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LAWRENCE LIVERMORE NATIONAL LABORATORY

EUV inspection of reticle defect repair sites

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SPIE Microlithpgraphy
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February 27, 2007 through March 1, 2007

EUV Inspection of Defect-Repair Sites
& Status of the actinic inspection tool

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Hakseung Han*, Obert Wood*

**current and former project managers*

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Fundamental questions remain for EUV reticles

Isolated Defects

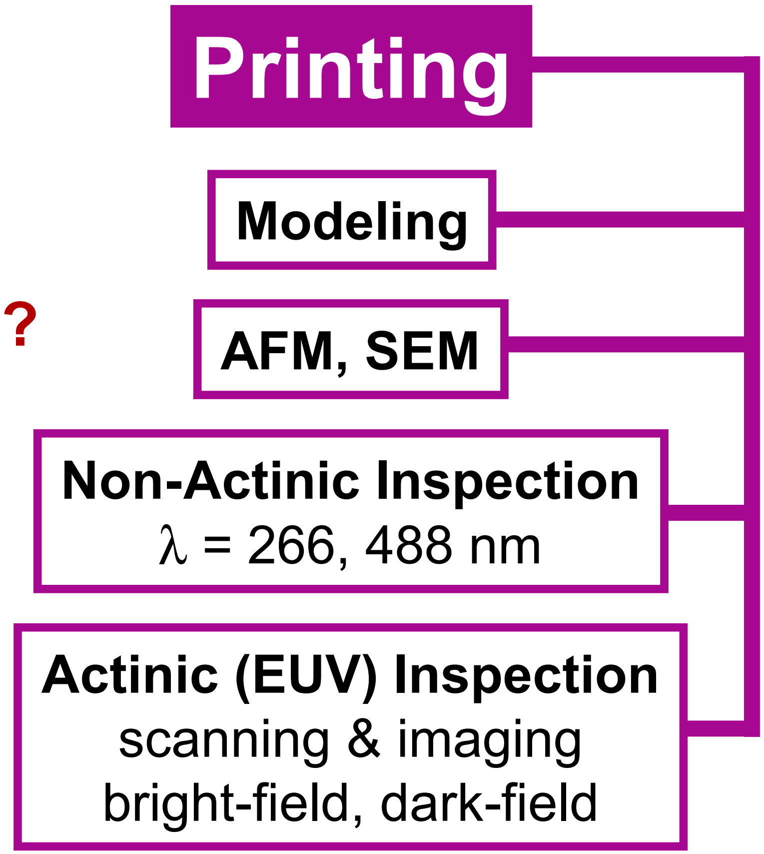
- Can we detect all printable defects?
- Are there "**actinic-only" defects?**
- Can mask-blank defects be **repaired?**

Pattern/Proximity Defects

- Can we use **aerial image data** to improve modeling?

Inspection tools

- **Performance**?
- Does inspection cause **damage?**



cross-comparison is the path to greater knowledge

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Different wavelengths see different ML structures

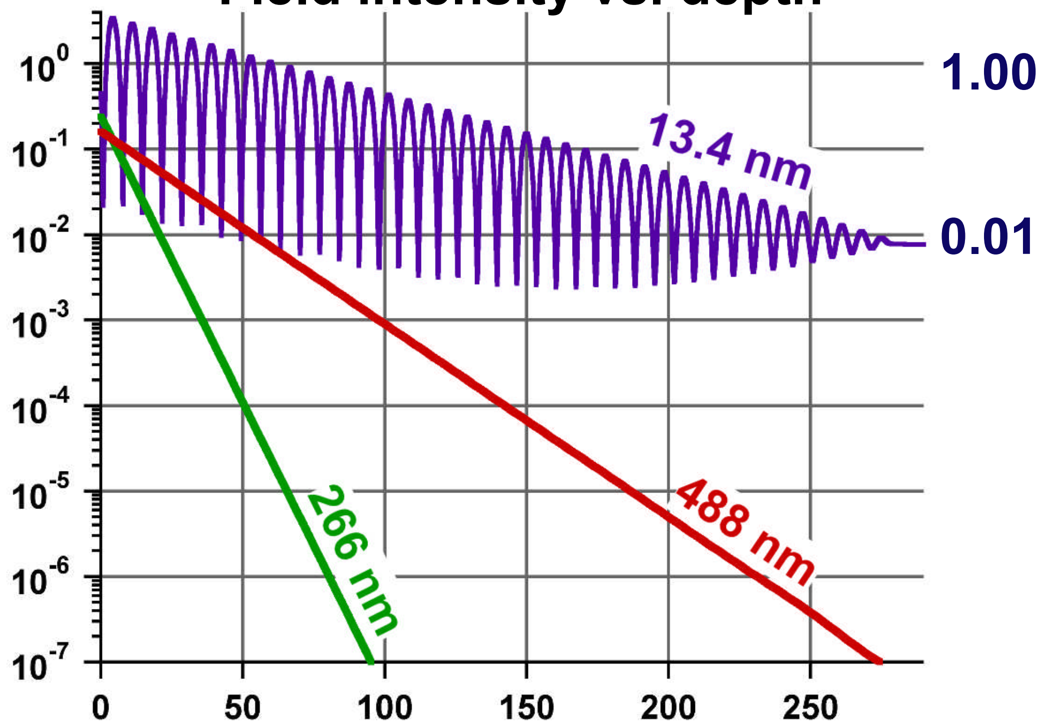
- **EUV light penetrates deeply** into the resonant ML structure
- **488-nm** and **266-nm** light barely reaches below the surface

Field Penetration for three λs

λ	"1%" depth	bi-layers
13.4 nm	215 nm	31
488 nm	53.6 nm	8
266 nm	20.6 nm	3

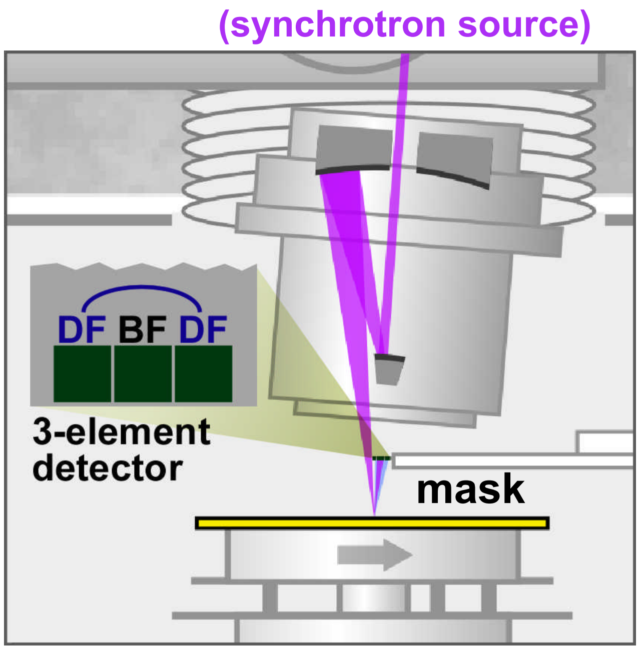
At-wavelength testing *probes the actual multilayer response.*

