NewSUBARU EUVL R&D Activities and EUV Mask Defect Inspection

**Center for EUV Lithography,
University of Hyogo**

Takeo Watanabe and Tetsuo Harada

Outline

1. EUV Research Activities at NewSUBARU
   Resist, Mask, Collector Mirror Evaluation
2. 3D Structure of EUV Mask
3. CSM (Coherent EUV Scatterometry Microscope)
   Pattern observation
   Standalone CSM
4. Micro-CSM (CSM Focusing type)
   Actual defect observation result
6. Summary

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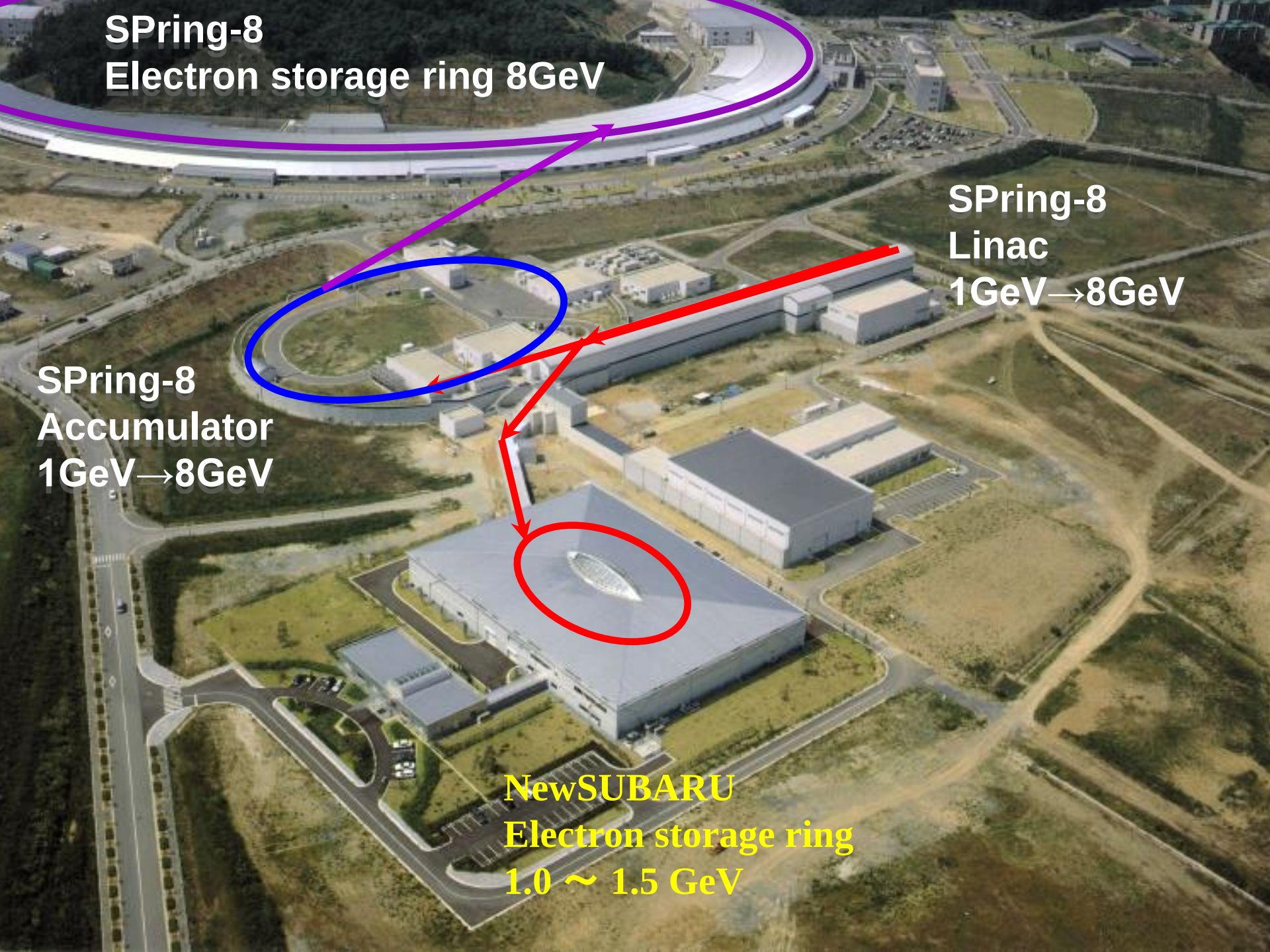
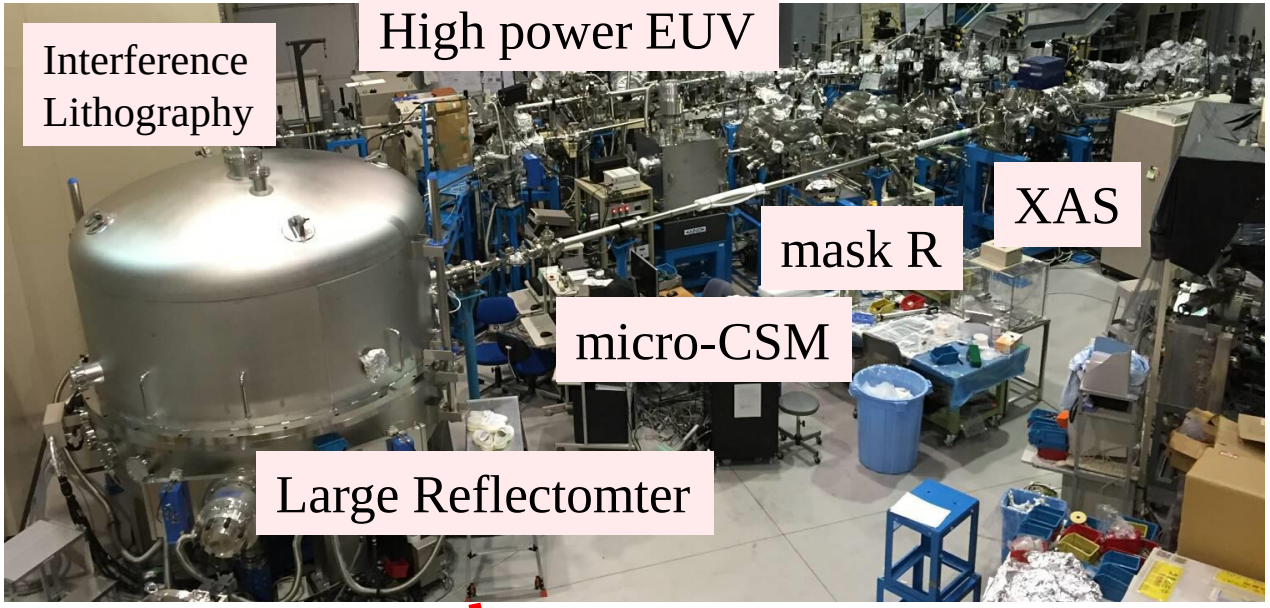

SPring-8
Electron storage ring 8GeV
SPring-8
Linac
1GeV→8GeV
SPring-8
Accumulator
1GeV→8GeV
NewSUBARU
Electron storage ring
1.0 ～ 1.5 GeV

Center for EUV Lithography

EUVL

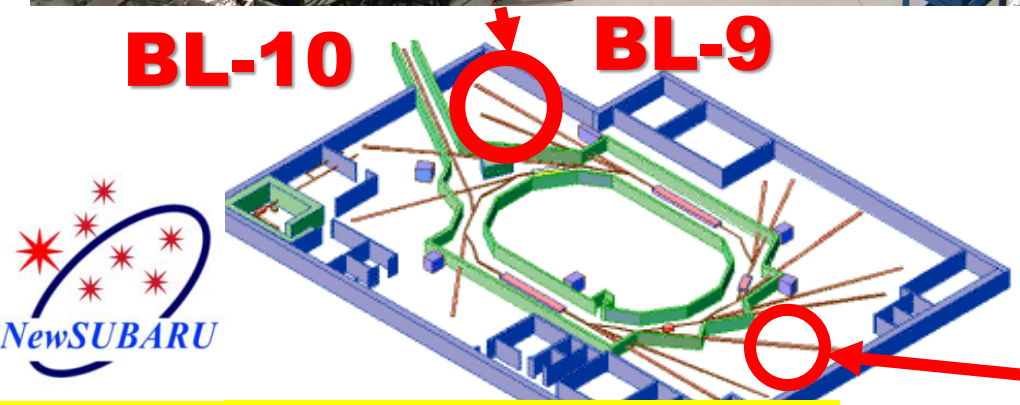
NewSUBARU Synchrotron Radiation Facility

in SPring-8 site



1) Resist P52
2) Mask P34
3) Large reflectometer of Collector mirror for EUV light source P25
4) Pellicle

