Blank Inspection Technology Development at EIDEC

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OUTLINE

1. EIDEC Blank Inspection Technology Development
2. ABI tool development
3. Defect Printability
4. Actinic Imaging technologies
5. Summary

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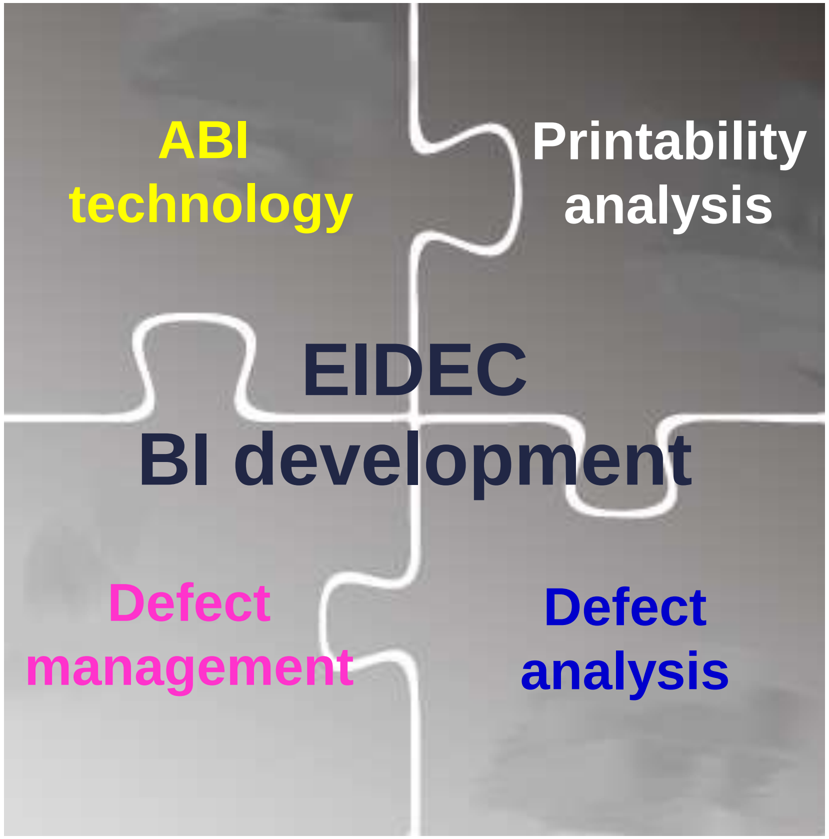
1. EIDEC Blank Inspection Technology Development



Bright field tool
(ABI, DUV,…)

MIRAI-Selete
ABI tool

exposure
experiment

NXEs

ABI HVM proto tool
/ Lasertec Corp.

MET

computer
simulation

ABI technology

Printability analysis

EIDEC BI development

Defect management

Defect analysis

EUV AIMS

AIT, SHARP

Defect mitigation
(fiducial strategy)

EUV microscope
（Tohoku University）

Defect repair
(EB, physical)

μCSM
(University of Hyogo)

Mask cleaning

physical analyses
（AFM, HIM, …）

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2. ABI tool development

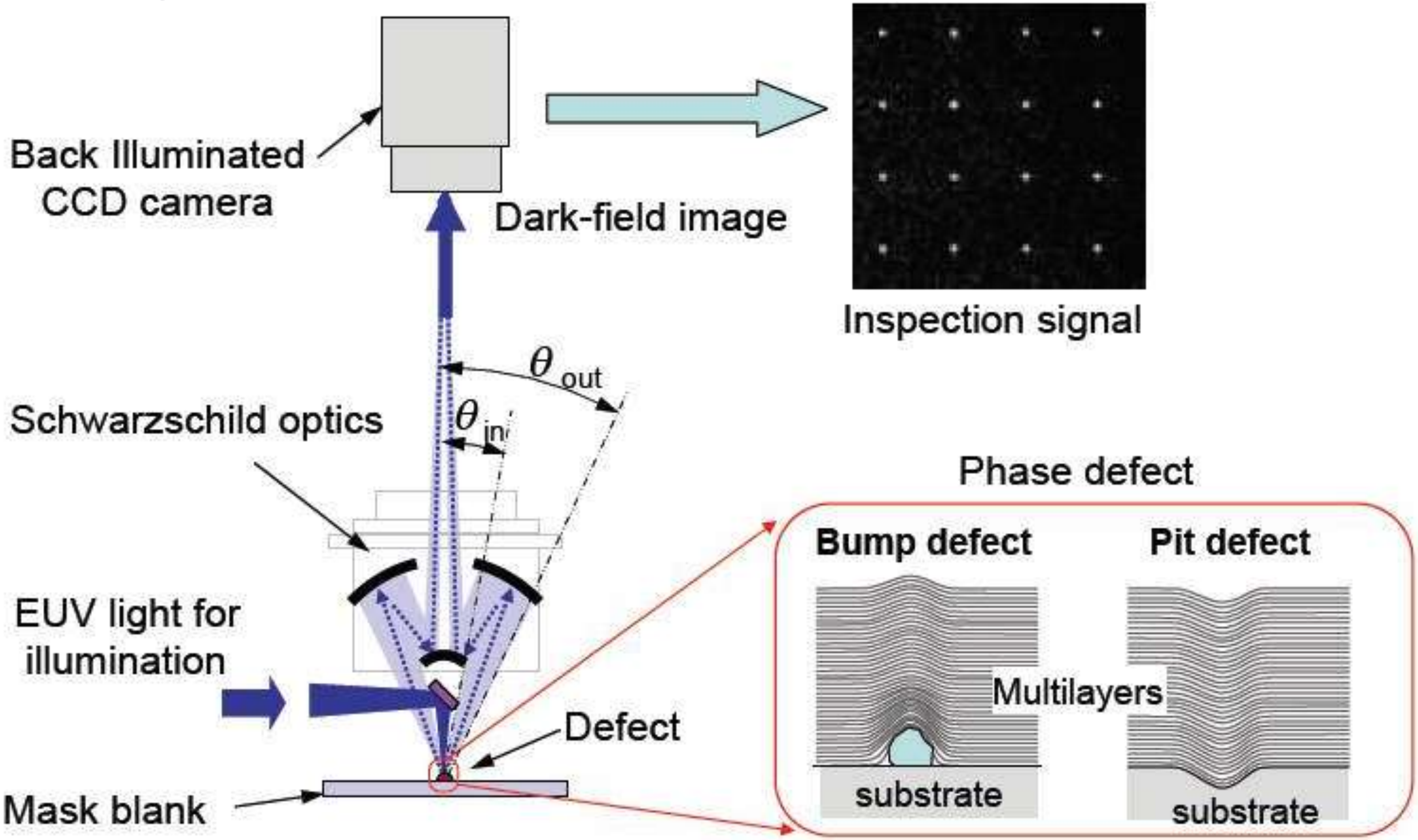
- EIDEC develops ABI tool for hp16nm HVM with Lasertec Corp. succeeding to the achievement of Selete

- Detection capability for1nmH/50nmW defect has been demonstrated
⇒ Analysing signal to improve detection and tool stability

- High magnification review optics for defect mitigation successfully provides 1200x magnified images
⇒ Accuracy evaluation and success rate estimation

- Explore ABI technology using MIRAI ABI tool

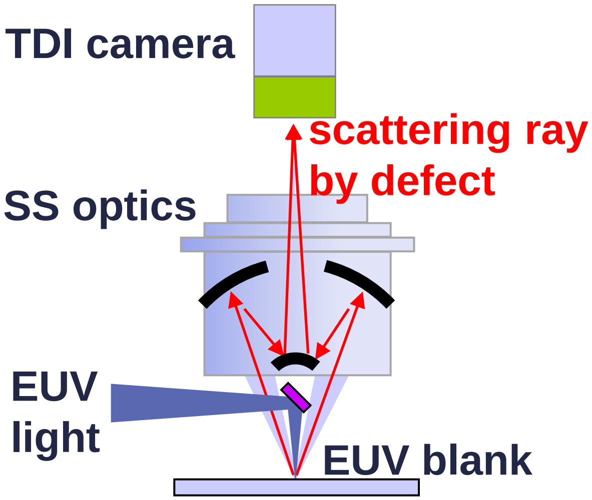
Advantage in dark field ABI

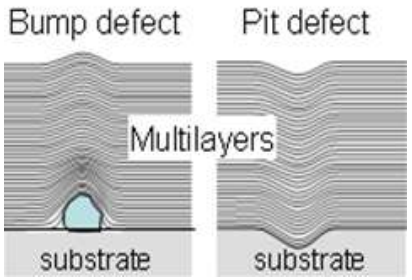


Terasawa T., Proc. of SPIE vol. 7271 (2009)

High S/N dark field actinic blank inspection avails high throughput and high sensitivity

