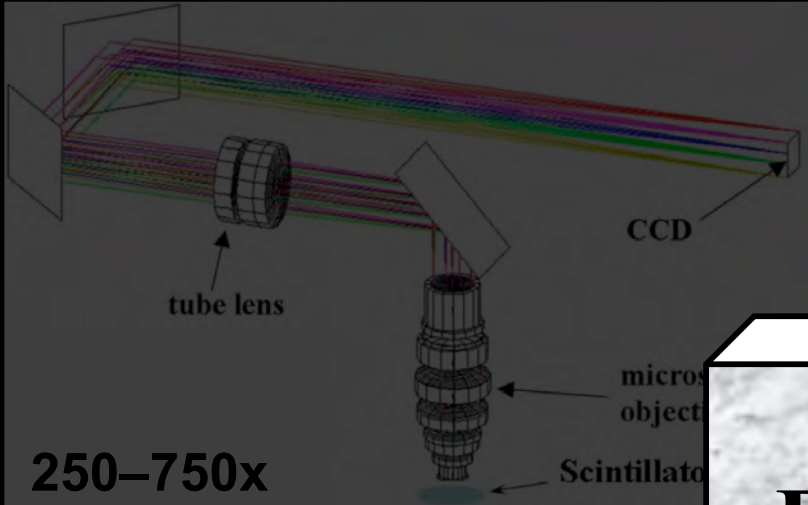
Source: **AIXUV**
(xenon gas discharge pinched plasma lamp)

Illumination: **Köhler**
 $\sigma = 0.2 - 0.8$ selectable



Booth, SPIE 5751, 2005

2005 Exitech RIM-13, Reticle Imaging actinic Microscope

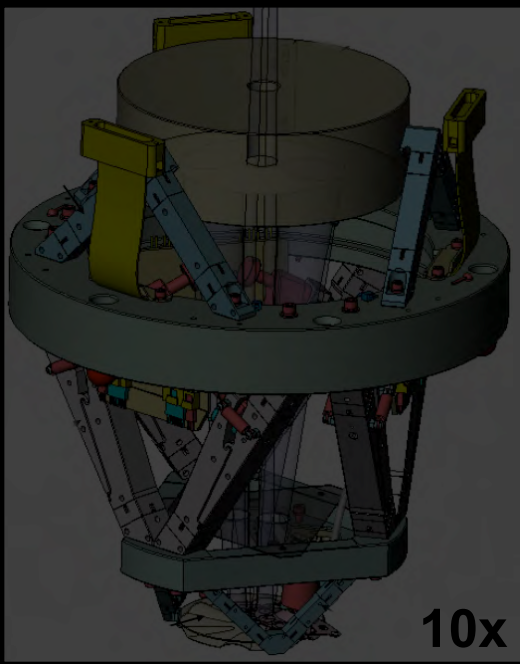


250-750x

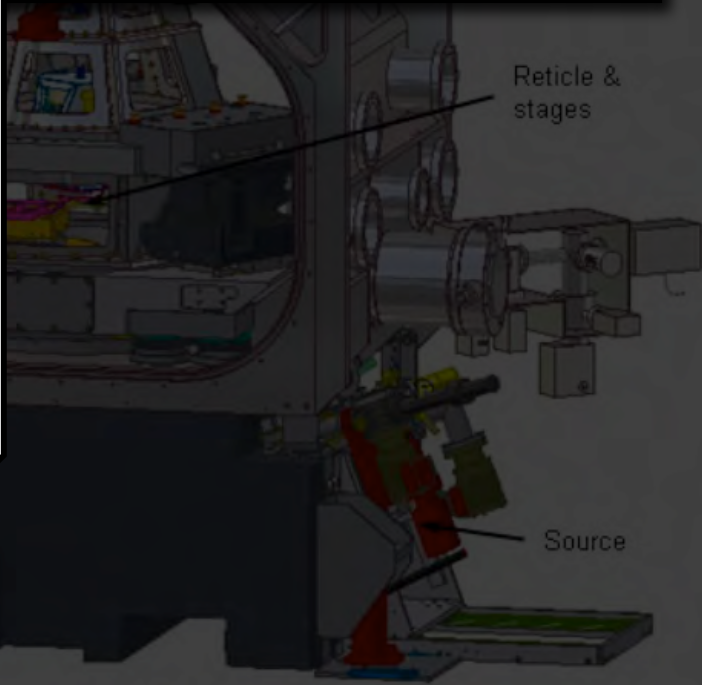
Source: **AIXUV**
(xenon gas discharge pinched plasma lamp)

Illumination: **Köhler**
0.8 selectable

R. I. P.
2003-2006



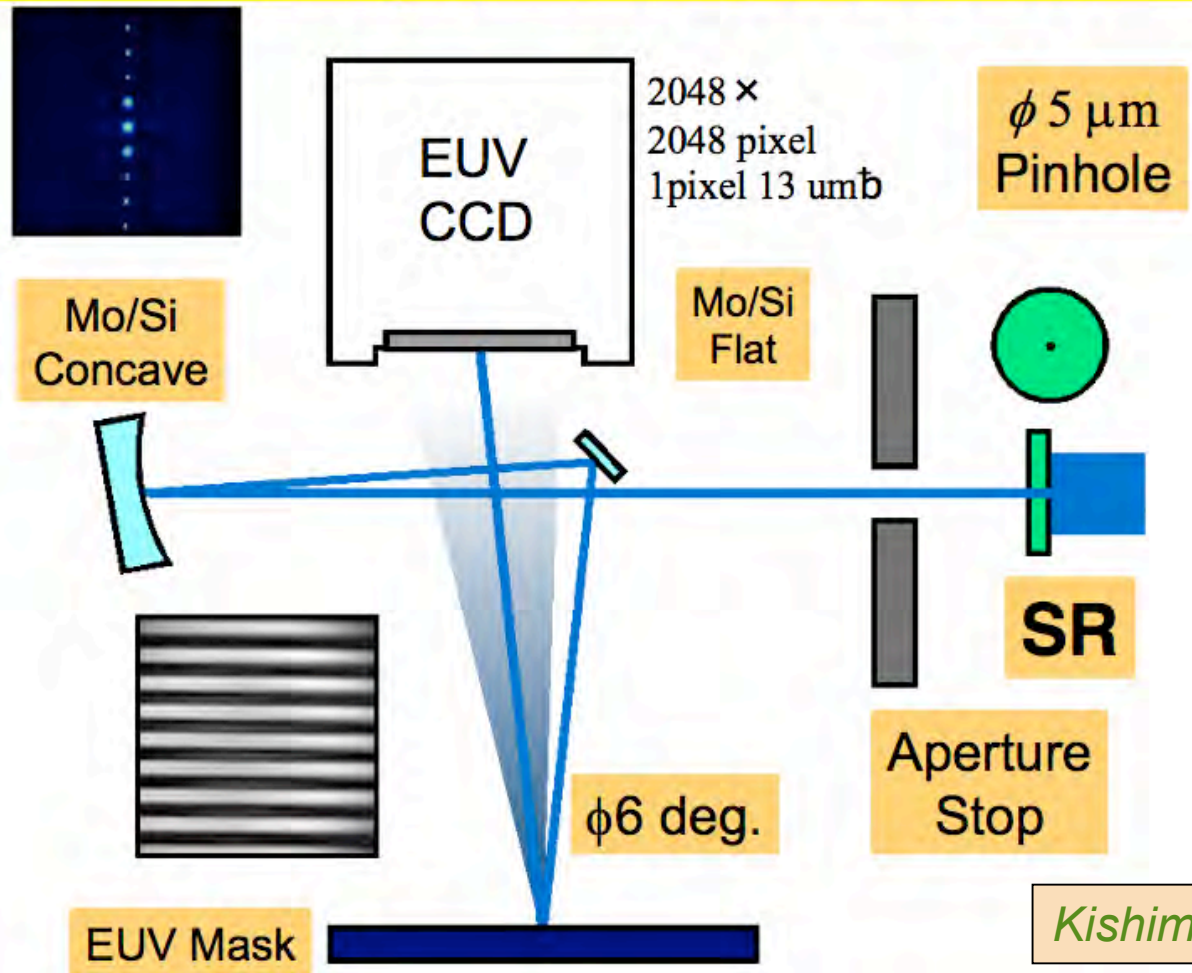
10x



(b)

COHERENT EUV SCATTERING MICROSCOPE (CSM)

A SR facility of "NewSUBARU" BL-3

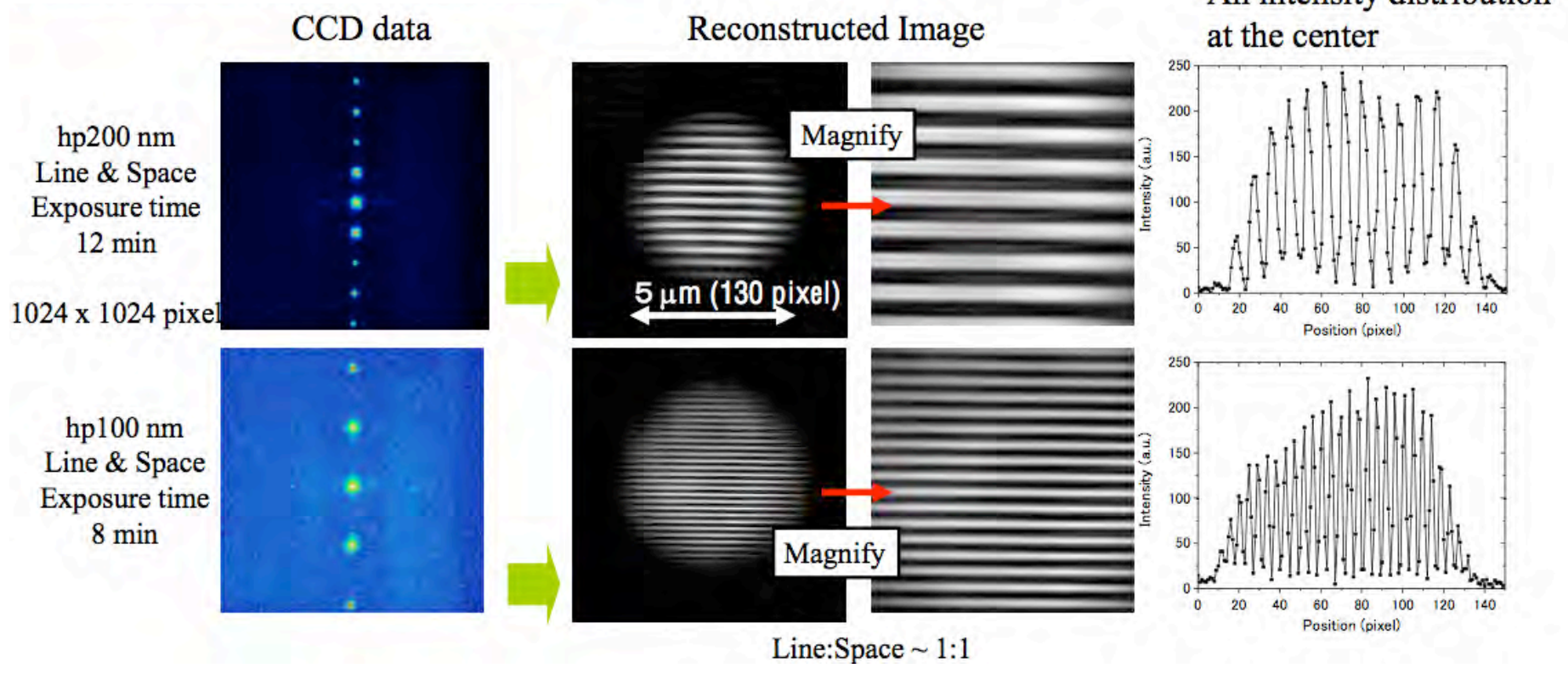


- (almost) no optics
- can reach high NA
- reconstruct entire through-foc. series mathematically

Kishimoto, JVSTB 27 (6) 2009

The periodic EUVL mask were observed by the CSM.