Microscopes (EUVM)
Resist EUV Sensitivity



BL-3

EUV & Soft X-ray

Three Beamlines for EUVL

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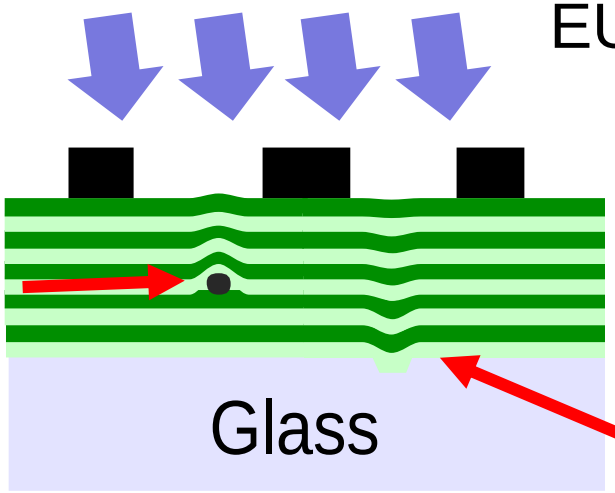
3D Structure of EUV Mask

EUV mask has 3D structure.



EUV wavelength 13.5 nm

Absorber (50 ~ 70 nm^t)

Mo/Si Multilayer (280 nm^t)

Pit

This 3D structure modulates reflection phase of EUV light.

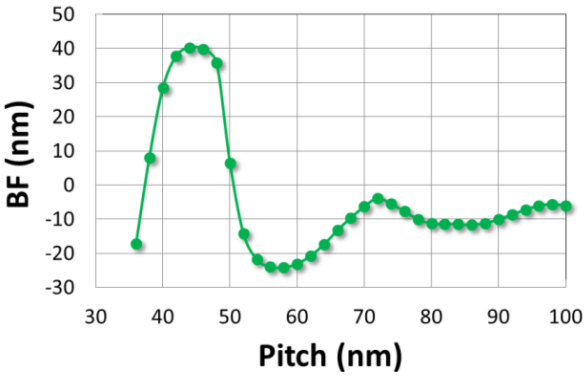
Aerial image of pattern strongly depends on its phase.

The phase modulation cause aberration called as “Mask 3D Effect”.

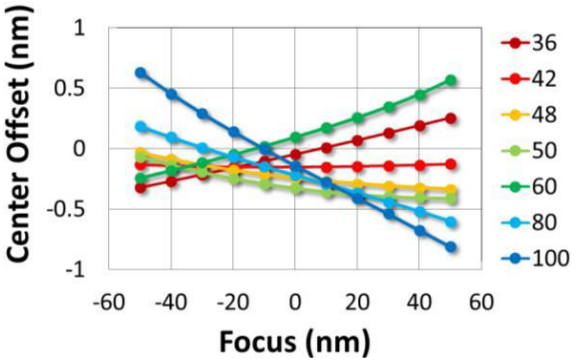
3D Defects of EUV Mask

Mask 3D Effect

- **Best focus shift**
- **Pattern shift through focus**
- HV bias
- Contrast loss
- 2 bar CD asymmetry



Best focus shift



Pattern shift

EUVL symposium 2016, L. van Look (imec).

The mitigation strategies were proposed to reduce “Mask 3D Effect”
For accurate mitigation, observation of pattern phase is significant.

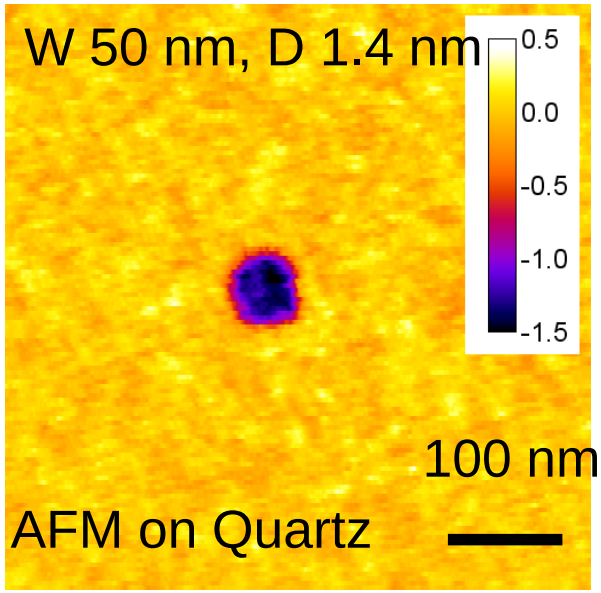
EUV Phase Imaging

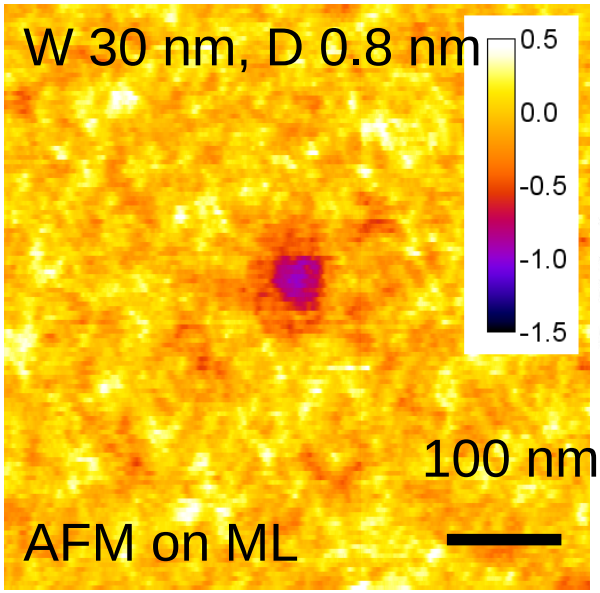
Phase Defect Inspection

Phase Defect

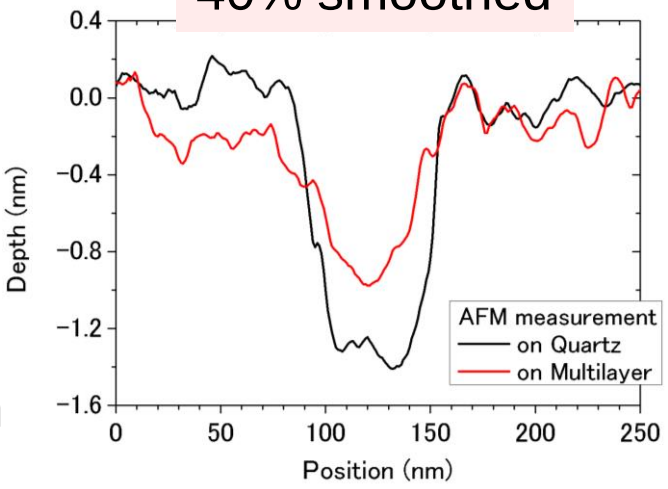
Defect printability depends on the reflection phase.
The surface shape was depends on the substrates shape, but slightly varied by stochastic.

stochastic





40% smoothed



Qz. vs ML.

