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EUV Lithography: New Metrology Challenges

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Outline of Presentation

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Introduction

EUVL Critical Technical Issues

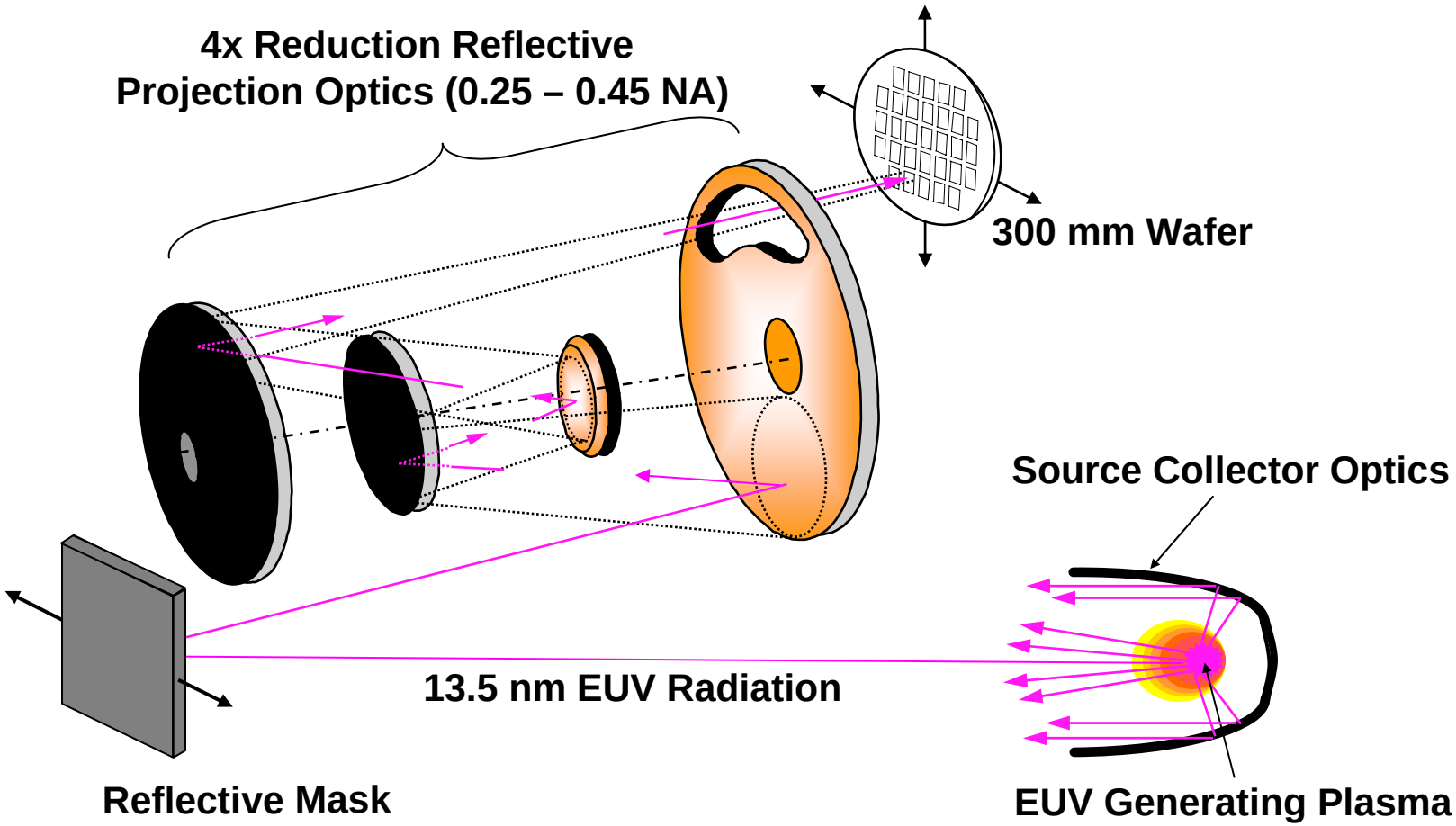
EUVL New Metrology Challenges

- Reflective Optics
- Reflective Masks
- EUV Resist Materials

Summary

Acknowledgements

Extreme Ultraviolet (EUV) Lithography



EUVL Advantages & Disadvantages

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Advantages:

- Wide process windows
- High throughput
- Extensibility

Disadvantages:

- Extreme system complexity
- Infrastructure immaturity
- High cost of ownership

EUVL Critical Technical Issues

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Top 3 Critical Issues

- Reliable high-power source & collector module
- Resist resolution, sensitivity, and line edge roughness met simultaneously
- Availability of defect-free masks

Other Critical Issues

- Reticle protection during storage, handling and use
- Projection and illuminator optics quality and lifetime

Ref: 2006 EUVL Symposium Steering Committee, October 2006

Metrology Challenges – EUV Optics

EUV Reflective Multilayer Coatings

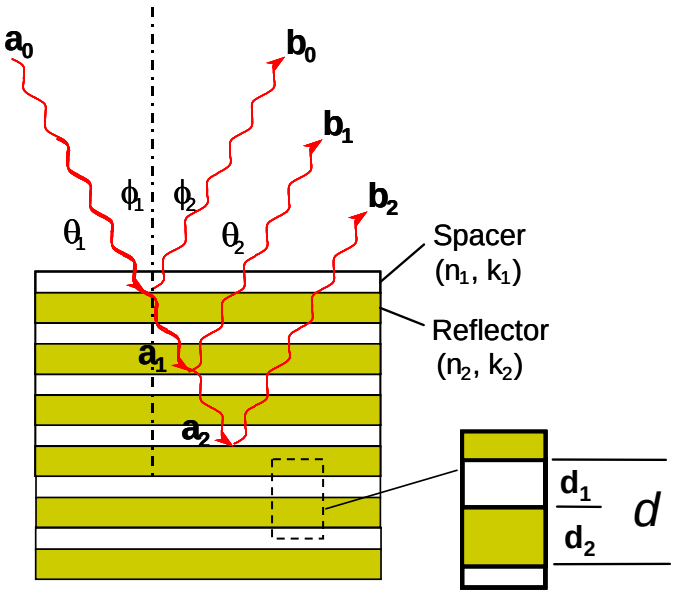
Aspheric Mirror Substrate Figure & Finish