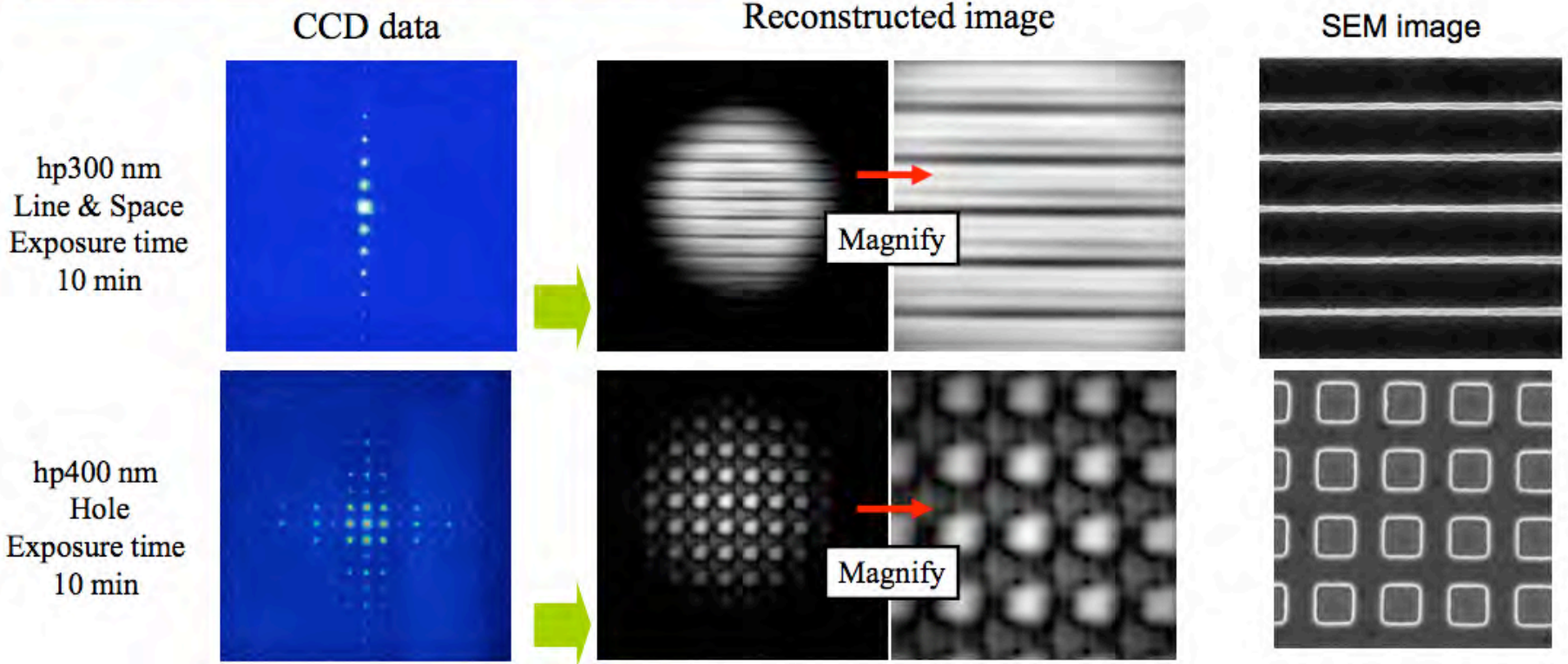
The oversampling ratio ~ 80



Harada, EIPBN 2009.

Kishimoto, JVSTB 27 (6) 2009

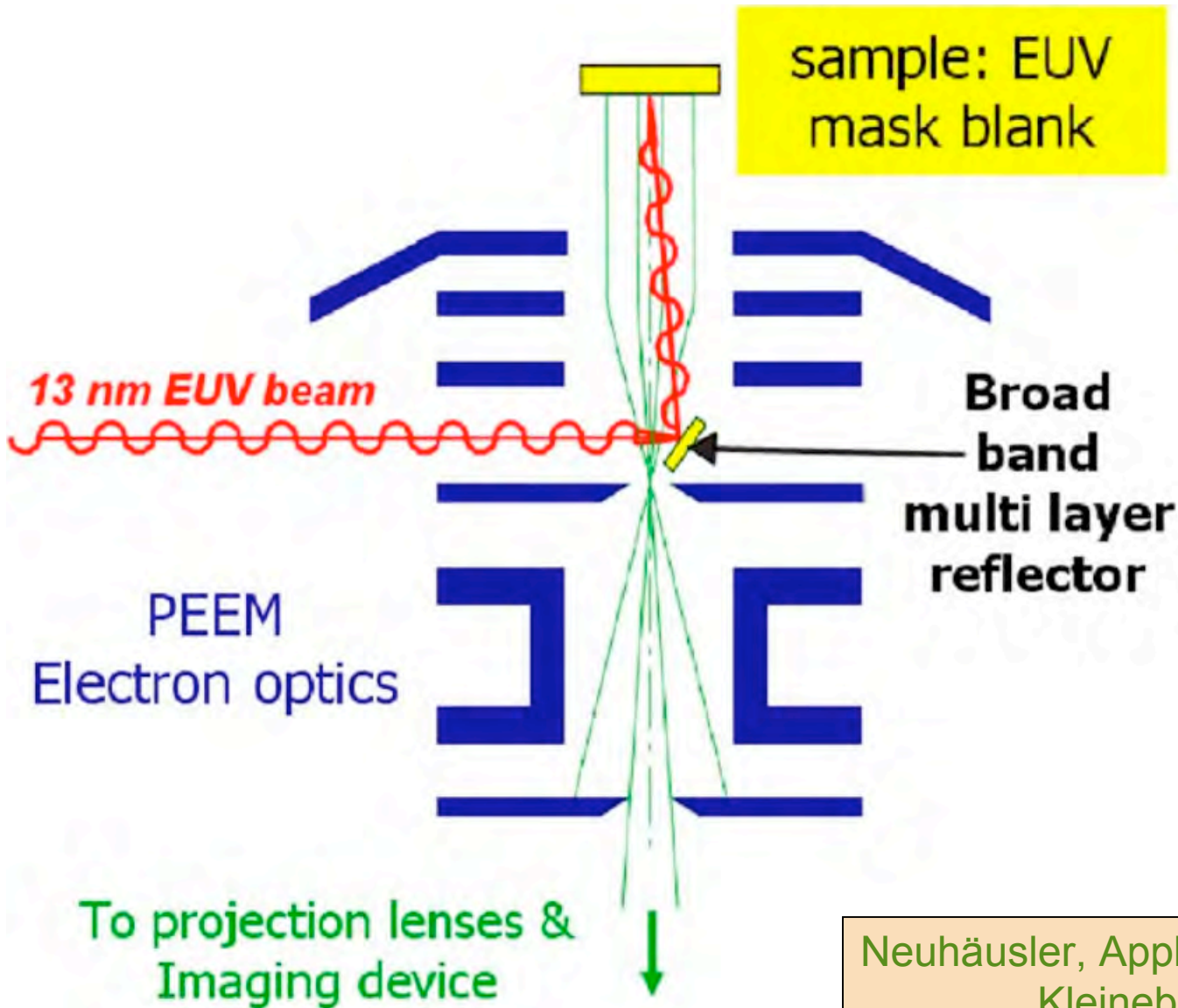
Narrow Line and Hole Patterns



The CSM reconstructed images have a good agreement with the SEM images.

Harada, EIPBN 2009.

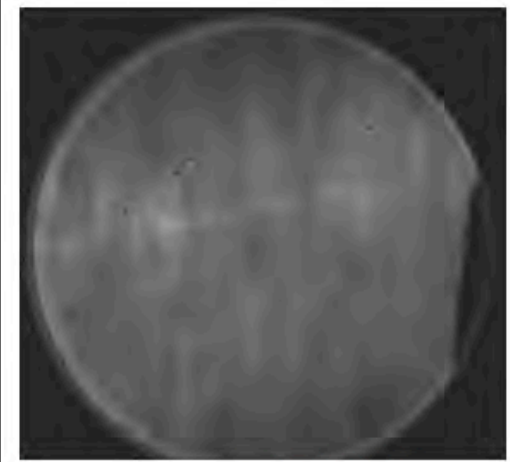
Kishimoto, JVSTB 27 (6) 2009



- EUV illumination
- PEEM e⁻ optics for imaging

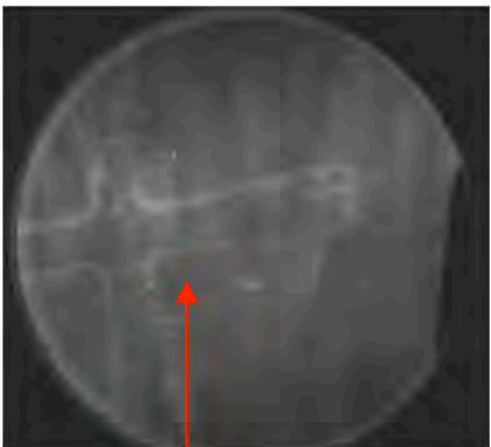
Neuhäusler, Appl. Phys. Lett. **88** (2006)
Kleineberg, SPIE **6151** (2006)