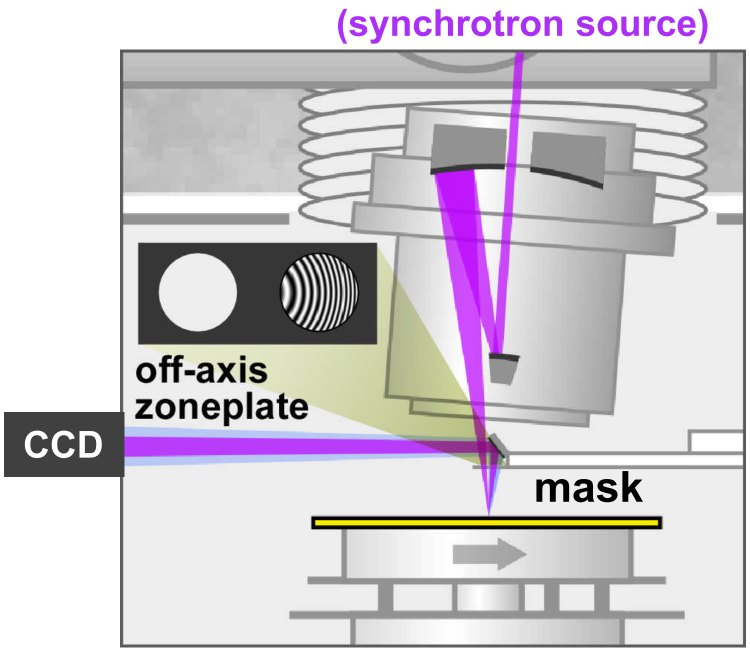
Field intensity vs. depth



The SEMATECH Berkeley Actinic Mask Inspection Tool

Worldwide, this is the only EUV mask inspection tool offering **imaging** *and* **scanning** in **dark-field** *and* **bright-field** modes.





Scanning reveals open-field defects, measures subtle mirror reflectivity changes not seen without EUV light.

Imaging uses a zoneplate lens to measure the aerial image directly, testing defect printability models without printing.

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SEMATECH Actinic Mask Inspection tool is fully operational

Scanning & Imaging in routine daily operation

Scanning

Bright-field *Reflectivity testing*
→ ≥1 μm spot
→ *R* measurements to ±0.1%

Dark-field *Scattering*
→ Finds printable defects
not seen by non-actinic tools.

Region-of-Interest identification
→ Used to locate regions of
interest for imaging.

*We find **actinic-only defects**, in dark-field and bright-field.*

Imaging

Exposure Time
→ **0.3–1.5 s** alignment & navigation
→ **20–35 s** for highest resolution

Resolution
→ **~100 nm**, Mask
~25 nm, 4× Wafer equivalent

Magnification
→ **~700x**, *direct to EUV CCD*

***NA* = 0.0625** (0.25 NA, 4x stepper)

***Higher resolutions** and custom pupil shapes are possible.*

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Actinic scanning-mode: *a 1-μm reflectometer*

Our **focused beam** probes **surface reflectivity** and **scattering** *micron-by-micron*.

ALS Beamline 6.3.2 **Reflectometer** (absolute *R*)	≥ 300 x 10 μm
Berkeley Actinic Mask Inspection scanning **Focal Spot** (relative *R*)	5 x 5 μm 3 x 3 μm 1 x 1 μm

In 2006 we studied:

- The **sensitivity** of actinic & non-actinic inspection tools
- The EUV response of open-field **defect-repair sites**
- **Damage** caused by mask inspection

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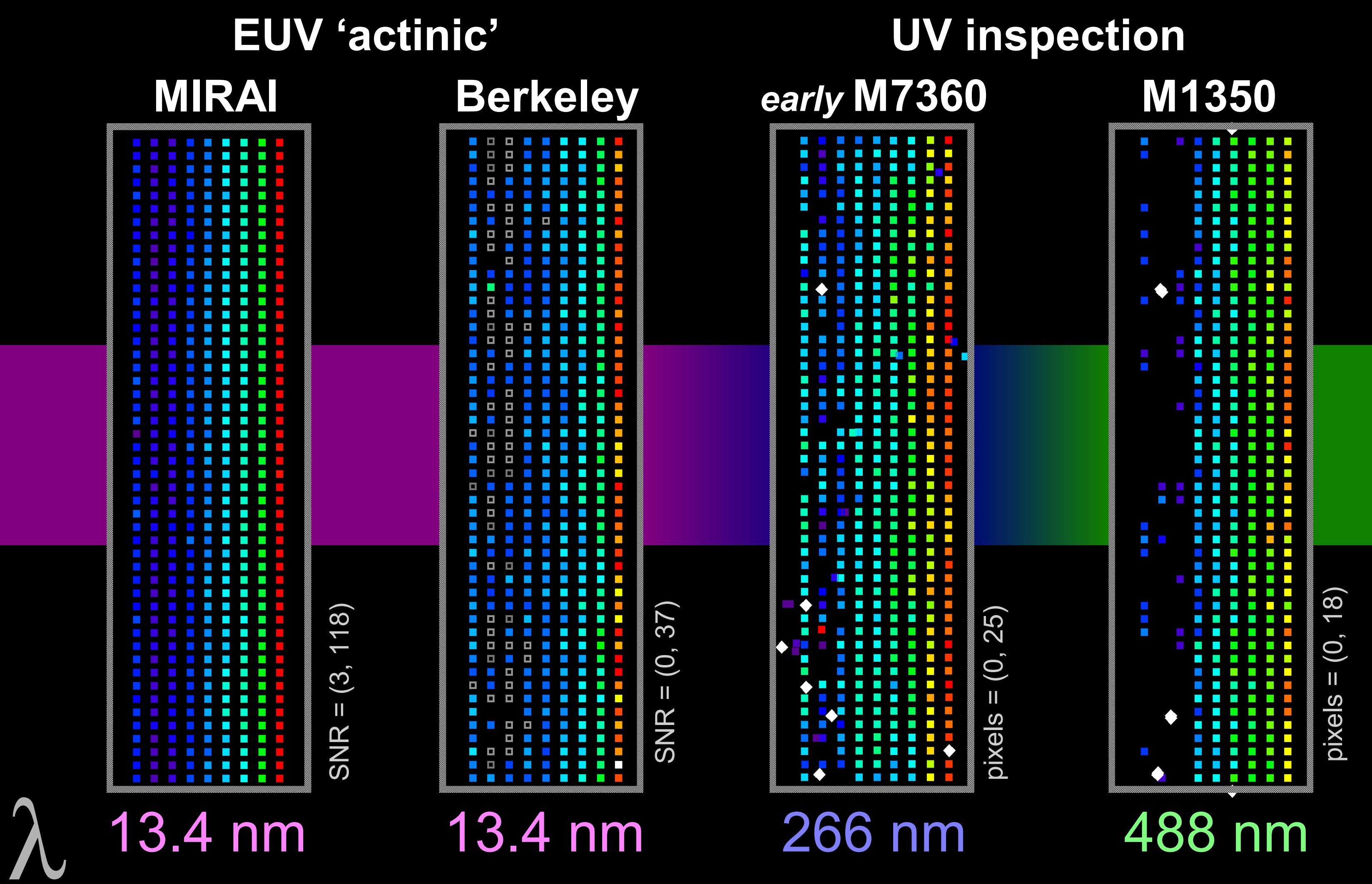
Earlier comparison of 4 inspection tools. . .



