SEMATECH Berkeley Actinic Inspection Tool (AIT)

“Benchmarking Mask Imaging with the Actinic Imaging Tool”

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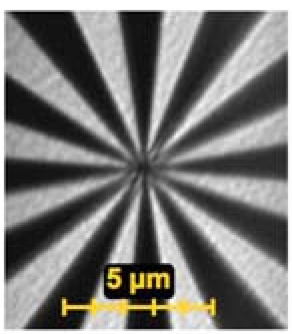
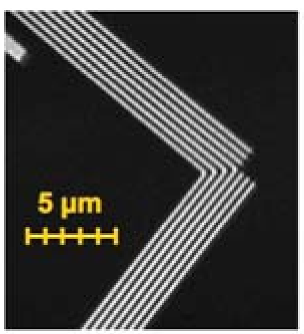
SEMATECH: Patrick Kearney, Wonil Cho

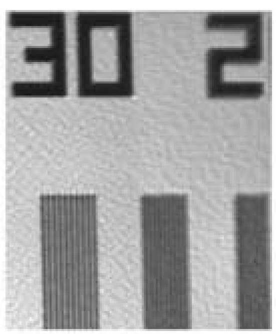
LBNL: Ron Tackaberry, Paul Denham, Jeff Gamsby, David Attwood



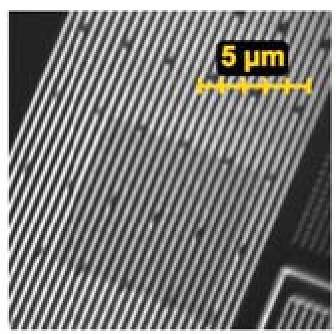
resolution test pattern
actinic image



200-nm hp elbows
actinic image

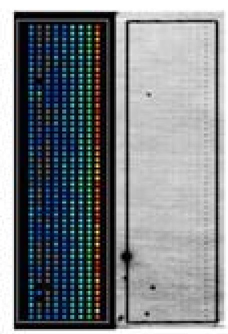


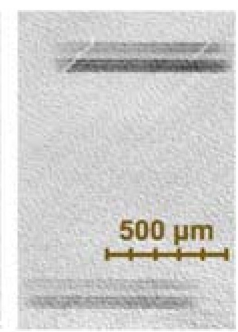
1:1 lines—clearly resolved to 125 nm hp
actinic image



defect-repair experiments
actinic image

off-axis zoneplate imaging lens
SEM


darkfield brightfield
programmed defects
actinic scans



UV inspection damage,
actinic scan

SUMMARY
aerial images through-focus • phase & amplitude defects

2007 Upgrades enabled remarkable improvement
Complete imaging-system re-design / re-build

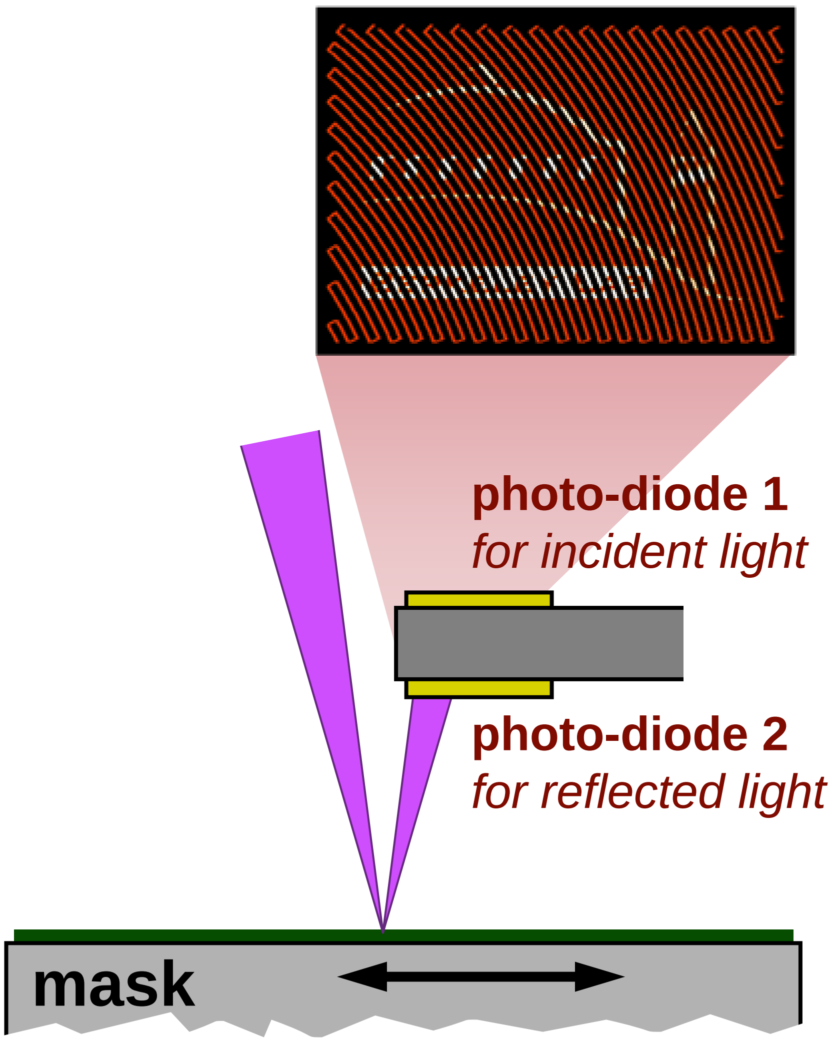
Operations are routine
April to October: 72 beam shifts, nearly 10,000 high-resolution images, individual and through-focus series

Throughput improvement
The AIT has collected up to 426 high-resolution images in 8 hours

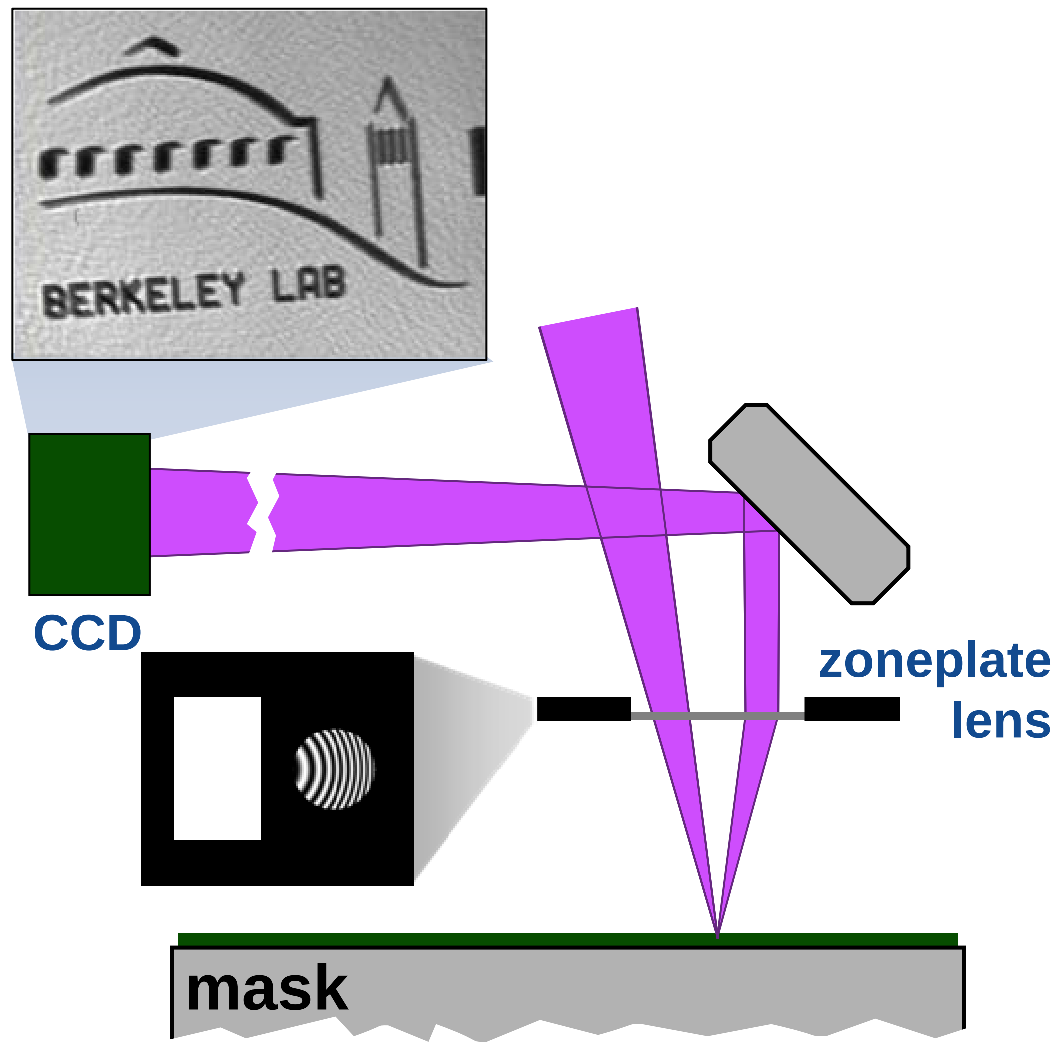
Extensive system testing
enabled optimization & provided baseline performance metrics.
SPIE Photomask, BACUS, Sept., 2007

