Overview of EUV Mask Inspection Systems in NewSUBARU

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Outline

1) Introduction
2) EUV Microscope (EUVM)
   Defect repairing result using FIB
3) Coherent EUV Scatterometry Microscope (CSM)
   - Image reconstruction
   - CD measurement repeatability
4) Summary

EUVM

EUV Microscope

1)Absorber pattern observation

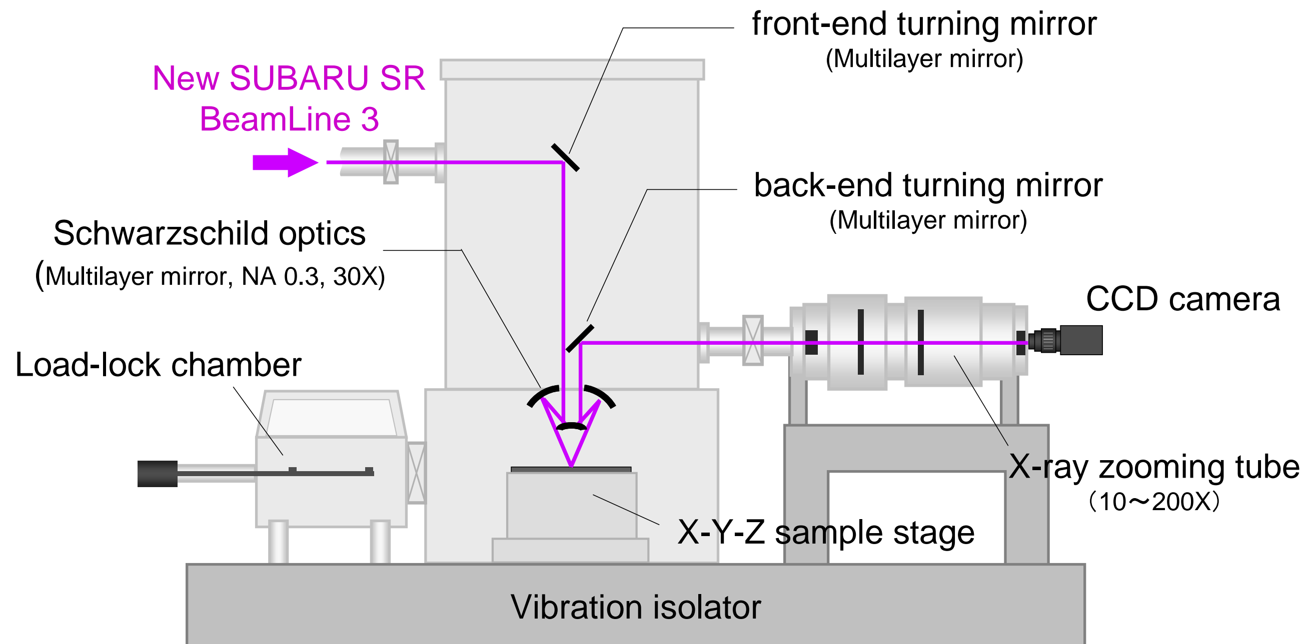
2) Programmed phase defect observation

3) Printability evaluation of programmed phase defect

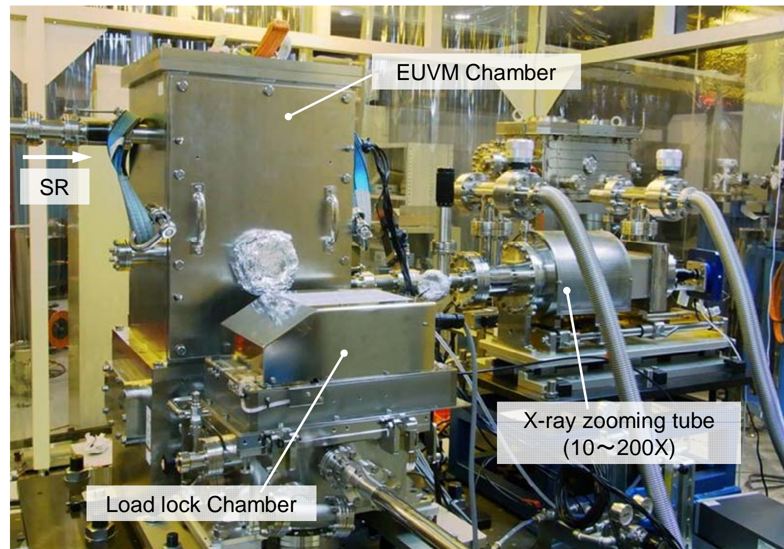
4) Line-cut defect repairing

EUVM

EUV Microscope (EUVM)



BL-3

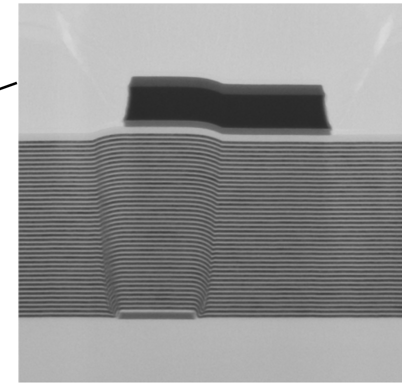


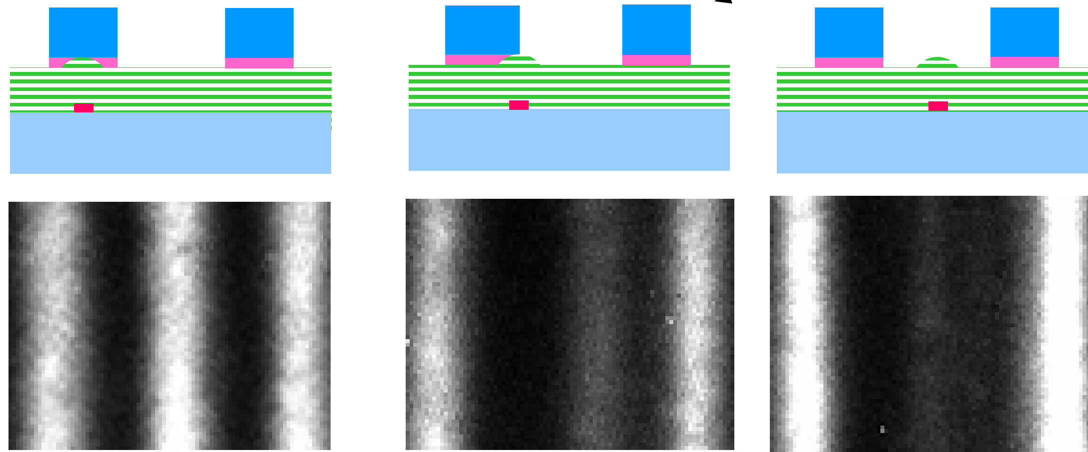
Light Source： BL-3 Bending magnet
Detection method： Bright field
Inspection period： 10～20 s / shot
Magnification： 300～6000 倍
Resolution： 50 nm (NA 0.3)
Vacuum pressure： 2.0×10^{-5} Pa