Goldberg, *et al.*, *JVST B 2006*

In collaboration with ***Lasertec,***
Y. Tezuka, T. Terasawa, P. Kearney

Bright-field revealed defects that do not scatter

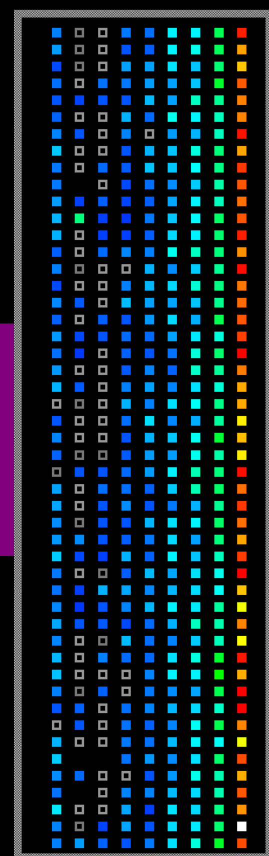
Phase defects **scatter** well
→ *buried bumps and pits*

Surface particles and contamination **absorb light** and scatter poorly,
→ especially µm-scale defects

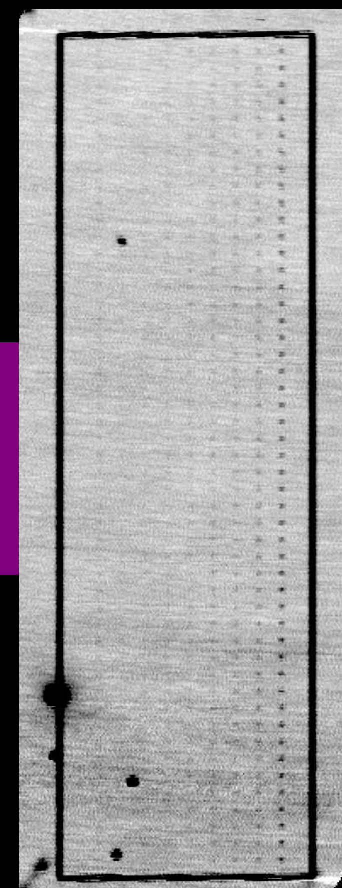
Actinic **DF only** could miss critical defects

BF only doesn't have enough sensitivity

EUV
dark-field
scattering



EUV
bright-field
reflectivity



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In collaboration with ***Lasertec,***
Y. Tezuka, T. Terasawa, P. Kearney

A multilayer-coated blank with 14 repair sites

Zeiss NaWoTec

Group I
A,B,C,D,E

Sites were etched as ditches (pits) with shallow sidewall angles in the range of 2°–4°.

Group II
F,G,H,I,J

SiO_2 was deposited in different thicknesses: 1.5–12 nm

Group III
K,L,M,N

Defects etched into the top layer to different depths. The area was covered with a ~5 nm SiO_2 protection layer

Note: *An ideal repair recipe was not found here, but we learn from the measurements.*

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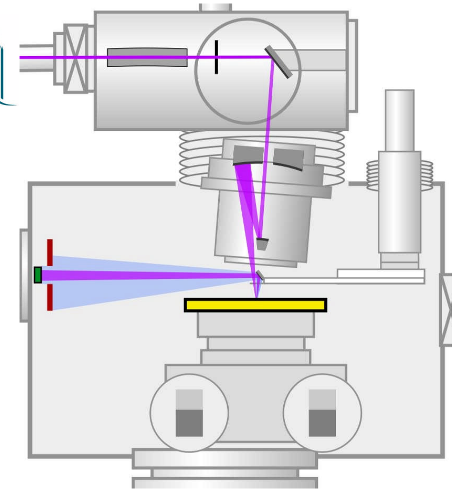
The repair sites were measured in five ways

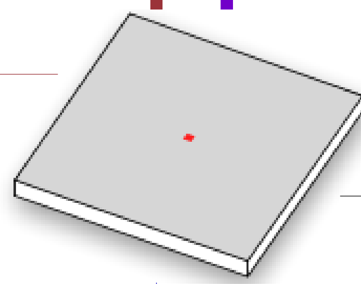
M1350

λ = 488 nm
Sematech N.
defect review

SEMATECH

Actinic (EUV)
BF / DF
scanning





Zeiss, NaWoTec

defect-repair mask

QuickTime™ and a
IFF (Uncompressed) decompressor
are needed to see this picture.