EUV Imaging System Wavefront Quality

EUV Reflective Multilayer Coatings

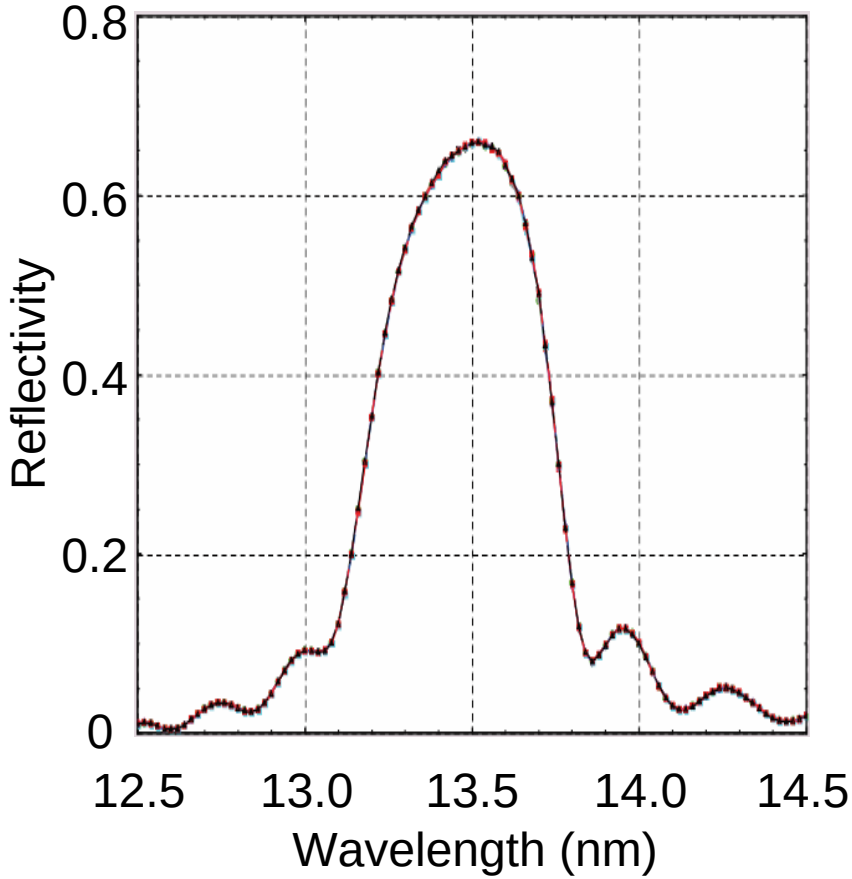
EUV Reflection by Bragg Interference

$$\lambda = 2d \sin \theta_1$$



Silicon Spacer, d_1 = 4.1 nm
Moly Absorber, d_2 = 2.8 nm

Reflectance of Mo/Si Multilayer



Ref.: R. Perera, EUV Technology – 2006 EUVL Symposium, Barcelona, November, 2006

Aspheric Mirror Substrates

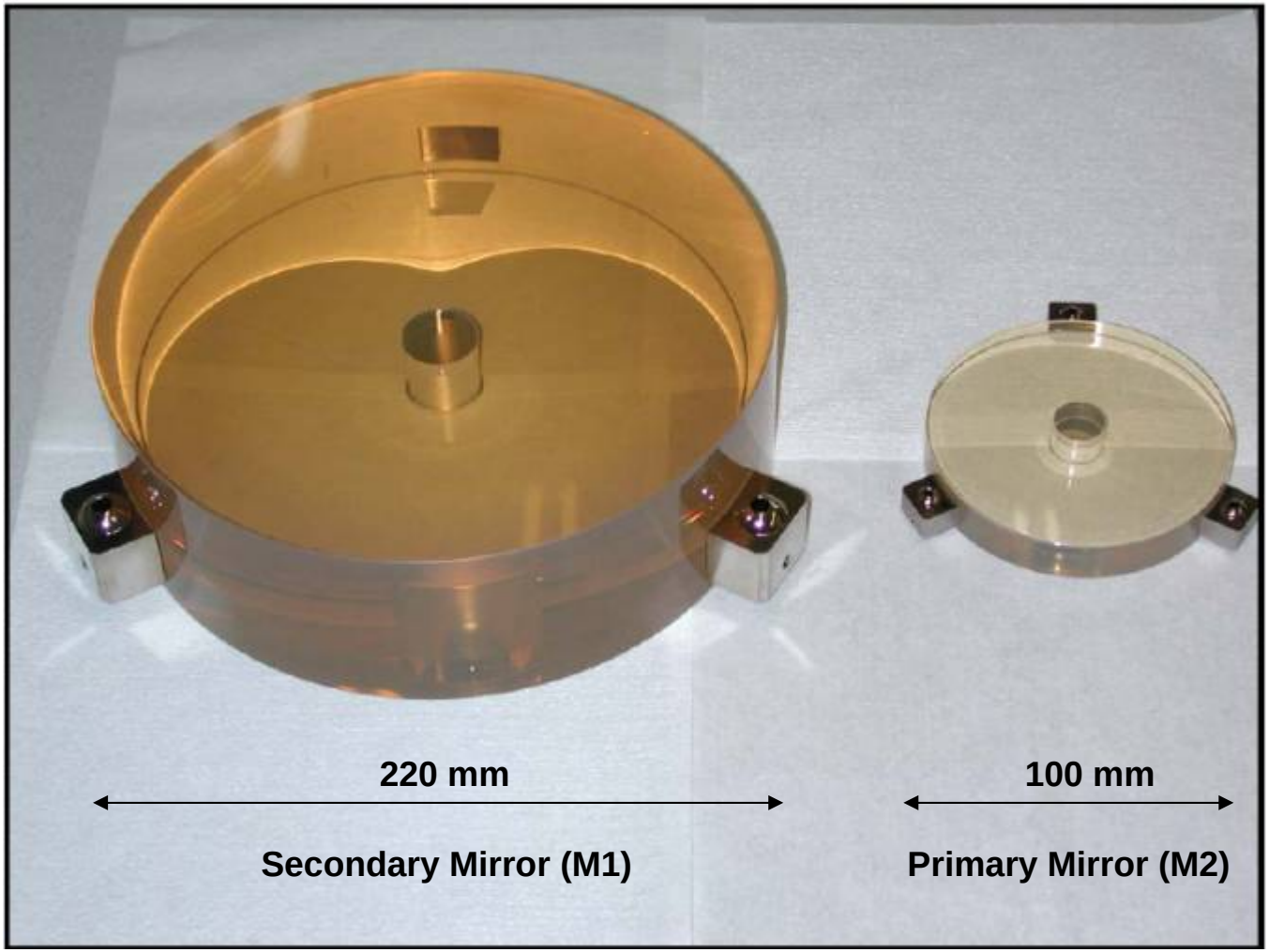
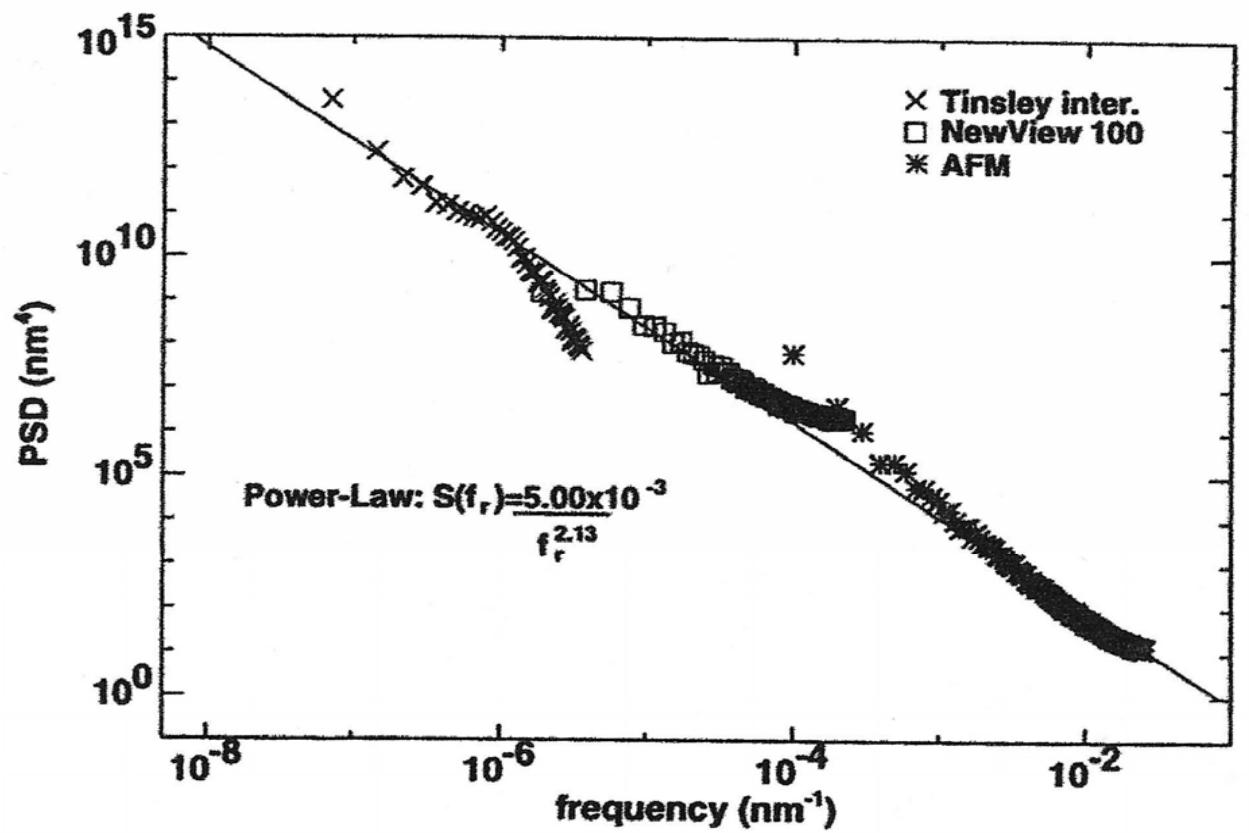