EUVM

Evaluation of printability

Influence of the phase-defect printability in L/S



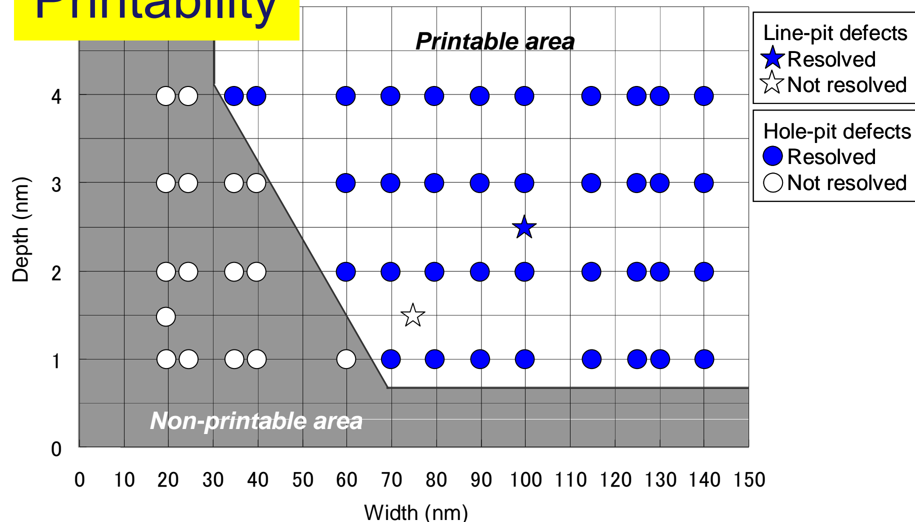


400-nm L/S , 12-nm-height bump

hp 400 nm

Influence of the printability confirmed by varying the position of the programmed defects.

Printability



The depth of the programmed-pit defects was controlled in high accuracy on the mask-blanks substrate.

Depth: 1～4 nm

Width: 20～140 nm

Printability of the hole and line programmed pit defects

EUVM

Repair of the Line-cut defects

The issues of the defect repairing utilizing CVD

1) Resistance to cleaning

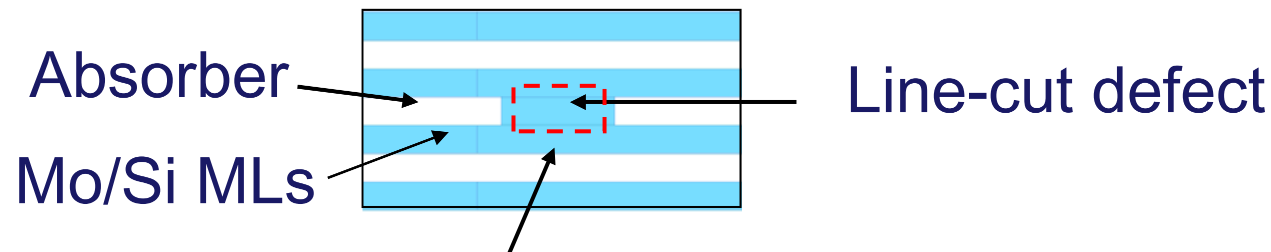
Since the CVD film includes carbon, the thickness of the CVD film can easily to decrease during the contamination cleaning.

→ Poor reliability in defect repairing

2) Since the shield capability of the CVD film at EUV wavelength has low shield capability, CVD film should be thick.

→ Increase the shadowing effect

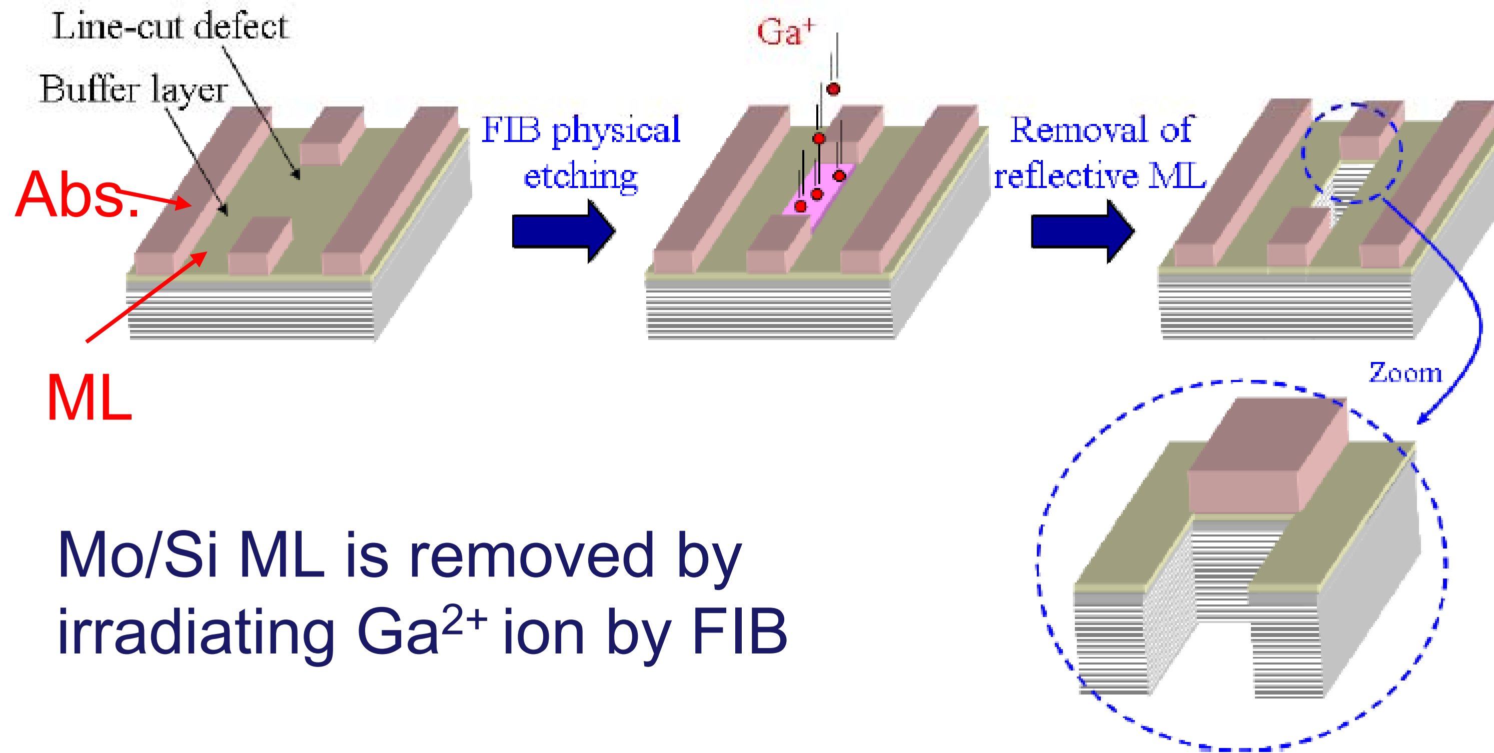
Verifying the effectiveness of FIB repairing by EUVM!!