SEM

AFM

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

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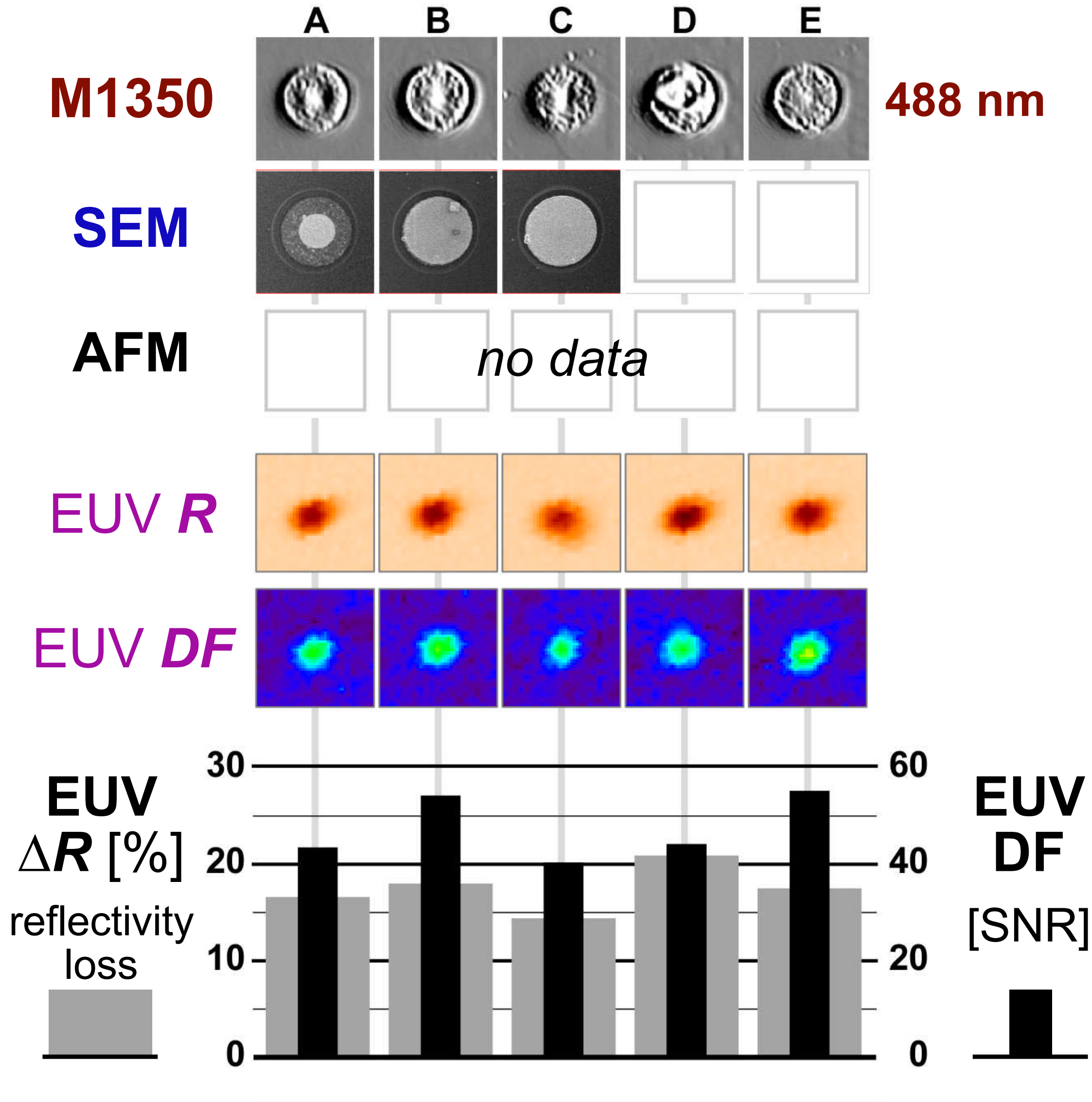
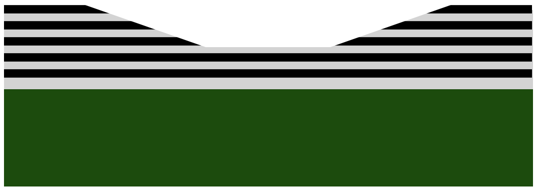
Measurements of Group I: *shallow ditches*





M1350:
→ High contrast

EUV:
→ Strong reflectivity loss
→ **Strong scattering**

sites dramatically
re-direct the beam

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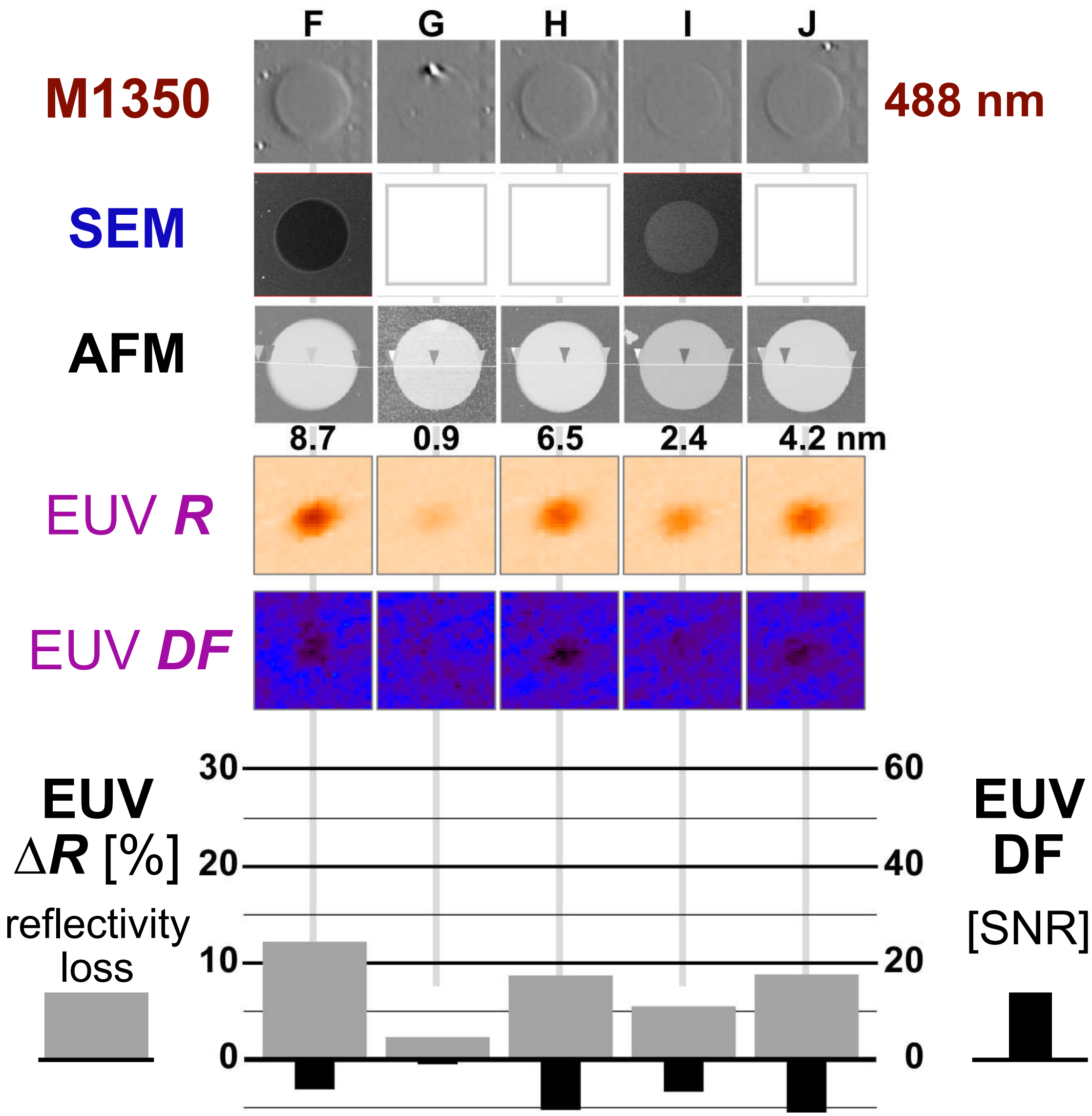
Measurements of Group II: *SiO_2 deposition*



M1350:

→ Low contrast

EUV:

→ Moderate reflectivity loss

→ **Suppressed scattering**

Absorption eliminates scattered light. Reflectivity drops with SiO_2 thickness.