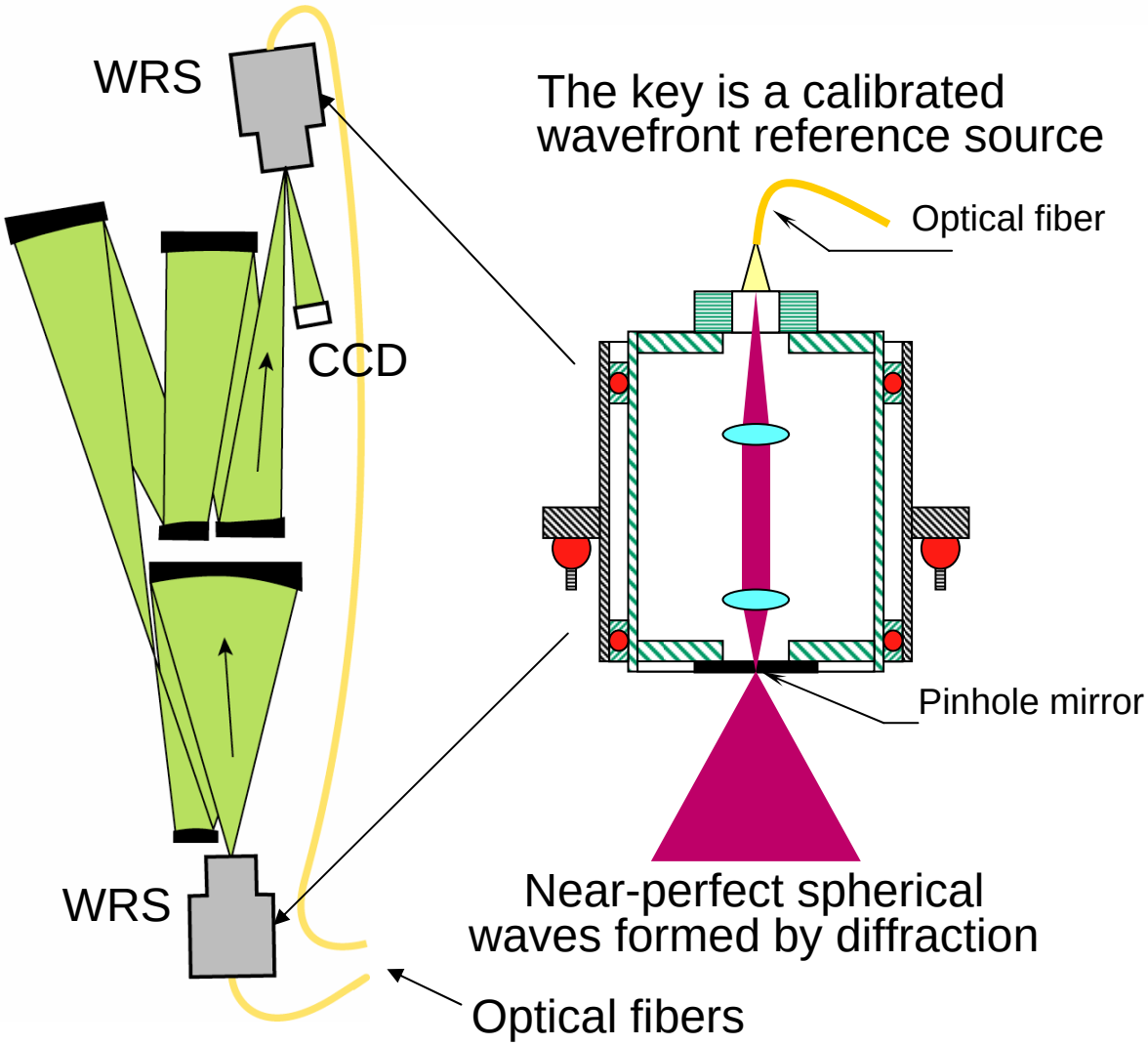
Photo of SEMATECH/Berkeley MET Optics Courtesy: John Taylor, LLNL