The area size of the FIB irradiation was optimized.

EUVM

Line-cut defect repairing by FIB



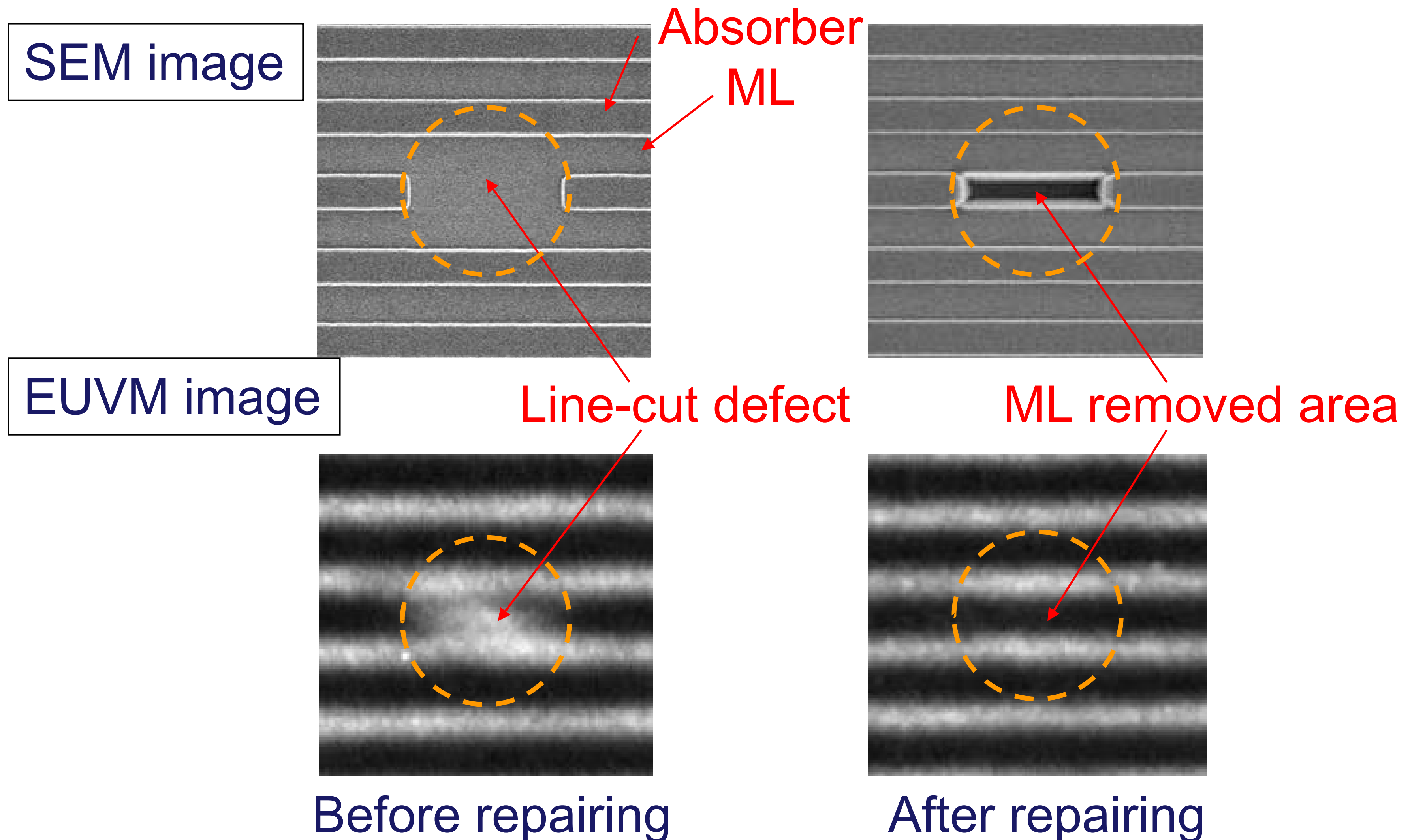
Mo/Si ML is removed by irradiating Ga^{2+} ion by FIB

FIB: Focused Ion Beam
Beam spot = ϕ12.5 nm
Accelerating voltage = 15 kV
Beam current = 2 pA

EUVM

The EUVM observation results of the line-cut repair by Ga+-FIB (1)