$\Delta R \approx -1\%$ for 2 nm SiO_2

2007 SPIE 6517-11
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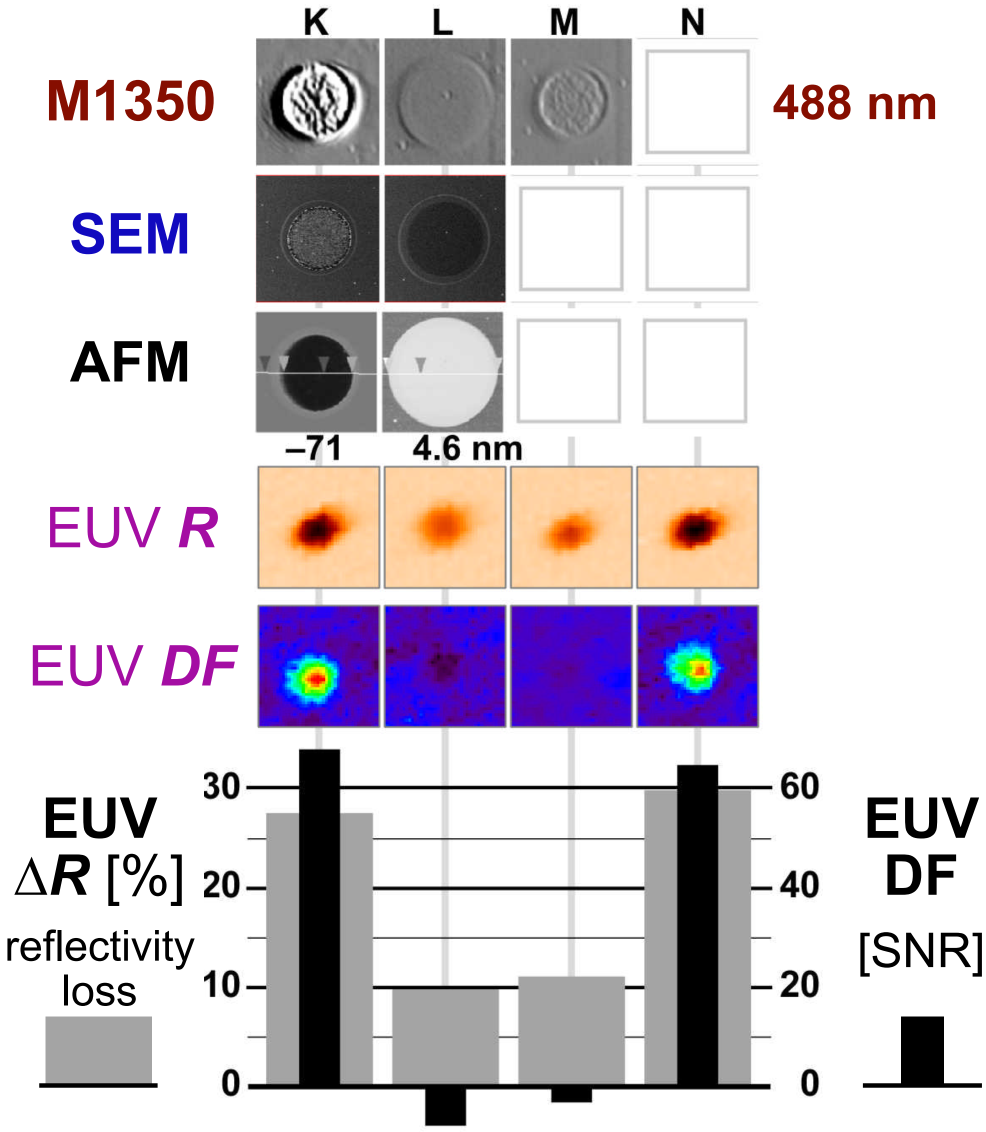
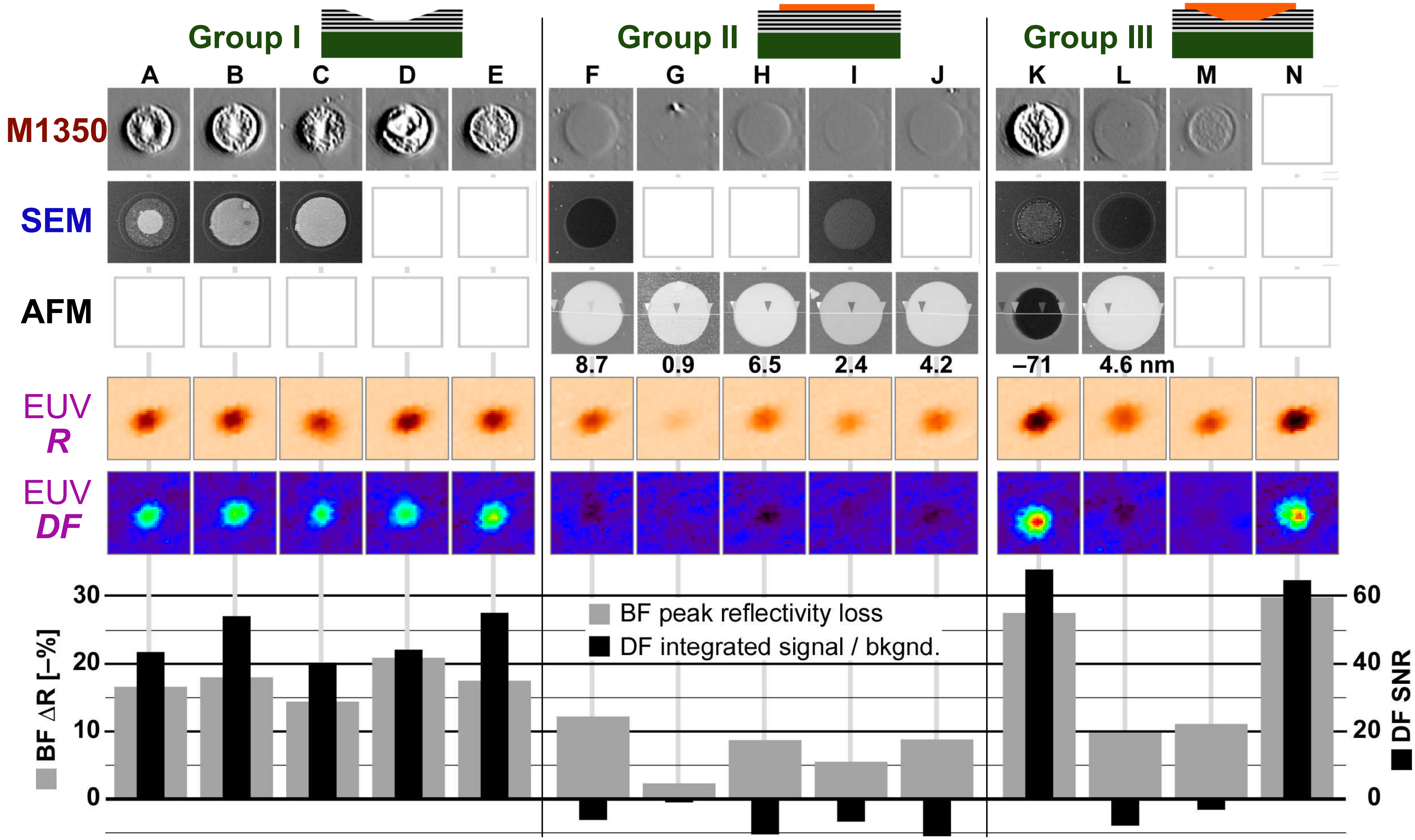
Measurements of Group III: *SiO_2 ditch protection*