Mirror Substrate Figure & Finish



Reprinted from D. Gaines et al., OSA Trends Opt. Photon. 4, 103-106 (1996) by permission of OSA

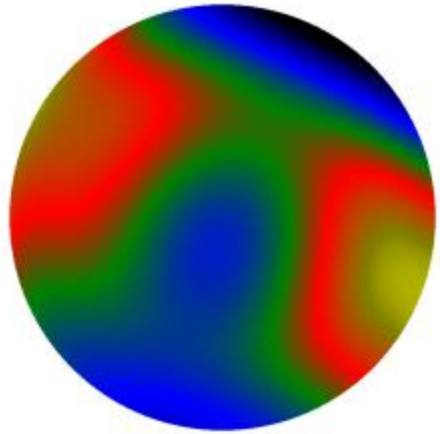
EUV Imaging System Wavefront Quality



The key is a calibrated wavefront reference source

Near-perfect spherical waves formed by diffraction

Both symmetric & non-symmetric errors are calibrated



Measured systematic error of WRS = 0.16 nm rms

Can be removed from measurement

Wavefront Reference Source Data Courtesy of John Taylor, LLNL

Metrology Challenges - EUV Masks

EUV Mask Blank Defect Inspection

EUV Mask Blank Flatness Interferometry

In the future, commercial mask shops are likely to need:

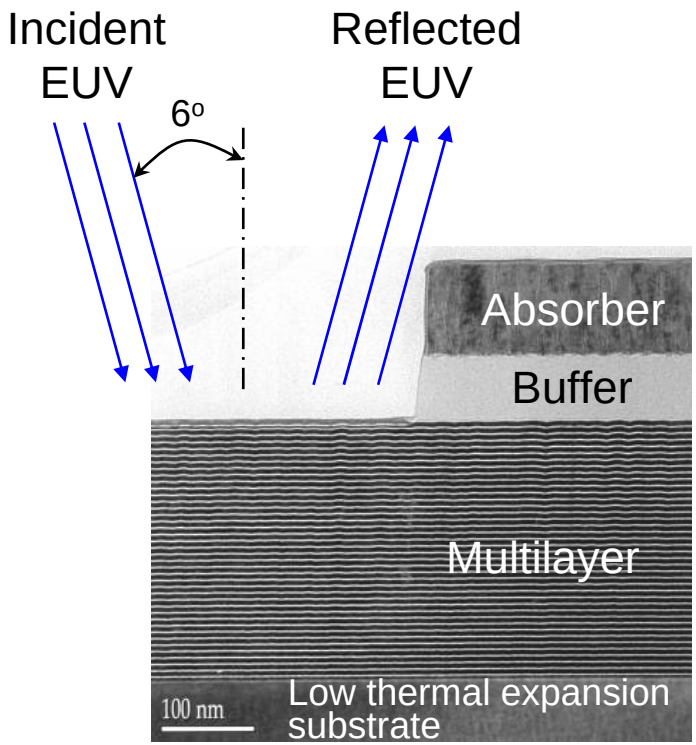
- an actinic defect inspection tool;
- a mask flatness interferometer; and
- an EUV reflectometer

EUV Reflective Mask Architecture

An EUVL reflective mask consists of buffer (e.g. SiO_2) and absorber (e.g. Cr, TaN) layers deposited over a multilayer reflector (e.g. Mo/Si).
Note: Buffer and absorber layers are etched to create the mask pattern.