Chronicle of ABI





POC by MIRAI I,II (2001-2005)
feasibility of ABI,
dark field ABI by AIST

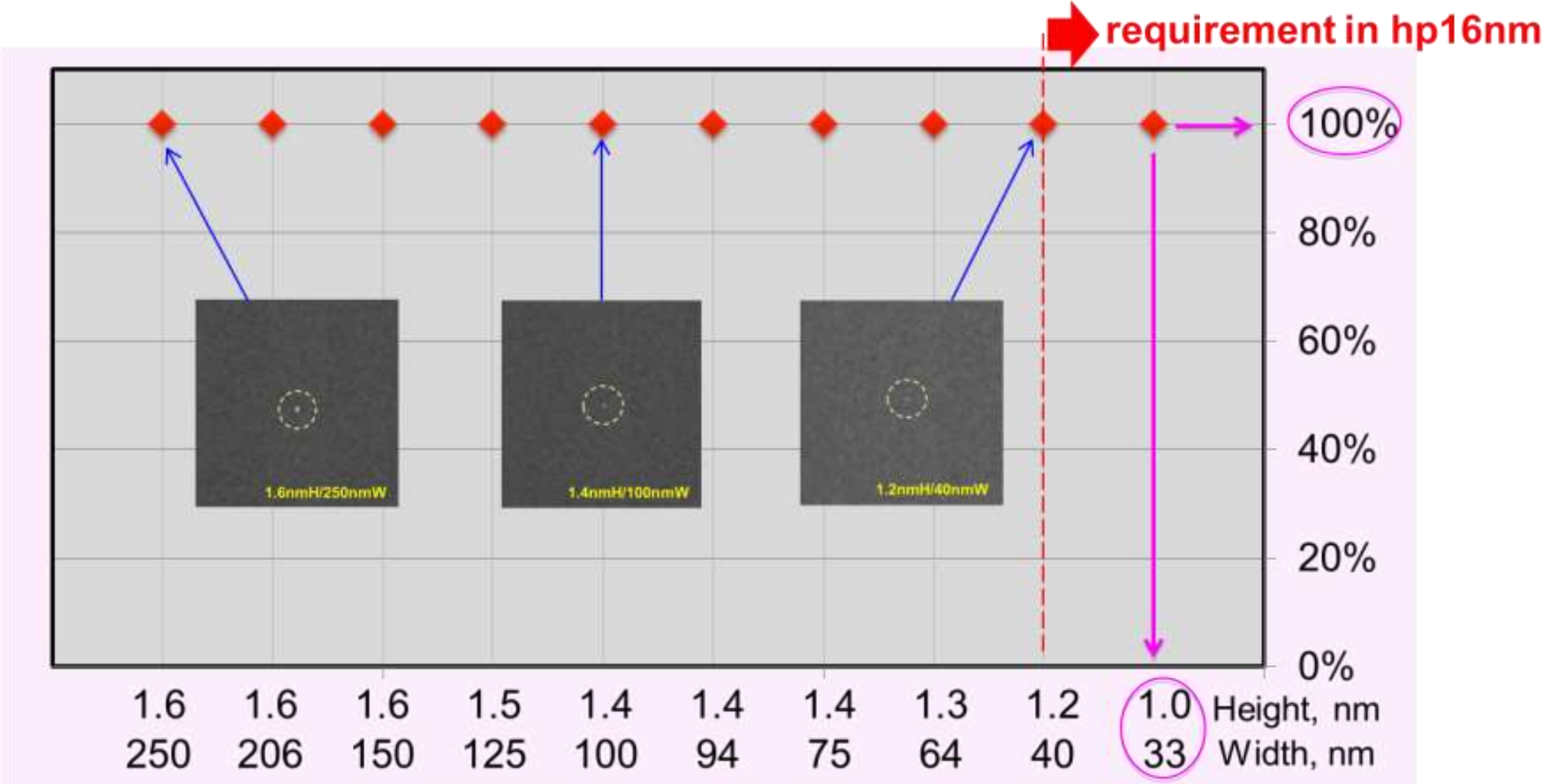
Proto by MIRAI-Selete(2006-2010)
full mask area ABI inspection

HVM by EIDEC(2011-)
ABI for hp16nm HVM
w/ Lasertec

-Development target-
1nmH/50nmW detection
in 45 min. scan

ABI consistent development strategy

“High Magnification Review Function for Defect Location Accuracy Improvement with EUV Actinic Blank Inspection Tool”, < *Session 5* >

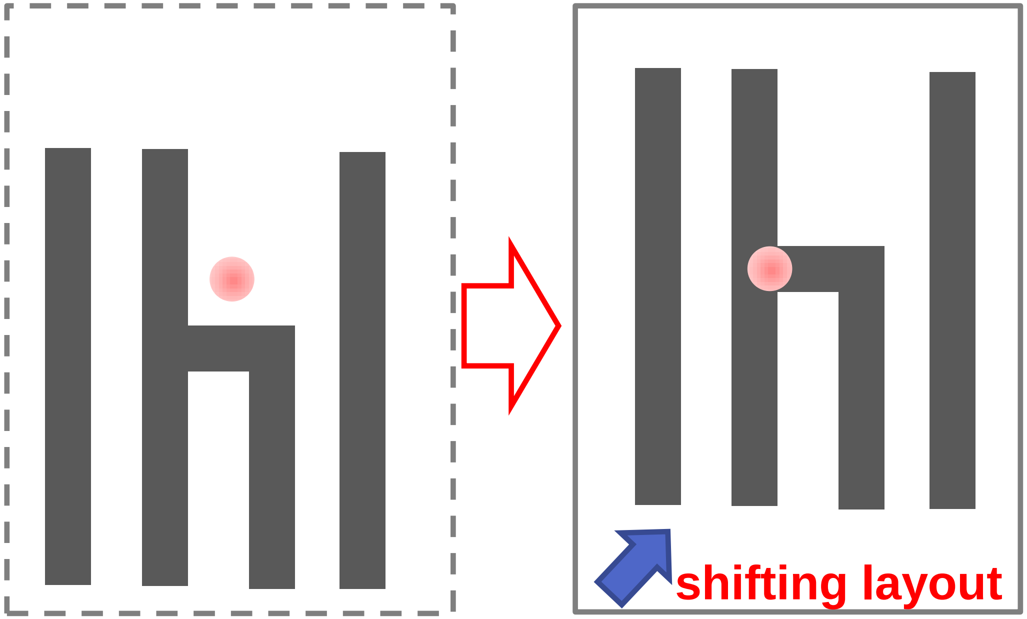


Capture Rate for programmed bump defects by defect size, nm, (based on 10 inspections)

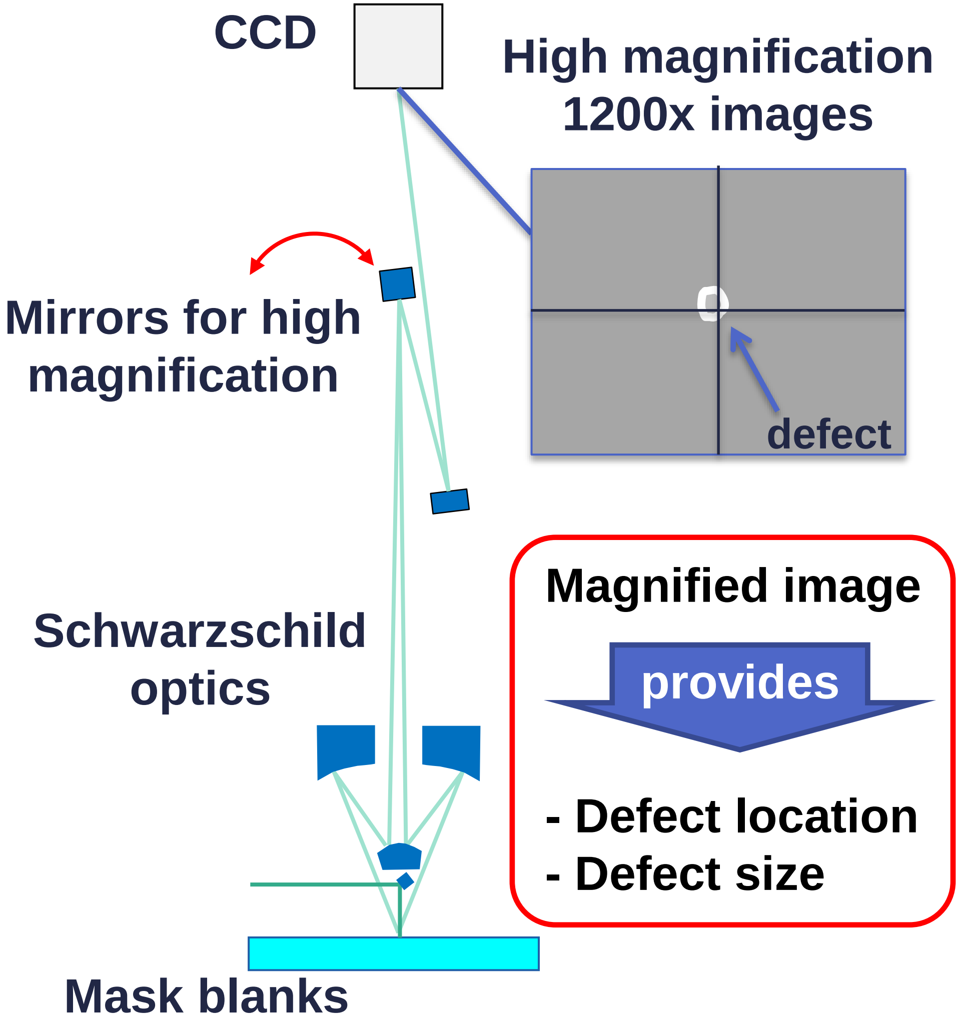
Tchikoulaeva A., SPIE Advanced Lithography 2013

Defect management

Defect mitigation, shifting layout to cover the defects, *requires* location accuracy