M1350:
→ Mixed results

EUV:
→ Mixed results

Some sites scatter strongly, others absorb light



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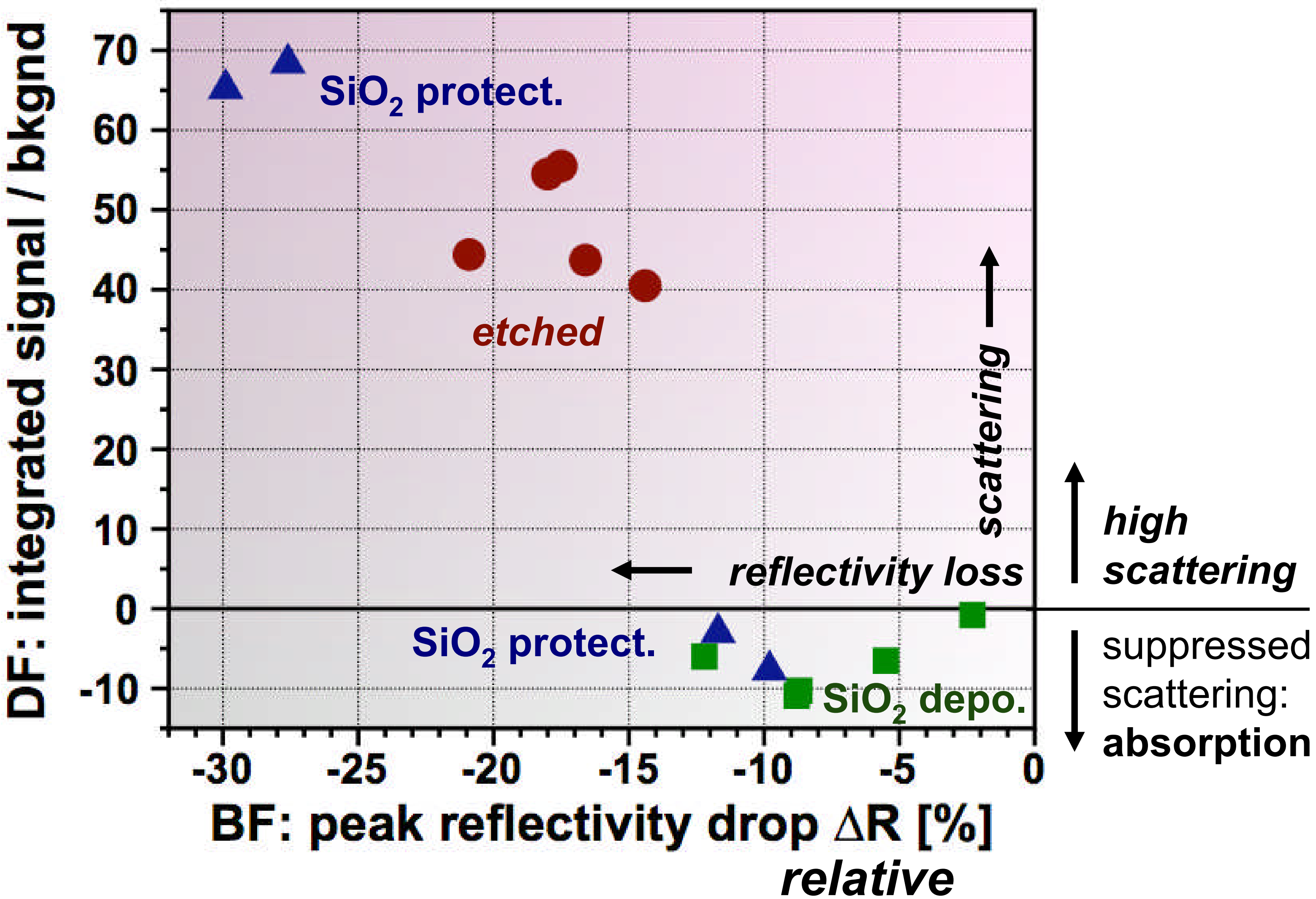
Actinic BF and DF correlation has no single trend