AIT System Overview: Two modes of operation

Mask Scanning
routine operation

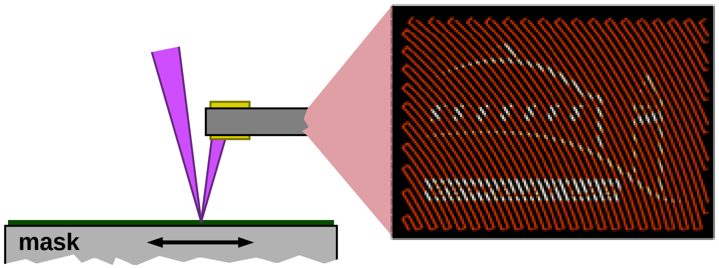


Zoneplate Imaging
routine operation



AIT System Overview: Operating Specs

Mask Scanning
routine operation

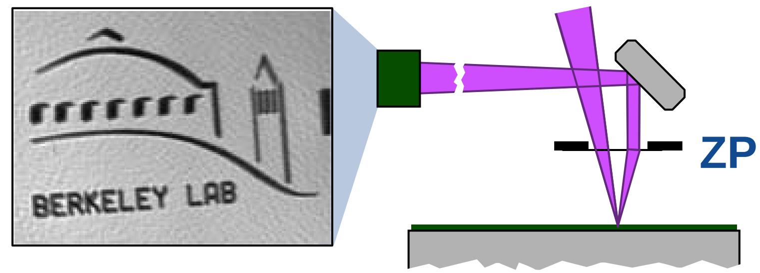


Bright-field *Reflectivity testing*
(reflectometer with a 1-μm spot)
- 1–5 μm spot size
- *R* measurements to ±0.1%

Dark-field *Scattering*
- Sensitive to small defects

Calibrated Reflectivity
- Measuring the incident and reflected signals sequentially

Zoneplate Imaging
routine operation



***NA* = 0.0625**
- like 0.25 NA, 4x stepper

Illumination
- 6° off-axis

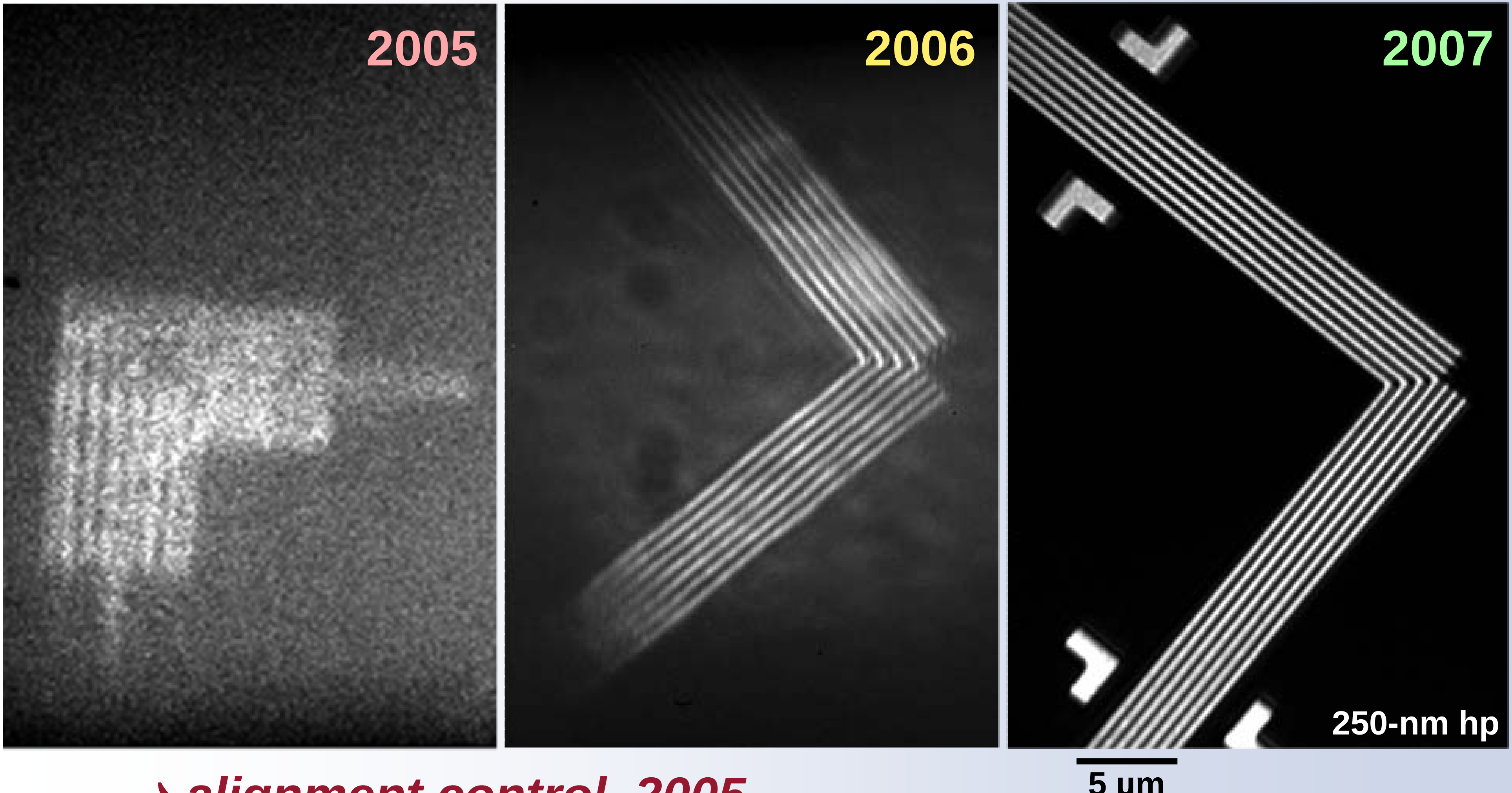
Exposure Time
- 10–30 s for high res.