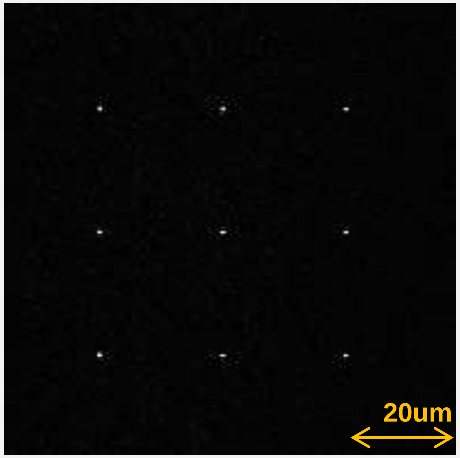
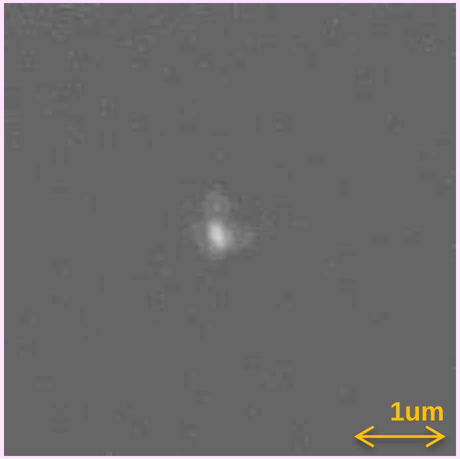
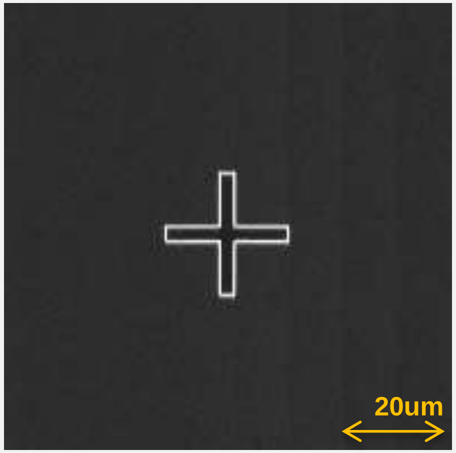
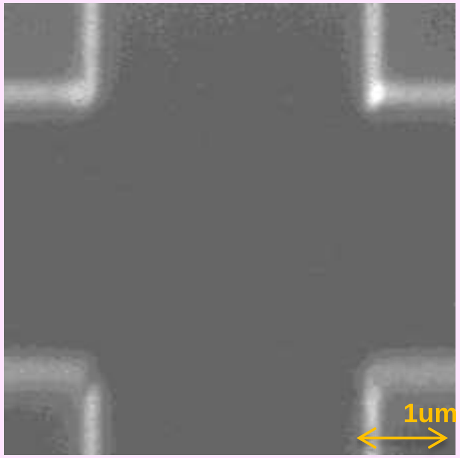


defect mitigation process



High magnification review optics on ABI

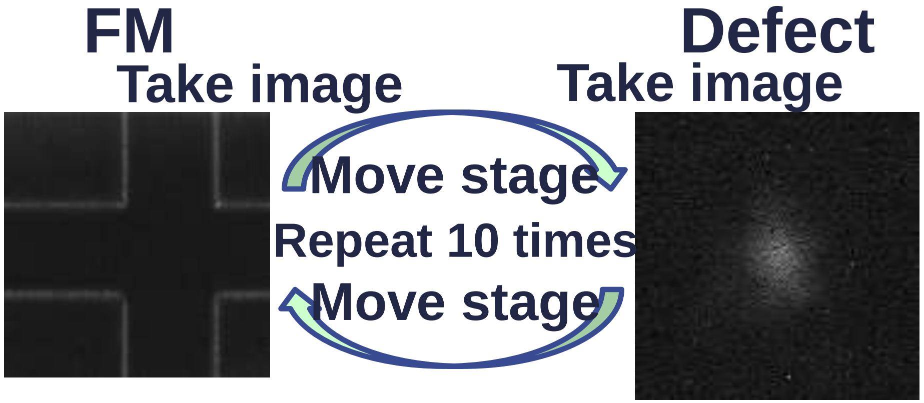
Image acquisition by review optics

	Low Mag. 26x	**High Mag. 1200x**
Phase Defect **H:2nm,W:190nm**		
Fiducial Mark		

Miyai H., PMJ2013

1200x high magnification review is available

“Defect location accuracy improvement with EUV Actinic Blank Inspection Prototype for 16 nm hp”, < *P-MA-20* >



FM

Take image

Defect

Take image

Move stage

Repeat 10 times

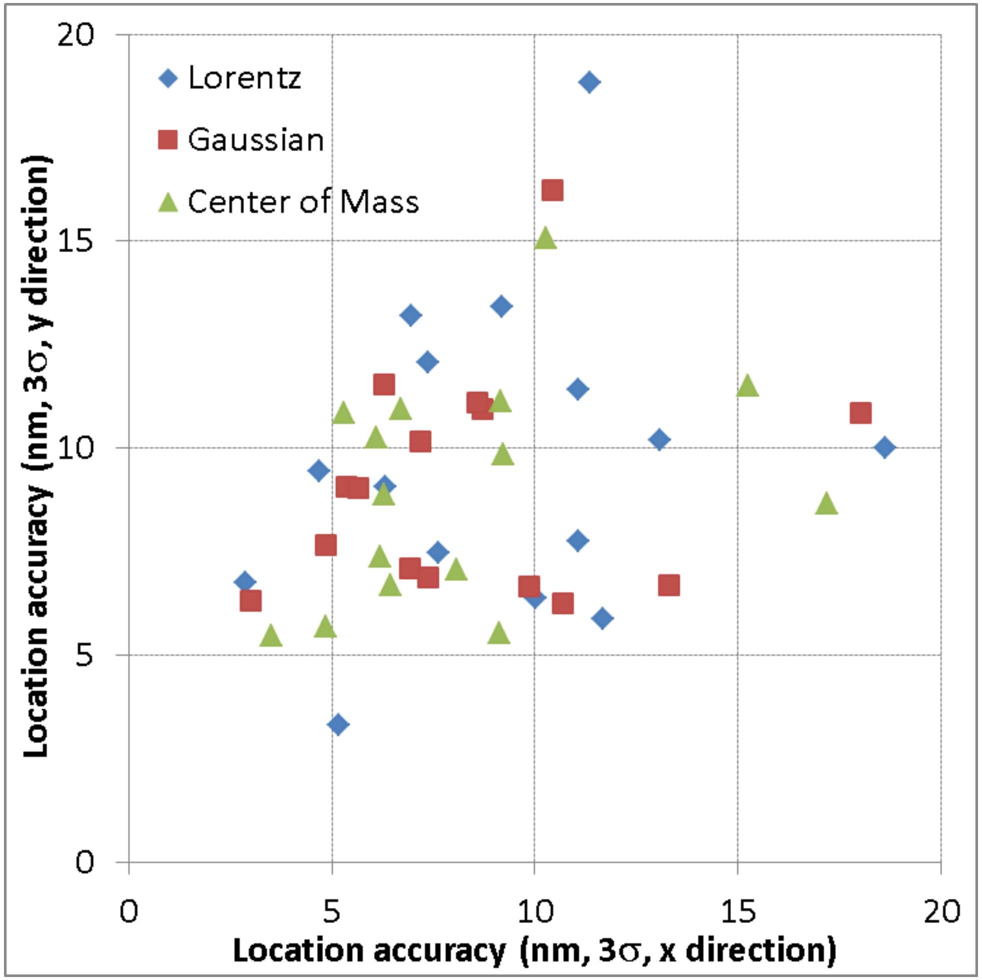
Move stage

Best method of location calculation:

Center of Mass

Worst case:

17.17 nm 3σ



Defect mitigation (allowable defects)

Success rate for 16nm design rule derived by Pei-Yang's study* on non-critical 22 nm

$$(\#\ of\ defects\ can\ be\ covered) = 615.07\left(\frac{X}{0.7}\right)^{-0.7}$$

$$X = (Defect\ size) + \boxed{A}\sqrt{(\sigma_P)^2 + (\sigma_A)^2}$$

where, (50 nm) (A by right table)

σ_P: *EB writer patterning accuracy* (5 nm)

σ_A: *Defect location accuracy* (5.72 nm)

*** Pei-Yang Yan, et al., SPIE 8322(2012)**

A	Success rate (%)
1	38
2	68
4	95
6	99.7

Success rate (%)	# of defects can be covered
38	28.07
68	25.73
95	22.22
99.7	**19.69**