SEM and EUVM images of line-cut defect in 225 nm L/S

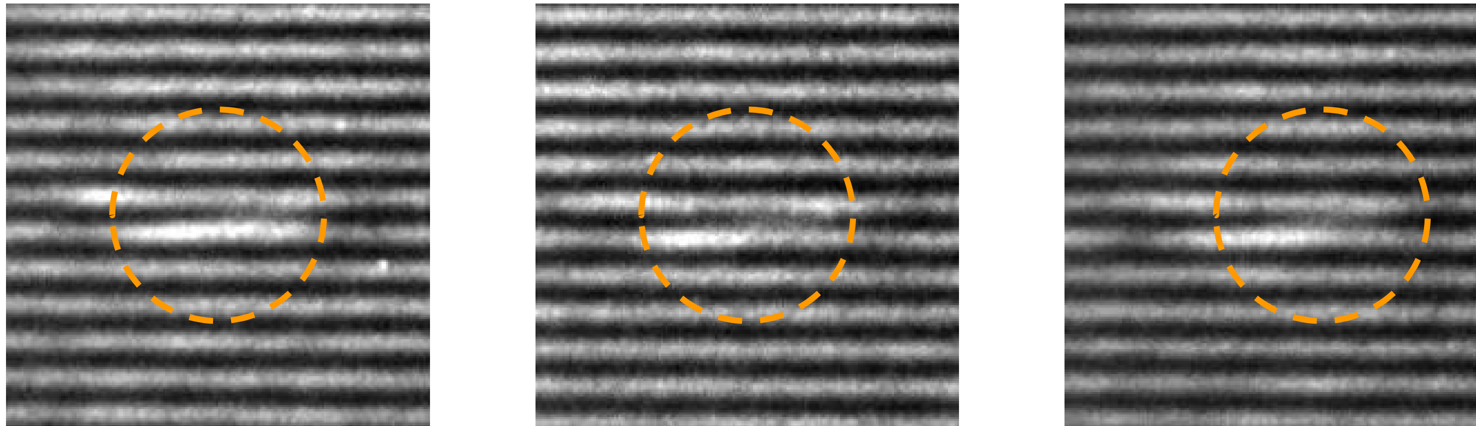


EUVM

The EUVM observation results of the line-cut repair by Ga+-FIB (2)

SEM and EUVM images of line-cut defect in 128 nm L/S

EUVM images



Small FIB irradiation area size Large

The FIB irradiation area size should increase!!

Conclusions

1) Printable and non-printable regions for the pit defects were confirmed.

2) 1-nm height programmed pit-type defect was confirmed to be printable.

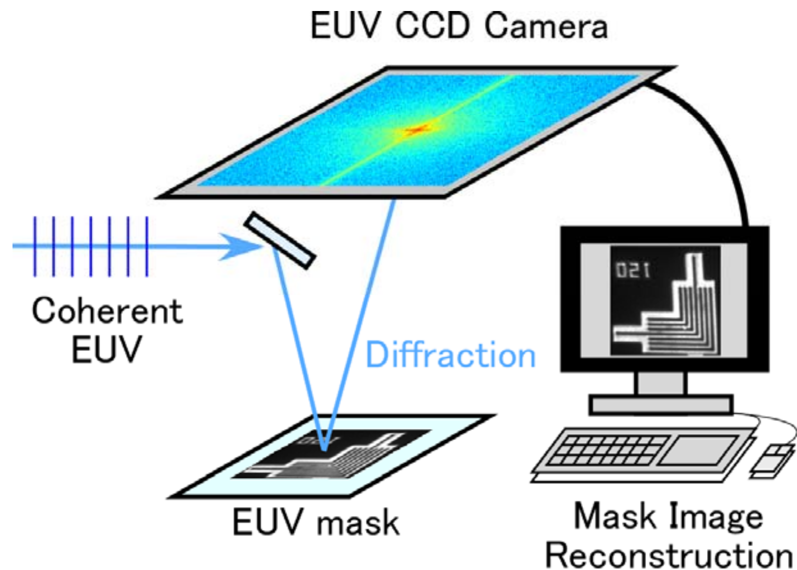
3) Line-cut defect was repaired by FIB, and the effectiveness of this method was confirmed by EUVM observation.

Coherent EUV Scatterometry Microscope

- Why CSM?
- Aerial Image Reconstruction
- Critical-Dimension Evaluation
- HHG EUV source
- Summary

CSM

Why CSM?