Full Field Patterned EUV Mask

Photo Courtesy: Scott Hector, Freescale



TEM Courtesy: K. Nguyen, AMD

EUV Reflective Mask Phase Defects

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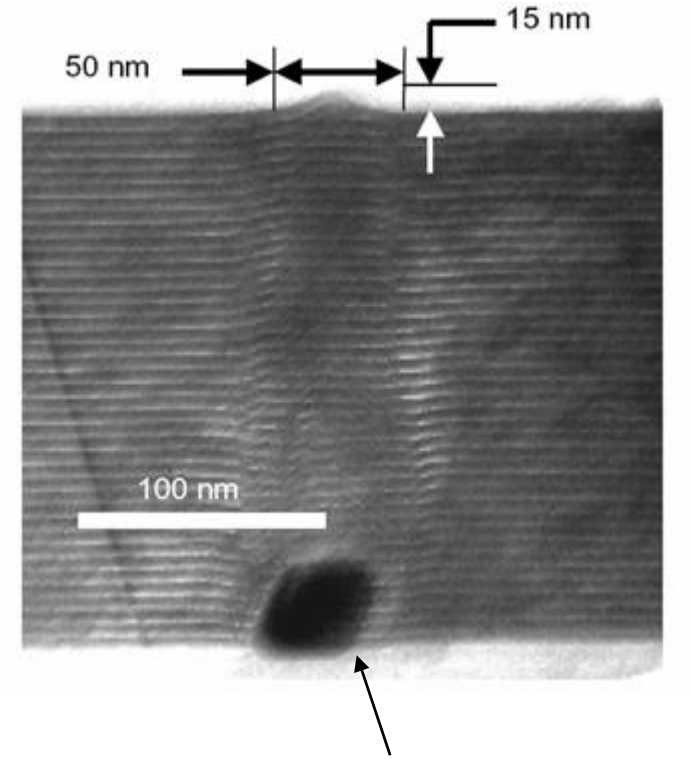
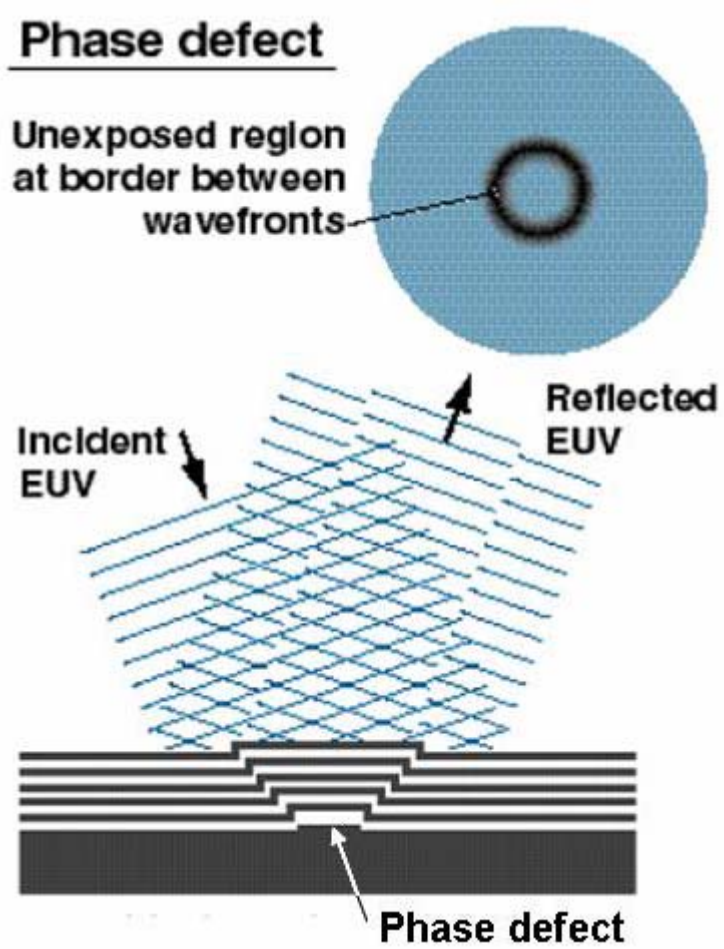
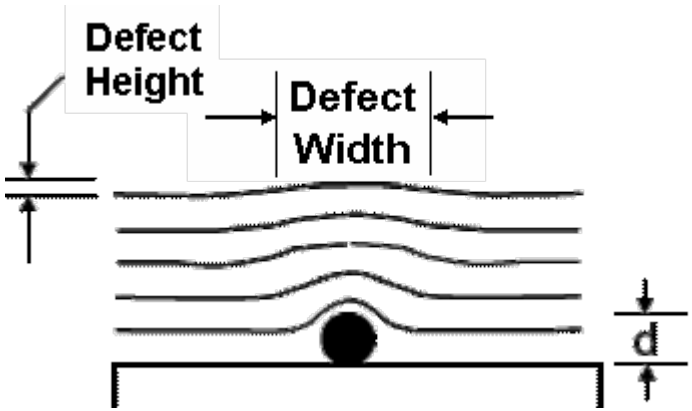
TEM Cross Section of Phase Defect