2006 At-wavelength PEEM (Kleineberg, et al.)



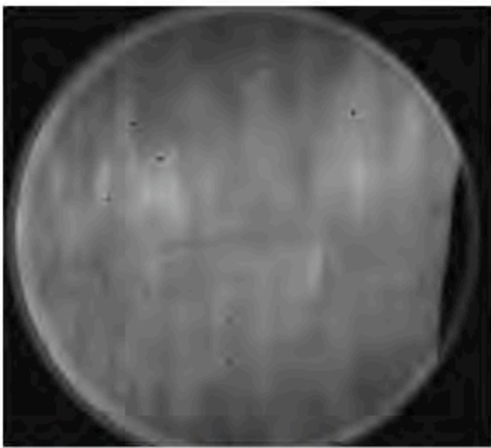
90.5 eV

10 μm



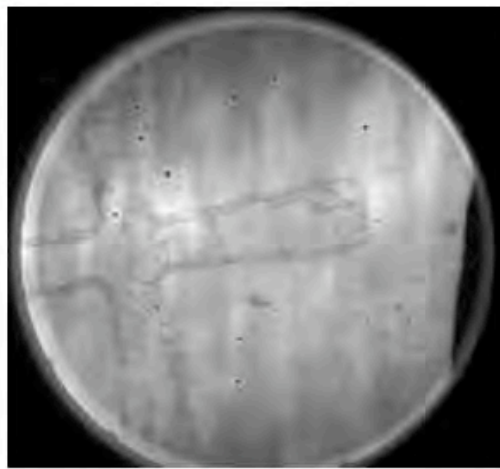
91.5 eV

Contrast reversal

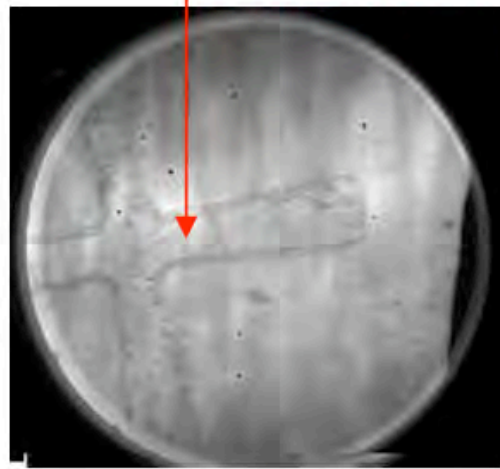


92.5 eV

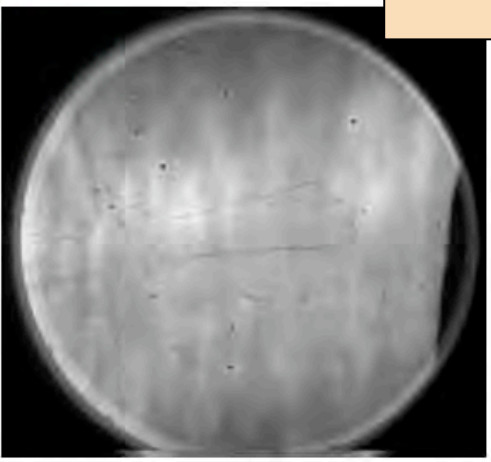
Kleineberg,
SPIE 6151
(2006)



93.5 eV

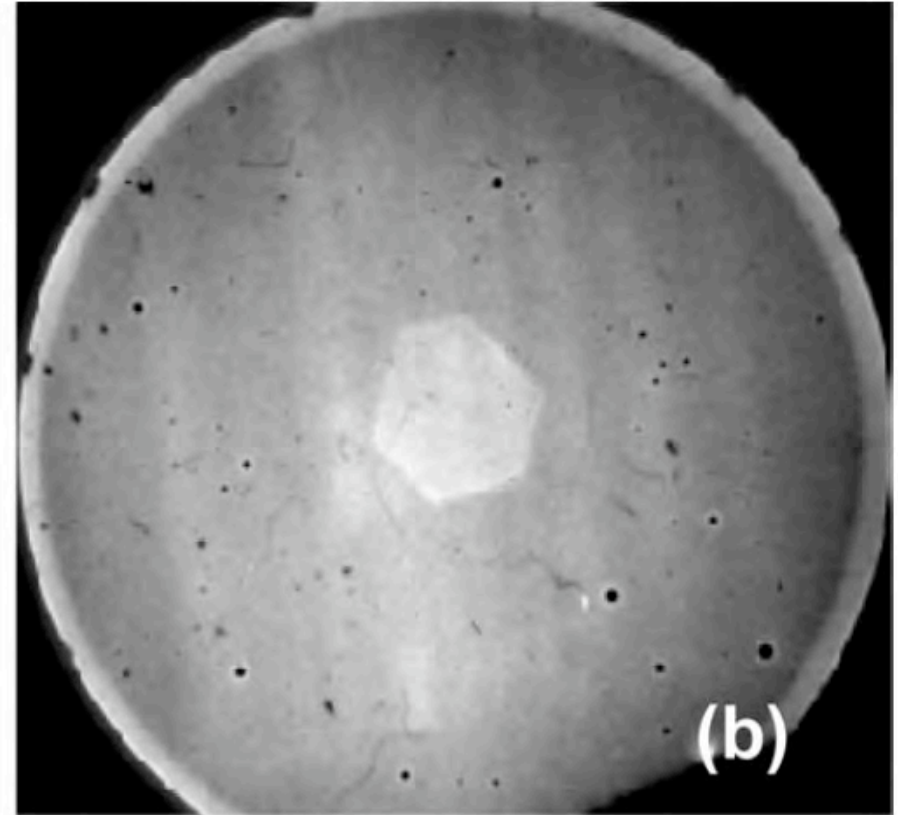
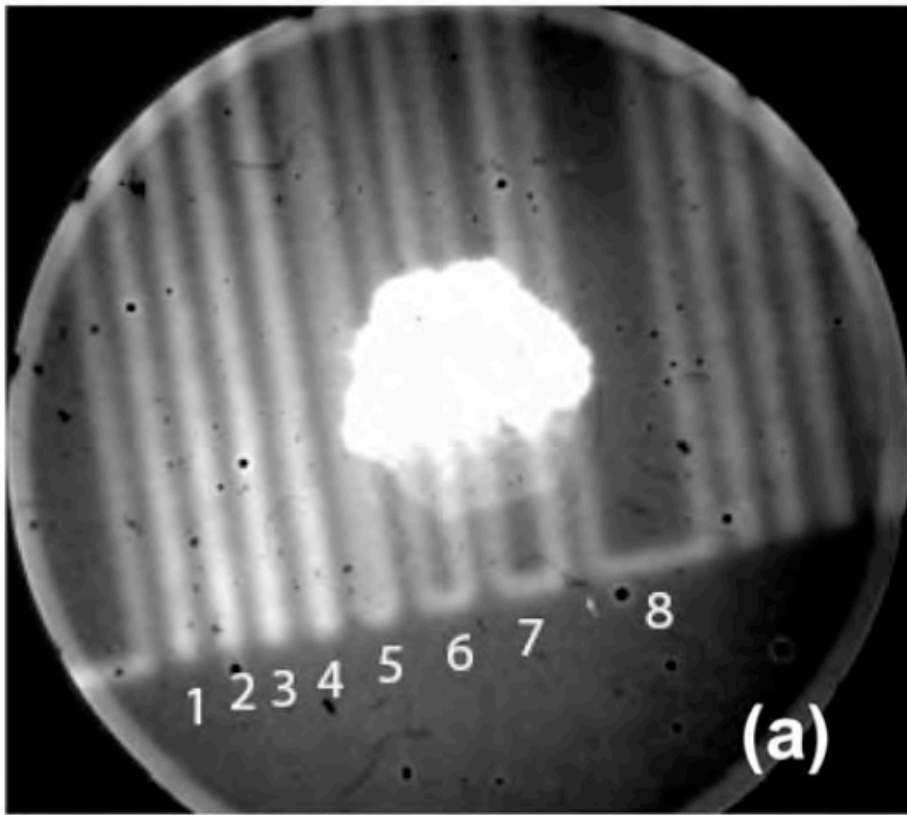


94.5 eV



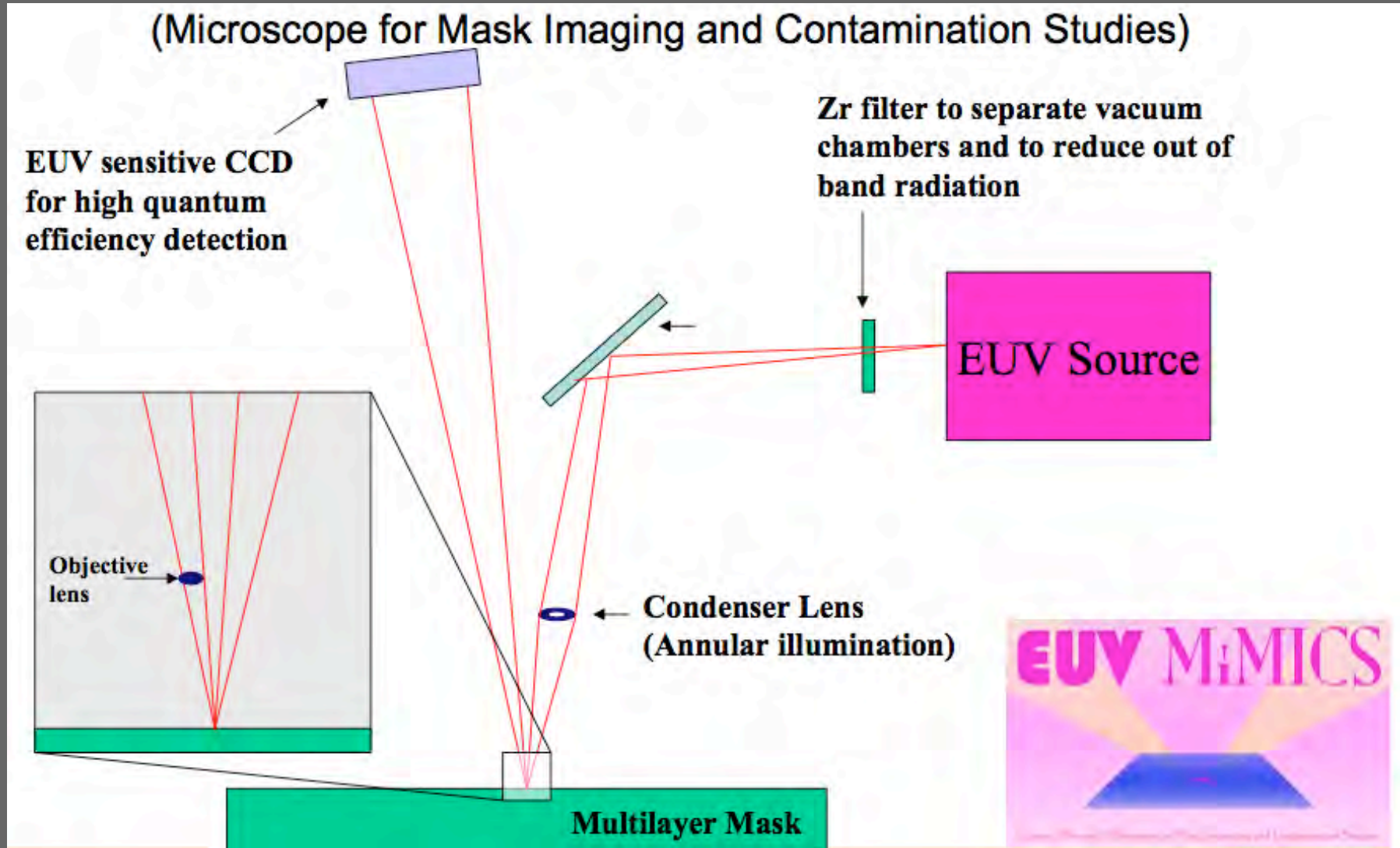
95.5 eV

2007 At-wavelength PEEM (Kleineberg, et al.)



Lin, *Optics Letters* **32** (13) (2007)