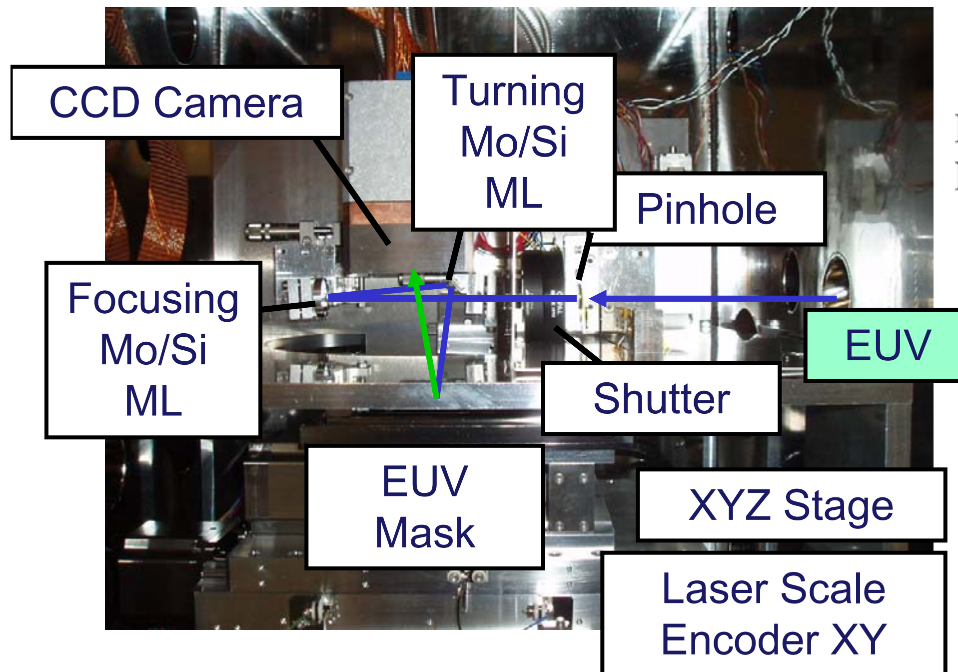
Defect Inspection + CD Evaluation

Simple, quick

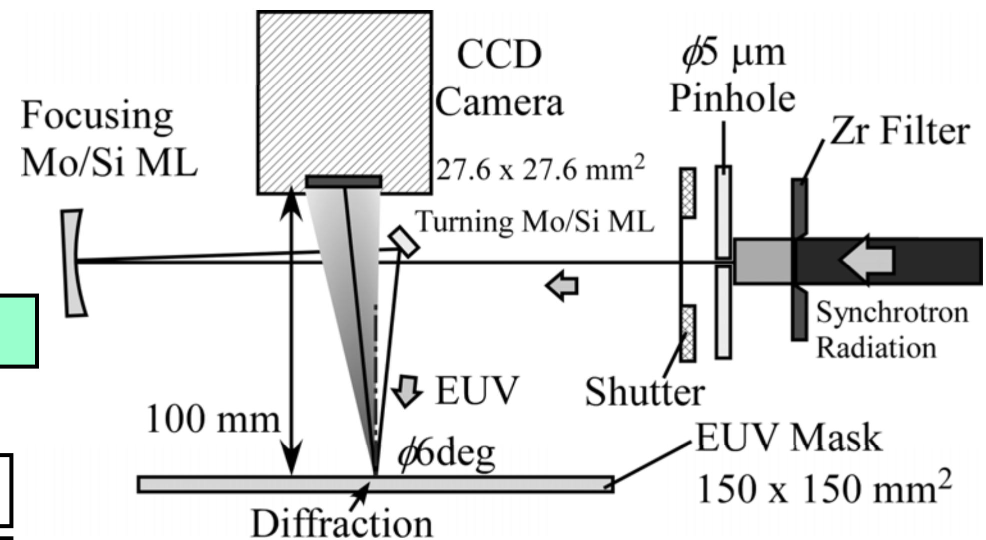
- LENS-LESS system
- Coherent EUV light is necessity.
- CCD camera records the diffracted light from the EUV mask.
- Aerial image is reconstructed by the diffraction image.
- Precious alignment is NOT required.

Coherent EUV Scatterometry Microscope

We developed the CSM demo system at NewSUBARU, synchrotron radiation facility.



Photograph



Schematic view

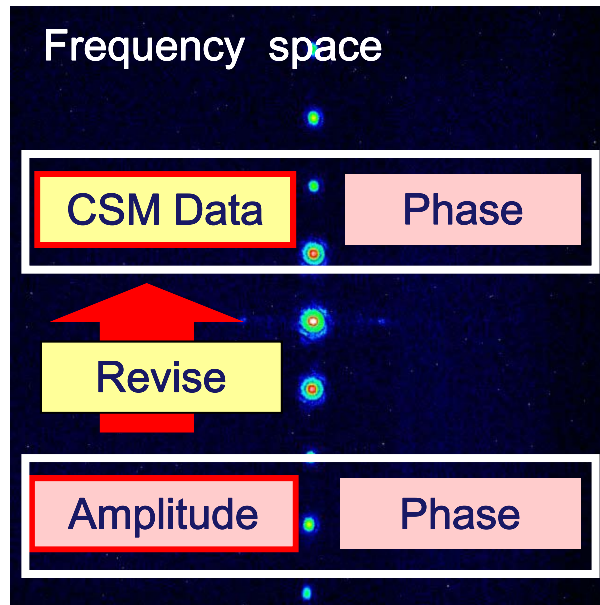
Field of view
ϕ 5 mm
Resolution
50 nm

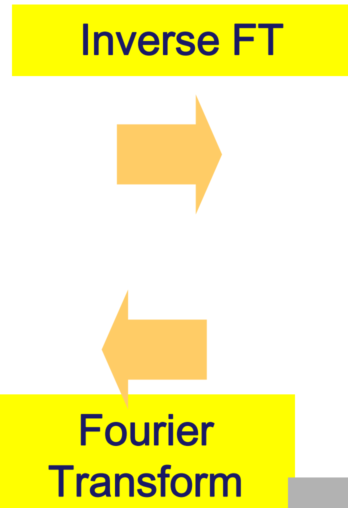
Angle of incidence is 6 deg. ~ EUV scanner

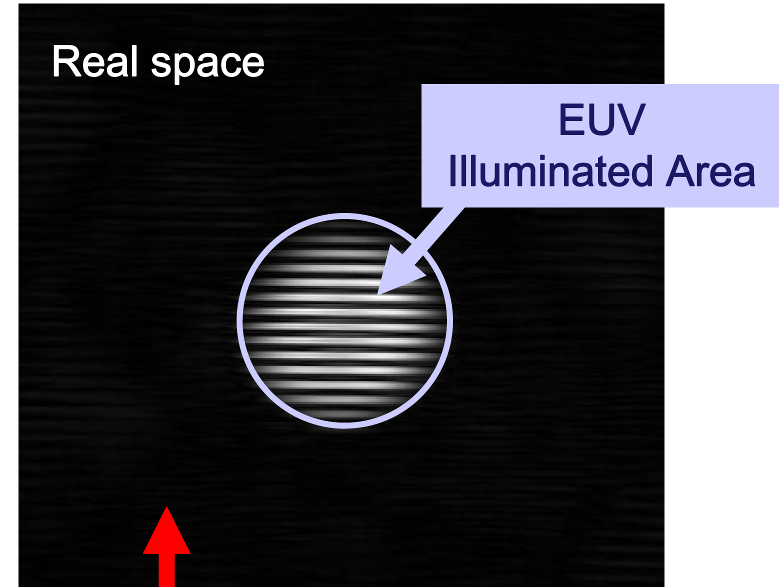
Imaging

HIO algorithm

Oversampling constraint

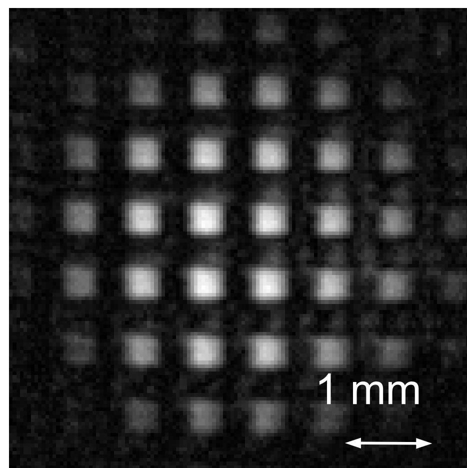






The amplitude information in non-illuminated area must be "ZERO".

hp-400-nm hole pattern



Iterative calculation with constraints.