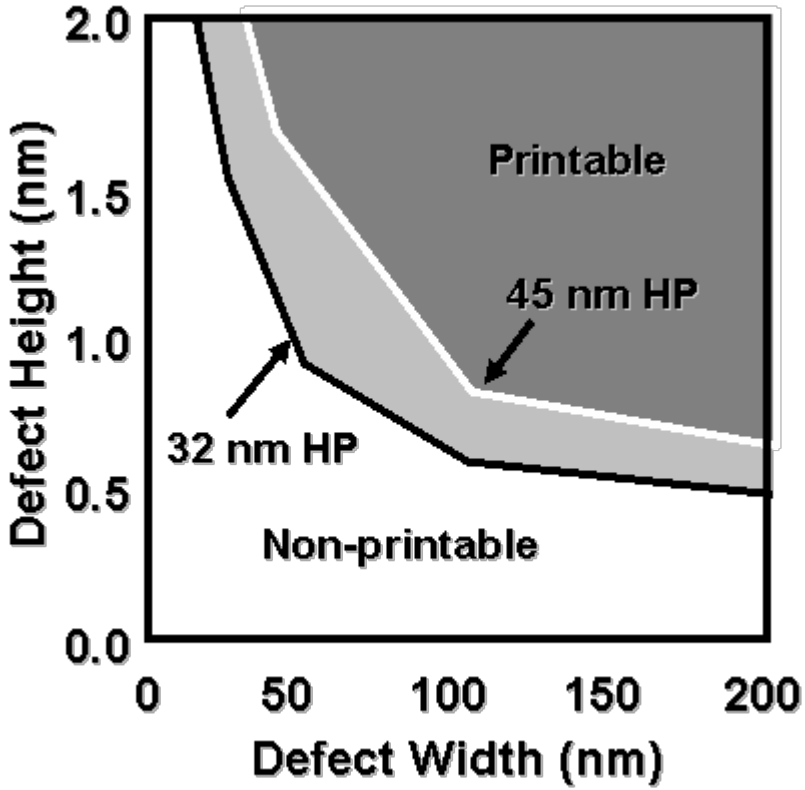




TEM Cross Section Courtesy: Lawrence Livermore National Laboratory

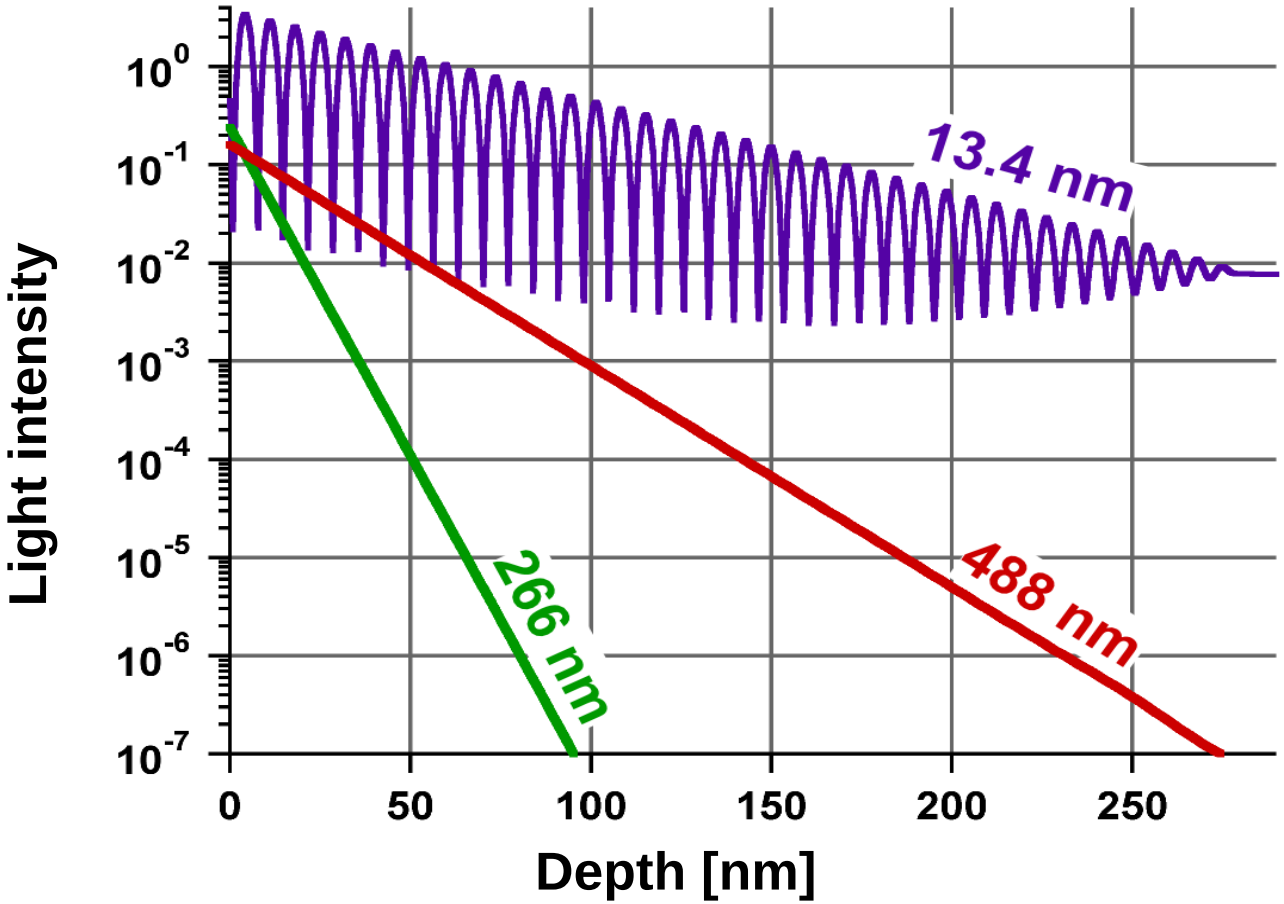
EUV Phase Defect Printability





Ref: E. M. Gullikson, et al., Proc. SPIE 5374, 791 (2004).

EUV Multilayer Coating Light Penetration



Ref: K. Goldberg et al., LBL – SPIE Advanced Lithography, Feb. 21, 2006

EUV Mask Blank Defect Inspection

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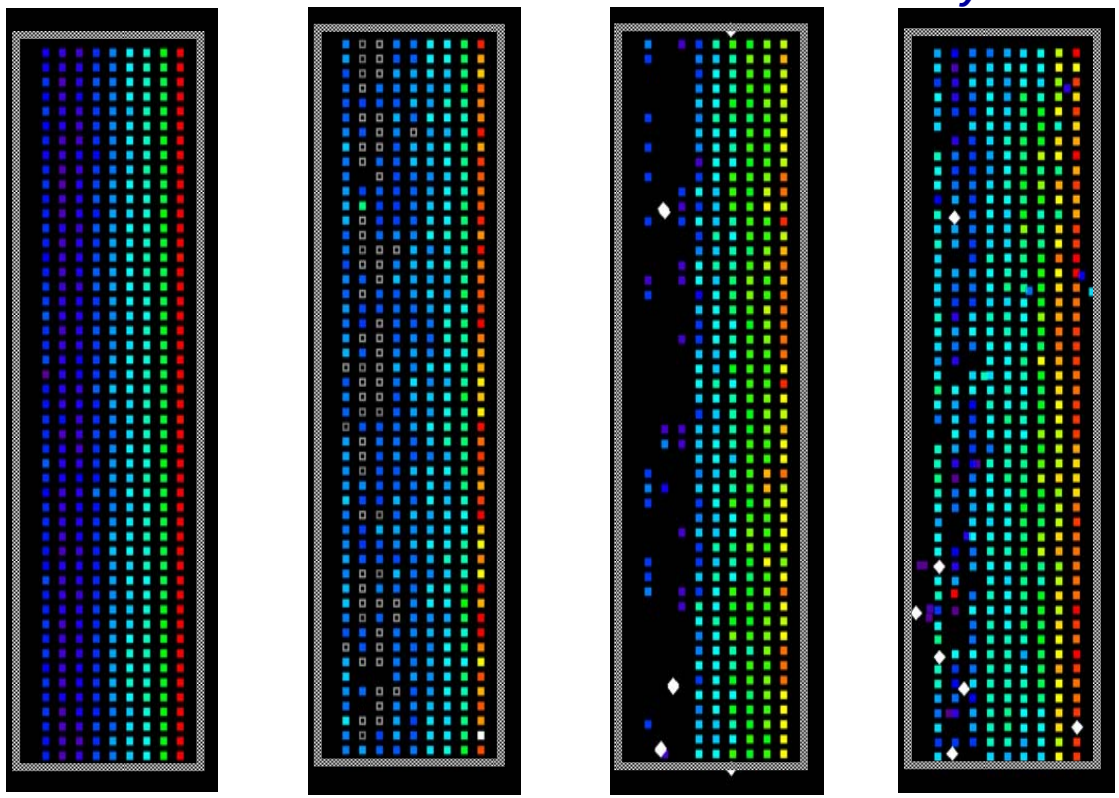
Programmed defect data from 4 inspection tools



Many multilayer defects are seen only with EUV inspection!