EUV Phase Imaging

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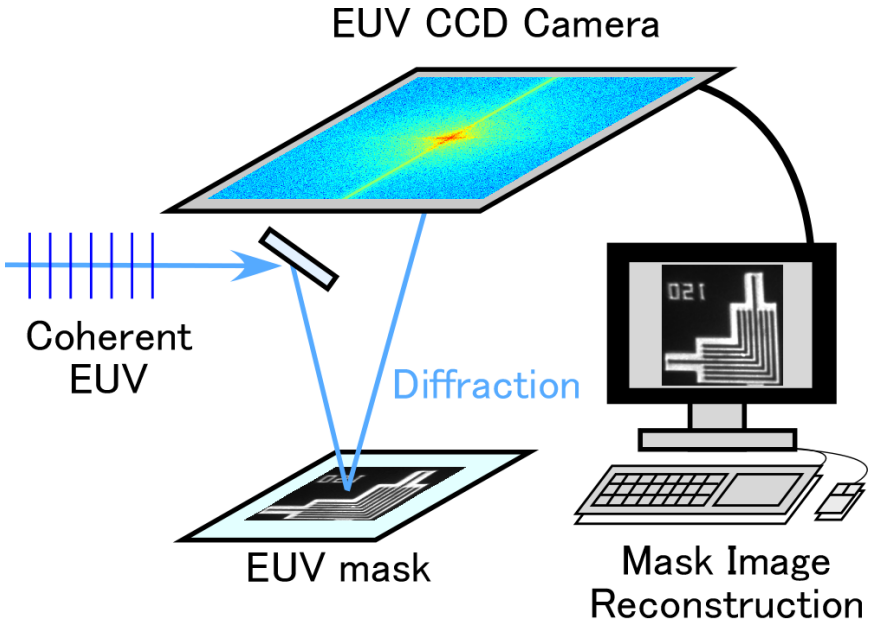
CSM: Coherent EUV Scatterometry Microscope

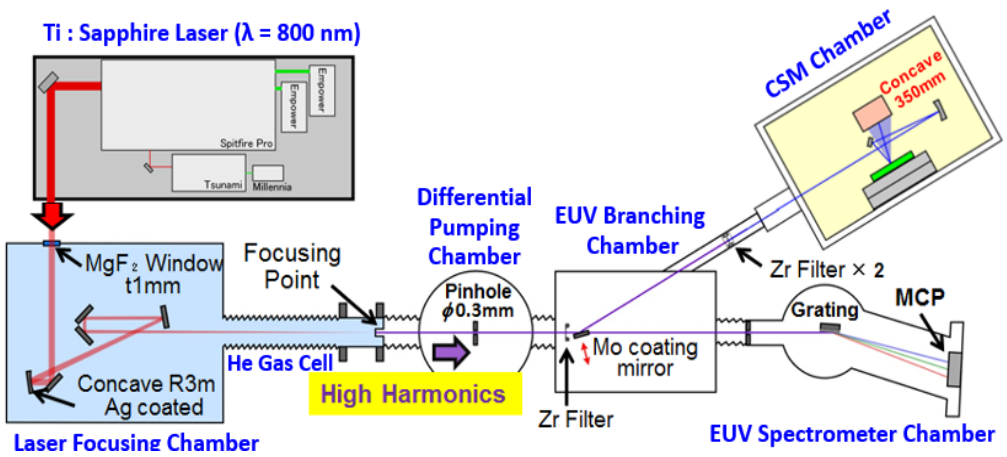
- Conventional EUV intensity image + **"EUV PHASE" image**
- Simple system, No imaging objective is used.
- Coherent EUV illumination (step and repeat, ptychography)
- Diffraction images were observed for the pattern reconstruction by iterative calculation



Recently, the PSI and Hanyang Univ. groups are developing the tools based on the same method.