Magnification
- ~670x, direct to CCD
- ~30-nm (mask) / pixel

Through-focus
- 0.05-μm *z* resolution
- > 0.1-μm steps

Field Size
- ~30-μm diameter
- 8-μm target quality area

Imaging Improvement: 2005 → 2006 → 2007 →

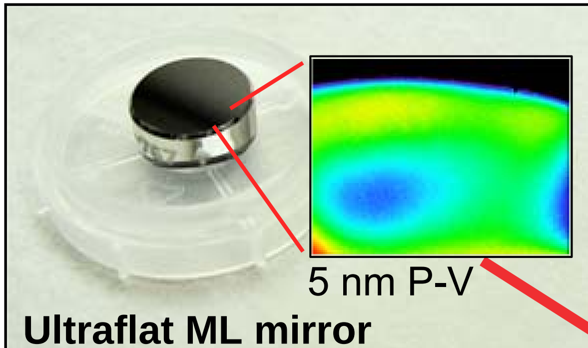


→ alignment control, 2005

→ vibration mitigation, 2006

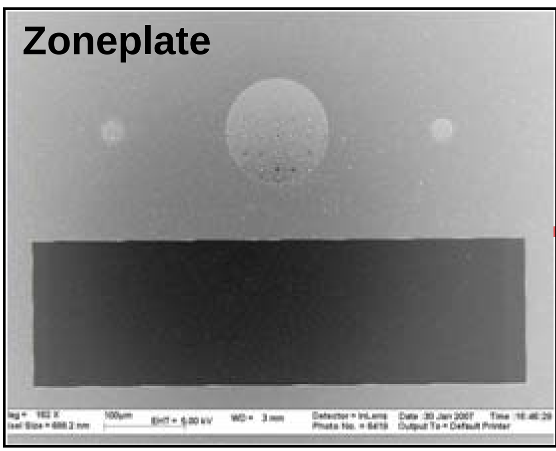
→ optics redesign / overhaul, 2007

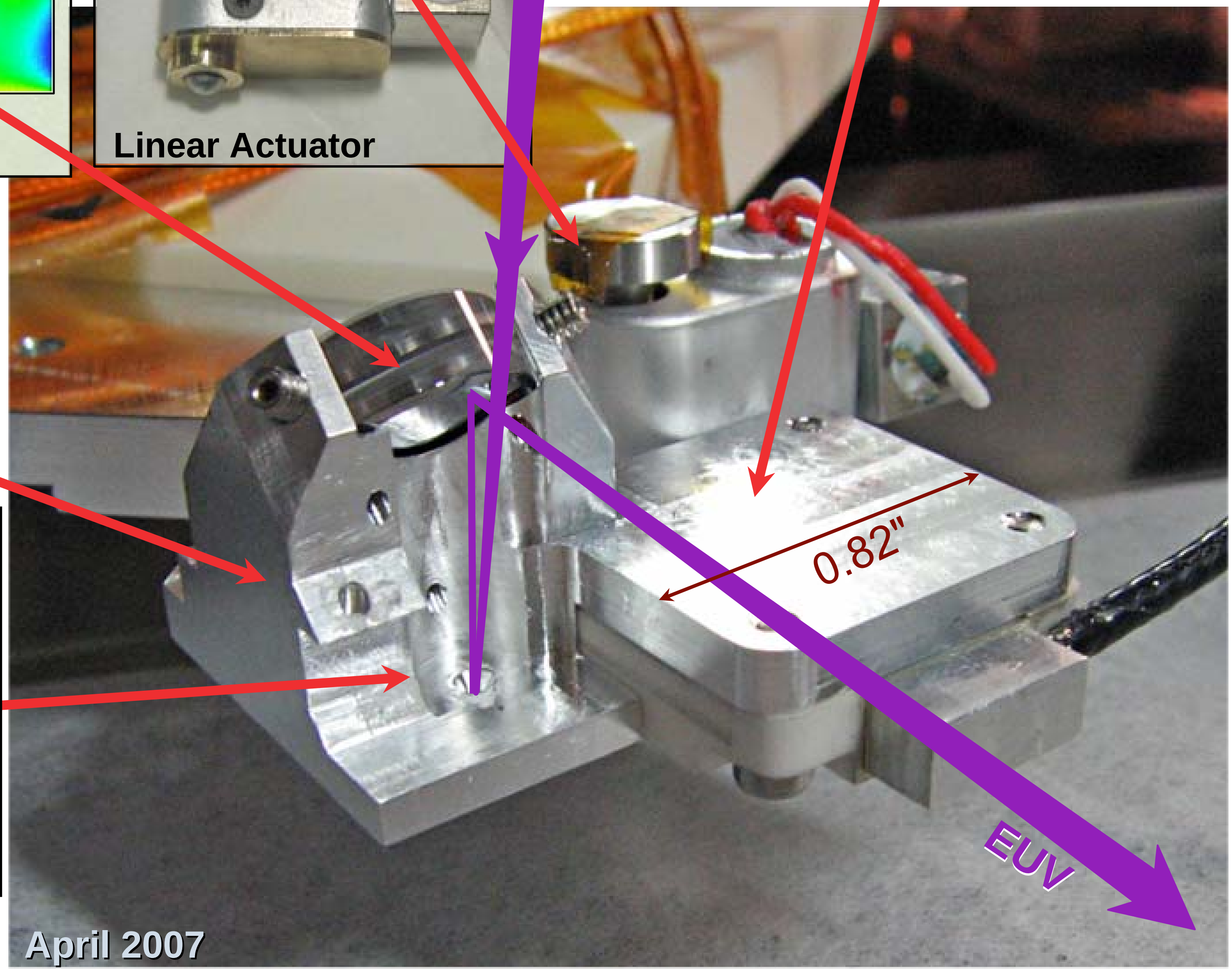
A new, multi-function, zoneplate focus-control holder makes high-quality imaging possible



Height Sensor
cap gauge provides
~0.2 μm *z* resolution

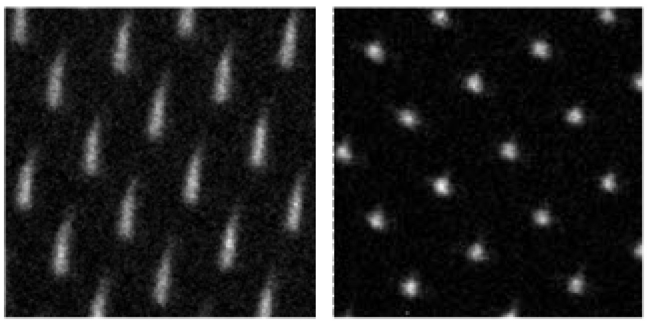
Alignment aid
hole and cross-hair
for initial beam-angle
alignment

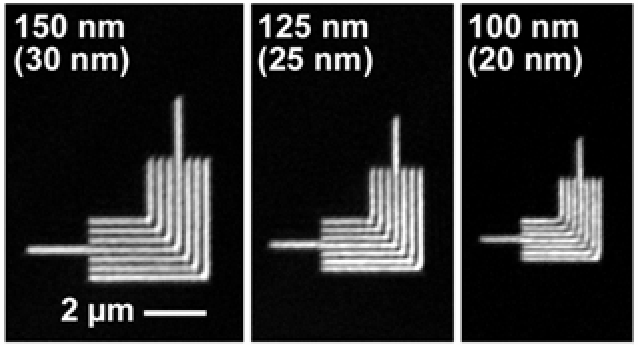


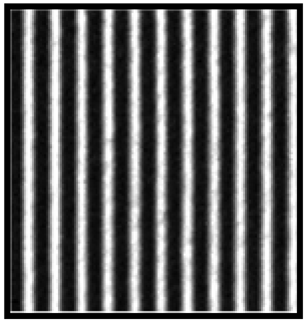


Performance Testing includes several metrics

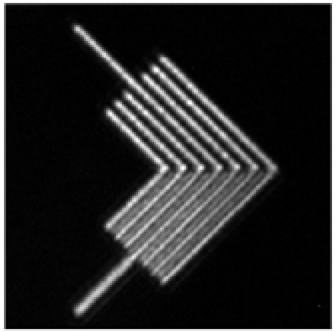
Significant Improvement
comes from careful system performance testing