Ref: K. Goldberg et al., 50th EIPBN, 2006

Mask Blank Flatness Interferometry

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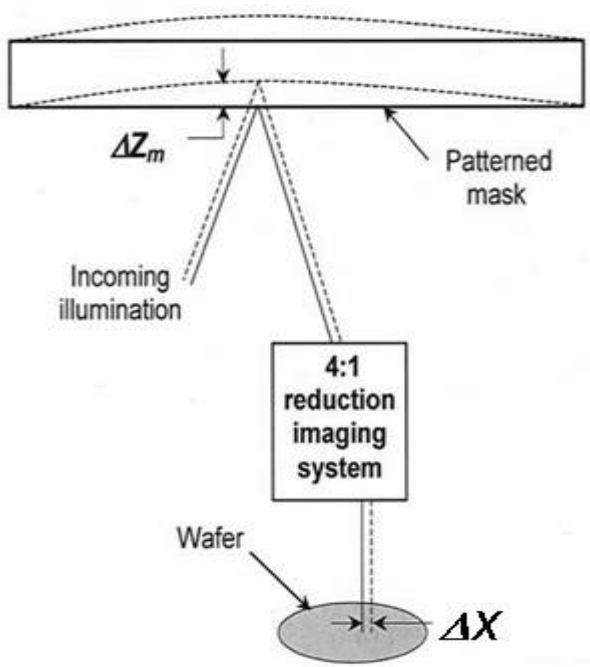
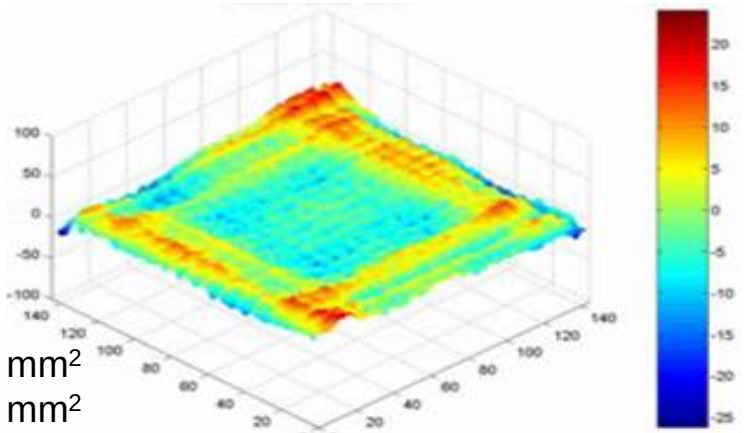
Non-Telecentric Illumination

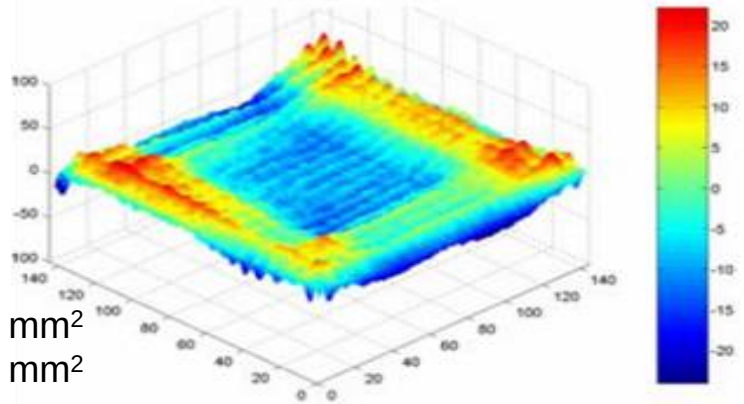


Blank Flatness Data

Frontside:
50nm @ 142x142 mm^2
43nm @ 120x140 mm^2



Backside:
51nm @ 142x142 mm^2
45nm @ 120x140 mm^2



Flatness in spec for 32 nm half pitch node!

Ref: H. Meiling et al., ASML – SPIE Microlithography Symposium, Feb. 21, 2006

Metrology Challenges - EUV Resists

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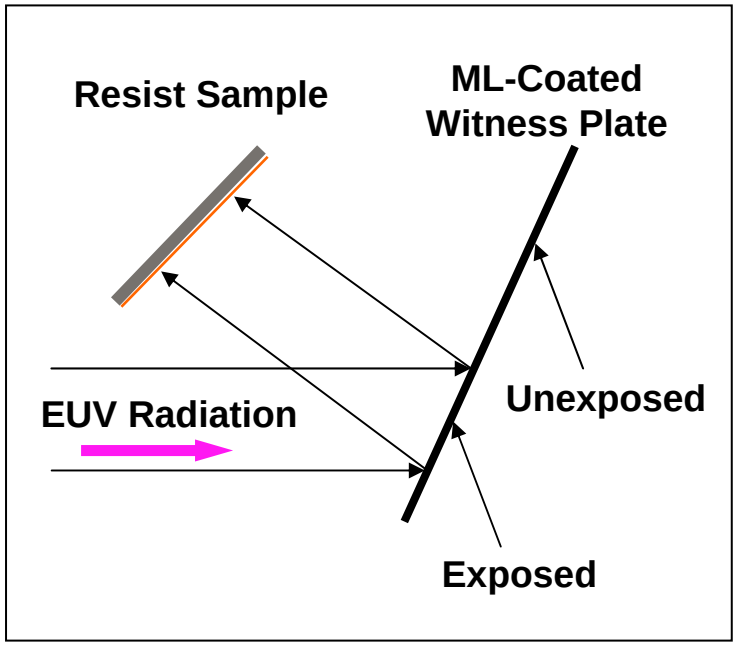
EUV Resist Outgassing