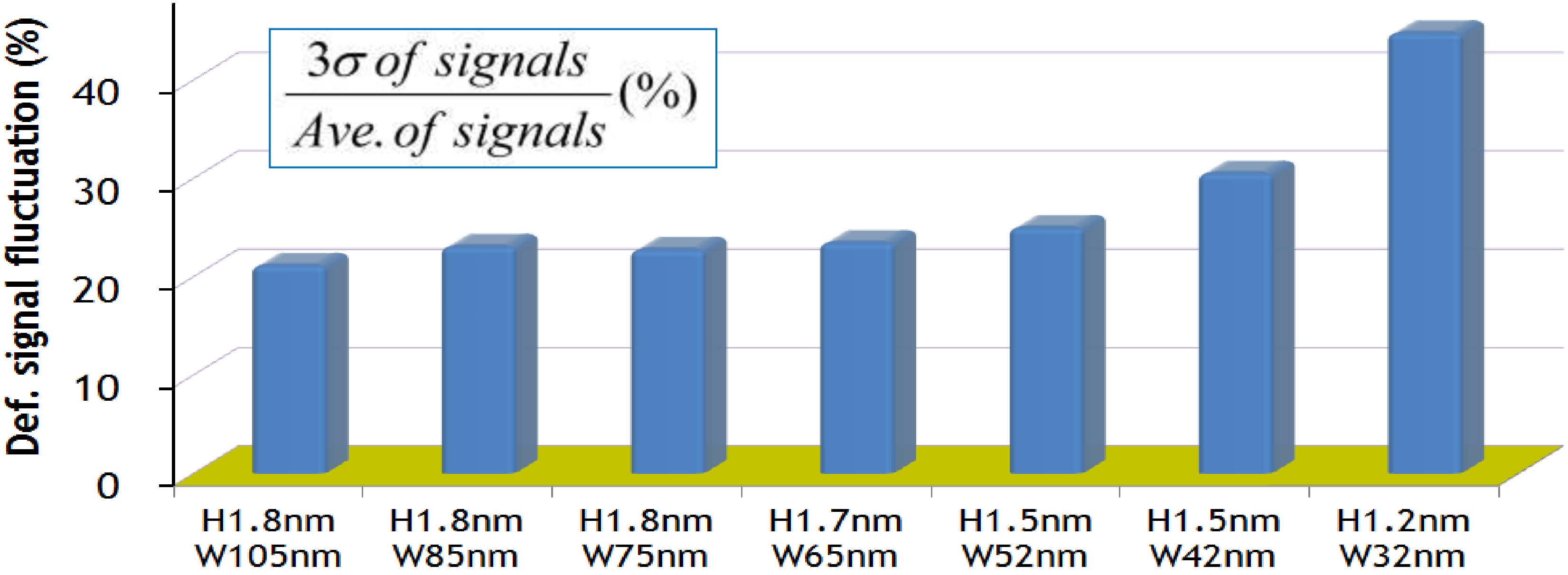
< 19 defects can be almost perfectly mitigated

"Understanding for defect size fluctuation in actinic inspection tool ", < *P-MA-33* >

- **What is the proper scale for measuring the inspection stability of the inspection tool?**

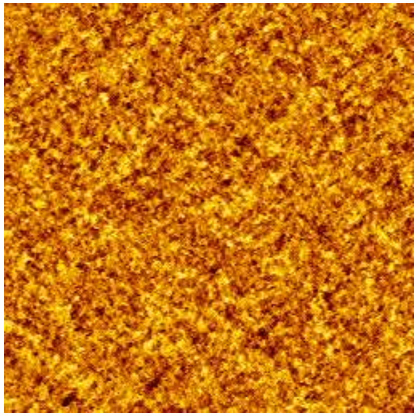
  → We can identify the tool performance through the distribution of defect signal regarding the same defects during the repetitive inspections.

- **Current level of MIRAI tool in EIDEC**

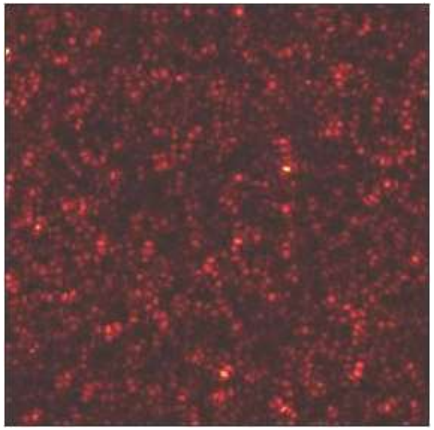


$$\frac{3\sigma\ of\ signals}{Ave.\ of\ signals}(\%)$$

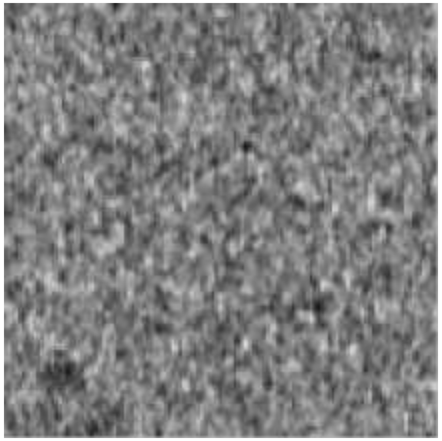
“Correlation Depth Analysis of Surface Roughness by Actinic Blank Inspection”, < *Session 11* >



AFM image

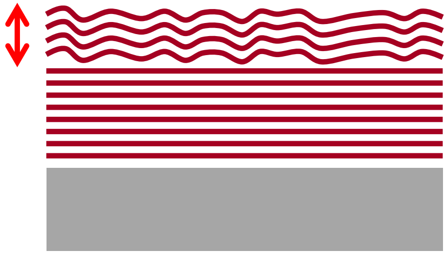


Simulated image



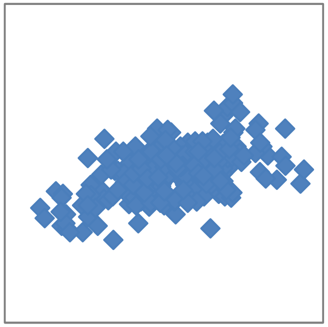
Cumulative ABI image

Correlation depth



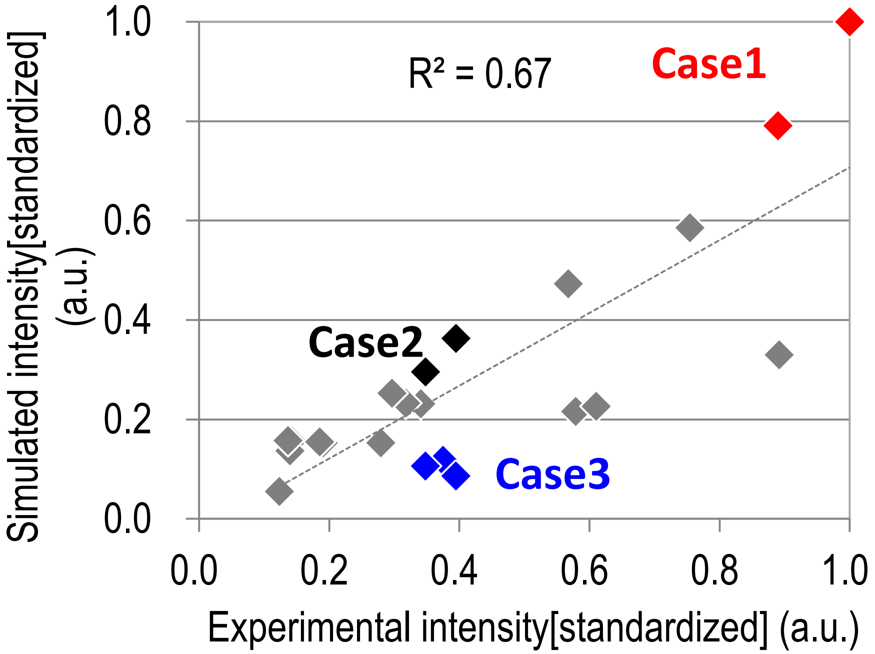
ML structure model

Correlation analysis

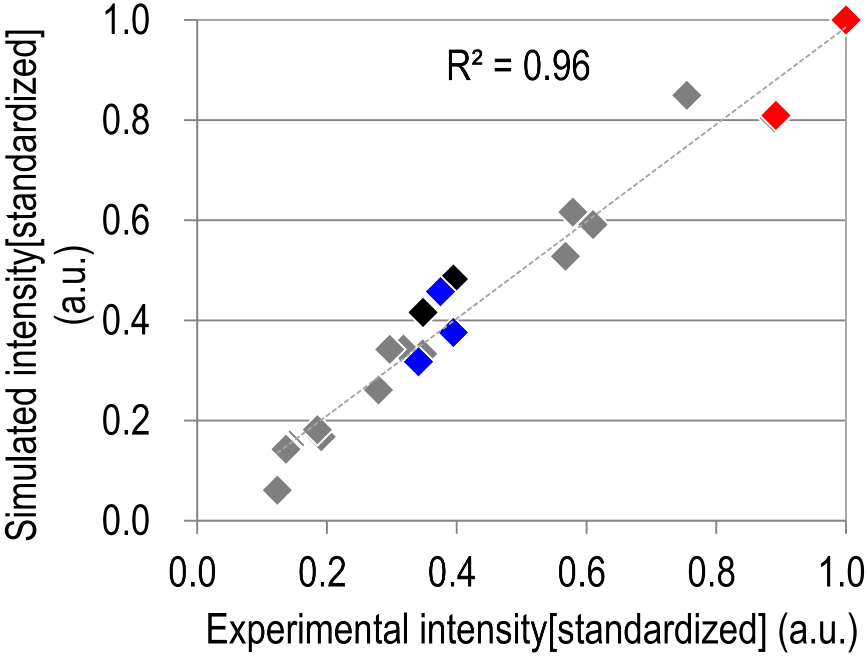


“Correlation Depth” of mask surface roughness was analysed using the actinic blank inspection (ABI) image

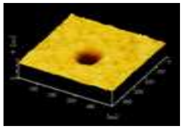
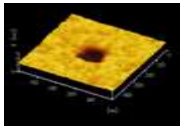
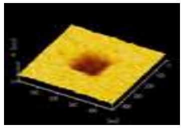
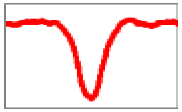
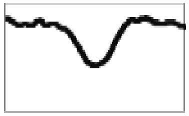
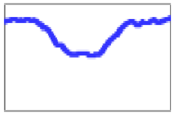
“Effect of phase defect characteristics on ABI signal intensity”, < *P-MA-32* >