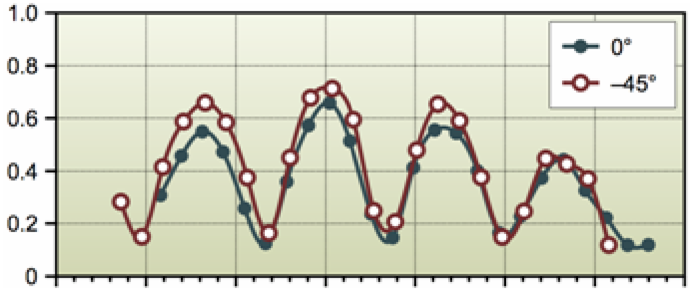


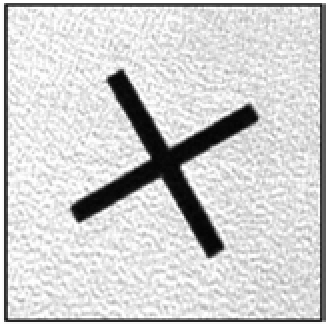


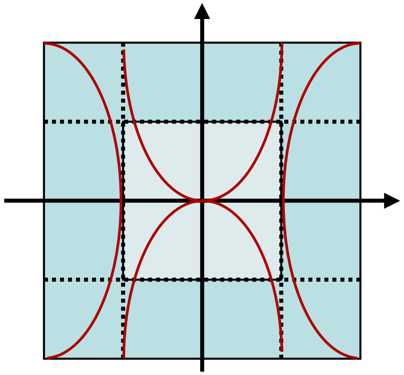


Illumination bandwidth control **Resolution testing** **LER / LWR**





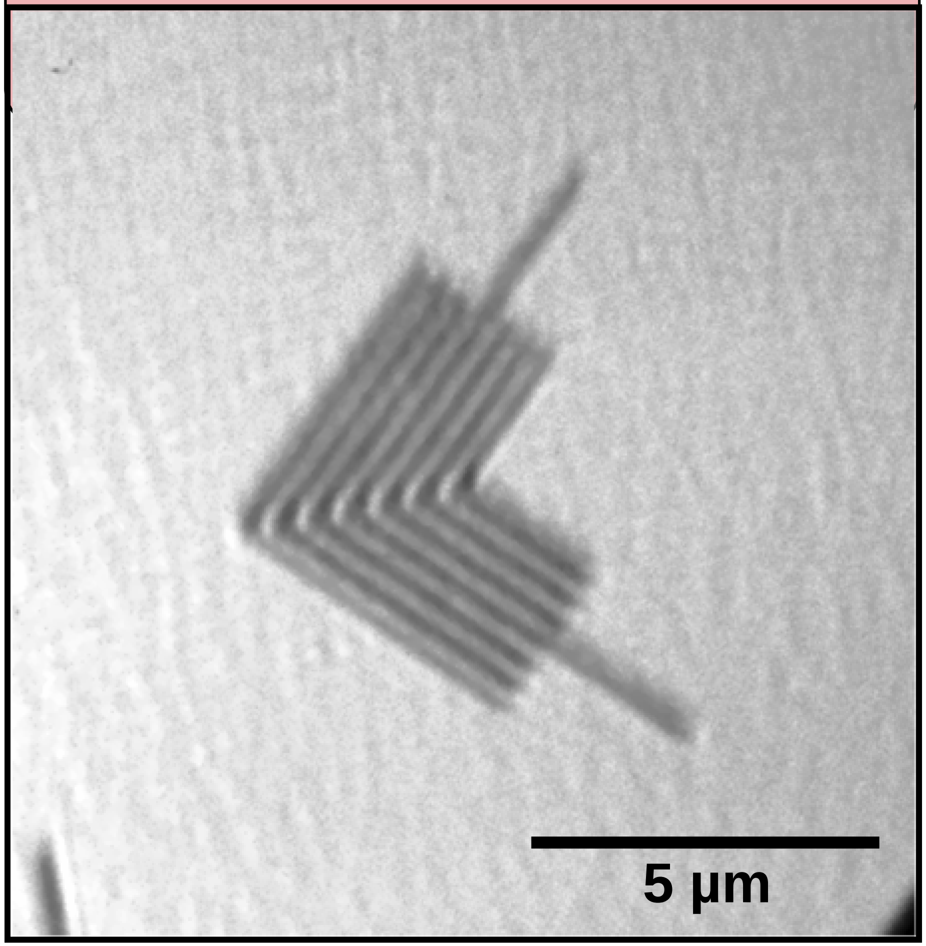




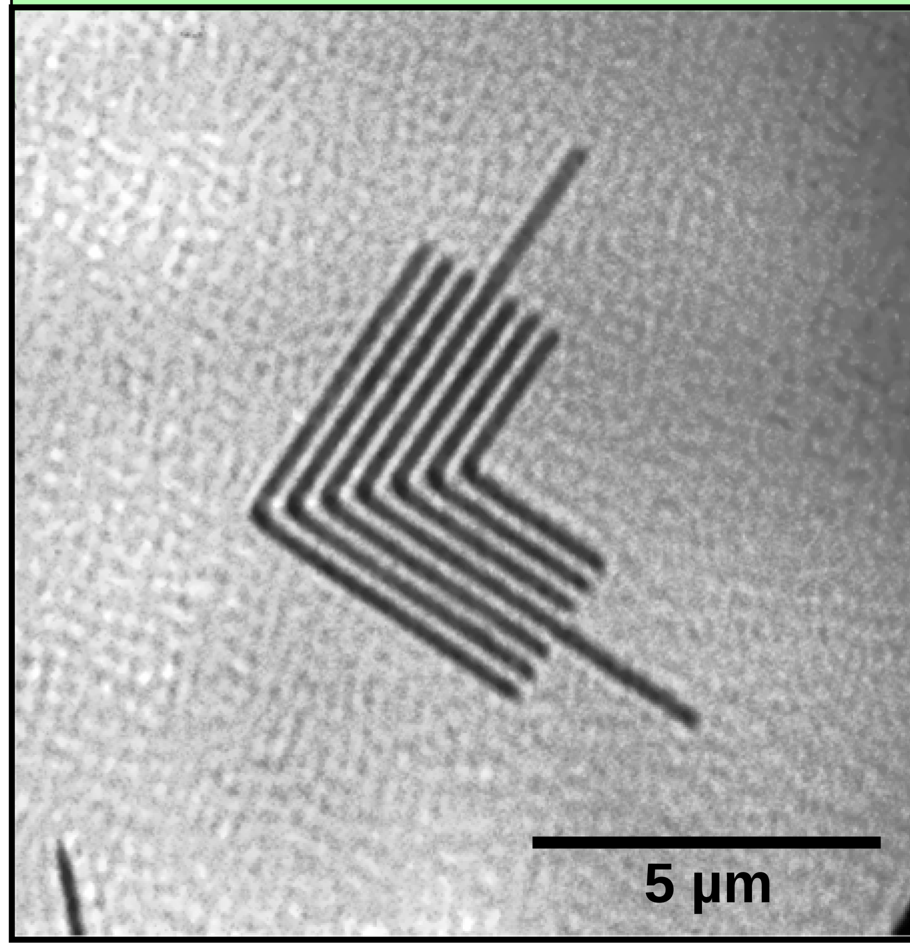
Aberrations **Coherence** **Flare** **Field of view**

Optimization leads to much sharper imaging and greater understanding.

July 25th, 2007 (before optimization)



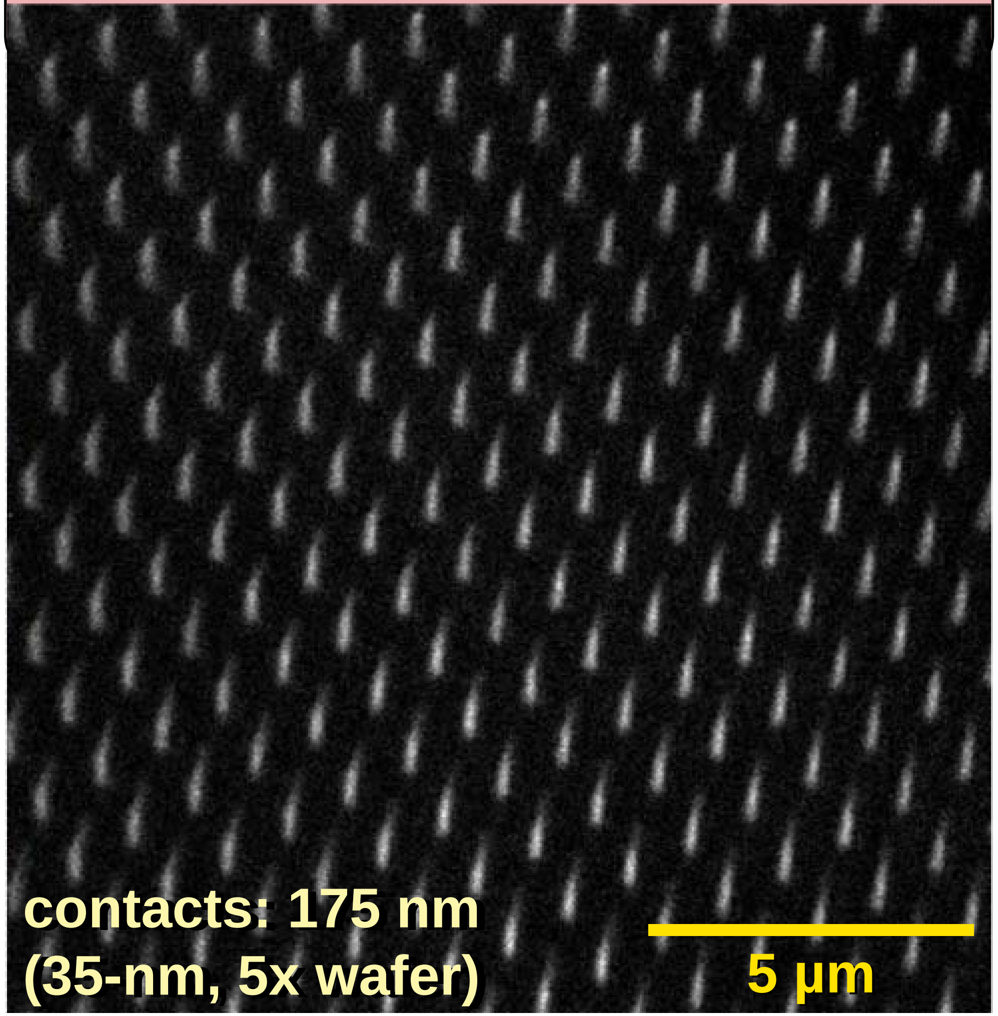
August 28, 2007 (after optimization)