CSM Systems in Univ. of Hyogo

Standalone CSM

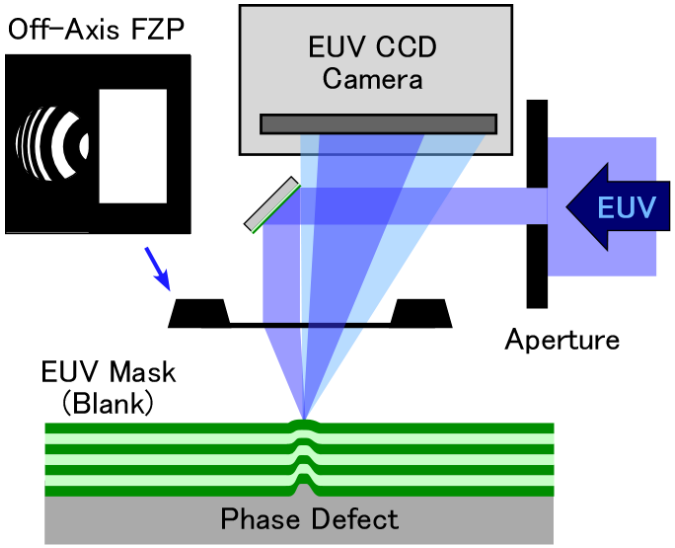


Focus size ϕ 1.8 mm
NA0.14

Mirror focusing

- Pattern phase observation
- Standalone source

Micro-CSM

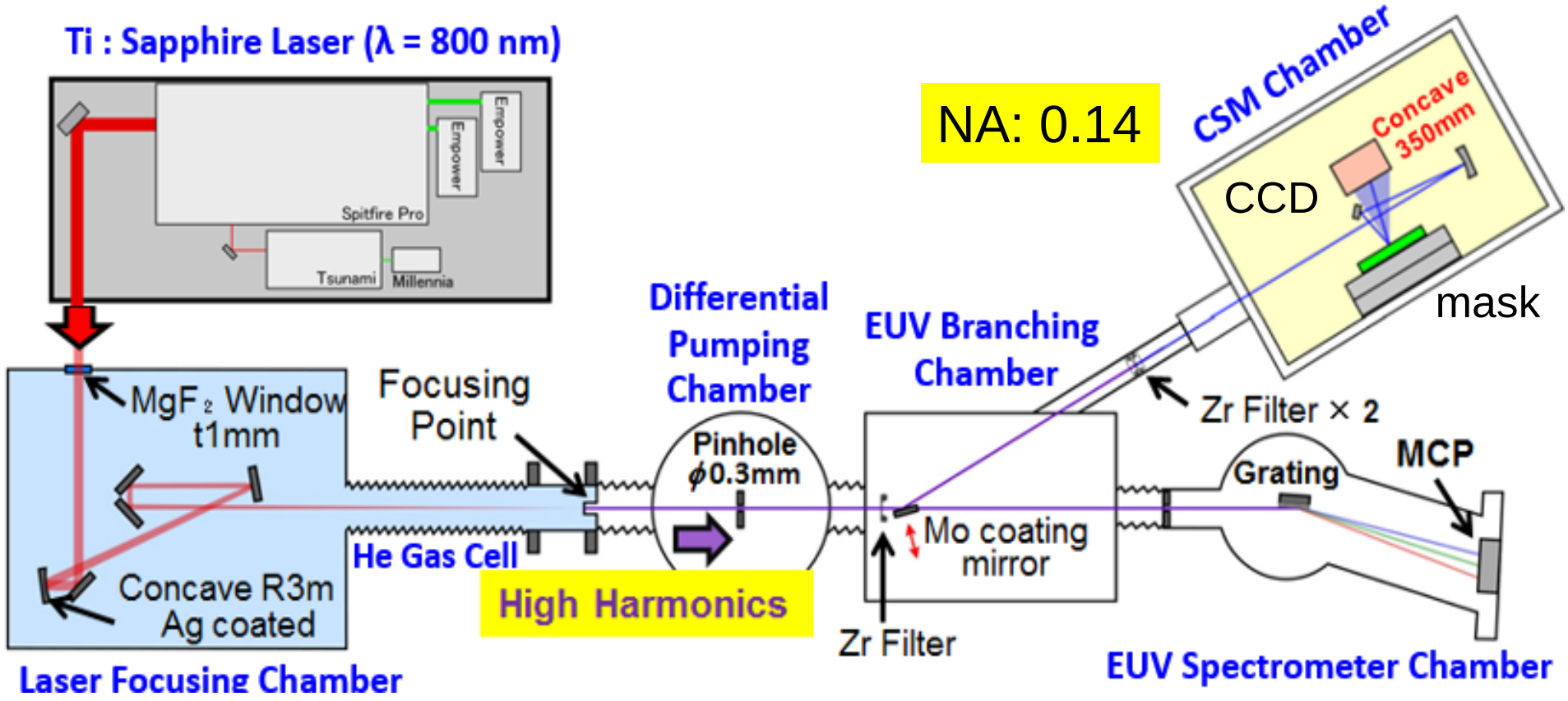


Focus size ϕ140 nm
NA0.27

Zoneplate focusing

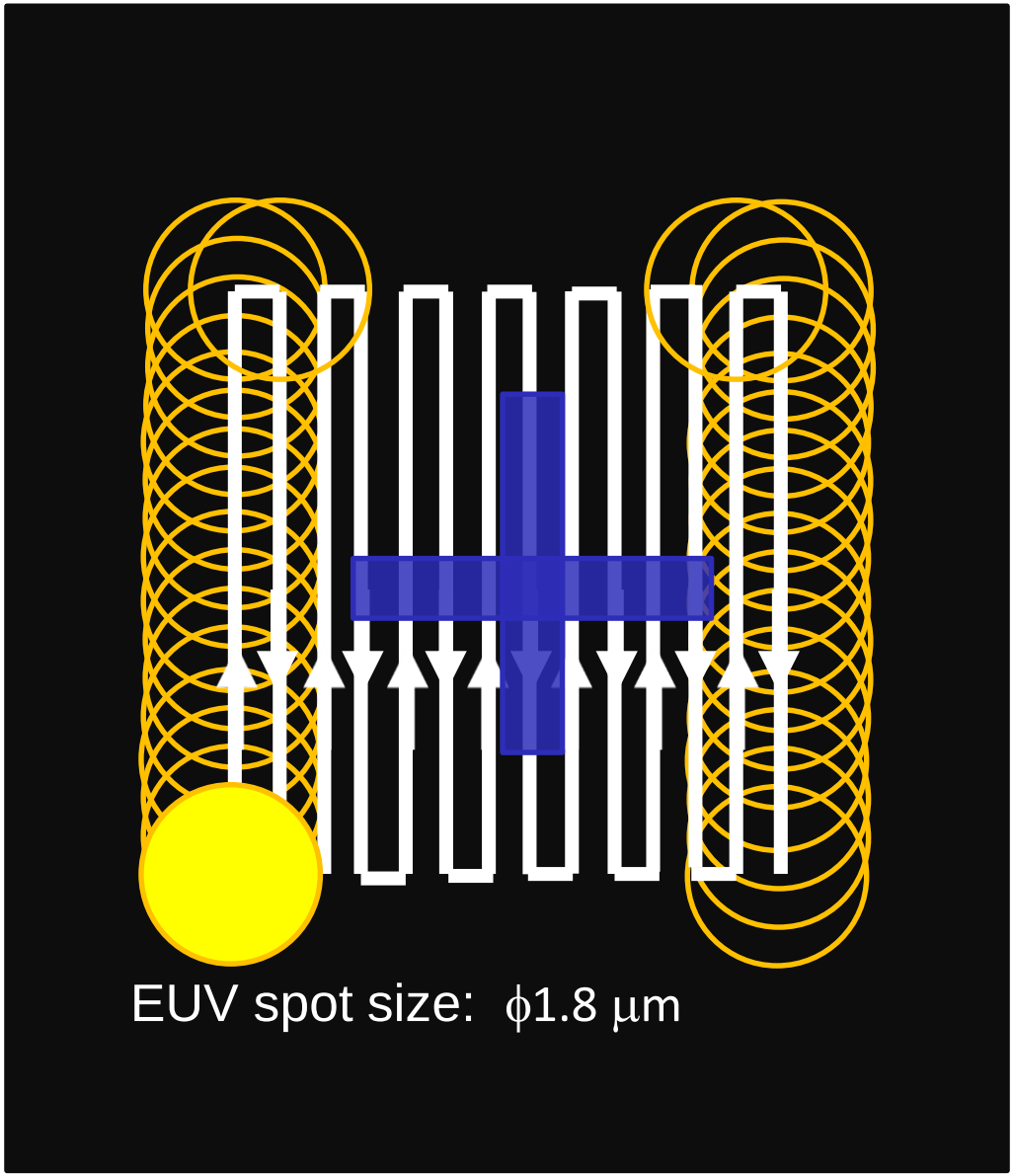
- Blank defect characterization
- Synchrotron light (Bending)

CSM with Standalone Source



- High harmonic generation EUV source
- 59th high harmonic (13.5 nm) of Ti:SAF laser (800 nm)
- EUV output: max **200 nW** (38 kW/mm^2-Sr)
- Beam size on the mask: **1.8 μm**

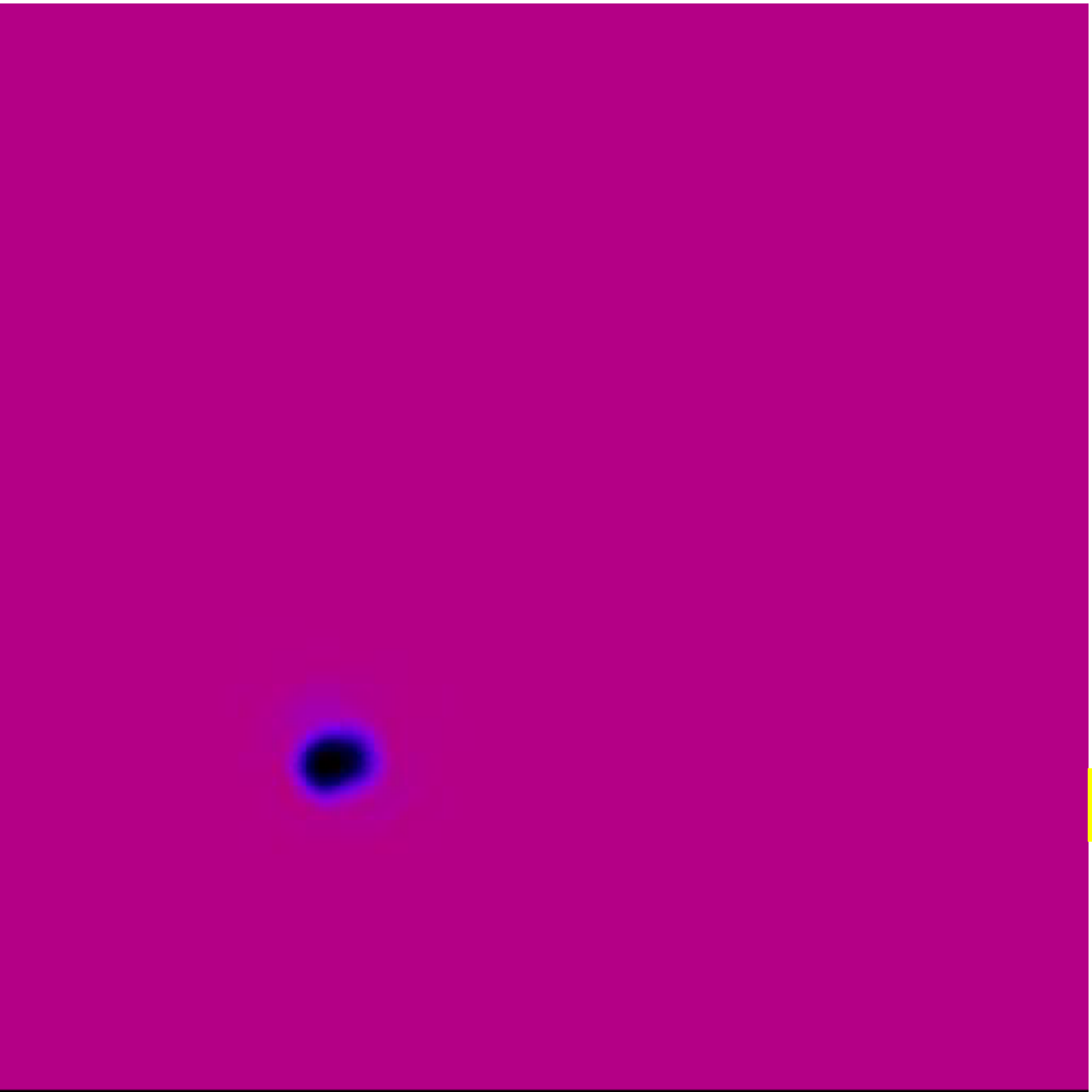
Observation Procedure and Image Reconstruction



Observation condition

- Scanning step size : 0.8 μm
- Measurement points : 15 × 15 points
- The exposure time at each point : 0.3 s
- The exposure dose : 71 pW (4.6 mW/cm^2)