Only periodic structure is reconstructed by HIO algorithm.
Suited algorithm is required for our CSM.

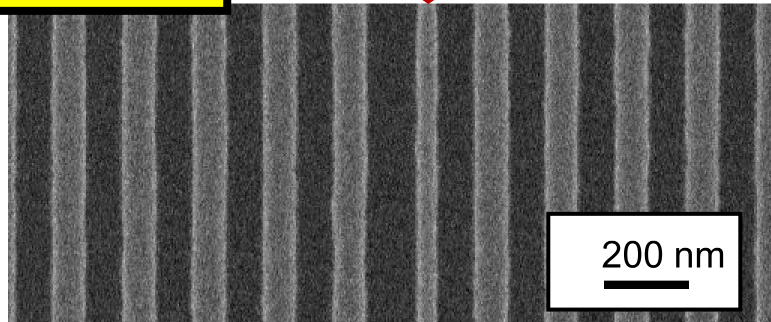
Imaging

Programmed defect

Program defect of line-width shrinkage

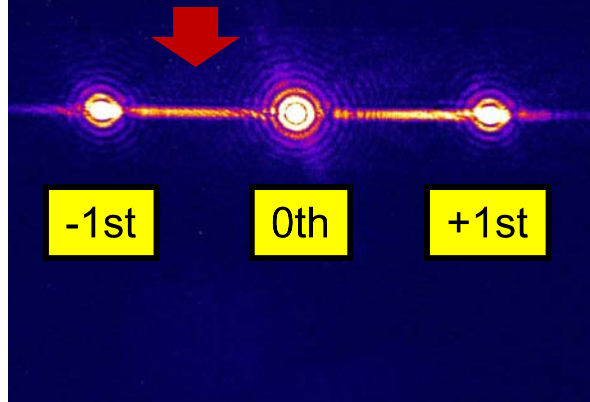
CD-SEM

Defect 30 nm width



88 nm L/S pattern

CSM CCD camera



Exposure time: 100 s

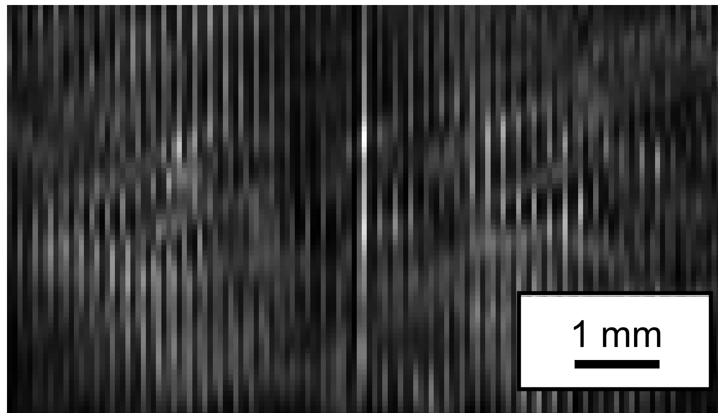
Programmed defect of a CD error in L/S pattern.
Diffraction signal of the defect was clearly recorded with CCD camera.

Imaging

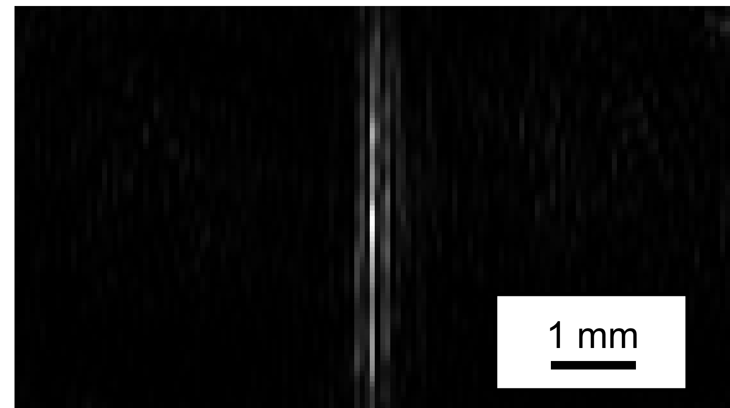
Programmed defect

Aerial image of defect was reconstructed by ptychography.