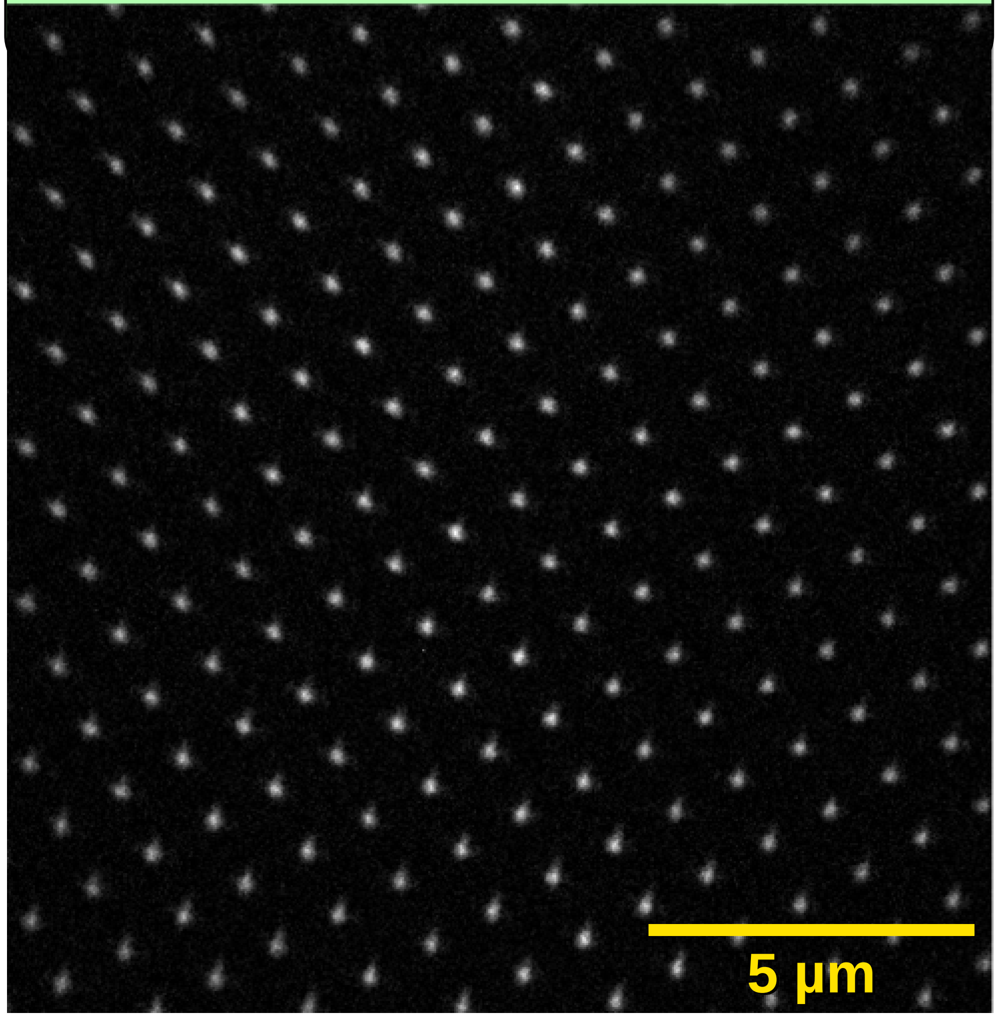
175-nm-hp on the mask
35 nm (5x wafer equivalent)

The zoneplate lens imposes a strict bandwidth limit
Contacts can reveal chromatic aberration

$\lambda / \Delta\lambda$ = 175 (0.57% BW)
broad-band



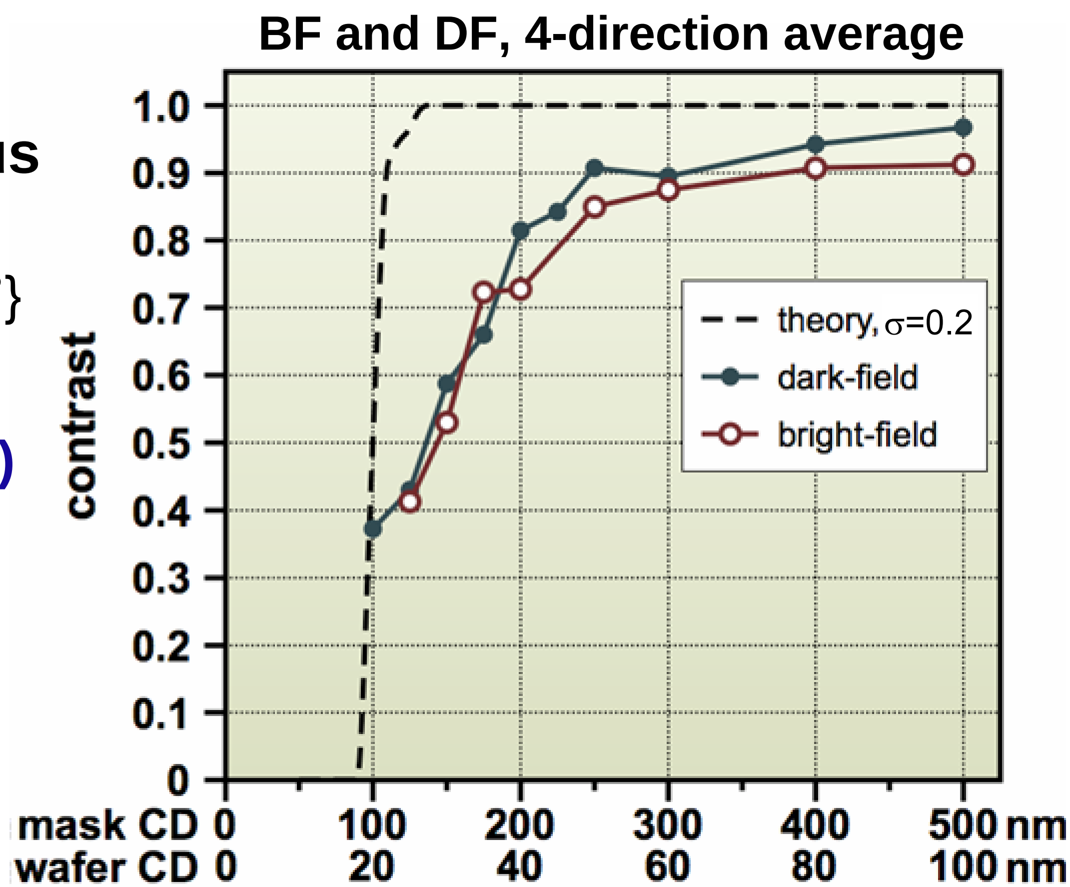
$\lambda / \Delta\lambda$ = 1370 (0.07% BW)
narrow-band



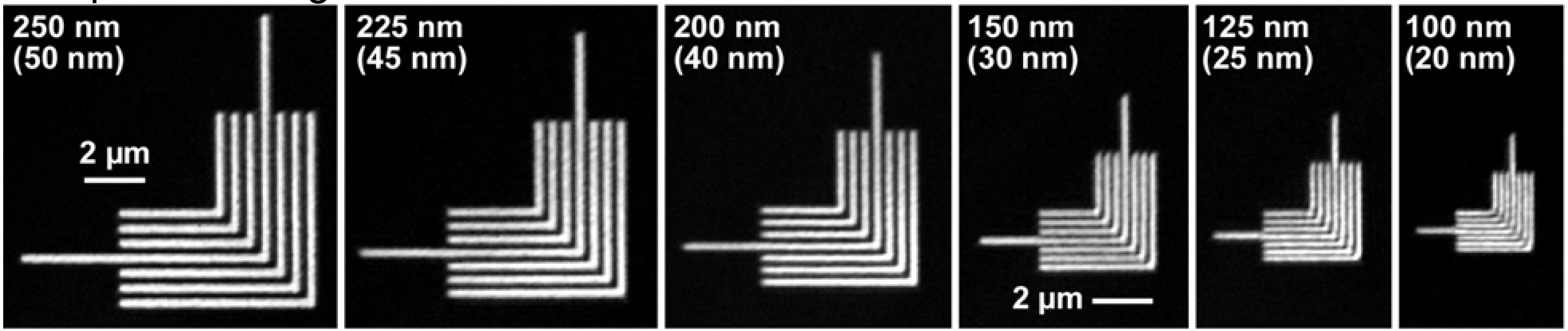
The bending-magnet's monochromator has **tuneable λ and $\Delta\lambda$**

CTF *(contrast transfer function)*

- **Measured contrast at best focus for a range of CD values**
  four direction avg. {0°,90°,45°,–45°}
- **Smallest features recorded**:
  100-nm 1:1 dark-field elbows **(mask)**
  (**20-nm** 5x wafer equivalent)
  (**25-nm** 4x wafer equivalent)
- Theoretical values are for σ **= 0.2** with no aberrations.