CSM Image Reconstruction Process



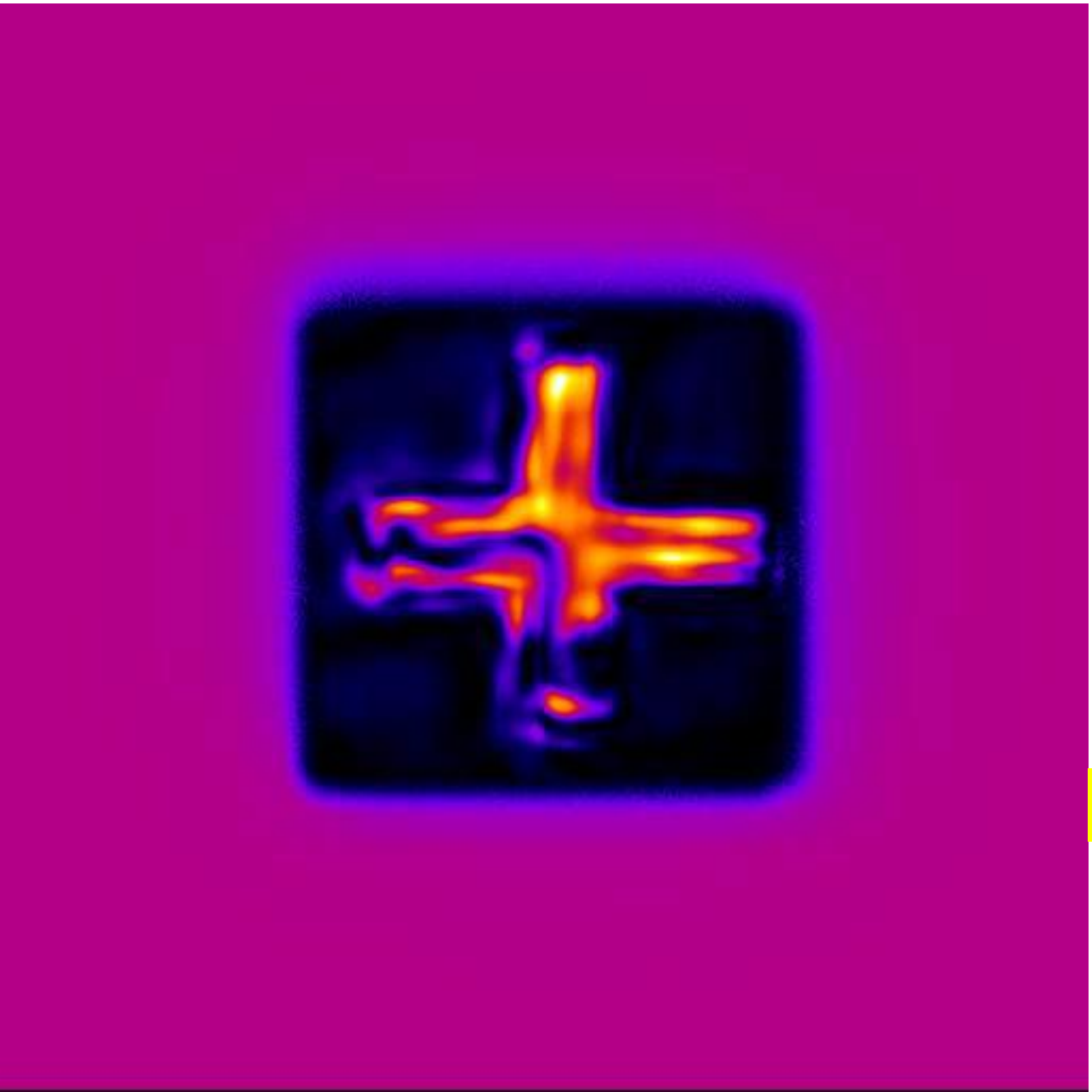
Reconstruction process with illumination scan

15 × 15 steps
1 – 5 iteration

Intensity image

2 µm

CSM Image Reconstruction Process

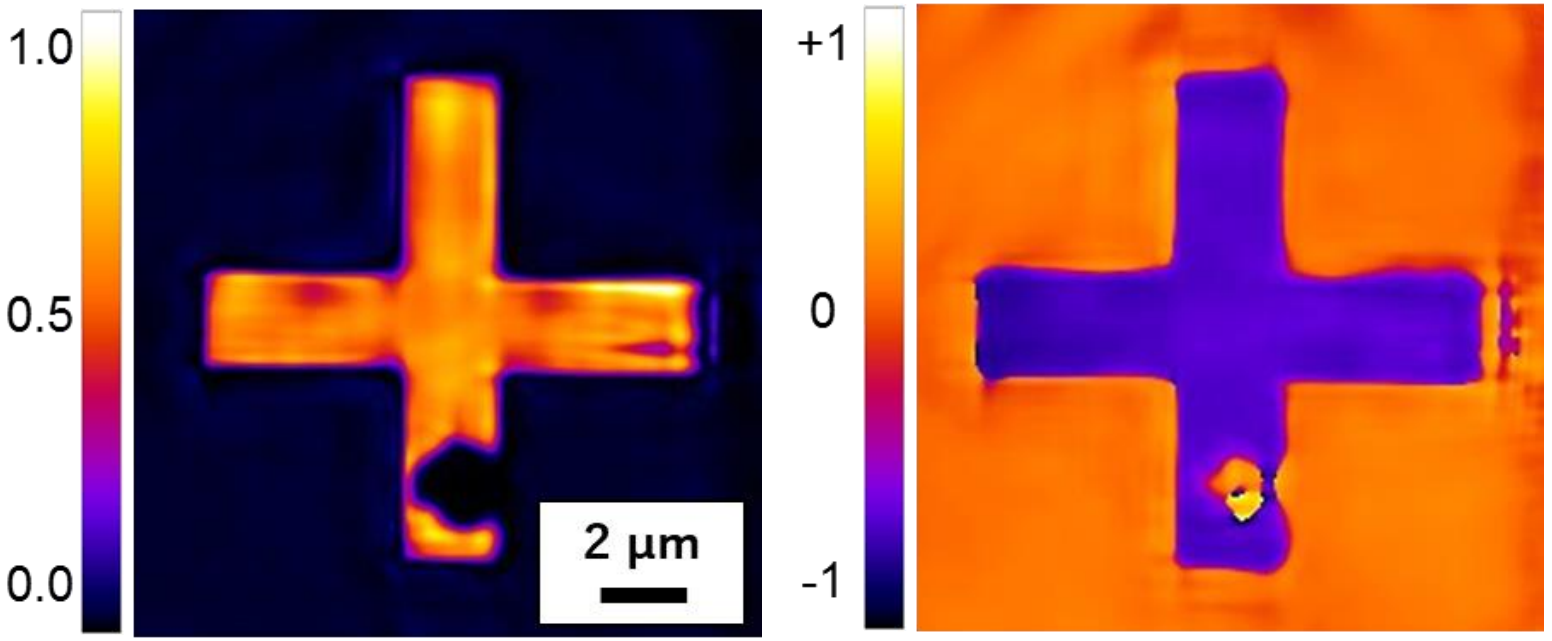


Reconstruction process with each reconstruction step (1 – 100 iteration steps)

Intensity image

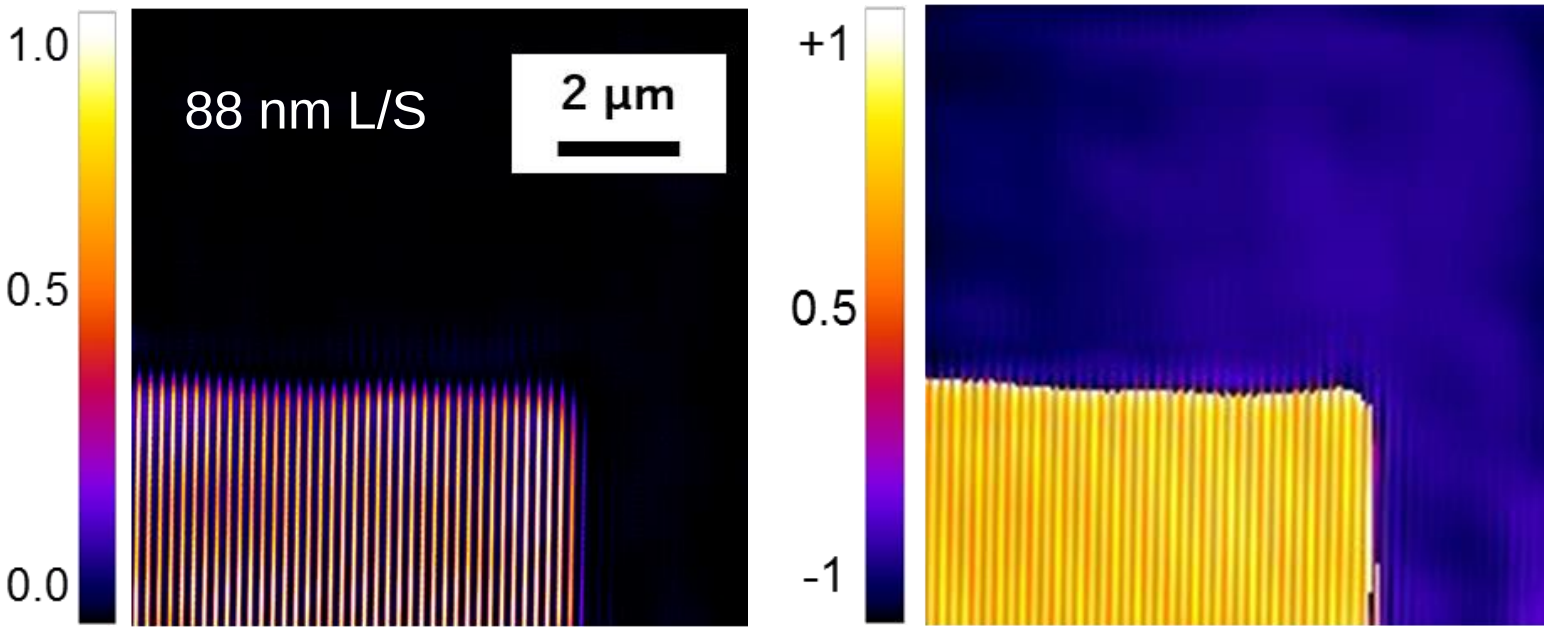
2 µm

Image Reconstruction Result



- "Cross-line pattern" and "defect" were well reconstructed.
- Absorber phase: 160° .
- Exposure time: 70 s (0.3 s × (15 × 15 steps), 22 nW condition)
- This defect would be an etch-error defect or a peeled-absorber defect.