2007 EUV MiMICS (Denbeaux *et al.*)



Denbeaux, *EUVL Symposium 2007*

Fan, *SPIE 7271, 2009*

2007 EUV MiMICS (Denbeaux et al.)



Denbeaux, *EUVL Symposium 2007*

Contamination of masks is routine

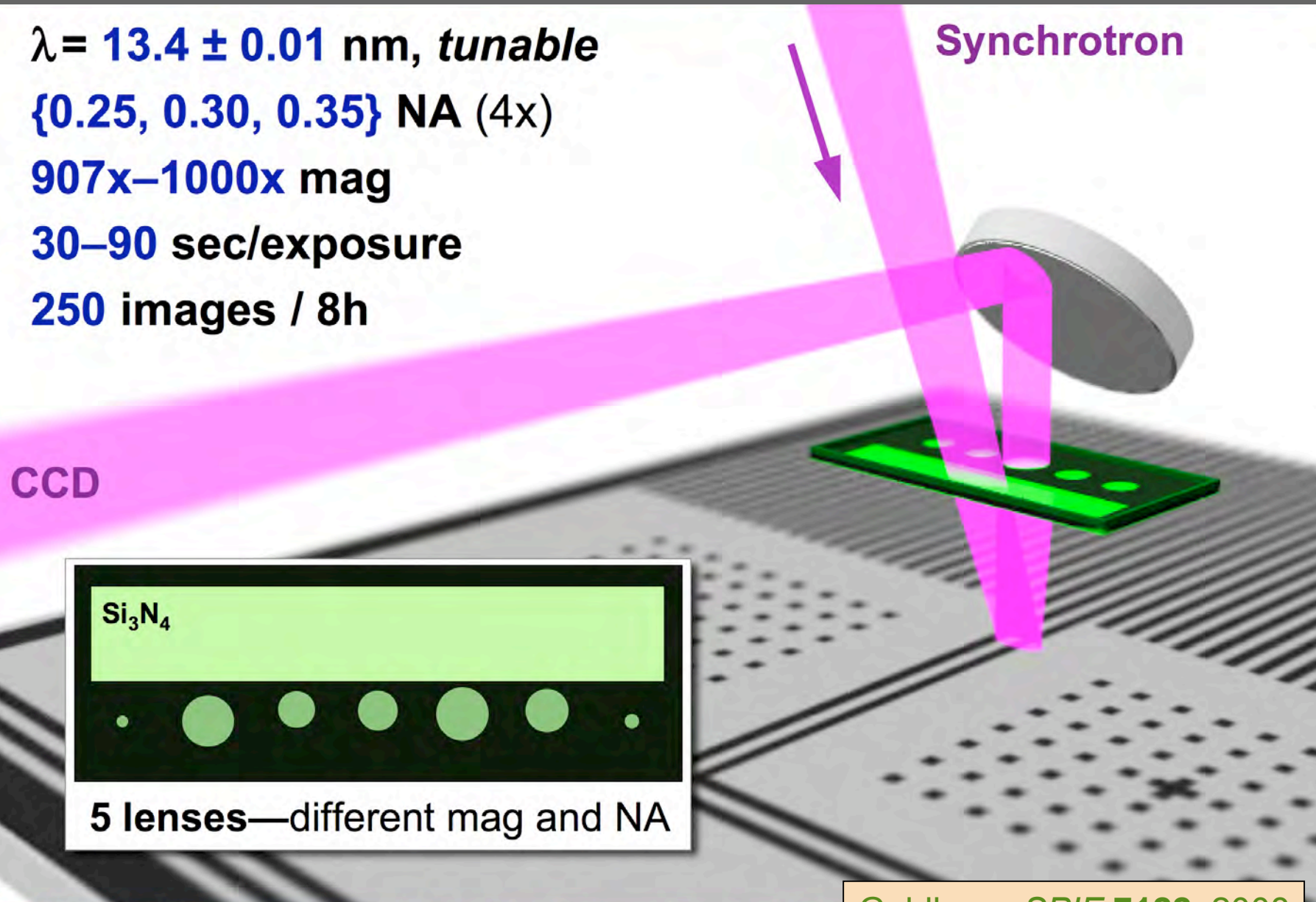


- Aperture designed to uniformly expose and contaminate fields of MET masks
- MET imaging results showing effect of contamination to be presented at a future conference

Denbeaux, *EUVL Symposium 2007*

2008 SEMATECH Berkeley Actinic Inspection Tool (AIT)

$\lambda = 13.4 \pm 0.01$ nm, *tunable*
{0.25, 0.30, 0.35} NA (4x)
907x–1000x mag
30–90 sec/exposure
250 images / 8h



Si₃N₄

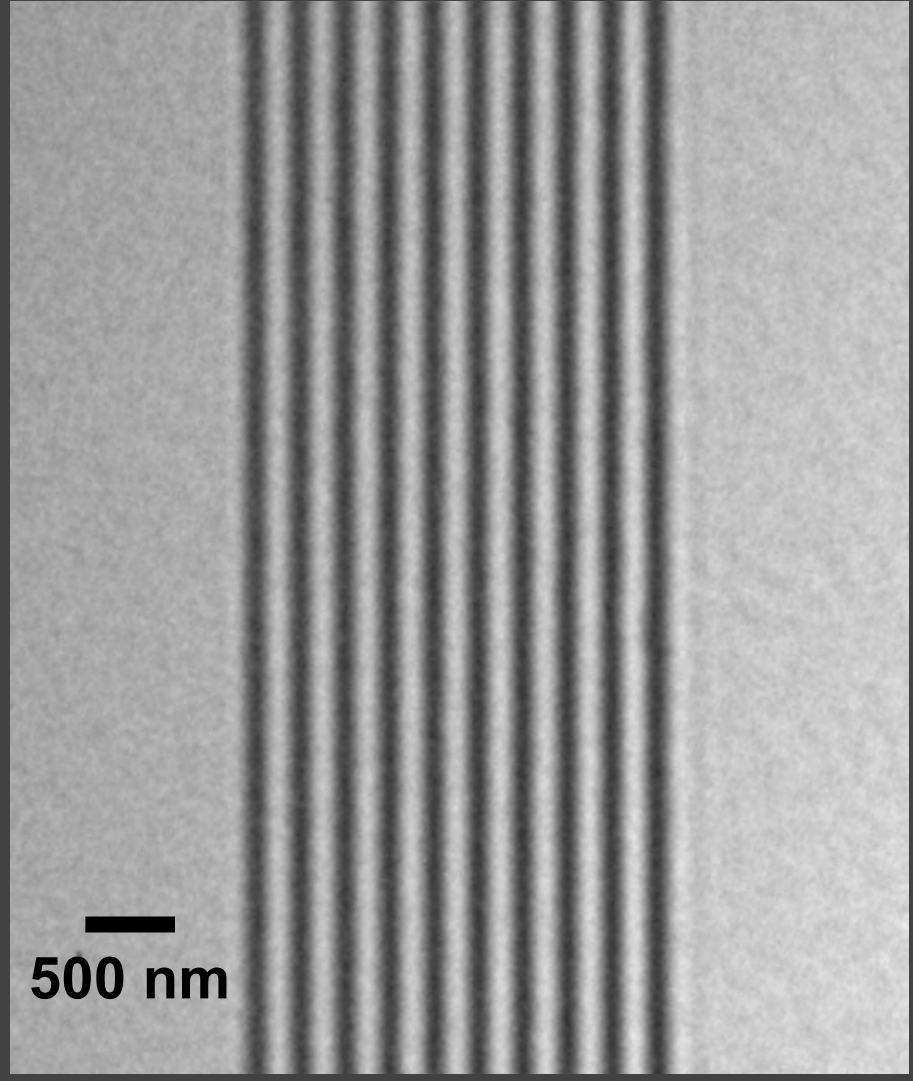
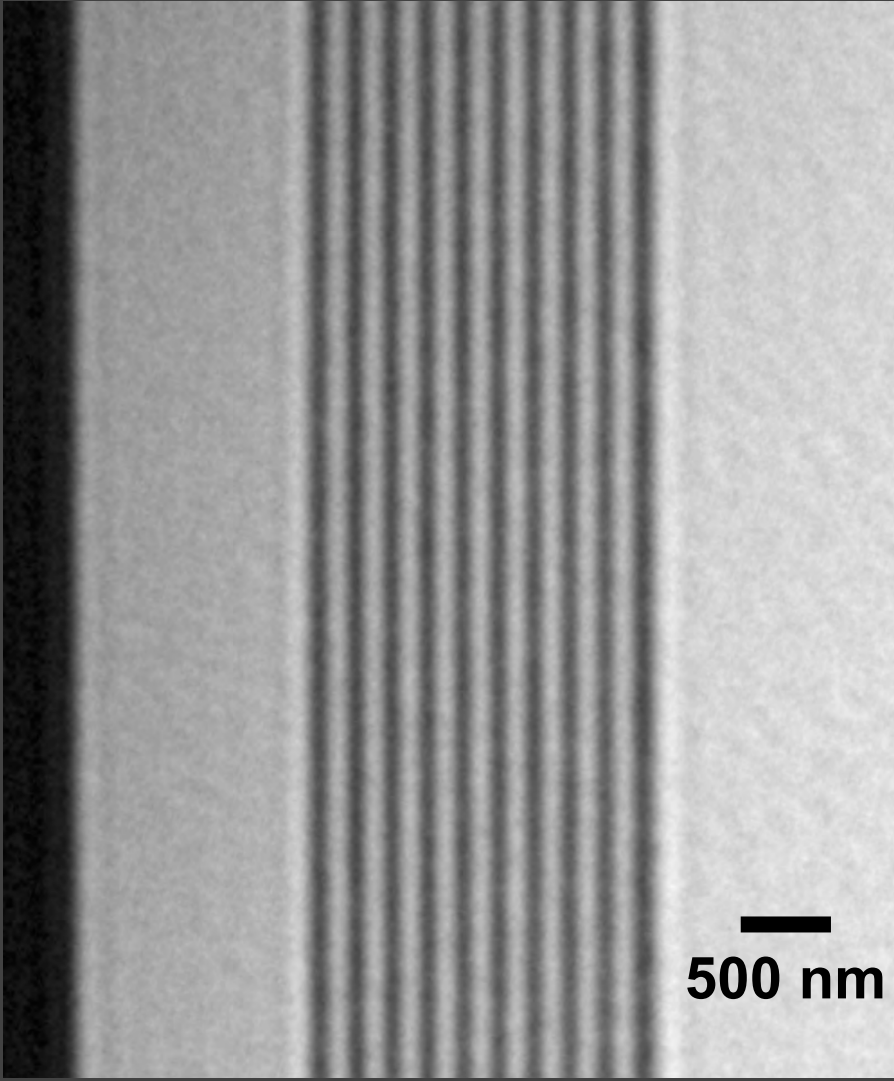
5 lenses—different mag and NA

Goldberg, SPIE 7122, 2008



hp: 100 nm (25 nm @ 4x)

hp: 125 nm (31 nm @ 4x)