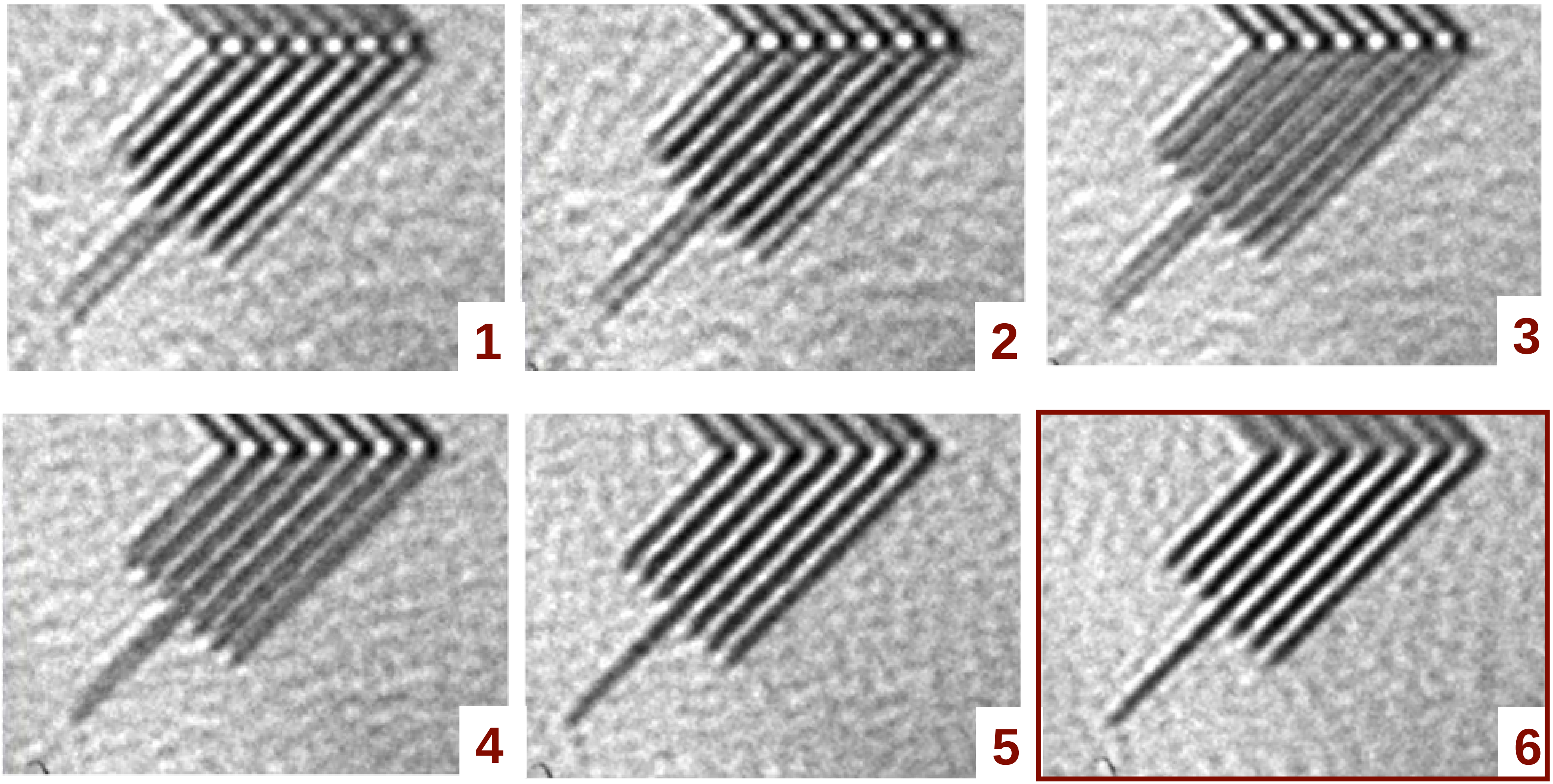
Sample test images



Measured coherence **is higher than anticipated** due to current illumination conditions

Measurement: Moving through focus, line-pattern contrast oscillates: *coherence.*

through-focus series



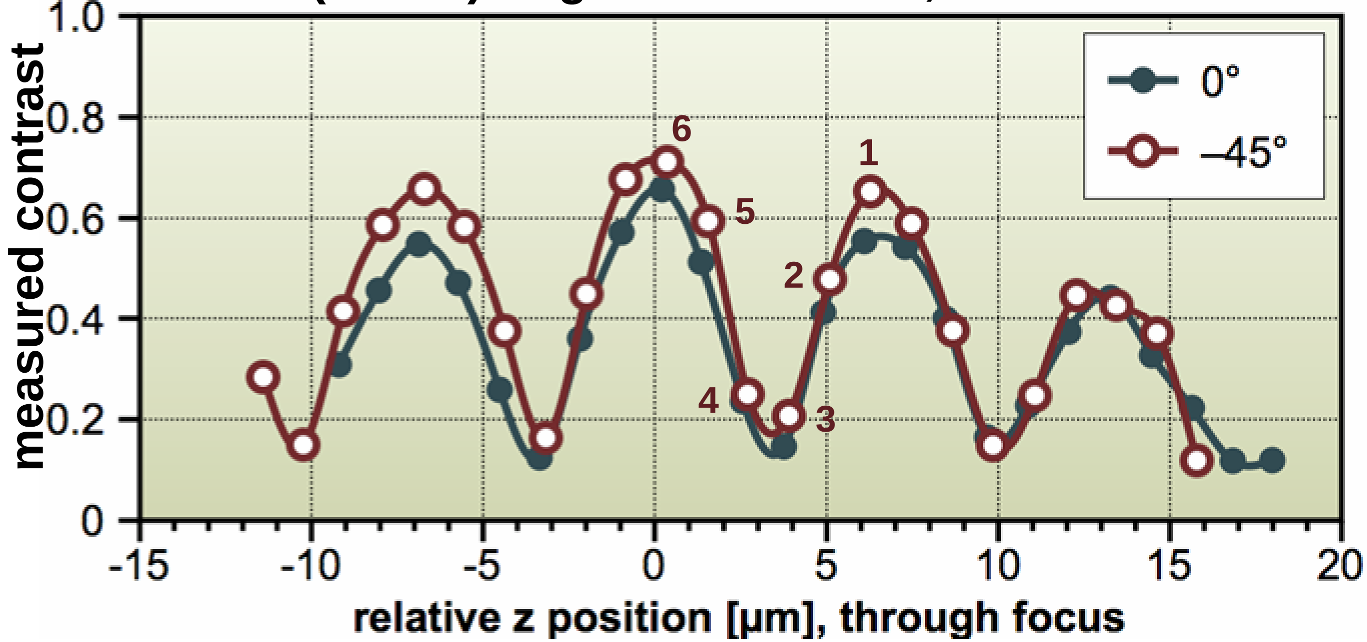
best-focus

150-nm (30-nm 5x) bright-field elbows, *static illumination*

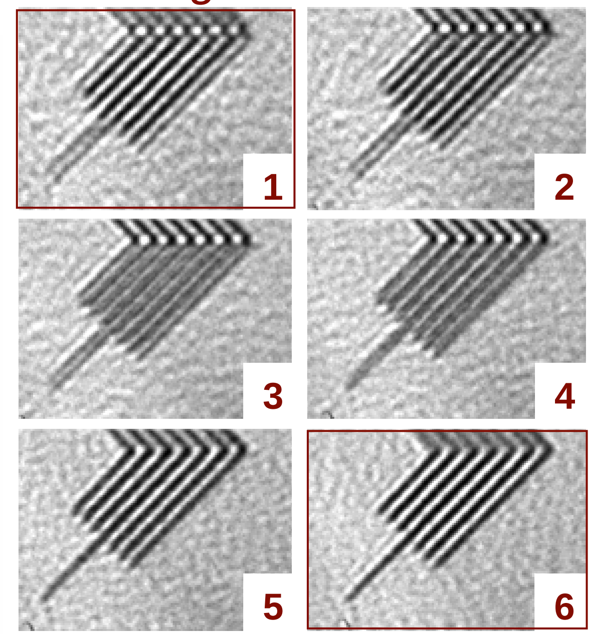
Measured coherence **is higher than anticipated** due to current illumination conditions

Measurement: Moving through focus, line-pattern contrast oscillates: *coherence.*

150-nm (30-nm) bright-field elbows, *static illumination*



through-focus series

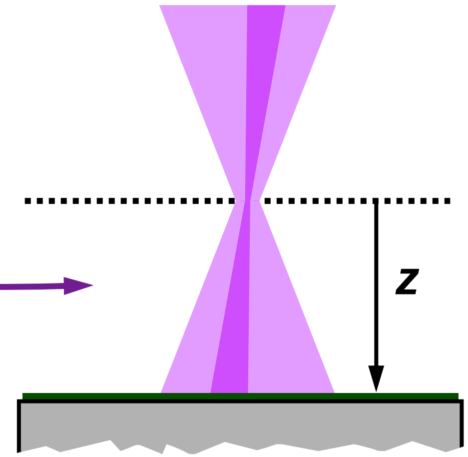


best-focus

Coherence: Measured σ ≤ 0.2.

WHY? AIT effective mask-illumination angle is narrow.

SOLUTION: Increase σ by *“scanning”.*
Must balance uniformity and σ requirements.



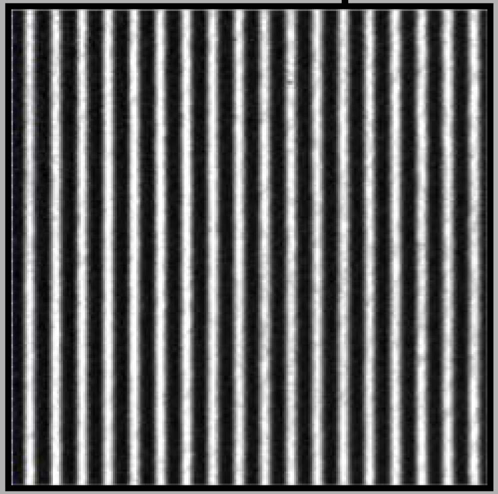
Aerial image tools can provide Mask LER data independent of photoresist properties

- Mask LER/LWR measurements require **uniform illumination** or careful calibration.
- Measurements are **sensitive to coherence**.
- We observe **small-scale intensity variation** that likely arises from mask roughness & coherence. This will affect the measured Mask LER/LWR.
- Illumination non-uniformity occurs on a longer length scale and **may be normalized** mathematically if the mask pattern is large and periodic.