Image Reconstruction Result



- Edge structure of 88-nm L/S pattern was well reconstructed.
- CSM observes pattern phase distribution (mask 3D effect).

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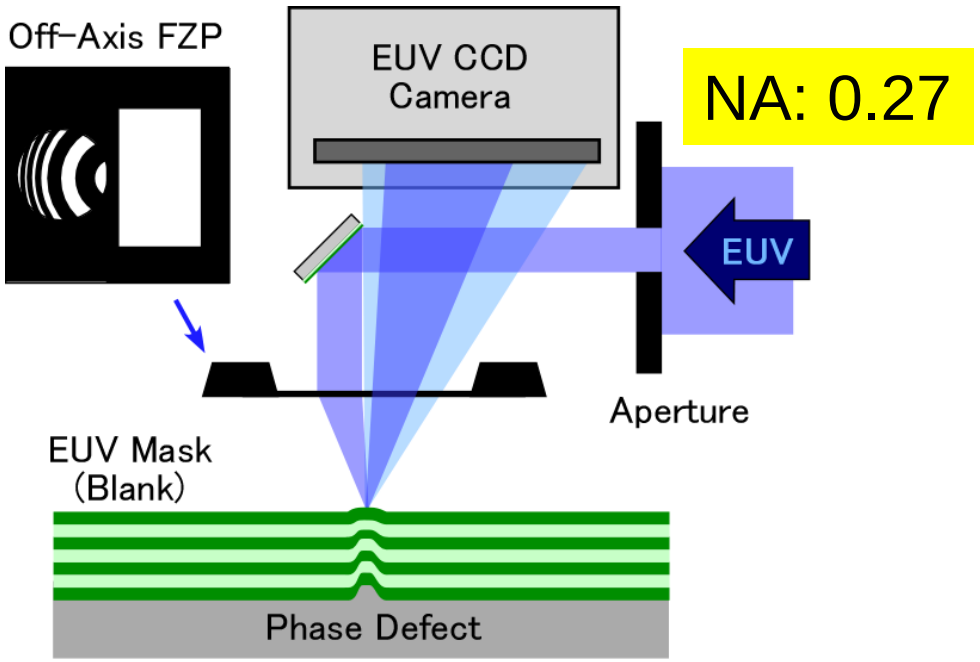
Configuration of μCSM System

@NewSUBARU BL-10

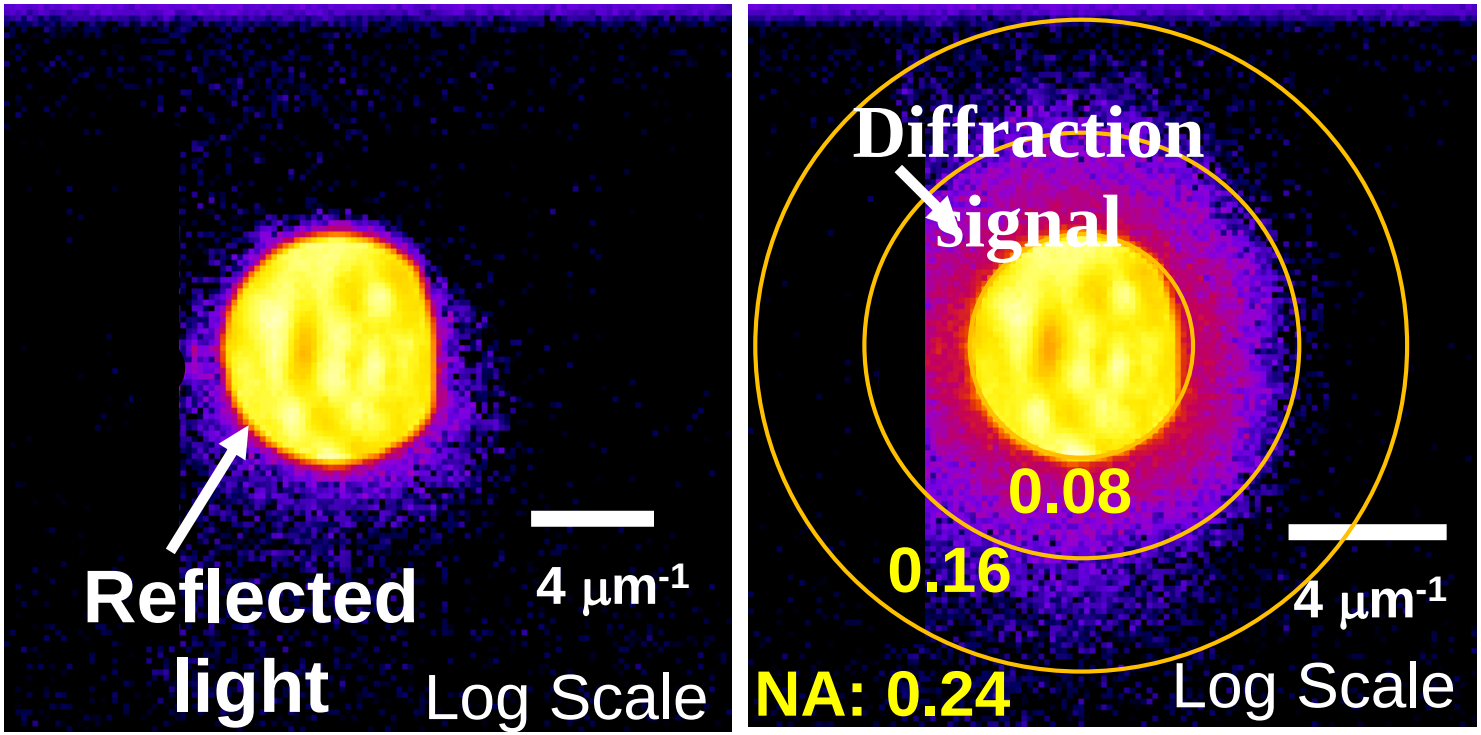


- Characterization of defects on blank.
- Illumination size: **ϕ140 nm**
- Synchrotron source (NewSUBARU, 2 pW, 11 mW/cm^2 on mask)
- Exposure time: 500 s (5 s × (10 × 10 steps))

Diffraction images observed by EUV CCD camera

No defect area

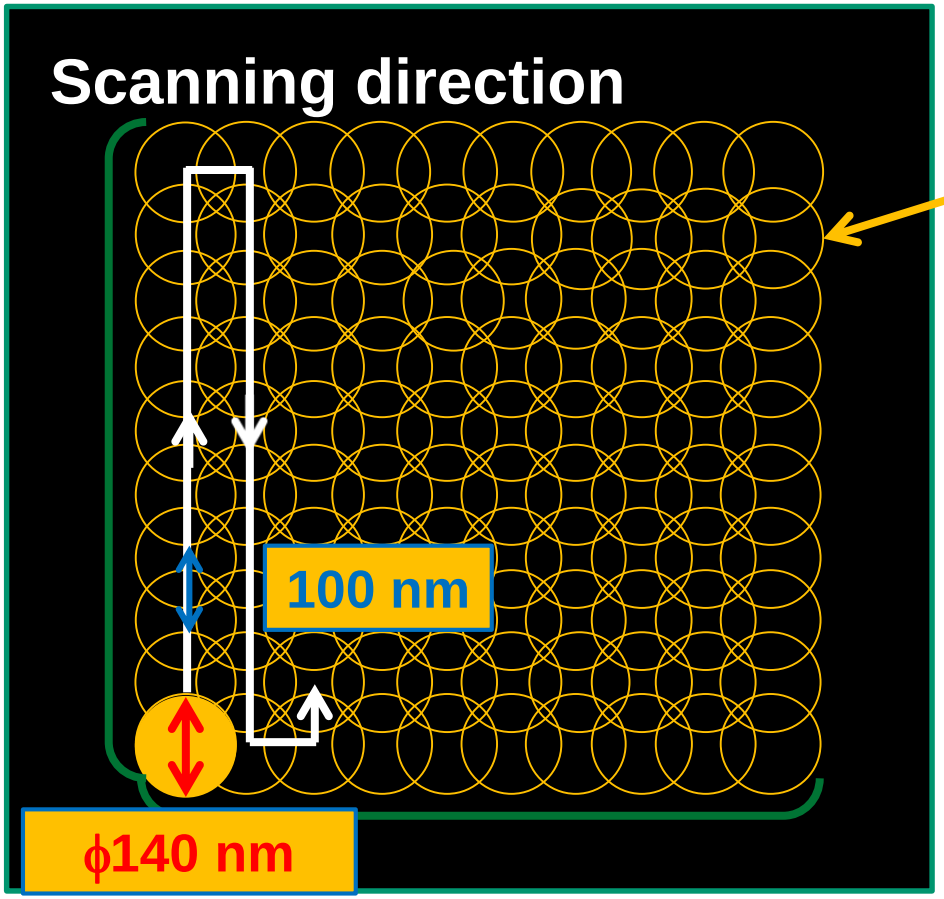
On defect position
(defect size: 60 x 60 nm^2)