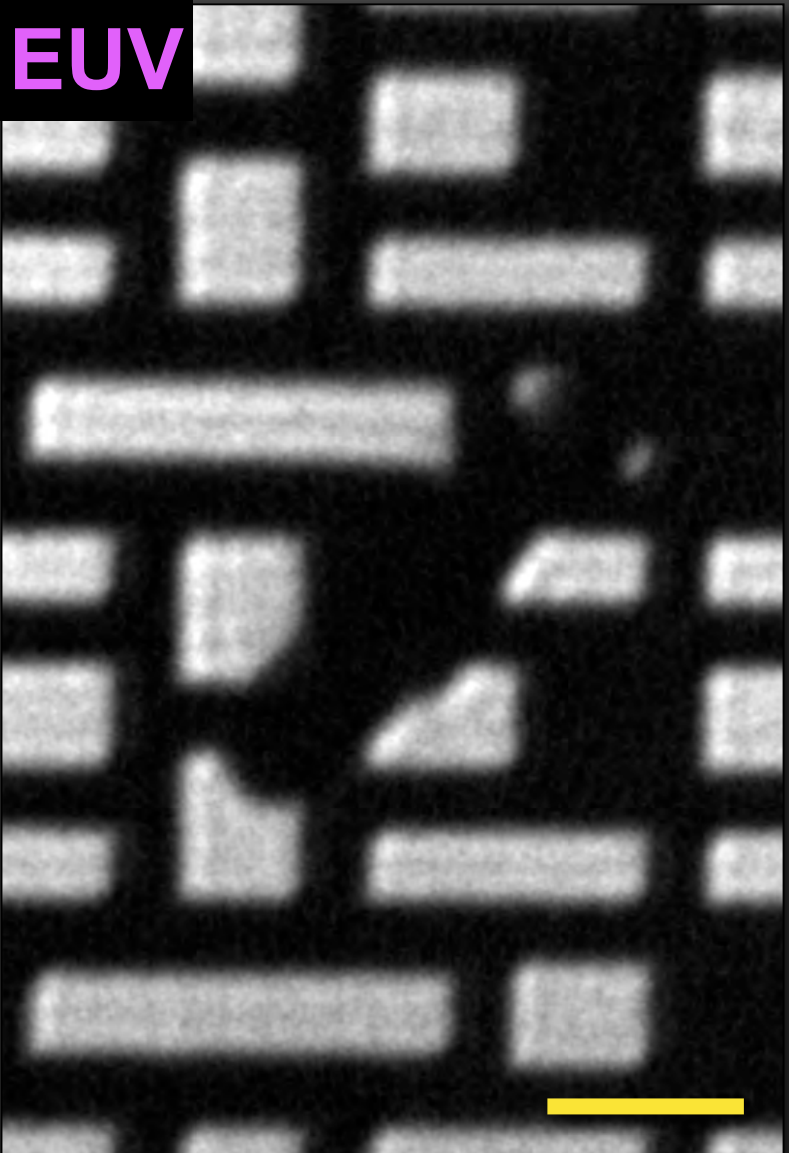
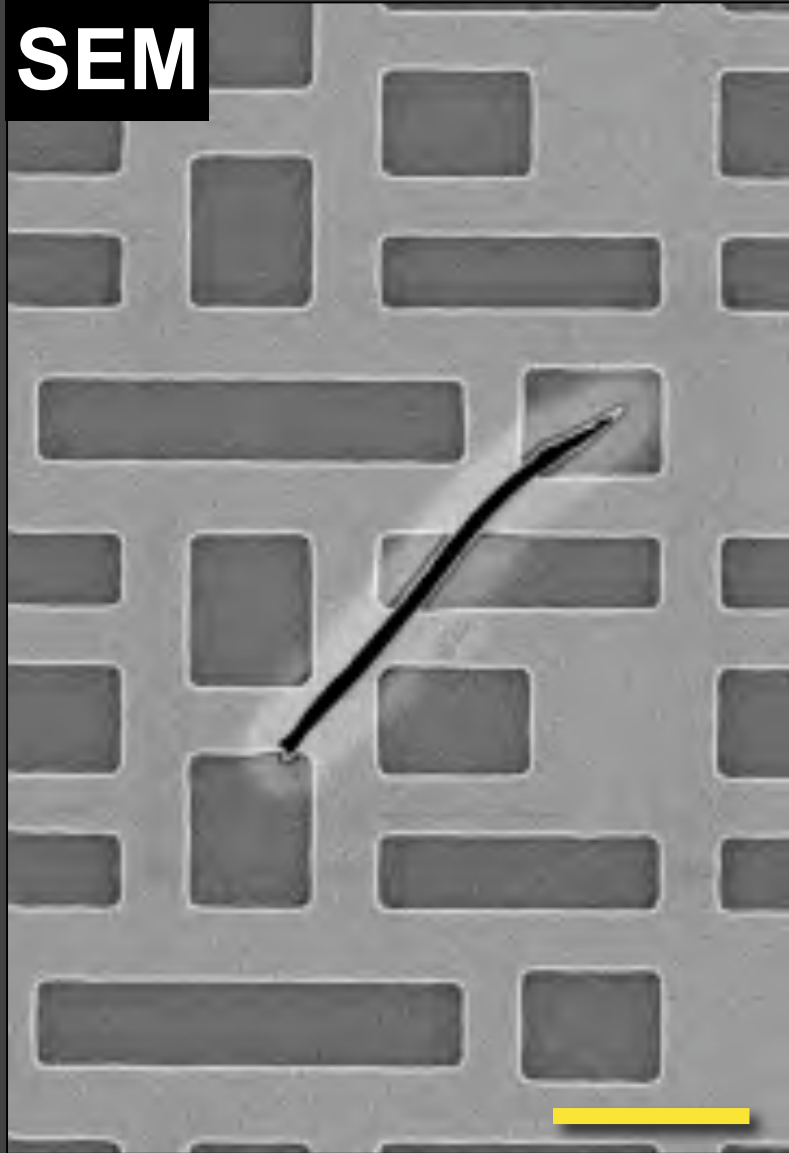


AIT (EUV) images

Goldberg, *EIPBN 2009*; *JVSTB 27* (6) 2009

native defects found on a full-field EUV mask

SEM images



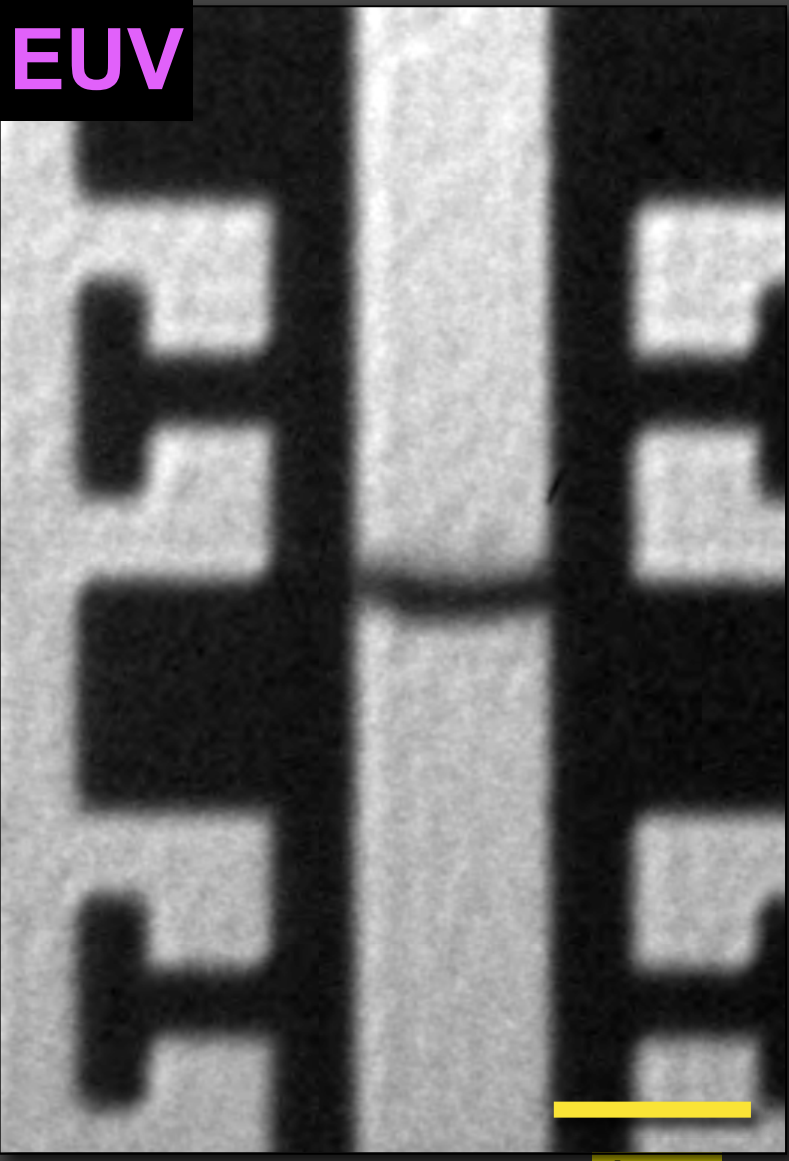
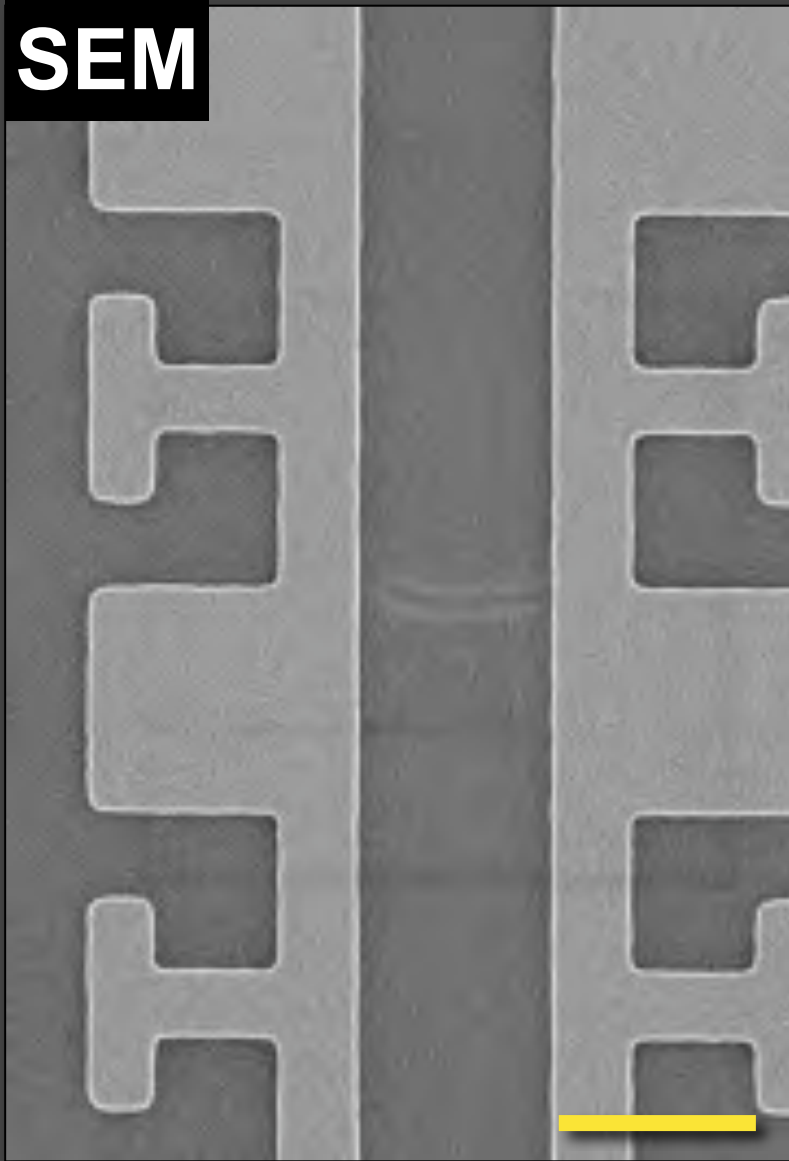
AIT (EUV) images