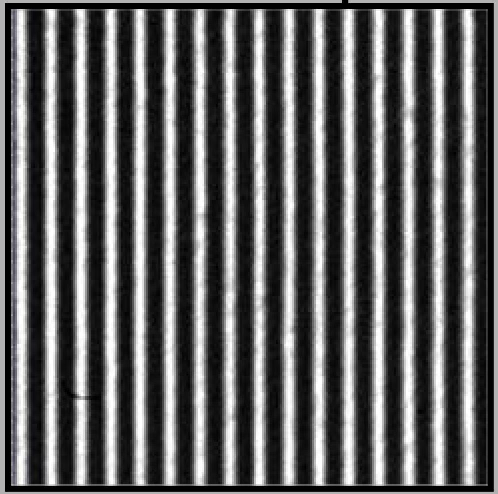
CD (5x wafer)	mask LWR* [nm]	mask LER* [nm]
250 (50)	**21.8 (4.4)**	**16.1 (3.2)**
220 (44)	**18.6 (3.7)**	**13.8 (2.8)**

* Values recently measured on one test mask.

220 nm hp



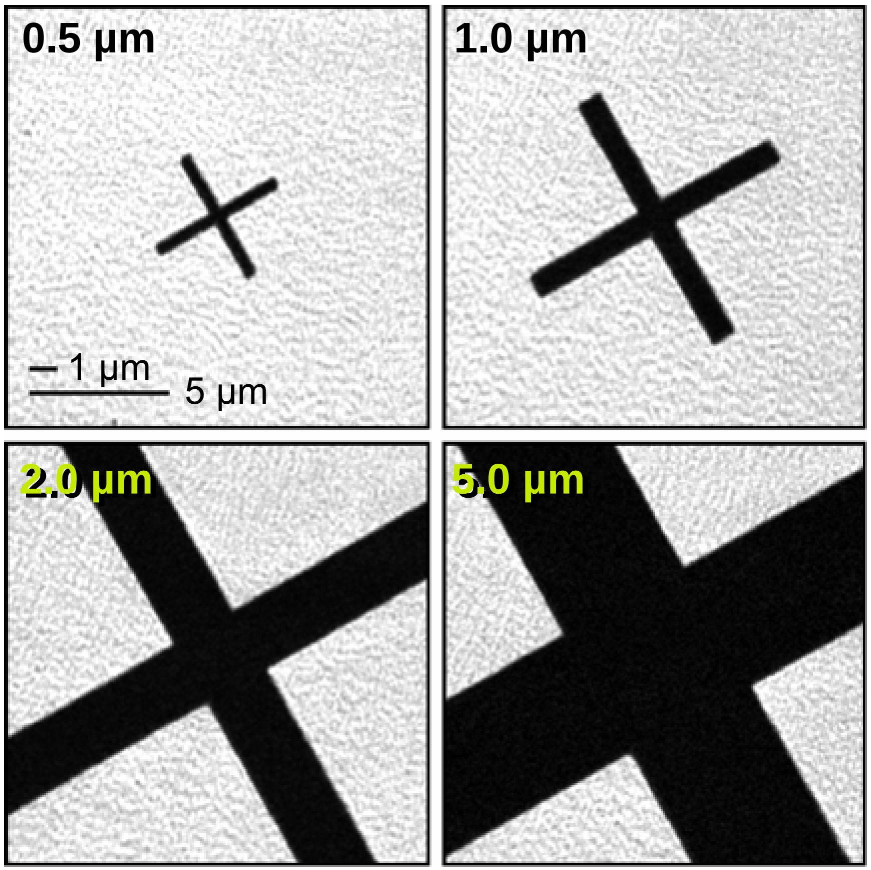
250 nm hp

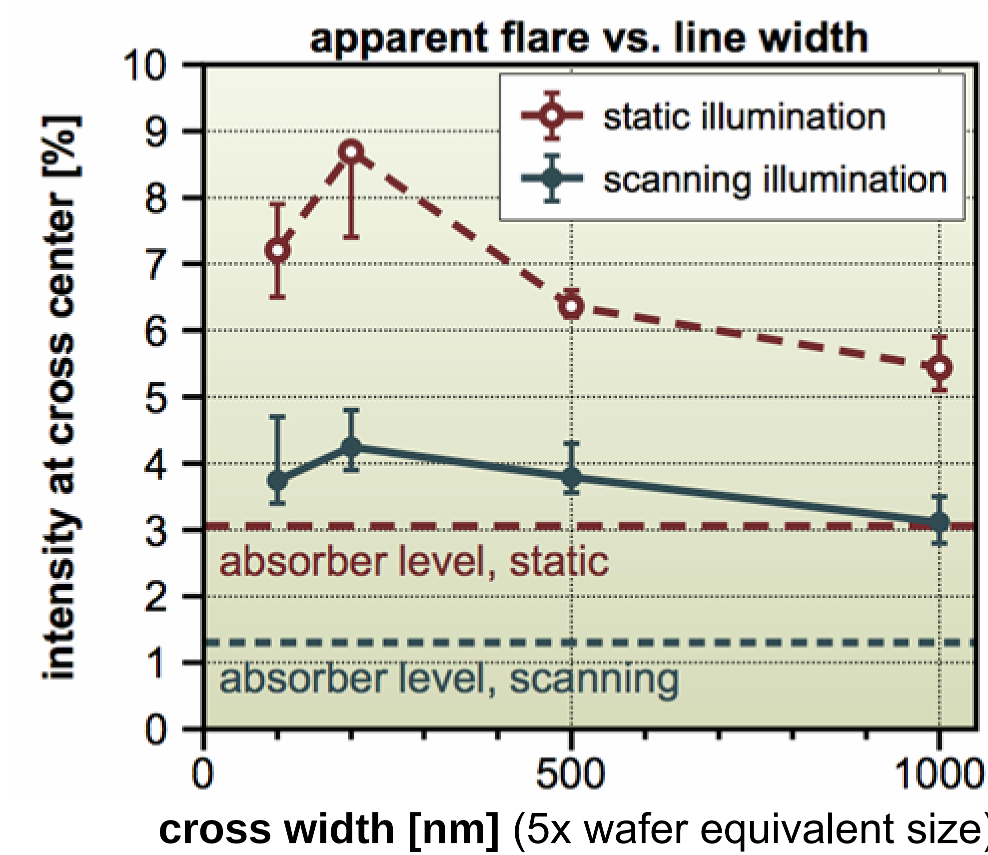


***8-µm wide** regions used for LER/LWR calculation*

Zoneplate lens flare is 2–3%

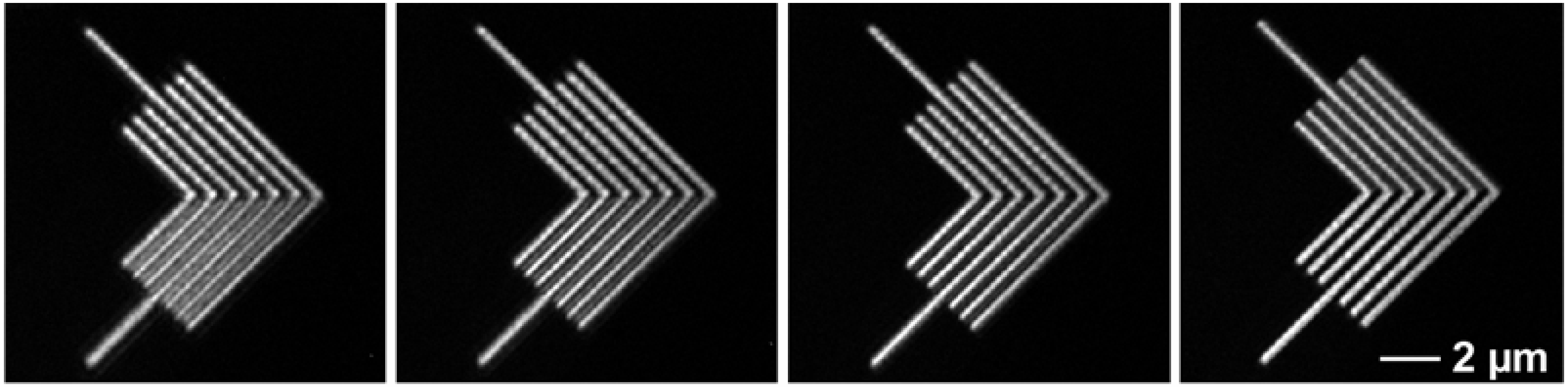
- **Flare was a major (*unknown*) concern for zoneplate imaging.**
- **Bright-field cross** measurements show that the flare intensity is **only 2–3%** above the absorber background reflectivity level.
- “Static illumination mode” has higher dark intensity b/c there is no shutter; light exposes the CCD during readout—***We will install a shutter soon.***