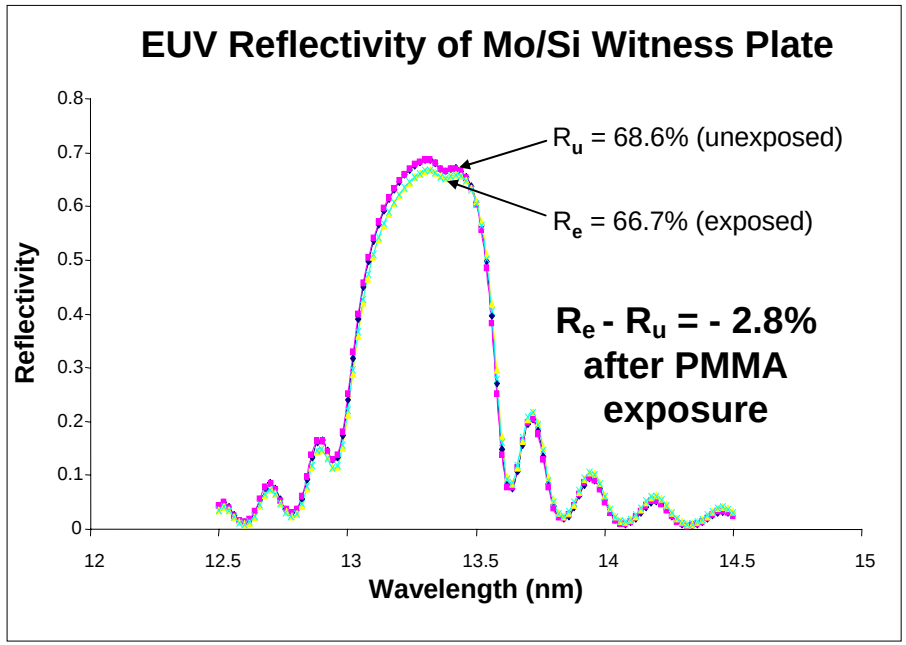
EUV Reticle Contamination

EUV Projection Optics Lifetime

EUV Resist Outgassing Metrology

Witness Plate Outgassing Test





If reflectivity loss is ≤ 2% then resist is safe for use

Ref.: G. Denbeaux, CNSE – 2006 EUVL Symposium, Barcelona, November, 2006

EUV Reticle Contamination

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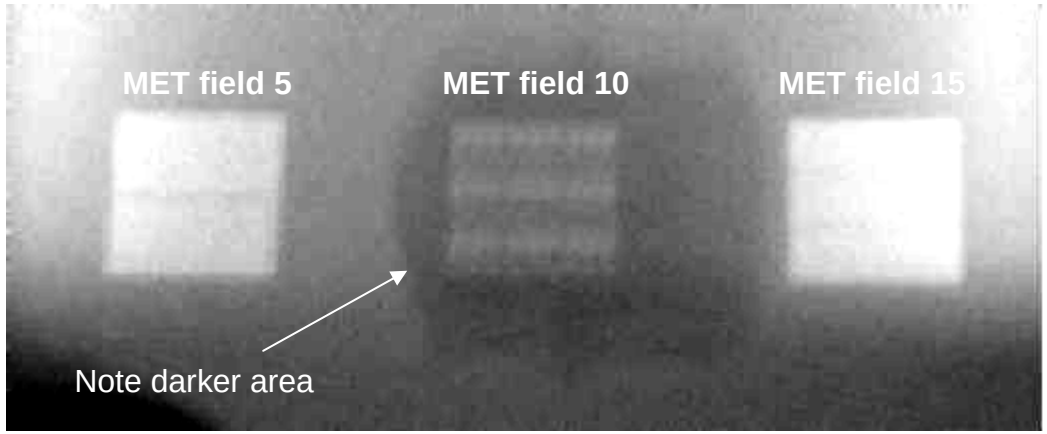
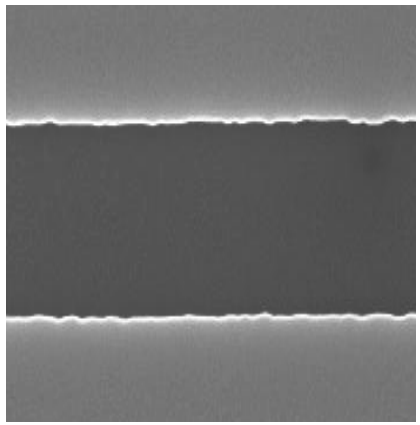
Photograph of Micro Exposure Tool Reticle



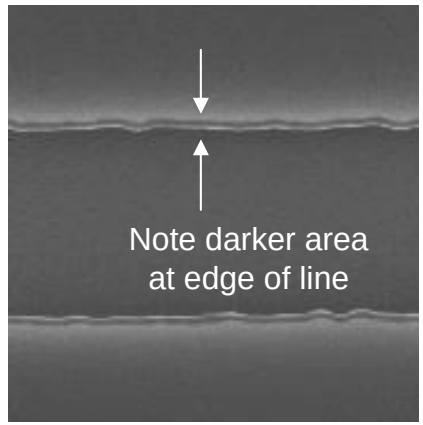
SEM Images

MET Field 3



500 nm hp lines

MET Field 10



500 nm hp lines

$\Delta CD_{10-3} = +64$ nm

Data Courtesy M. Malloy, SEMATECH EUV RTC, Albany, NY

EUV Projection Optics Lifetime

Degradation of peak reflectivity decreases throughput.

- **70% to 69% results in 85% of original source power (assuming 11 normal incidence mirrors)**

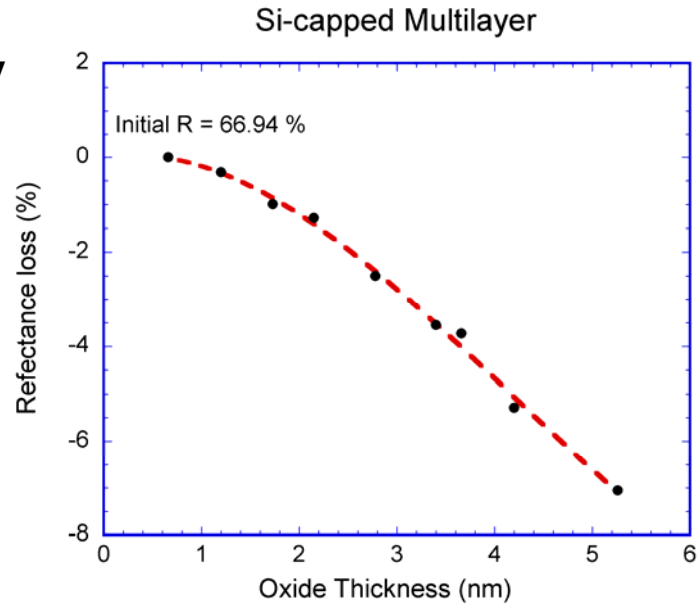
Degradation of reflectivity uniformity impacts CD control.

Lifetime of projection optics are limited by

Carbon deposition

Oxidation

Photographs Courtesy of H. Meiling, ASML



Status: Optics lifetime (HVM Spec): 1% reflectance loss in 30,000 hours
Optics lifetime (Currently): 1% reflectance loss in 230 hours

Summary

If the current rate of progress in EUV sources, masks and resists can be maintained over the next few years, EUVL could be ready for high volume manufacturing of semiconductor chips in 2012 or 2013.

Before this can happen, EUVL technological maturity must be demonstrated by the performance of the EUVL R&D tools delivered this year and by the readiness of EUVL infrastructure to support the introduction of EUVL pre-production tools later this decade.

Infrastructure readiness includes having the metrology in place to qualify the wavefront of the projection optics, to locate and inspect defects on multilayer-coated masks, and to ensure that resist materials do not outgas excessively.

Acknowledgements

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