Reconstructed aerial image



Defect enhancement

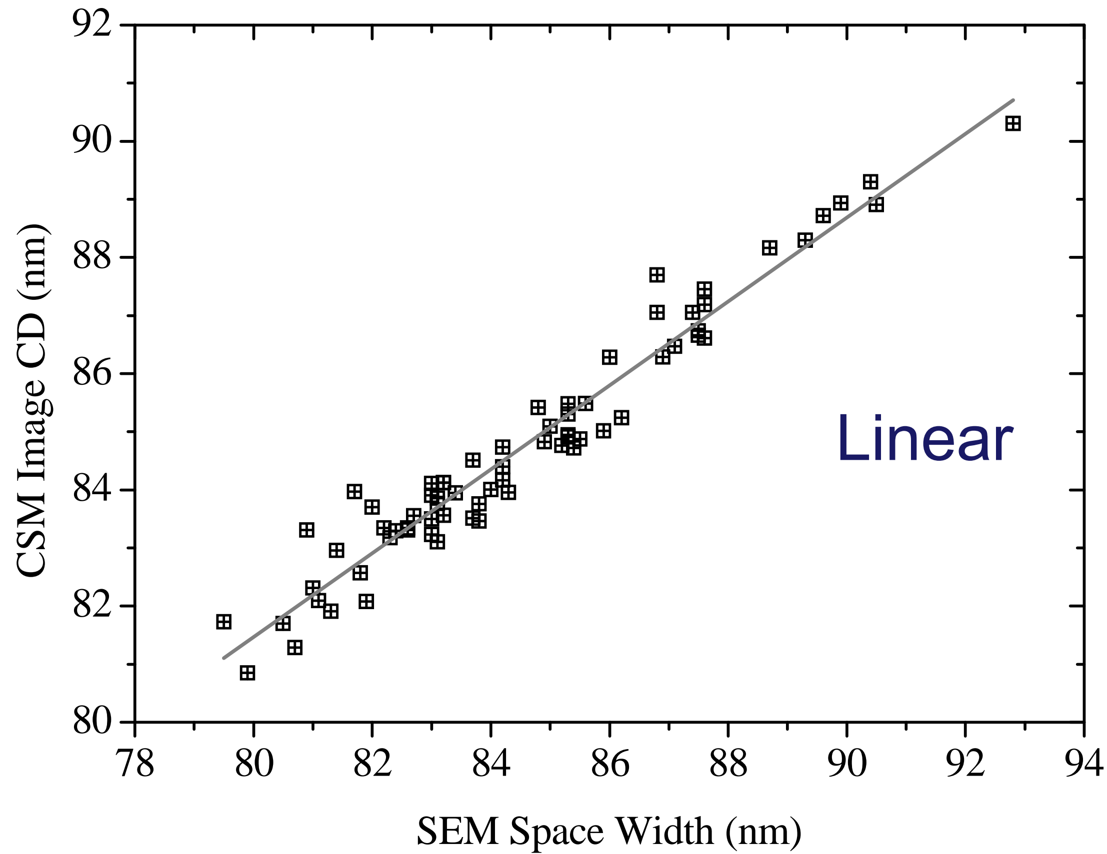


Clearly distinguished.

Defect line is reconstructed.
Fluctuation of L/S patterns.
To enhance the defect, periodic signal was filtered out.

CD

Correlation between CSM and CD-SEM

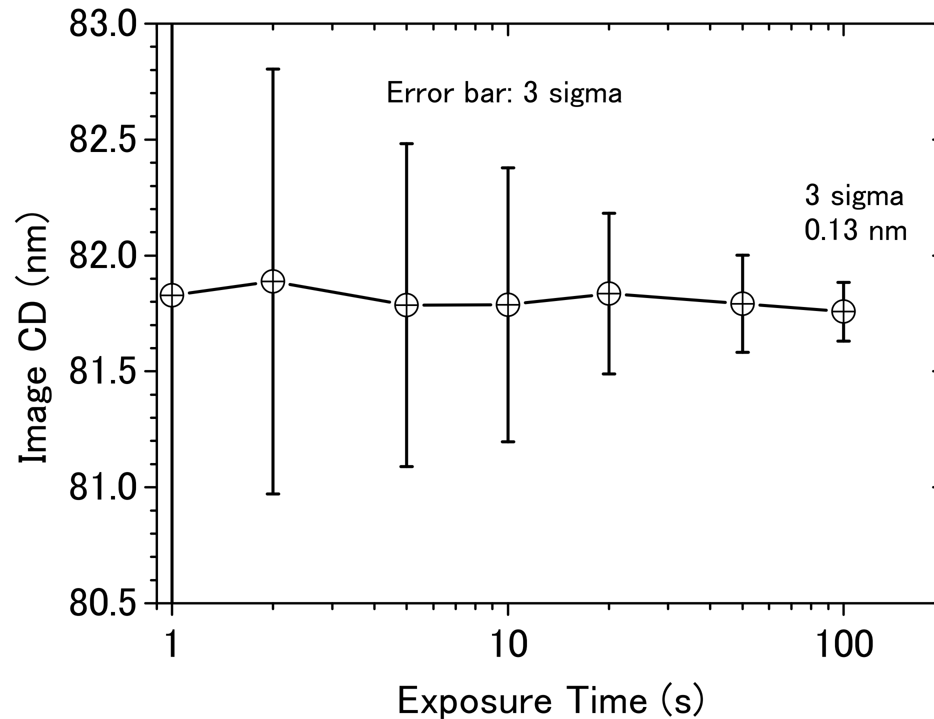


Linear

CSM result is well corresponding with the CD-SEM result.

CD

Repeatability of CD Evaluation



CD value obtained by the number of 20 measurements at same position varied with exposure time from 1 s to 100 s.

Error bar is 3 sigma deviation from the average CD value.

Repeatability can be improved with increasing the exposure time.

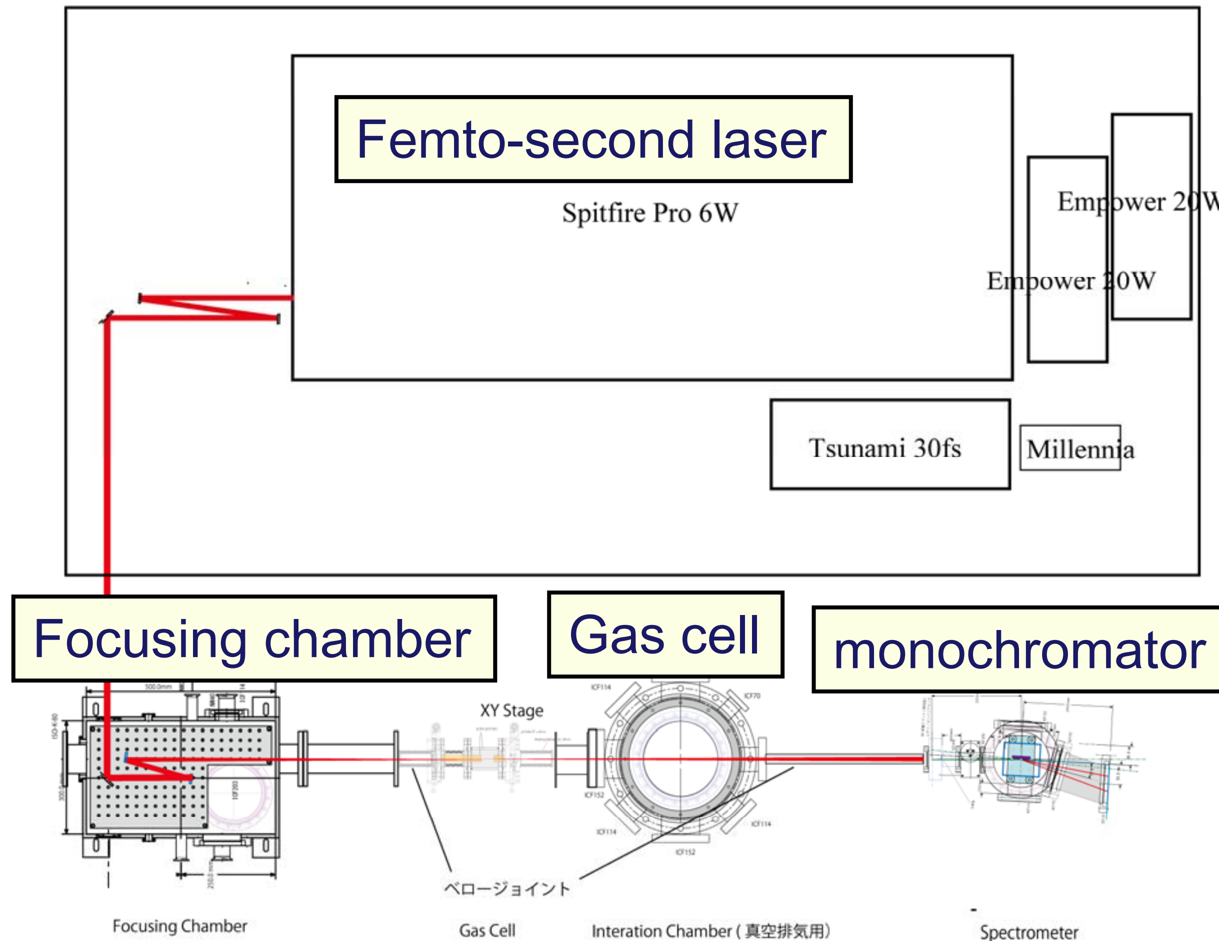
Exposure time	Repeatability
20 s	0.3 nm (3σ)
100 s	0.13 nm(3σ)