1 μ m

LaFontaine, Global Foundries

native defects found on a full-field EUV mask

SEM images



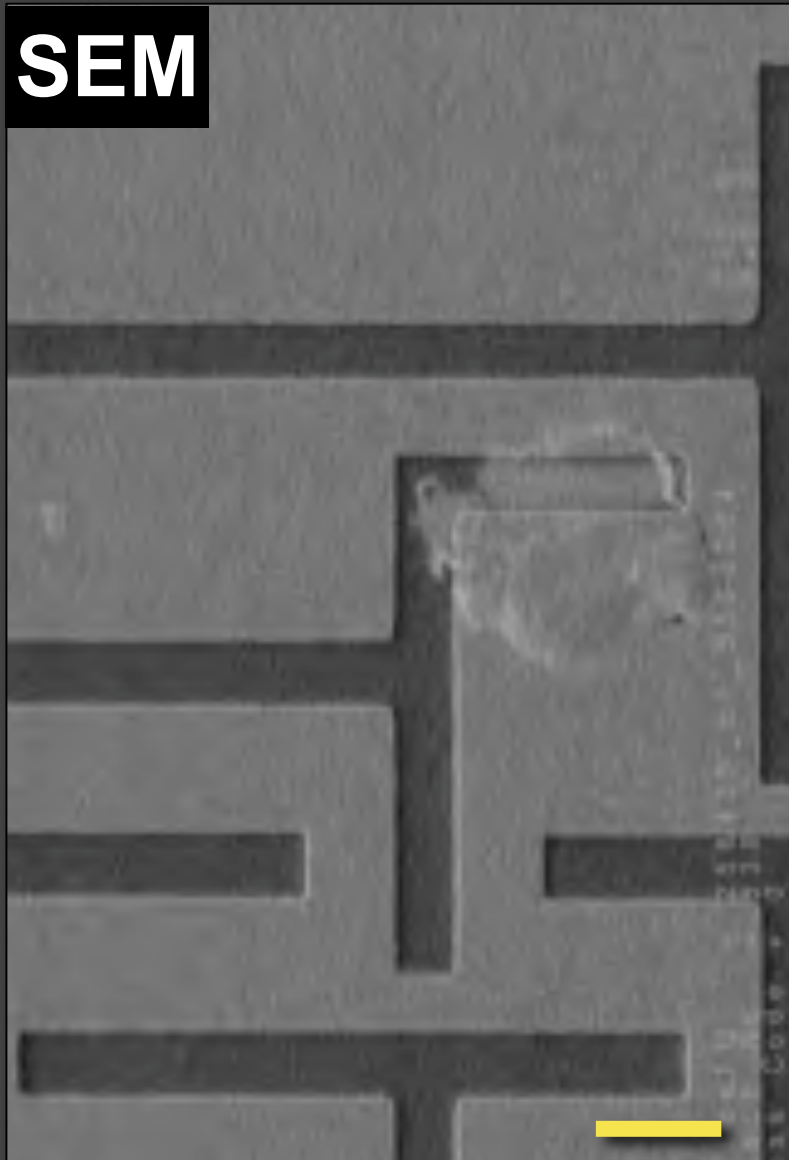
AIT (EUV) images

1 μ m

LaFontaine, Global Foundries

native defects found on a full-field EUV mask

SEM images



AIT (EUV) images

1 μ m

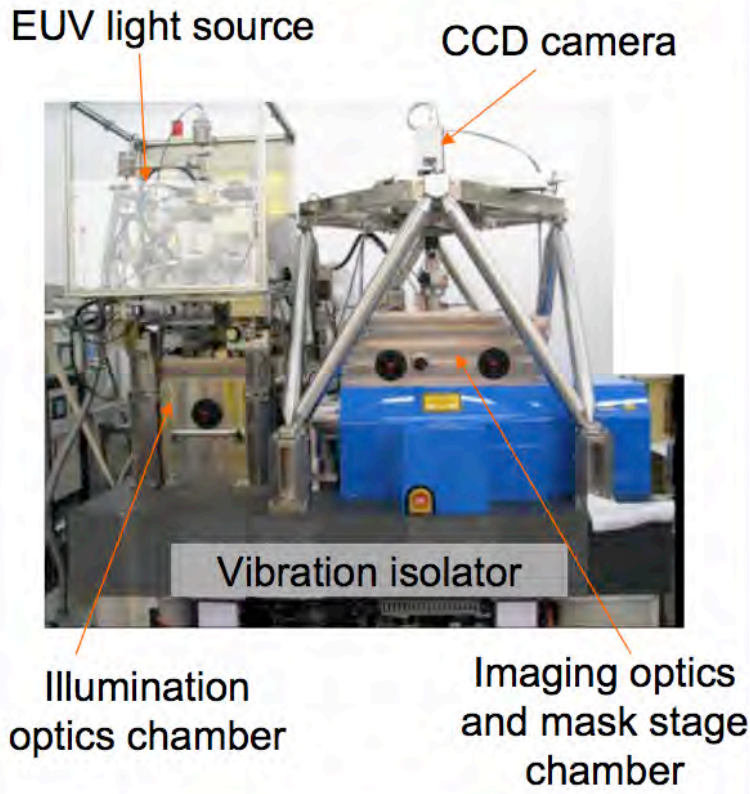
LaFontaine, Global Foundries



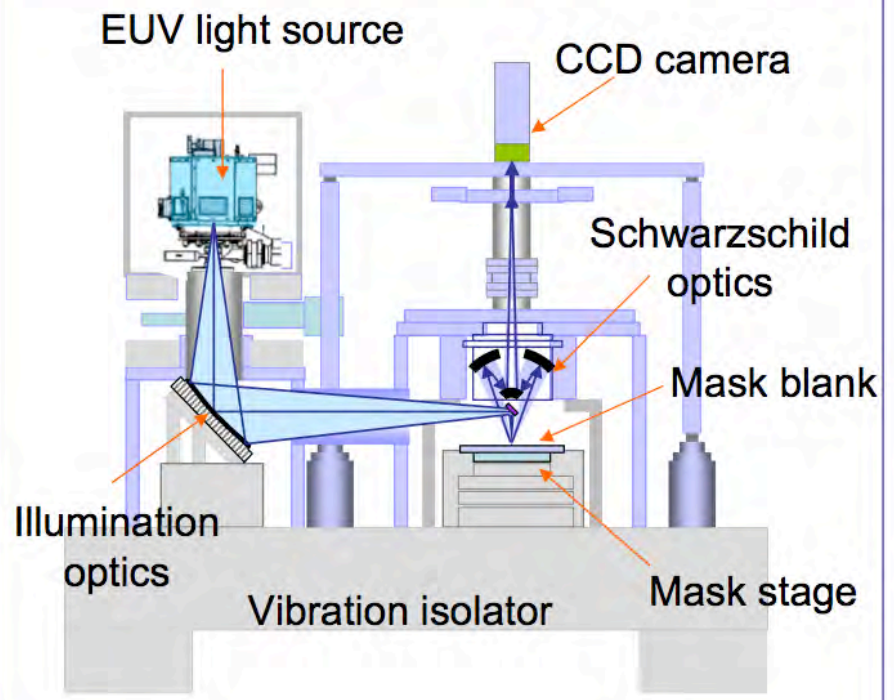
Inspection tool built at MIRAI-Selete



Setup of the tool



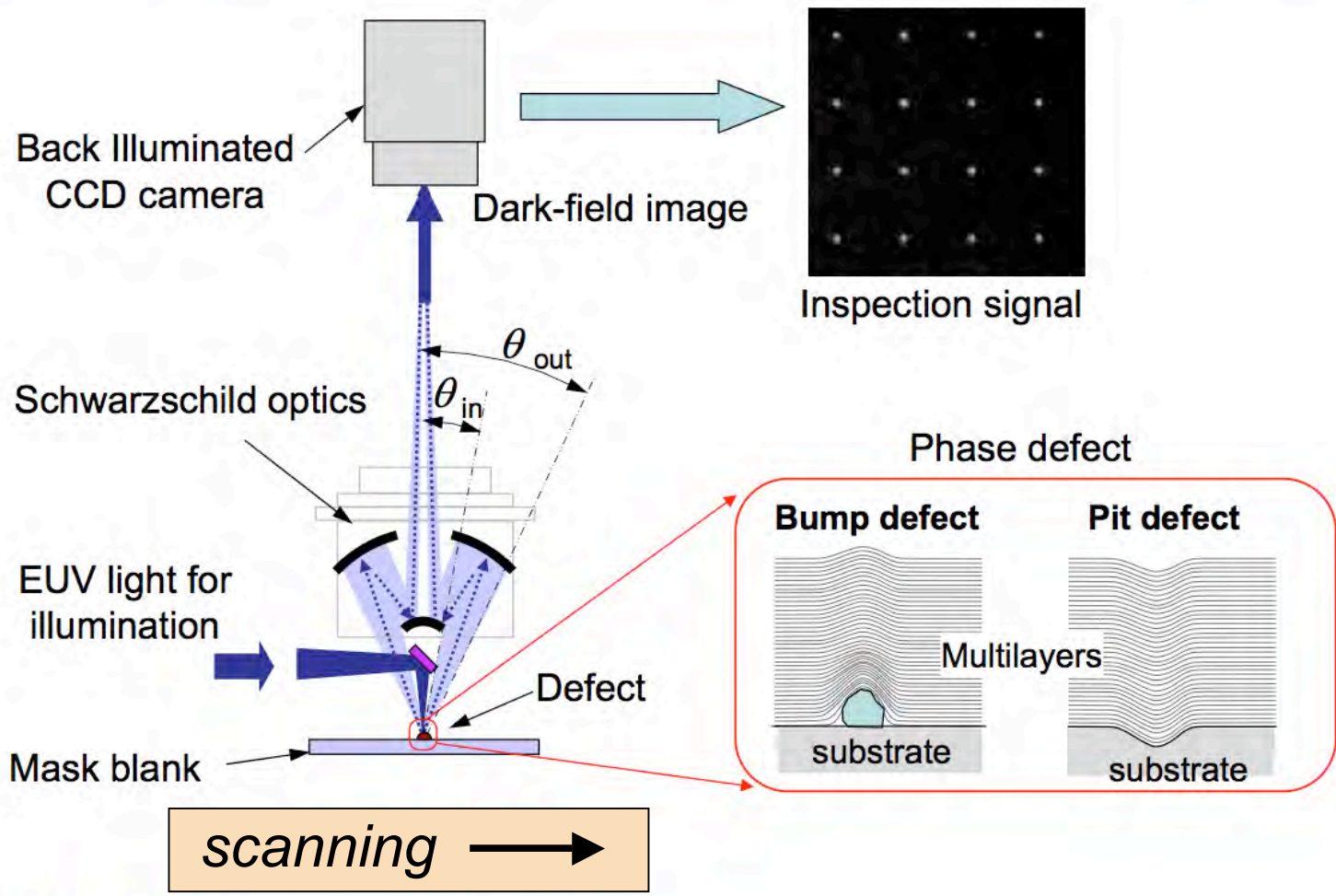
Inspection optics design



26x imaging
 $0.1 < NA < 0.25$

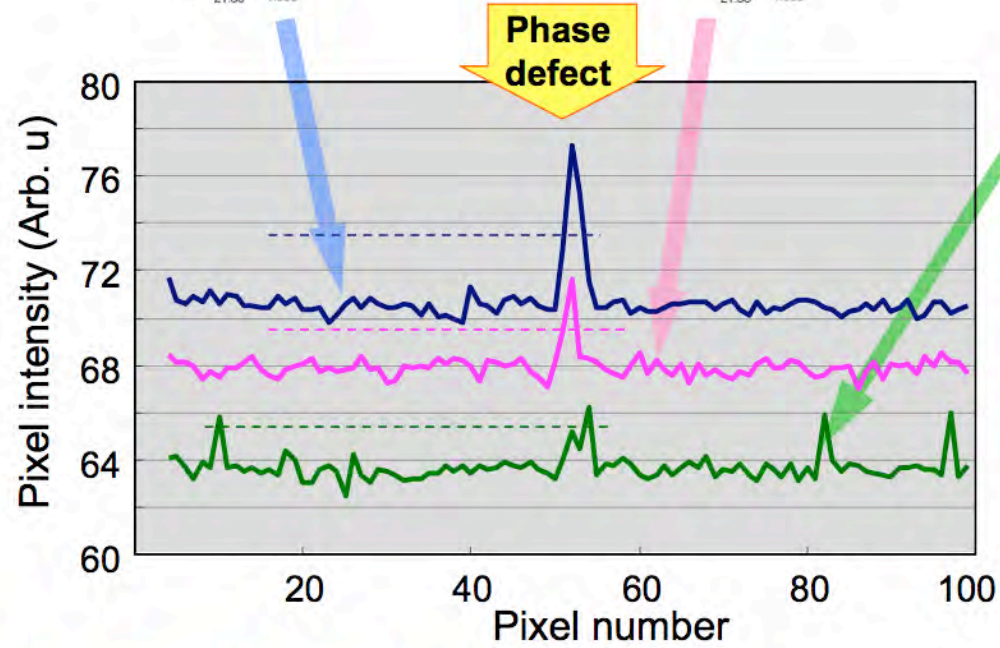
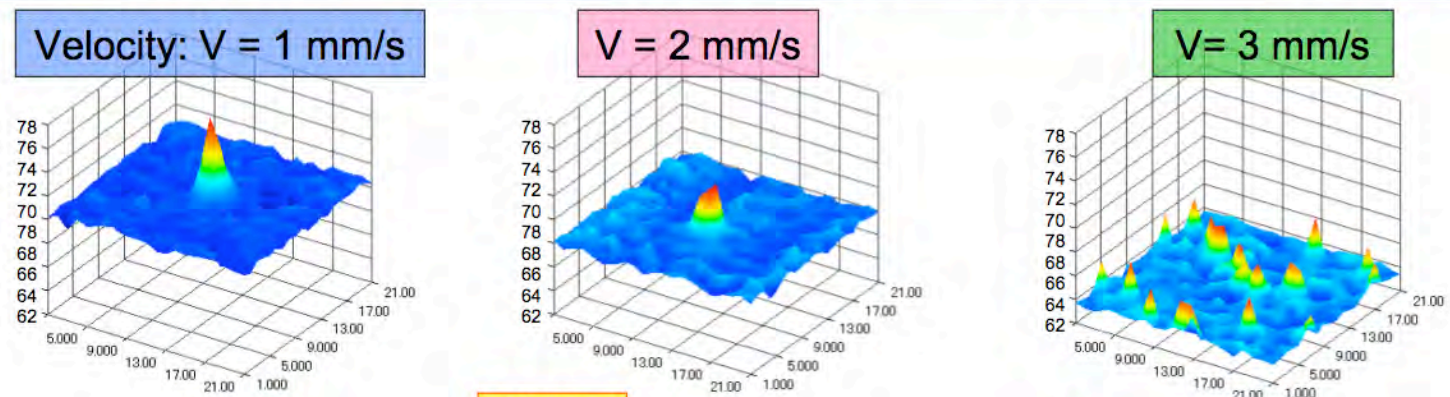