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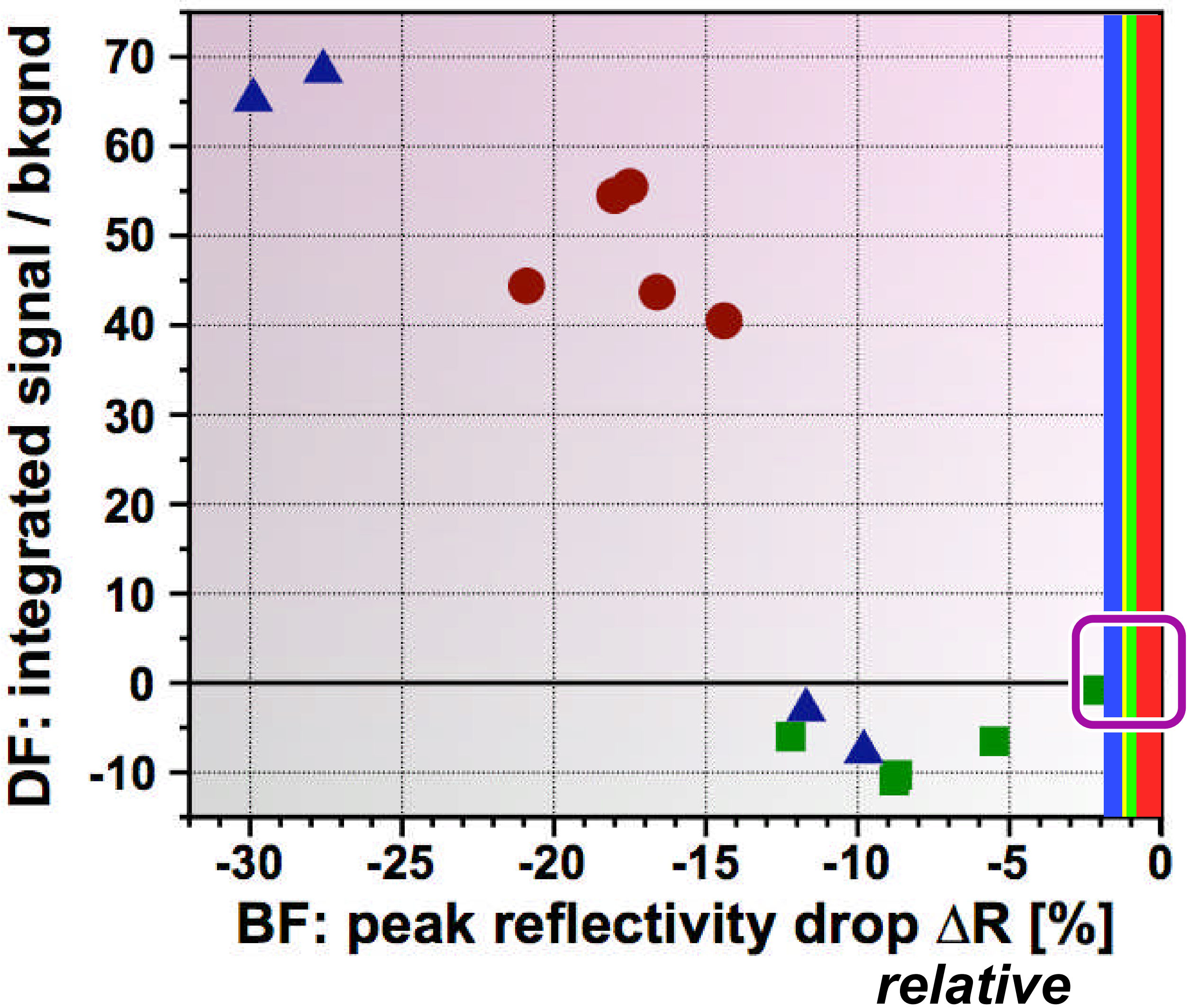
These sites are well beyond the SEMI P-38-1103 reflection uniformity standard



<u>Allowed Δ***R*** (abs)</u>

Class A: ≤ 0.5%

Class B: ≤ 0.7%

Class C: ≤ 0.8%

Class D: ≤ 1.2%

Perhaps the correlation here matters little since we are **so far beyond the allowed Δ*R***

Perhaps we should only consider *this* region

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Discussion

EUV light penetrates deeply into the resonant structure.
UV inspection probes the surface only: *depth* = 20–50 nm (3–8 bi-layers)

In *scanning-mode* the SEMATECH Berkeley actinic tool operates like **a 1-μm EUV reflectometer**.

We learn from measuring repair-test sites,
although an **ideal repair recipe** of this type was **not found**

Actinic inspection with **DF-only** or **BF-only** can miss critical defects!
- **DF has higher sensitivity** to small defects (due to flare, SNR, etc.)
- However, **DF may not see** μm-scale **absorptive** surface regions.

The SEMI P-38 standard may not adequately address reflectivity changes on the μm-to-mm length scale.

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Additional Topics

- Inspection damage
- Imaging pattern defects
- System upgrades in progress

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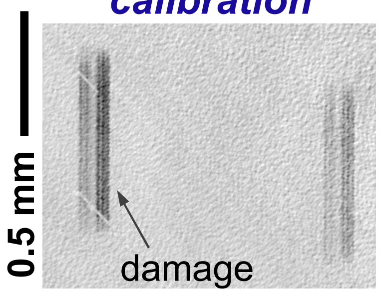
We measured reflectivity losses caused by *inspection damage*

High power inspection (all kinds) *can damage masks*

- A mask was prepared to **assess the damage threshold** of the Lasertec M7360, during qualification.
- **Actinic BF** saw narrow damage ($\Delta R_{rel} \leq -6\%$) at high power.
  – Some of the regions are ***undetectable*** in the Lasertec tool itself.
- Damaged areas may be **too small** for normal reflectometry.

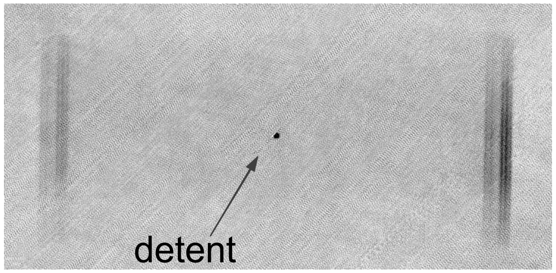
Actinic BF scans of Lasertec inspection regions **intentionally damaged** with different operating modes and power levels.