Defect model : Gaussian model

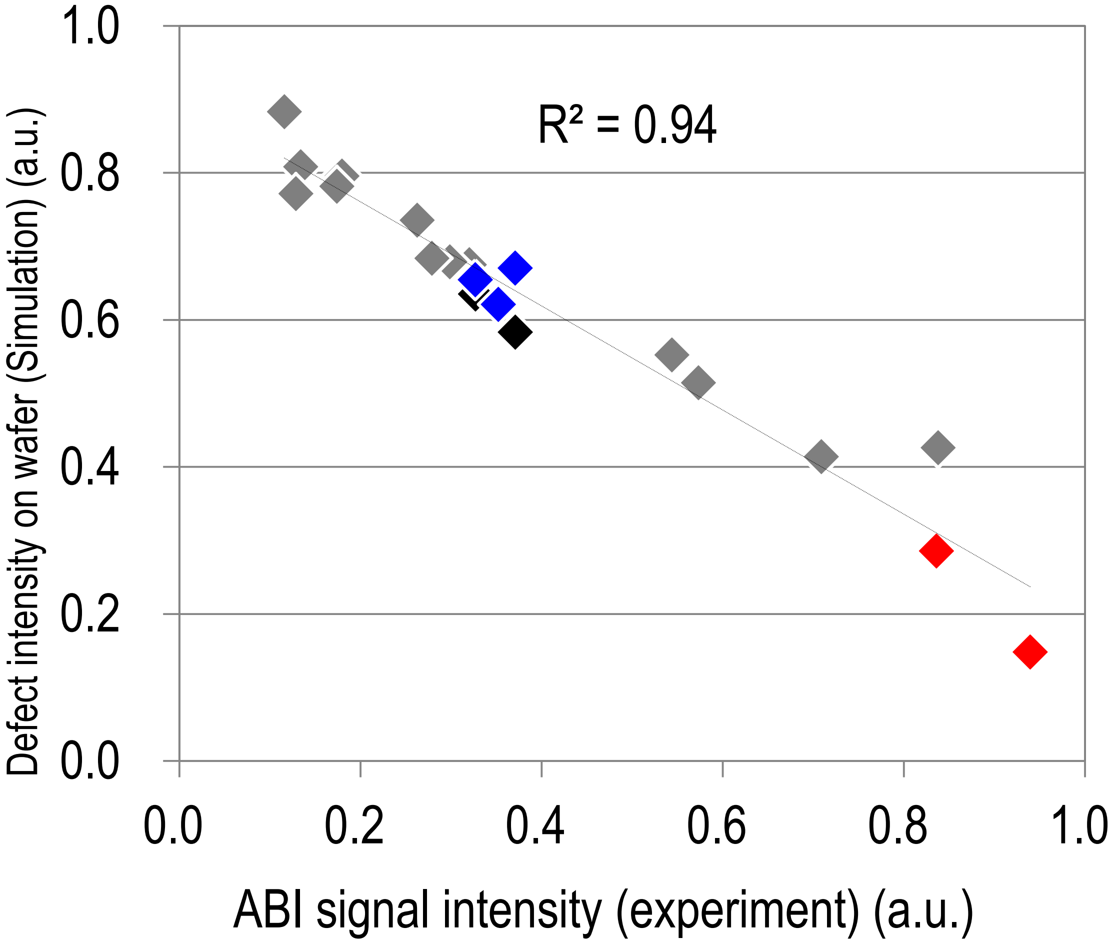


Defect model : 3D-AFM model

	Case.1	Case.2	Case.3
AFM image			
Cross section			

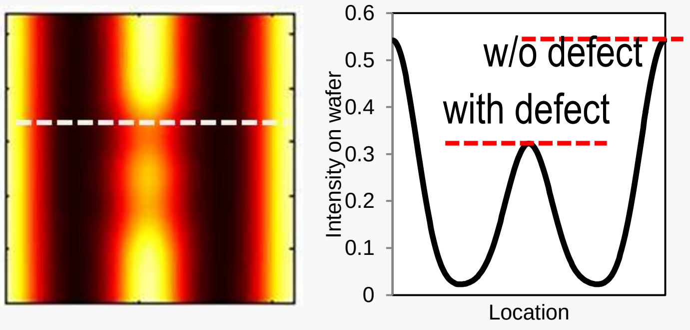
Defect geometry = topography determines ABI signal intensity

ABI defect signal analysis (cont.)



Wafer impact as a function of ABI intensity

- ✓ Simulation condition :
  NA=0.33, σ=0.8, Conventional,
  6deg, Hp=27nm, L/S
- ✓ Defect intensity on wafer = (Intensity with defect) / (Intensity w/o defect)



ABI can exactly predict wafer impact

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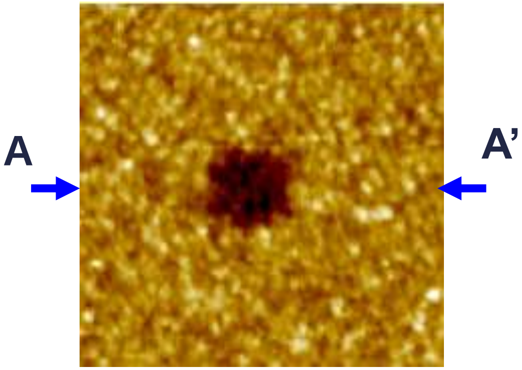
3. Defect Printability

- Lithographic impact of blank defects evaluation through exposure experiments

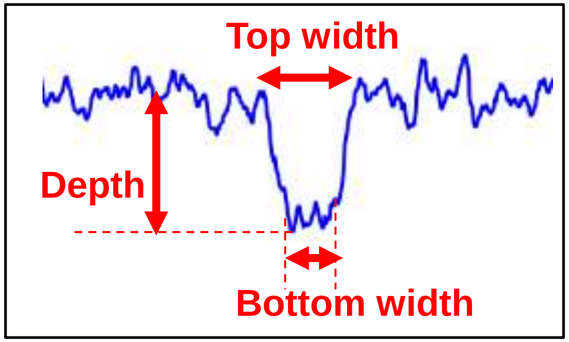
- Exploring computer simulation techniques to accurately predict printing image taking
topography (geometrical defect information)
and
morphology (surface information)
into account

“Accuracy verification of phase defect printability prediction with various defect shape models ”, < *P-MA-37* >

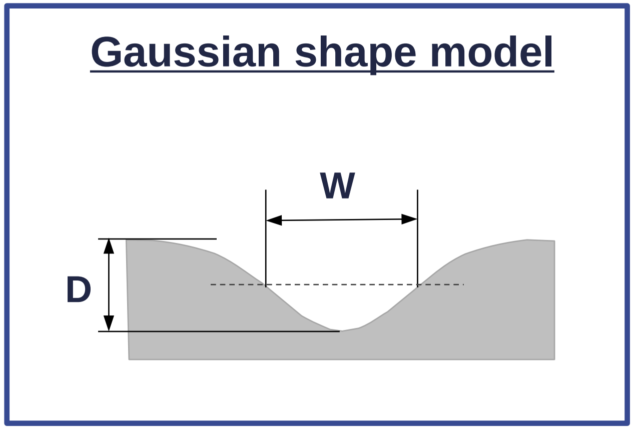
AFM measurement of pit phase defect

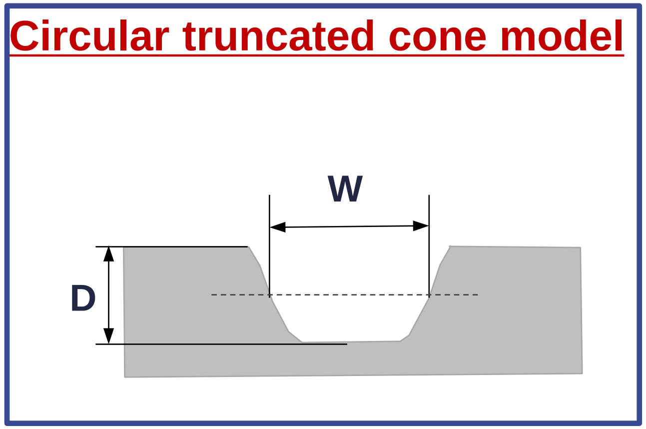


Profile along line A-A’