CD repeatability of 0.3 nm (3σ) satisfies the ITRS requirement of 0.65 nm (3σ) for 22 nm node.

HHG

High harmonic generation (HHG) EUV source

Collaboration work with RIKEN



Schematic of HHG system

Wavelength conversion of Sub TW laser of 800 nm

Laser spec.

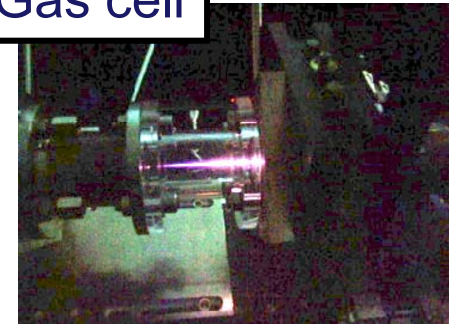
- wavelength : 800 nm
- Pulse width : < 40 fs
- Pulse energy : 6 mJ
- Repetition rate : 1 kHz

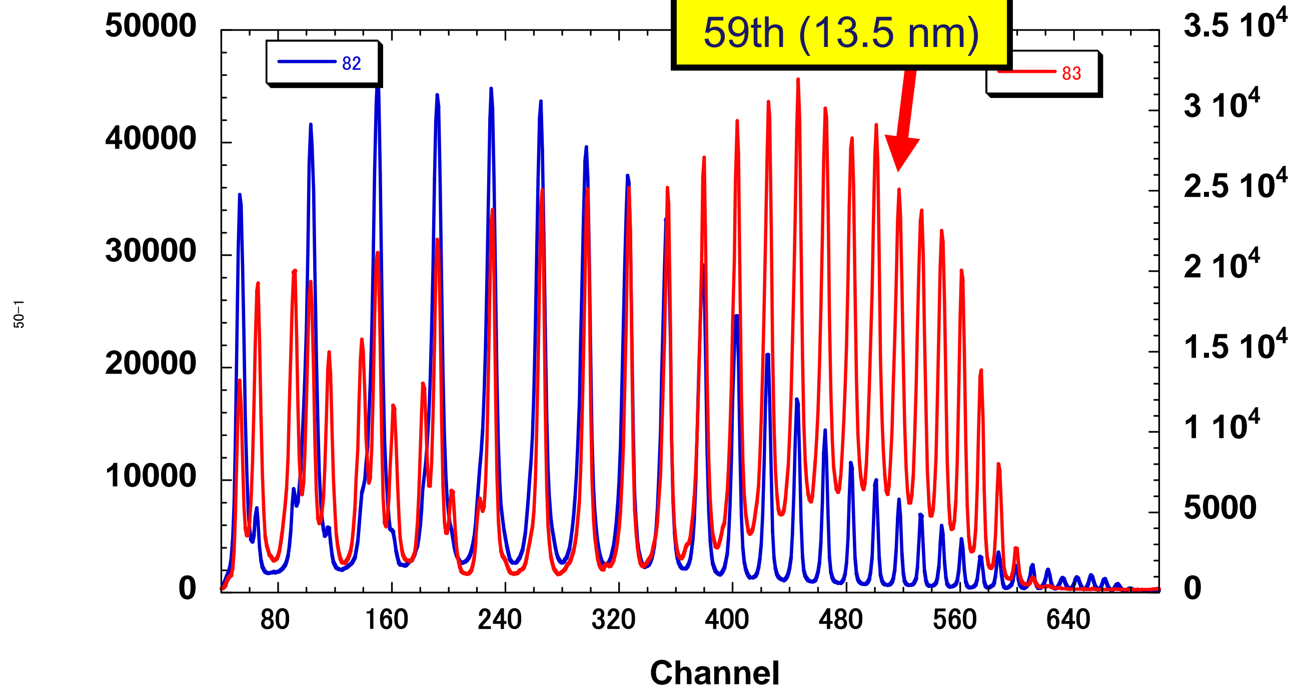
Full Spatially coherent

Experimental Result

HHG Spectrum

Gas cell





EUV output of 59th generation is optimized

1 nW output is expected.

CSM

Conclusions

1) For EUV mask evaluation, we have developed the coherent EUV scatterometry microscope.

2) Aerial image of EUV mask was reconstructed by the CCD camera (amplitude) image.

3) CD evaluation result of 88-nm L/S pattern is well corresponding with the CD-SEM result.

4) Repeatability of CD measurement satisfies the ITRS requirement for 22 nm node.

5) The EUV intensity of the high harmonic generation (HHG) is 1,000 times brighter than that from the bending magnet.

CSM is effective and powerful tool for EUV mask evaluation.

Summary

1) CSM is simple and cheap EUV mask inspection system.

2) Detailed figure of the defects can be obtained by EUVM.

3) After the inspection using CSM, detailed figure can be obtained to feed back to the fabrication process of the EUV actinic mask.