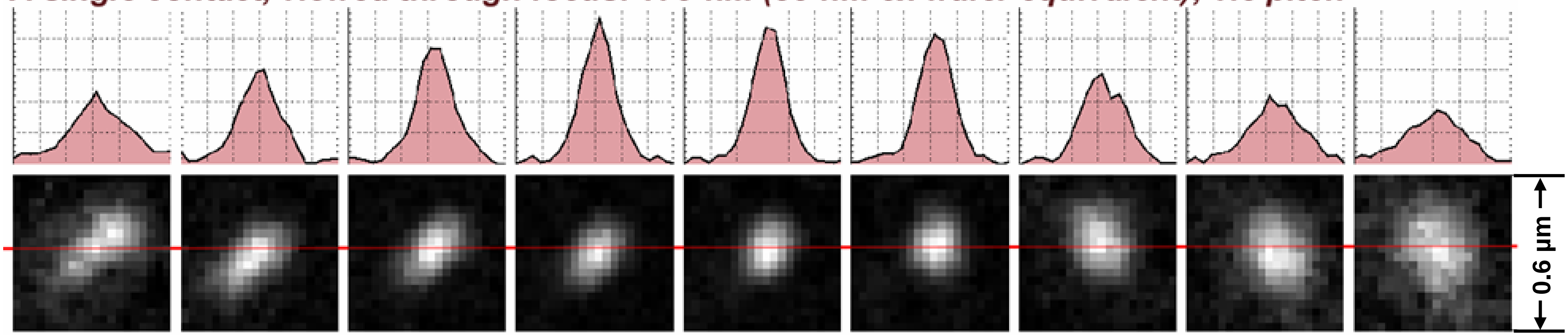
Astigmatism is currently the primary aberration at the center of the CCD field

- **Astigmatism is field-position dependent** → *we can find the "zero-point."*
- Elbows & contacts are very sensitive to astigmatism.
- *Astigmatic displacement,* Δ*z* = ~5 μm (~200 μm for a 5x wafer) at CCD center.
  → ~2-nm RMS wavefront error, or $\lambda_{EUV}/7$.



z = 3.35 1.15 -1.12 -3.38 μm

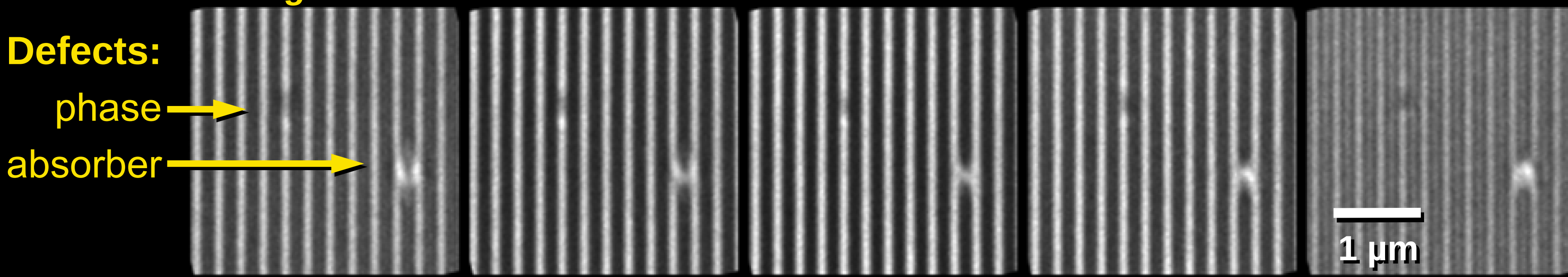
A single contact, viewed through focus: 175-nm (35-nm 5x wafer equivalent), 1:5 pitch



z = –4.15 –3.13 –2.10 –1.04 0.00 1.00 3.00 4.00 4.97 μm

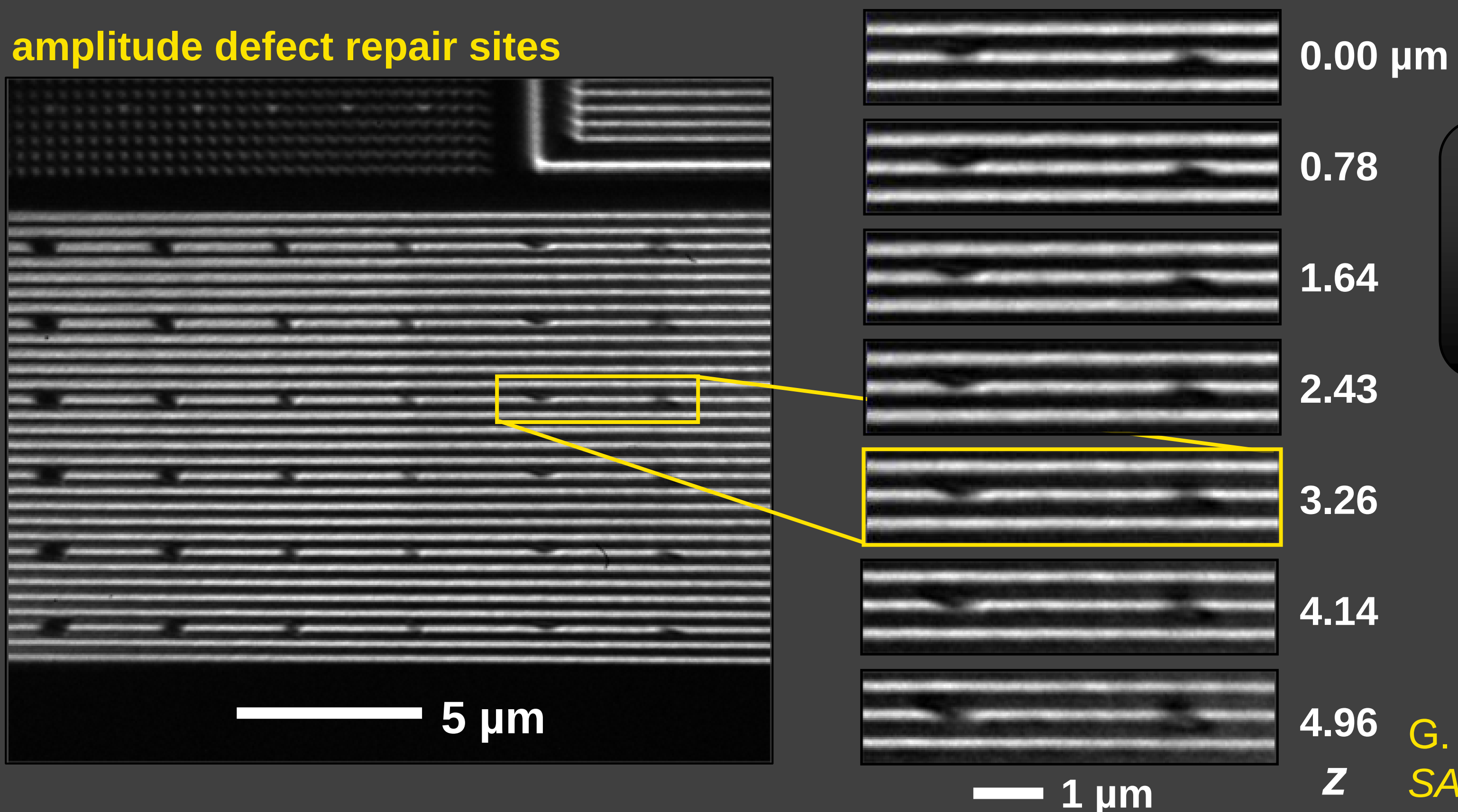
Sample Phase defects and Absorber pattern defects

through-focus



W. Cho, *et al. SPIE Photomask BACUS* 2007

amplitude defect repair sites



Aerial Images

G. Yoon, *et al.*
SAMSUNG

Overview and Outlook

Routine operation for SEMATECH Member Companies

Common Issues Investigated

buried phase defects • amplitude defects • defect repair
mask contrast • AIT performance • laser damage

High Data Throughput

- **30 different masks** have been inspected in 2007 so far.
  (Several masks were inspected multiple times or on consecutive shifts.)
- Up to **450 images per shift**, 250–300 is routine
- Up to **28 through-focus series per shift**
- Nearly **10,000 high-resolution images** in 2007
  through-focus series & individual

Areas for Improvement

improved contrast • higher-NA • illumination uniformity
data analysis • aberration reduction across the field