Pit phase defect model

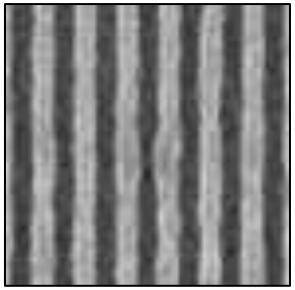
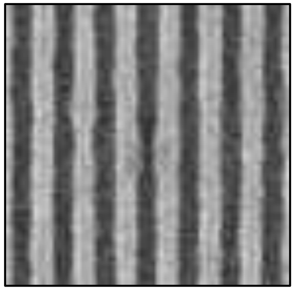
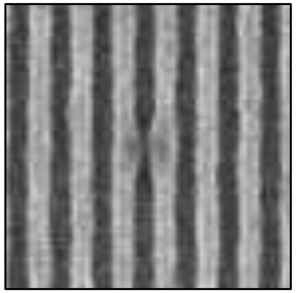
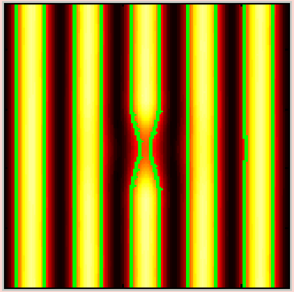
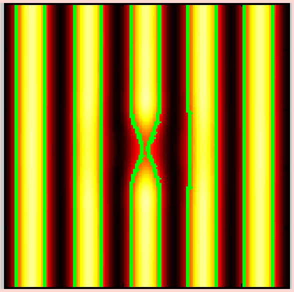
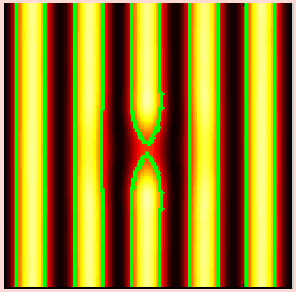
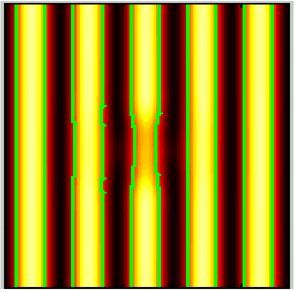
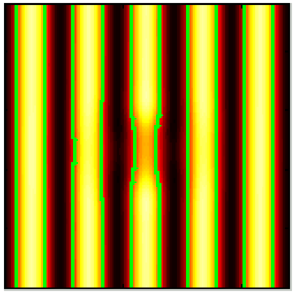
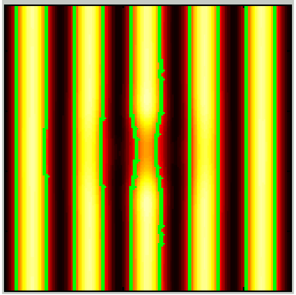

<u>Gaussian shape model</u>


<u>Circular truncated cone model</u>

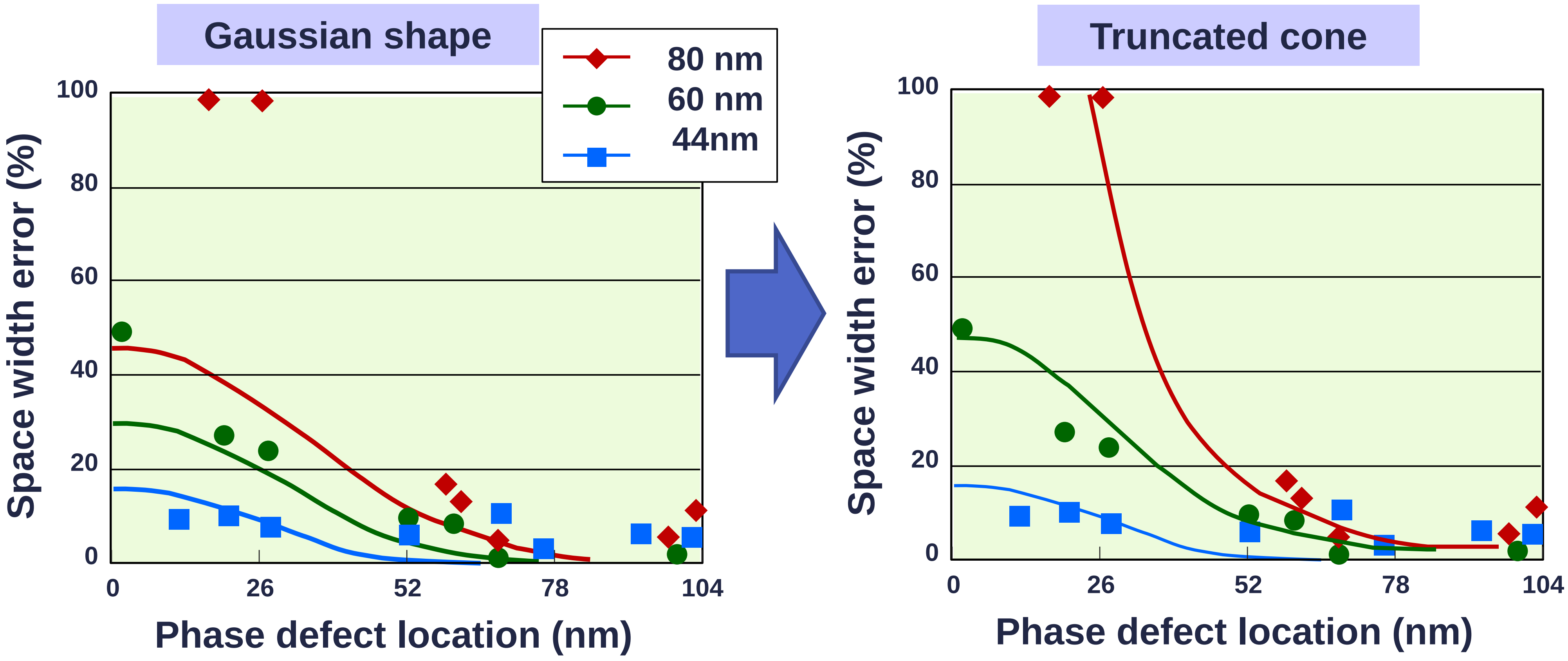
Take measured defect geometry into lithographic simulation

Gaussian shape ⇒ <u>Circular truncated cone shape</u>

Defect printability vs. defect geometry (experiment)

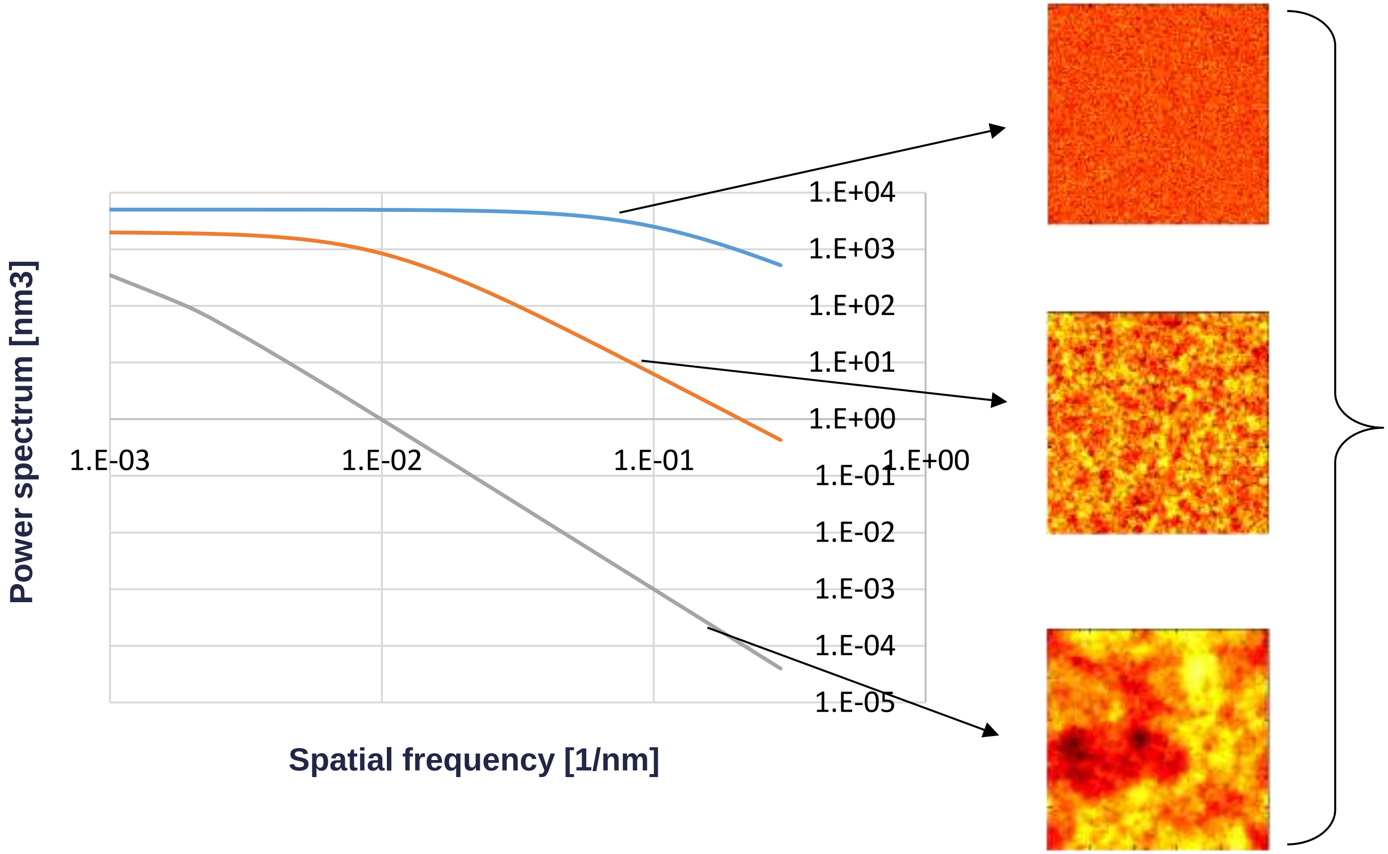
Defocus [nm]	-30	0	30
Printed 24 nm L&S, **Pit phase defect @mask** **(W=80 nm, D=1.9 nm)** **NA=0.25, Dipole**			
Simulated images **- Truncated cone model**			
Simulated images **- Gaussian shape model**			

Defect printability vs. defect geometry (analysis)



CD error prediction accuracy improvement using the truncated cone shape defect model