The diffraction signal from the defect appeared by surrounding the reflected chief light.

Defect scanning method (ptychography)

Scanning for the defect



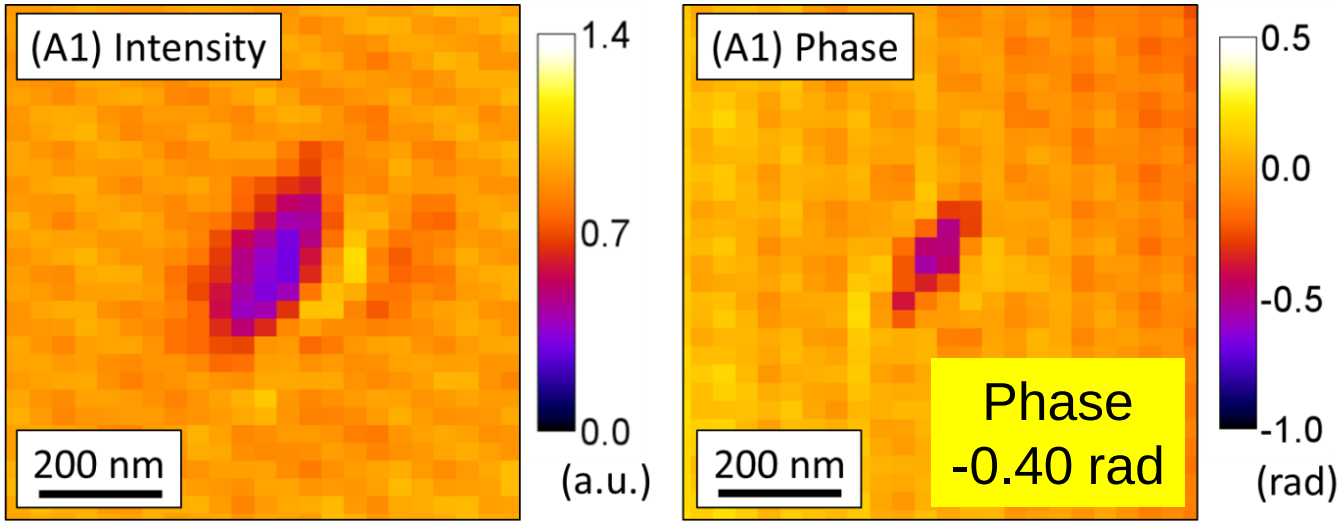
The micro-CSM observes the defect with step and scan to obtain the diffraction images.

Scanning condition

- Illumination size 140 nm
- Step size 100 nm
- 10 x 10 points
- Total scan area 1 x 1 μm^2
- Total observation time 10 min

Phase information is reconstructed from multiple diffraction images.