calibration



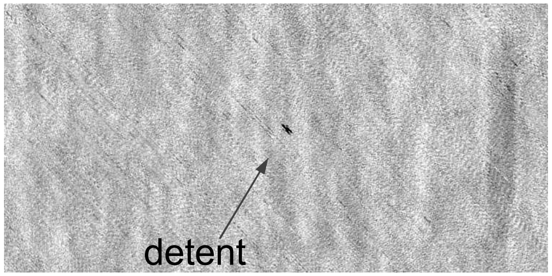
5 @ full power
ΔR_{max} = –5.4%

defect review



20 @ full power
ΔR_{max} = –2.1%

defect review



1 @ lower power
ΔR_{max} = –0.8%

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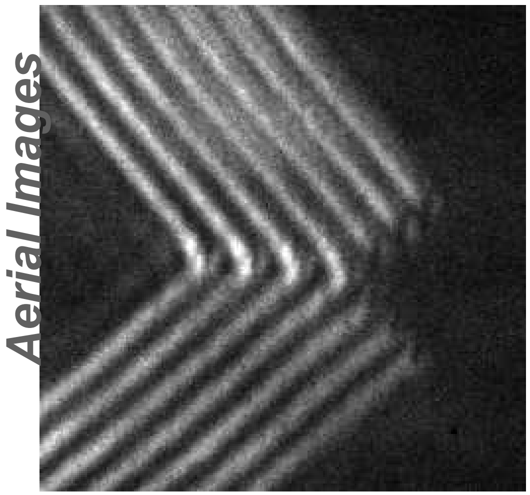
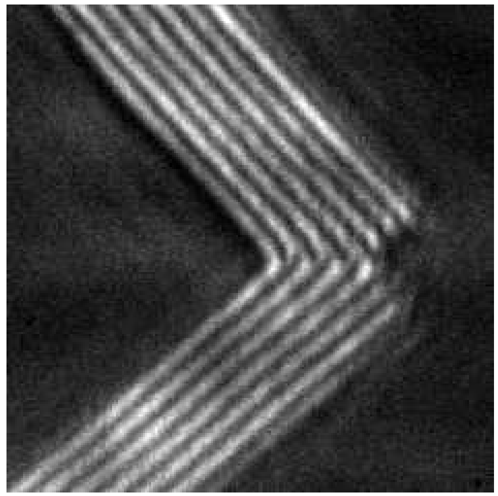
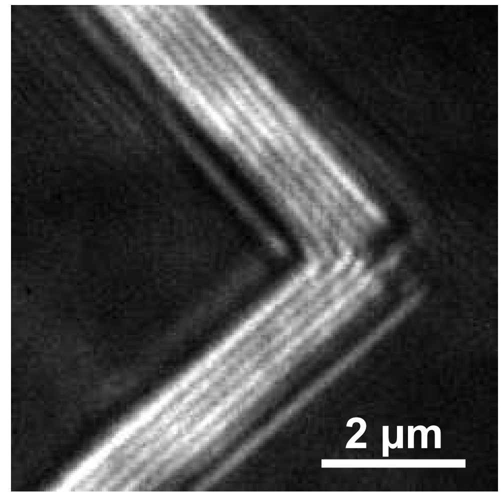
In collaboration with
***Lasertec,* P. Kearney, H. Kusunose**

Early tests resolved elbow images down to 100-nm (mask), 25-nm (4x wafer equivalent)

- **System Resolution** is currently designed to match a 4×, 0.25-NA stepper.
- **Illumination:** 6° incidence. Partial coherence: $\sigma_x > 1.0$, $\sigma_y = 0.7$







half-pitch: 250 nm	**150 nm**	**100 nm** (mask)
62.5 nm	**37.5 nm**	**25 nm** (4x wafer equiv.)

Imaging is performed with **EUV light, directly**

- There is **no scintillator**, **no conversion** to visible light, and **no microscope** objective.
- Consequently the measurements are **linear**.

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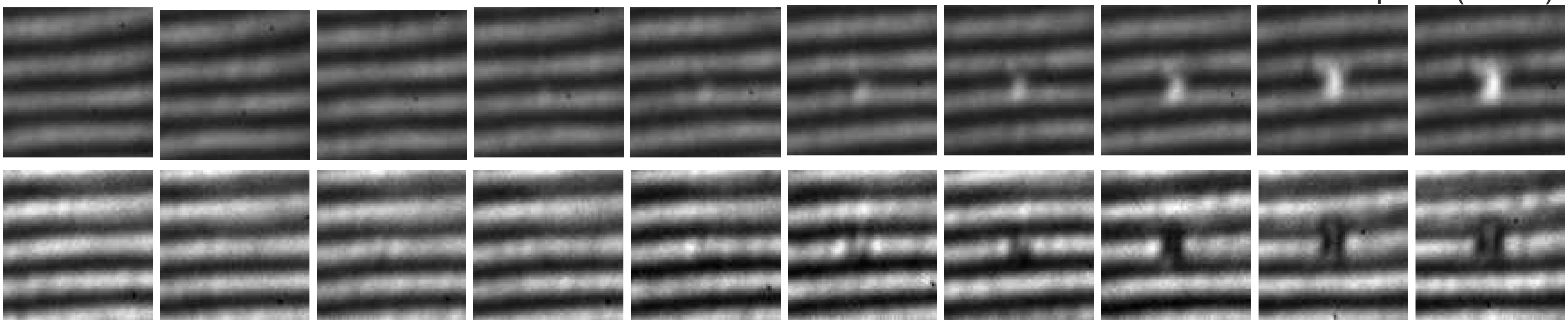
In collaboration with
T. Liang, *Intel*

Measuring the aerial image: size series, through focus, and repair sites

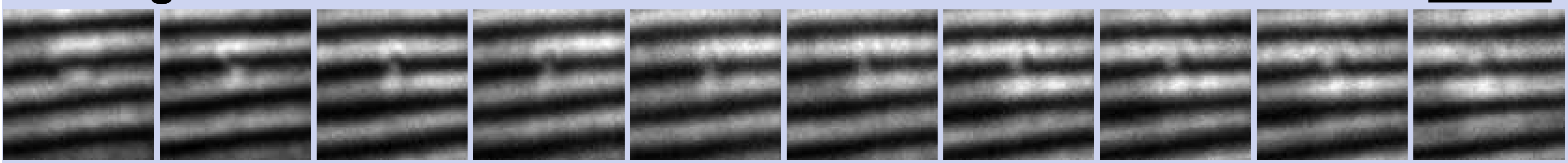
Size series: bright and dark defects

300 nm half-pitch (mask)
75 nm half-pitch (wafer)



Through-focus series

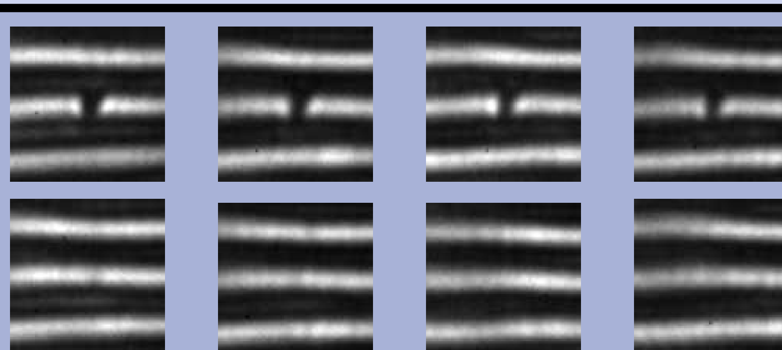
2 µm



Defect repair studies

2 µm

half-pitch: 450 nm (mask)
112.5 nm (wafer)



Complete series with ≥ 17 images were collected in **30-40 minutes.**

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In collaboration with
C. Holfeld *AMTC*, B. LaFontaine *AMD*

AMD ADVANCED MASK TECHNOLOGY CENTER SEMATECH

Actinic tool performance upgrades: *in progress*

- New **vibration stabilizer**
- **Through-focus actuation** with ~50-nm height resolution
- Higher-quality **zoneplate lens** with features to help align the pupil
- **Ultra-flat turning mirror** to remove small-scale distortions in imaging
- **Incident-beam photo-diode** for absolute *R* calibration
- **Various alignment aids**

And special thanks to. . .

LBNL: Seno Rekawa, Drew Kemp, Ron Tackaberry, Su-Jane Lai

LLNL: John Taylor

Intel: Erdem Ultanir, Ted Liang, Alan Stivers

Zeiss: Klaus Edinger

SEMATECH: Stefan Wurm, Kim Dean

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