Actinic dark field inspection optics



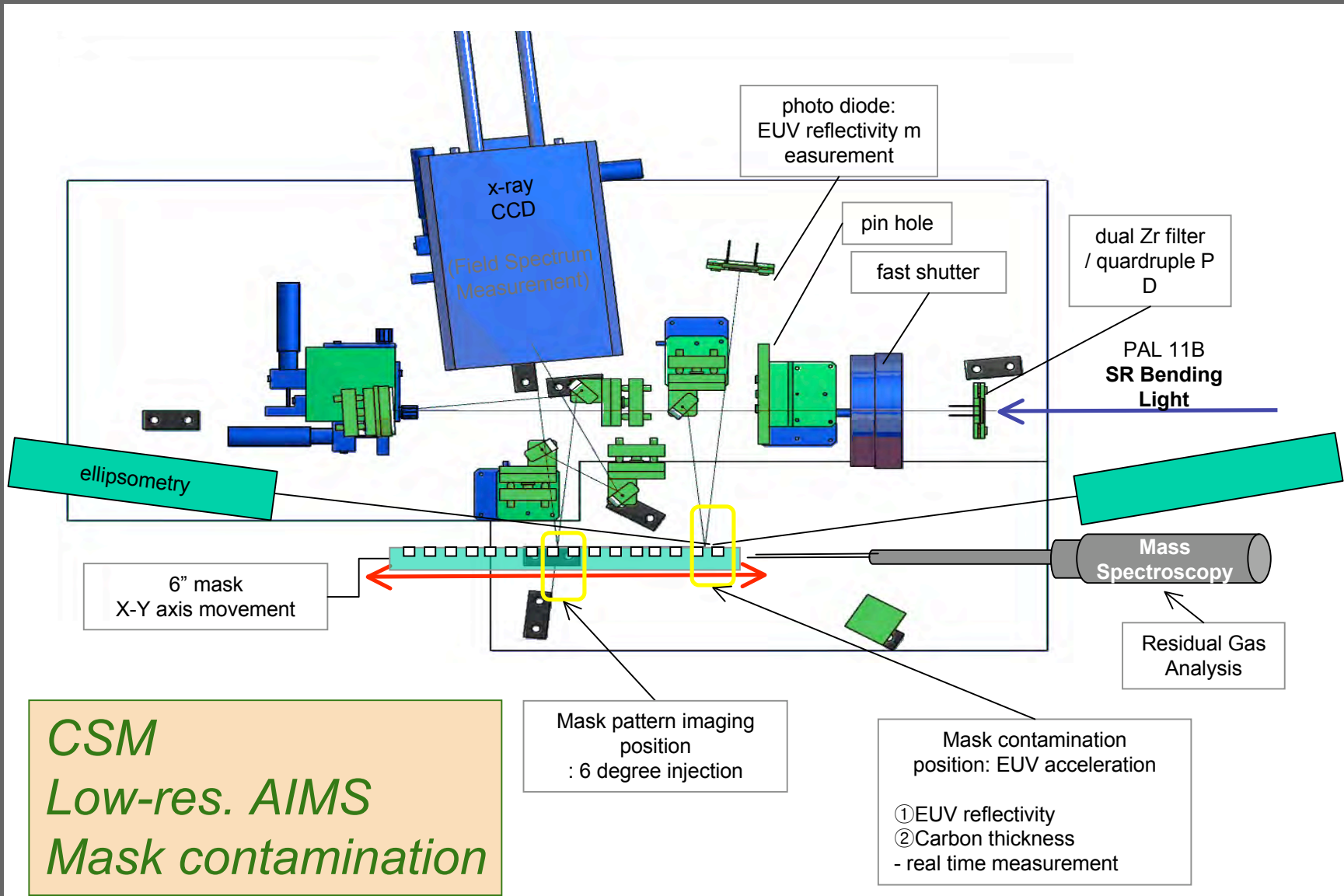


Signal intensity depending on stage velocity *Selete*



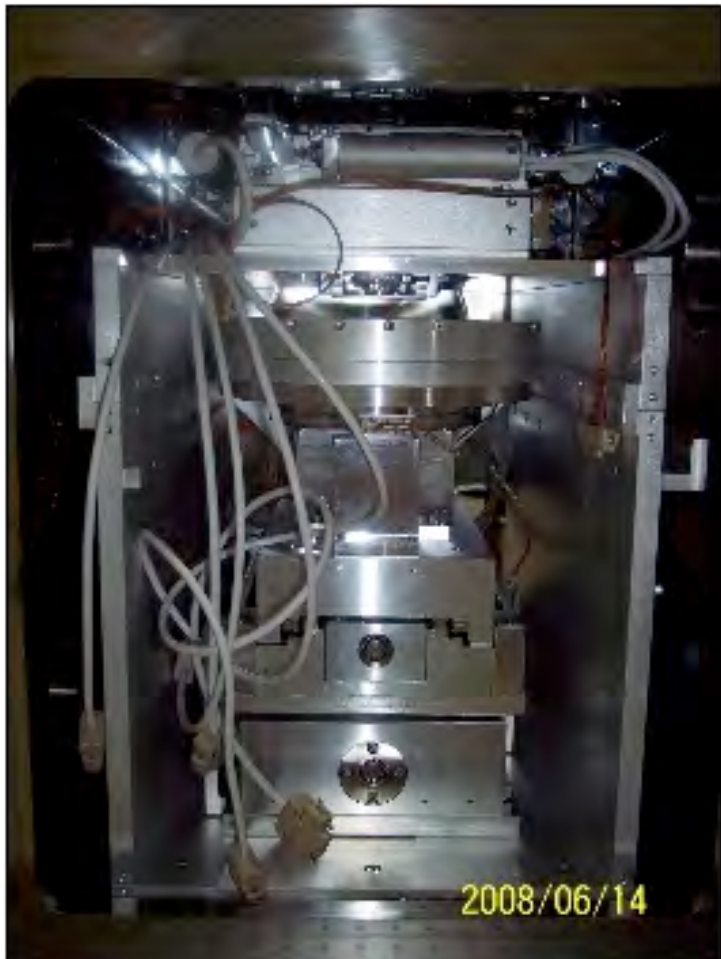
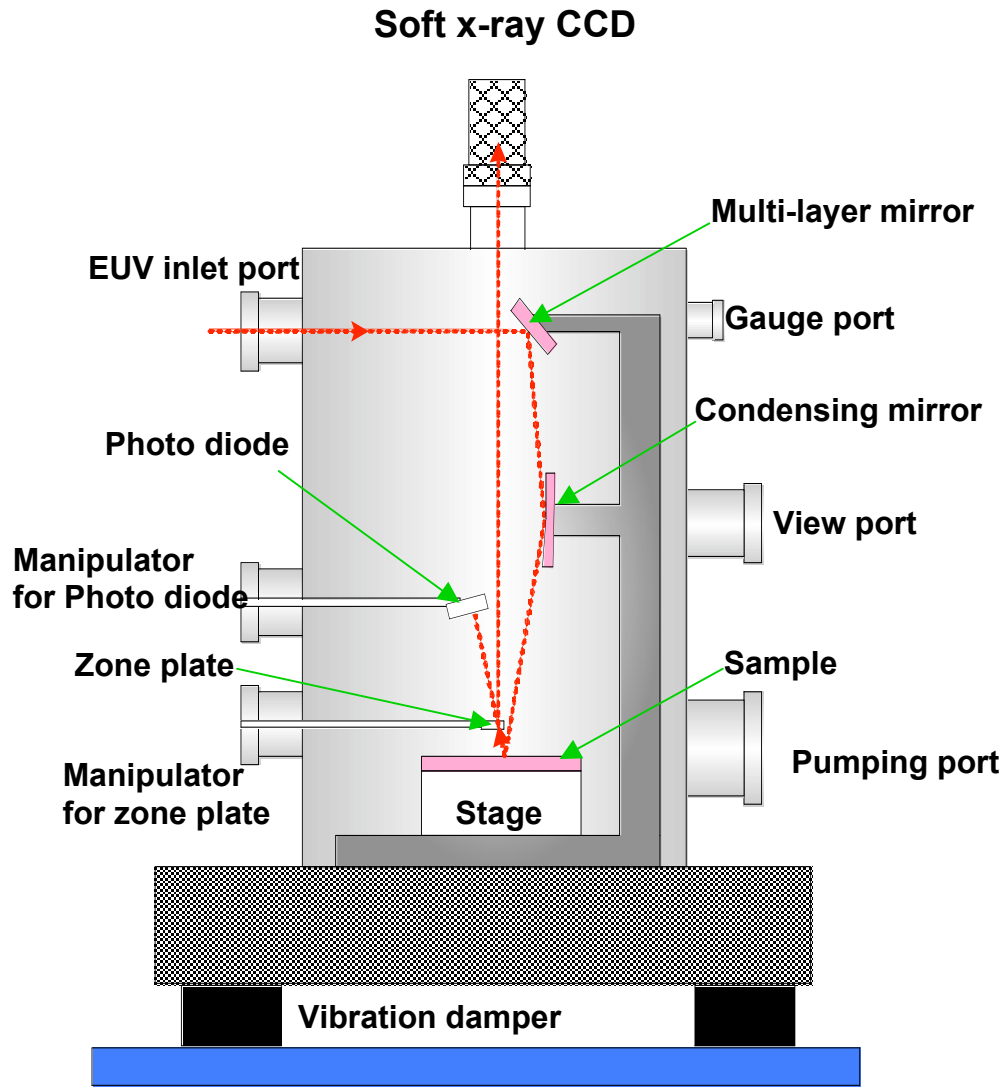
Pixel intensity of detecting phase defect of 100 nm in width and 2.5 nm in height

late-2009 Hanyang AIMS and CSM (Ahn, et al.)

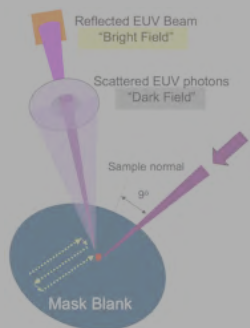


CSM
Low-res. AIMS
Mask contamination

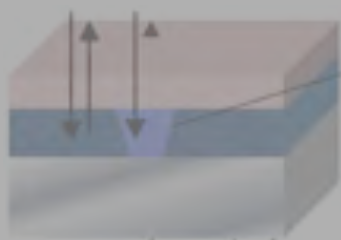
Zoneplate-based AIMS



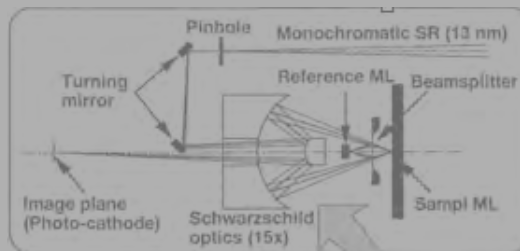
2009: Past, Current, and Future Projects



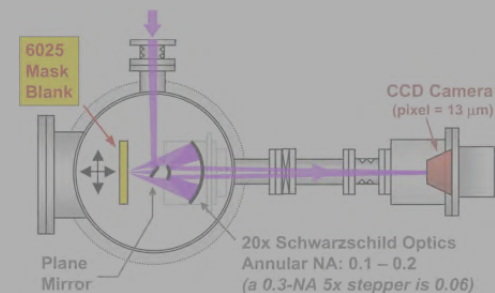
EUV LLC/LBNL



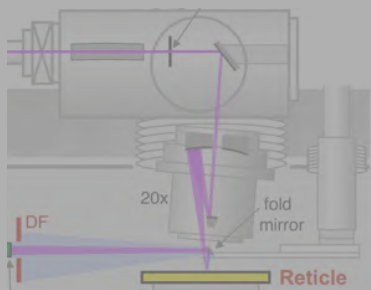
Lucent



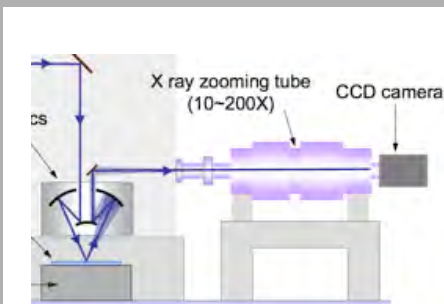
NTT



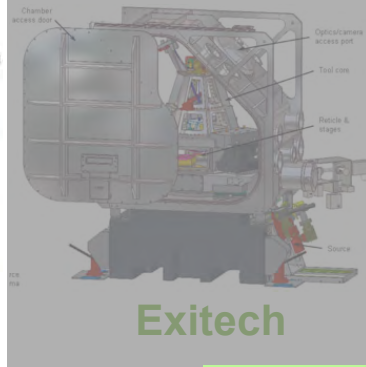
MIRAI



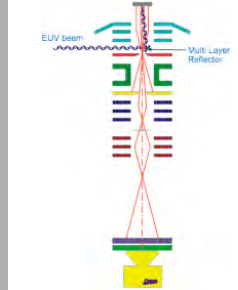
SEMATECH/LBNL



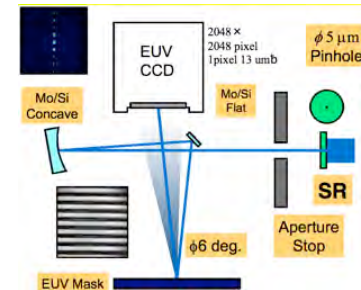
U. Hyogo



Exitech



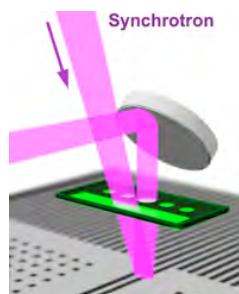
U. Bielefeld



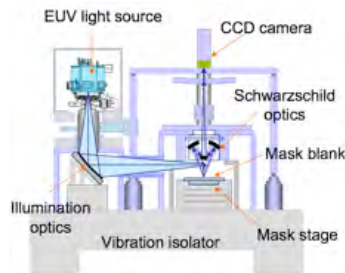
U. Hyogo



INVENT/CNSE

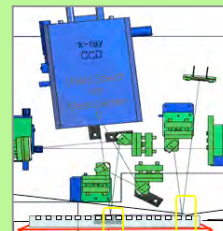


SEMATECH/LBNL

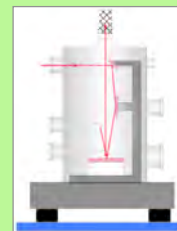


MIRAI/Selete

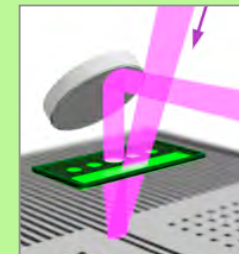