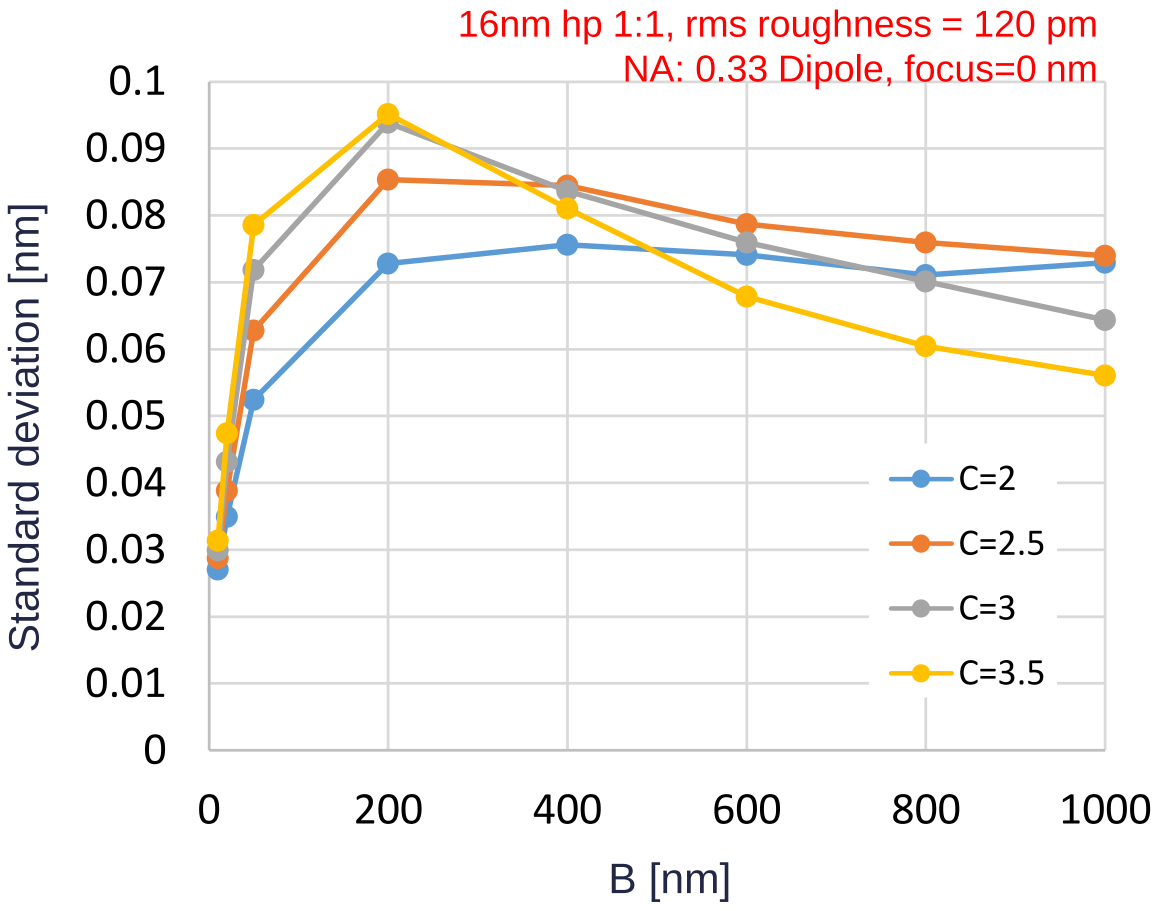
"Mask surface roughness effects on EUV lithography performance", < *P-MA-38* >



Brings different Litho. impact?

- **It is curious and important to analyze the effect of the shape of surface roughness PSD on lithography performance.**

PSD dependent CD fluctuation


16nm hp 1:1, rms roughness = 120 pm
NA: 0.33 Dipole, focus=0 nm

Generate PSD by $\boldsymbol{k}$-correlation model as

$$\boldsymbol{PSD(f)} = \frac{\boldsymbol{A}}{\{\boldsymbol{1} + (\boxed{\boldsymbol{B}} \cdot \boldsymbol{f})^{2}\}^{\frac{\boxed{\boldsymbol{C}}}{2}}}$$

in k-correlation model

- At low spatial frequencies ($f \ll 1/B$) the PSD is constant and equals A.
- At high spatial frequencies the PSD is scaled as $1/f^{C}$.
- B is related to a correlation length.

\- Correlation between the "knee" and design
\- CD deviation determined by fractal

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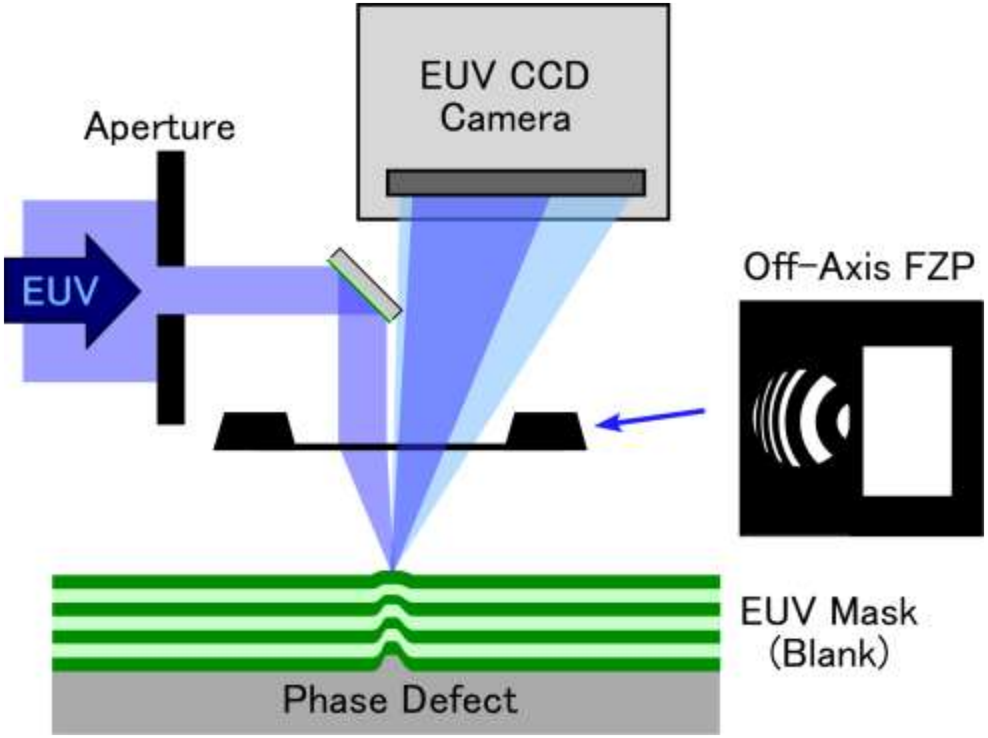
4. Actinic Imaging technology

- Micro Coherent Scatterometry Microscope (CSM), to analyse defect property, resolves <30nm width multilayer defect on an EUV blank
(work with University of Hyogo)

- EUV bright field microscope provides <hp16nm EUV mask images and identifies phase defects

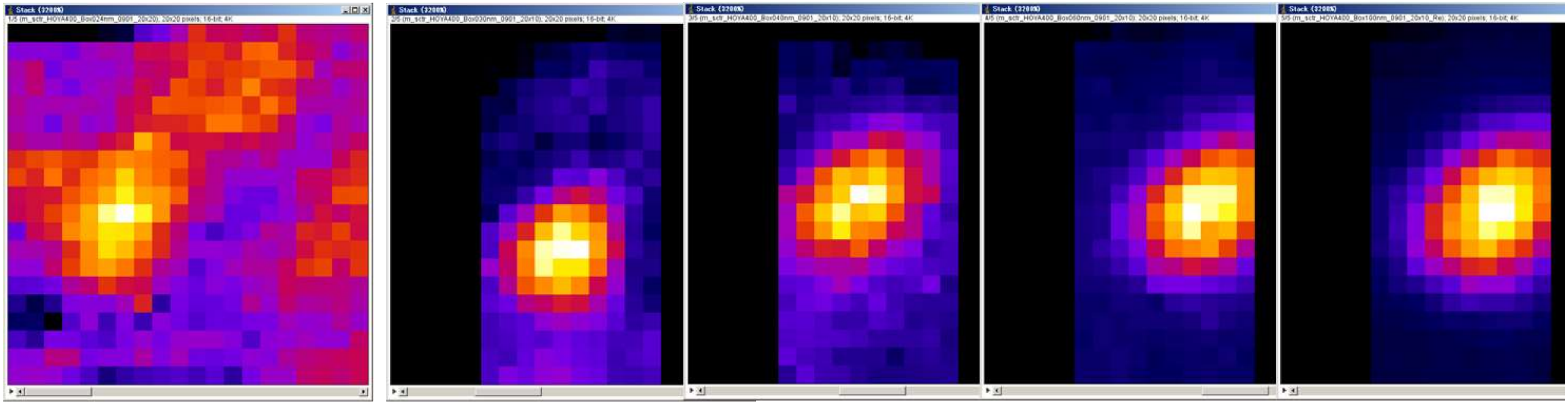
“Development of Coherent EUV Scatterometry Microscopes for EUV Mask Evaluation”, < *Session 9* >
“Development of Micro Coherent EUV Scatterometry Microscope for EUV Mask Defect”, < *P-MA-31* >