Future...



Hanyang U. / Pohang



(proposal)



SEMATECH / LBNL

Bridge Tool



Bryan Rice
Director of lithography
SEMATECH

6/30/2009— . . . The high- volume manufacturing (HVM) solutions needed for 22 nm manufacturing “do not exist, and funding is a big problem. . . .”

“Mask blank inspection tooling has no commercial suppliers who have committed to building the tool,” Rice said, with identical challenges in **mask defect review** and **mask pattern inspection**.

<http://tinyurl.com/EUVMaskToolFunding>



Bryan Rice
Director of lithography
SEMATECH

6/30/2009— . . . The high- volume manufacturing (HVM) solutions needed for 22 nm manufacturing “do not exist, and funding is a big problem. . . .”

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<http://tinyurl.com/EUVMaskToolFunding>

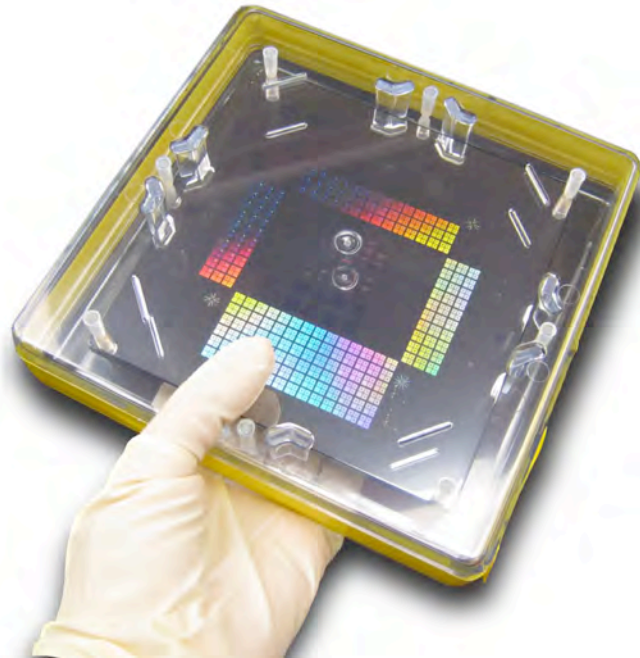


Barack Obama,
U.S. President

YES, WE CAN!

**Let's build an actinic Bridge Tool
to fill the gap!**

Special Thanks to:



Vivek Bakshi, Hiroo Kinoshita,
Jeff Bokor, Seongtae Jeong,
Chris Walton, Scott Hector,
Steve Spector, Yoshihiro Tezuka,
Tsuneo Terasawa, Jinho Ahn,
Bruno LaFontaine, Pei-Yang Yan,
Ulf Kleineberg, **and the members
of their teams!**