Micro CSM to analyse defect property by diffraction image

Defect images obtained by micro CSM

University of Hyogo annual report, 2013



24 nm

30 nm

40 nm

60 nm

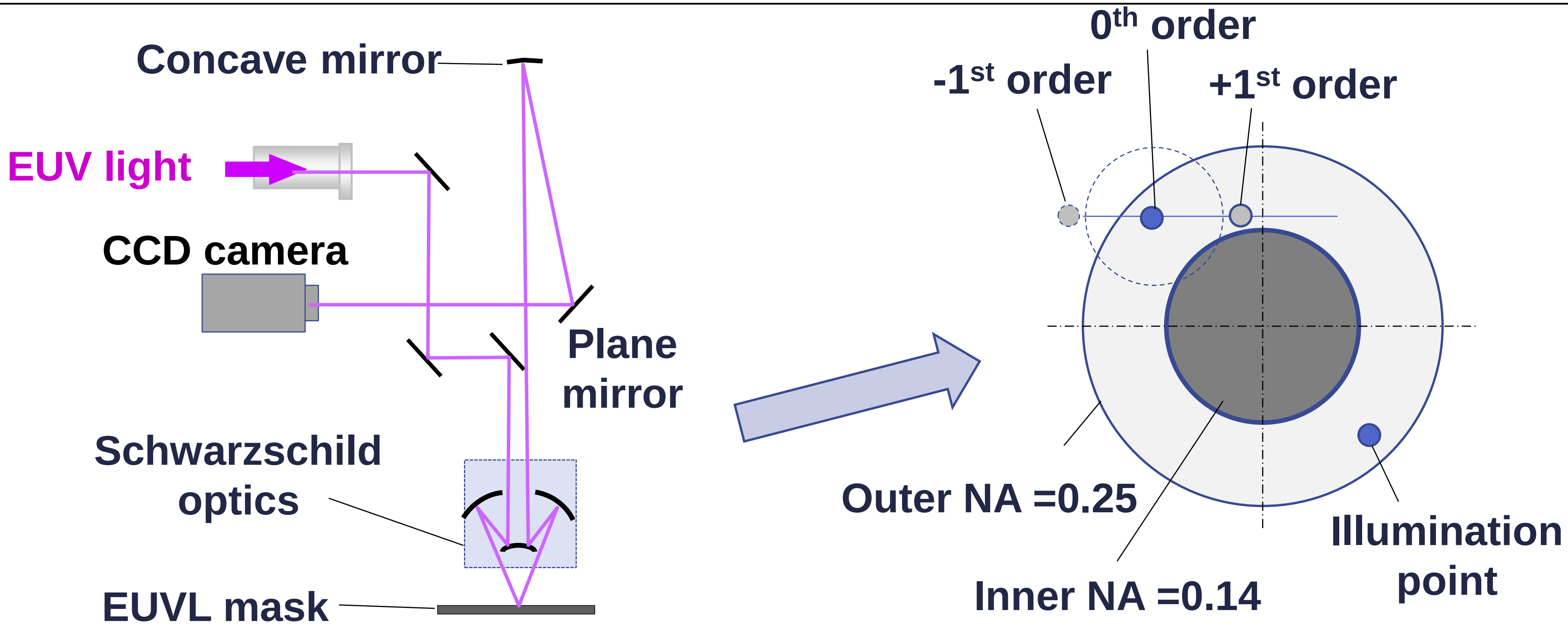
100 nm

Pseudo-color : integrated scattering intensity (white/yellow/red/purple/blue/black)

Scan XY: fine stage 50nm step 20X20 positions

Identify <30nmW phase defect by micro CSM

“Design, Fabrication, and Test of an EUV Mask Imaging Microscope for Lithography Generations with sub-16 nm Half Pitch”, < *Session 9* >

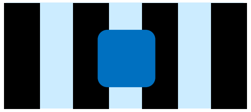
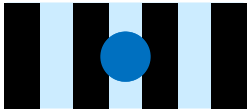
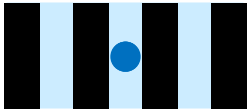
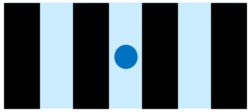
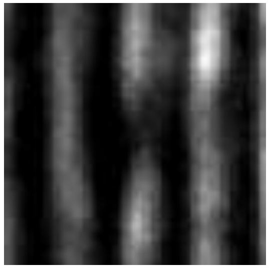
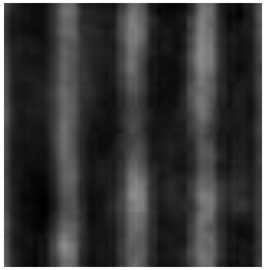
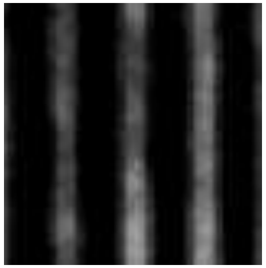
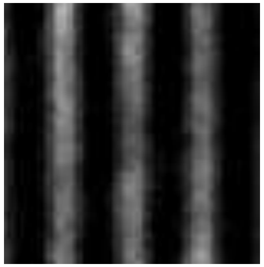
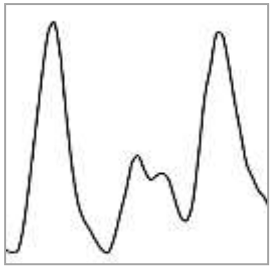
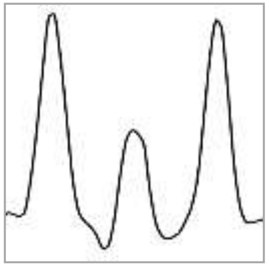
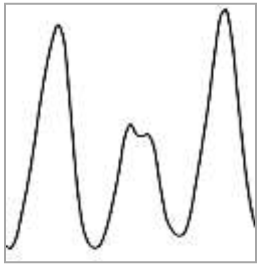
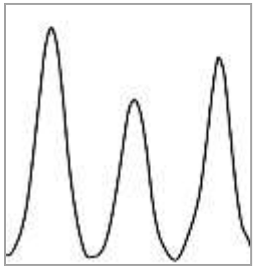


Schematic of the microscope and pupil of the optics

EUV x1500 microscope to observe lithographic impact by defect for <hp16nm development

Observation (defect size dependence)

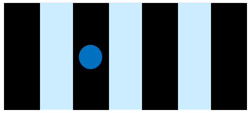
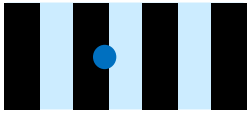
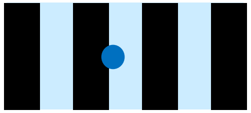
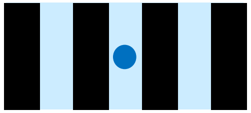
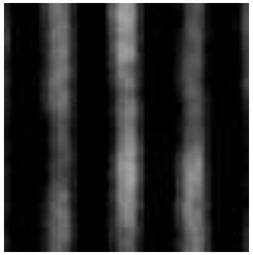
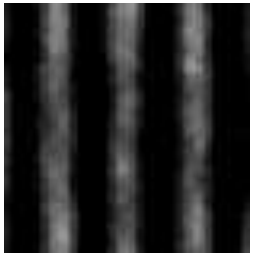
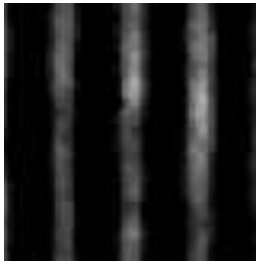
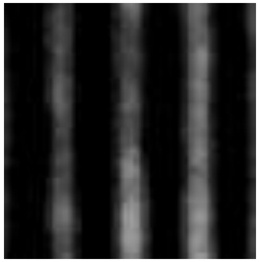
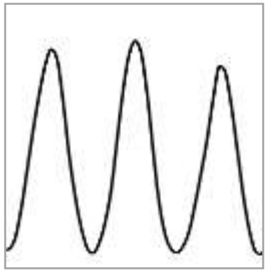
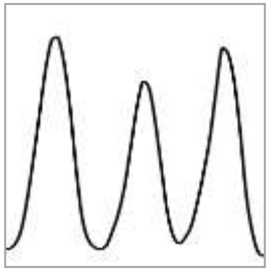
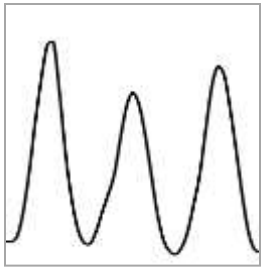
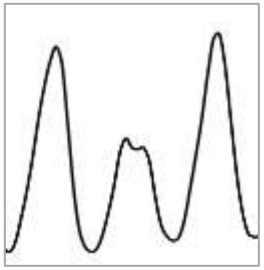
Amano T., BACUS 2013

Defect size [nm] Height/ FWHM	2.5/ 106.8	2.5/ 79.8	1.8/ 57.4	1.4/ 55.2
Mask design				
EUV microscope image				
Intensity profile				

Defect size dependent EUV microscope images of the hp64nm L/S with phase defects

Observation (defect location dependence)

Amano T., BACUS 2013

Defect position	- 4 nm	+ 24 nm	+ 44 nm	+ 64 nm
Mask design				
EUV microscope image				
Intensity profile				

Defect location dependent EUV microscope images of the hp64nm L/S with 1.8nmH/57.4nmW phase defect

OUTLINE

1. EIDEC Blank Inspection Technology Development
2. ABI tool development
3. Defect Printability
4. Actinic Imaging technologies
5. Summary

5. Summary

- *ABI tool for hp16nm HVM* with high magnification review function will be available

- ABI signal and lithographic impact are determined not by SEVD but by *topography* of the defect

- Lithographic impact of surface roughness is determined not only by rms but also by *morphology*

and

- ABI technology development for hp16nm and beyond, *micro CSM* for defect analysis, and, *EUV bright filed microscope* for defect evaluation are prepared

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END