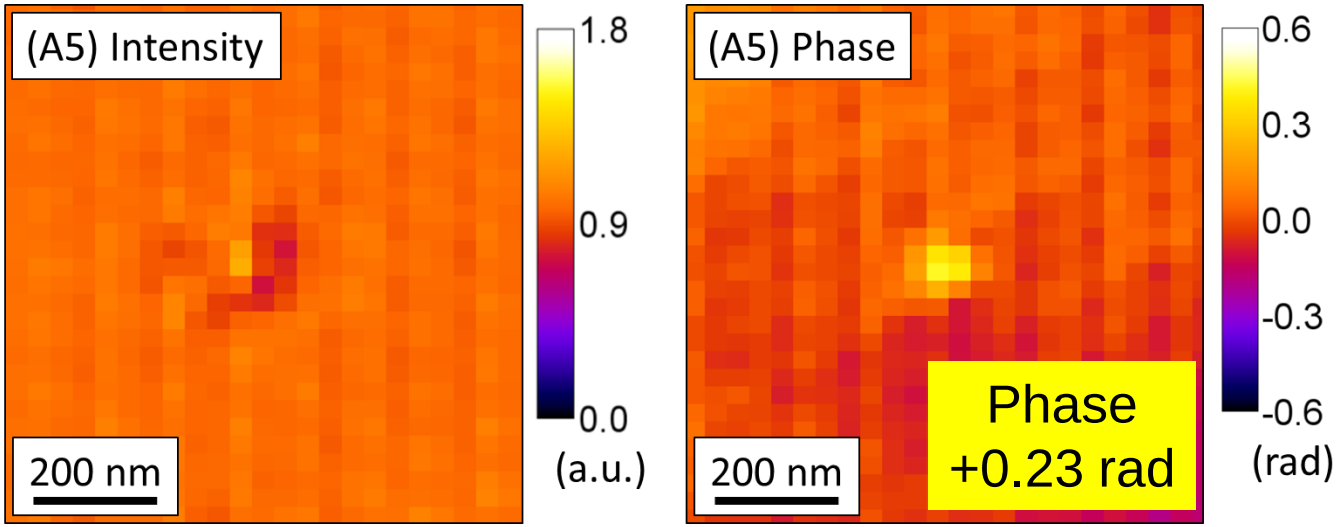
Observation Result of Actual Defect



AFM
$240 \times 57 \times +31.5\ nm^3$

Absorber Defect

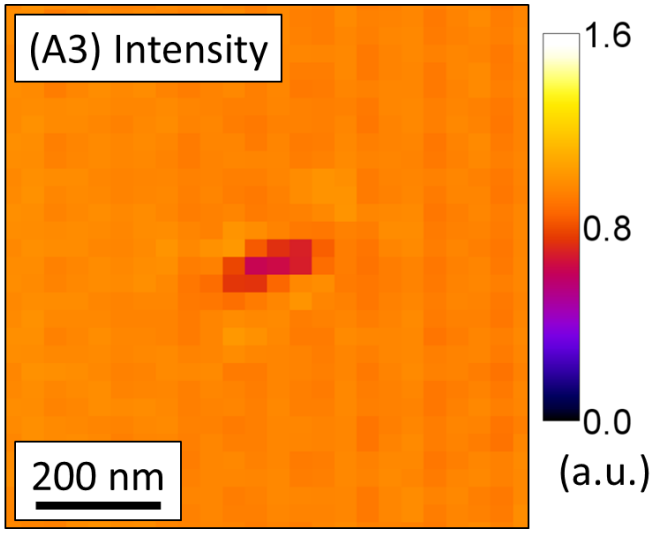
High defect
Not large phase shift

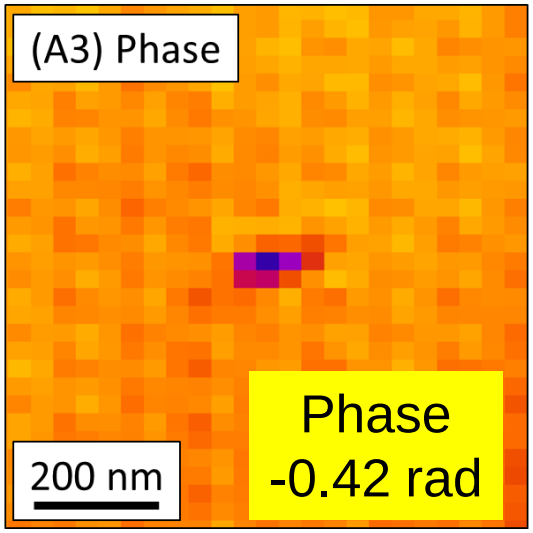


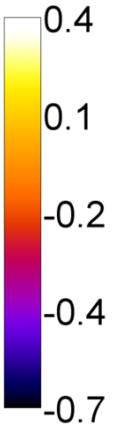
AFM
$48 \times 45 \times -1.5\ nm^3$

Pit-type
Phase defect

Observation Result of Actual Defect

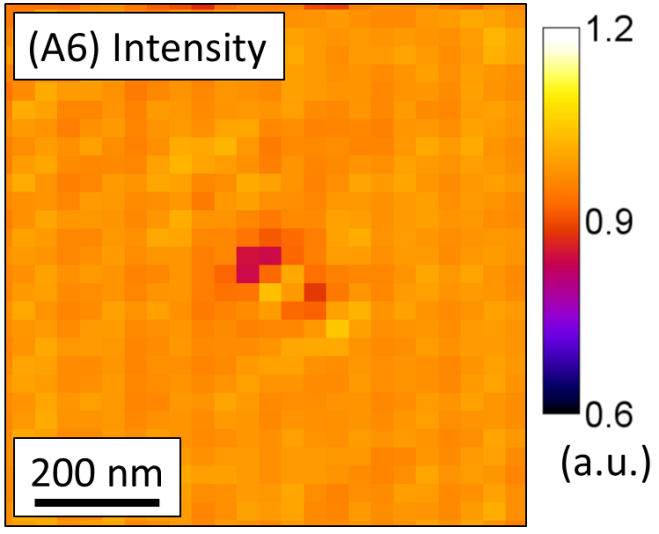


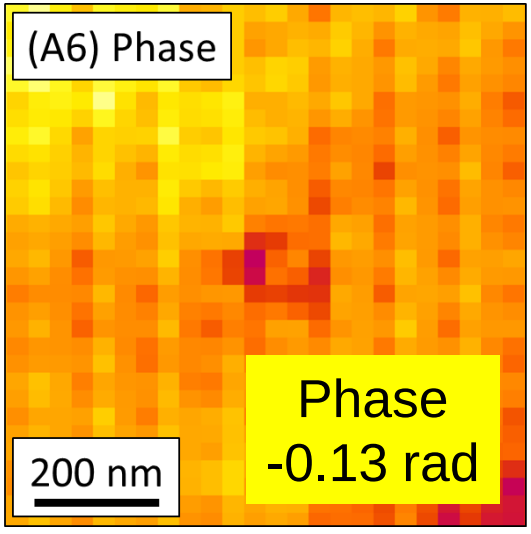


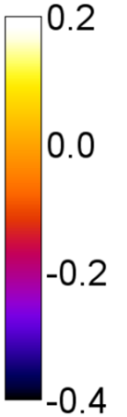


AFM
$70 \times 34 \times +2.1\ nm^3$

Bump-type
oval-shape
Phase defect





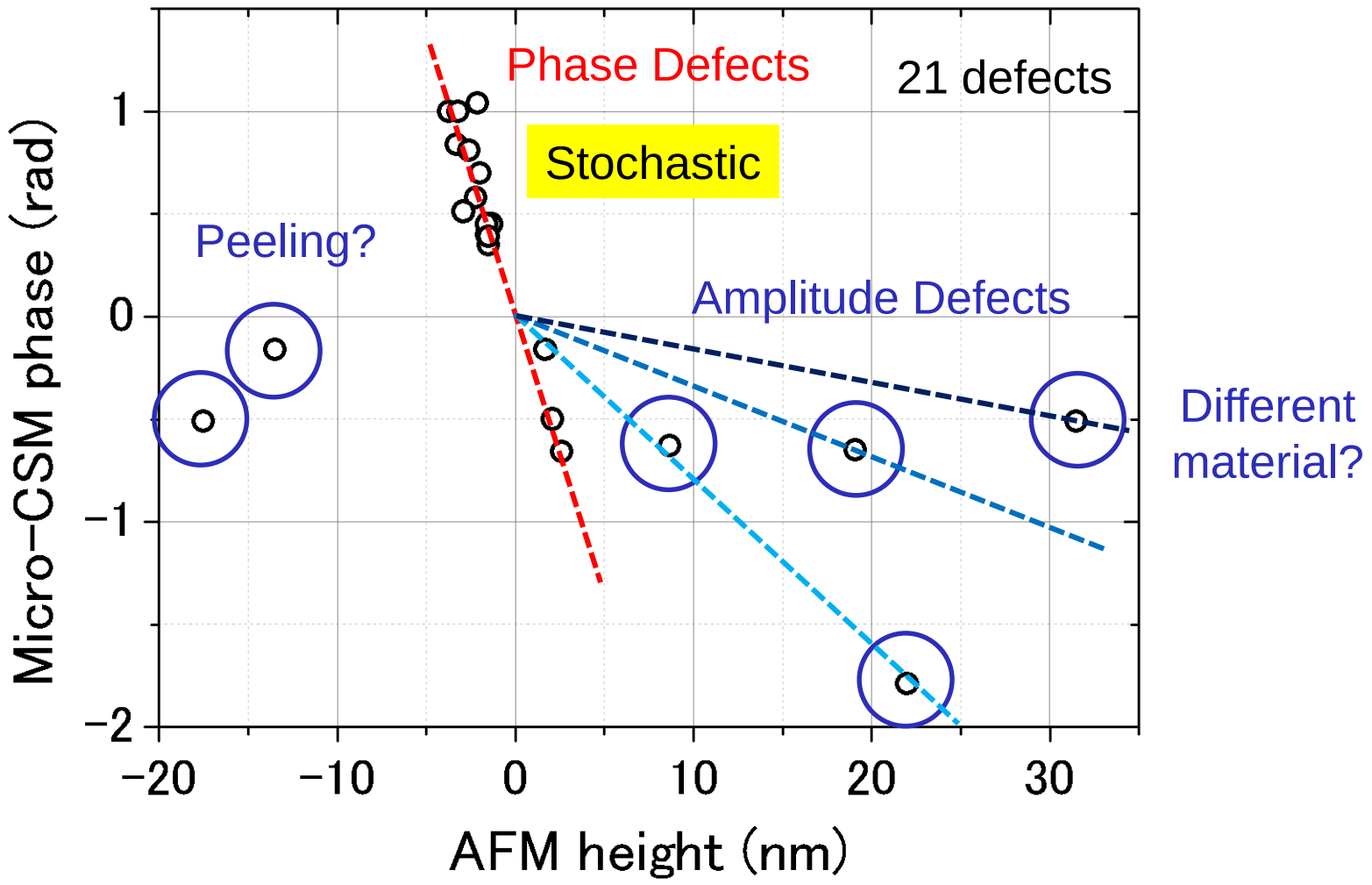


AFM
$33 \times 28 \times +1.7\ nm^3$

Bump-type
Phase defect

Smallest size

Observation Result of Actual Defect



Summary

- Fundamental research of EUV is processing at NewSUBARU, and resist, mask inspection, and collector mirror evaluation tool are developed.
- We have developed CSM systems for EUV phase and intensity imaging. **EUV PHASE IMAGING** is important to evaluate “mask 3D effect” and “phase defect”.
- Standalone CSM system demonstrated pattern observation of cross pattern, absorber defect and L/S pattern.
- Micro-CSM system demonstrated actual defect characterization of phase defect and amplitude defect. (30 nm size)
- For factory use, EUV source and CMOS camera are key components. (under development)

Future System Plan

Goal: EUV (phase and intensity) REVIEW tool for FACTORY-USE.

Coherent EUV Source

- High harmonic generation, **38 kW/mm^2-Sr**, very high brilliance
  Estimated total exposure time: **8 s**, 630 pW on mask
  (Current condition: 70 s, 71 pW, 0.3 s × (15 × 15 steps))
- Standalone system for blank defect characterization

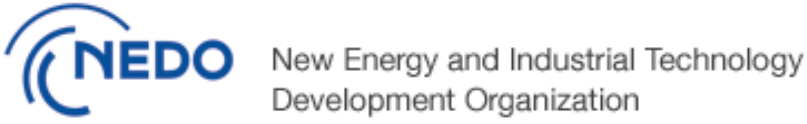
Image sensor

- The readout time of CCD sensor is very slow.
- Current readout time: 1013 s (4.5 s × (15 × 15 steps))
- CMOS system is under development.
- CMOS readout time: **7.5 s** (**35 ms** × (15 × 15 steps))

Acknowledgement

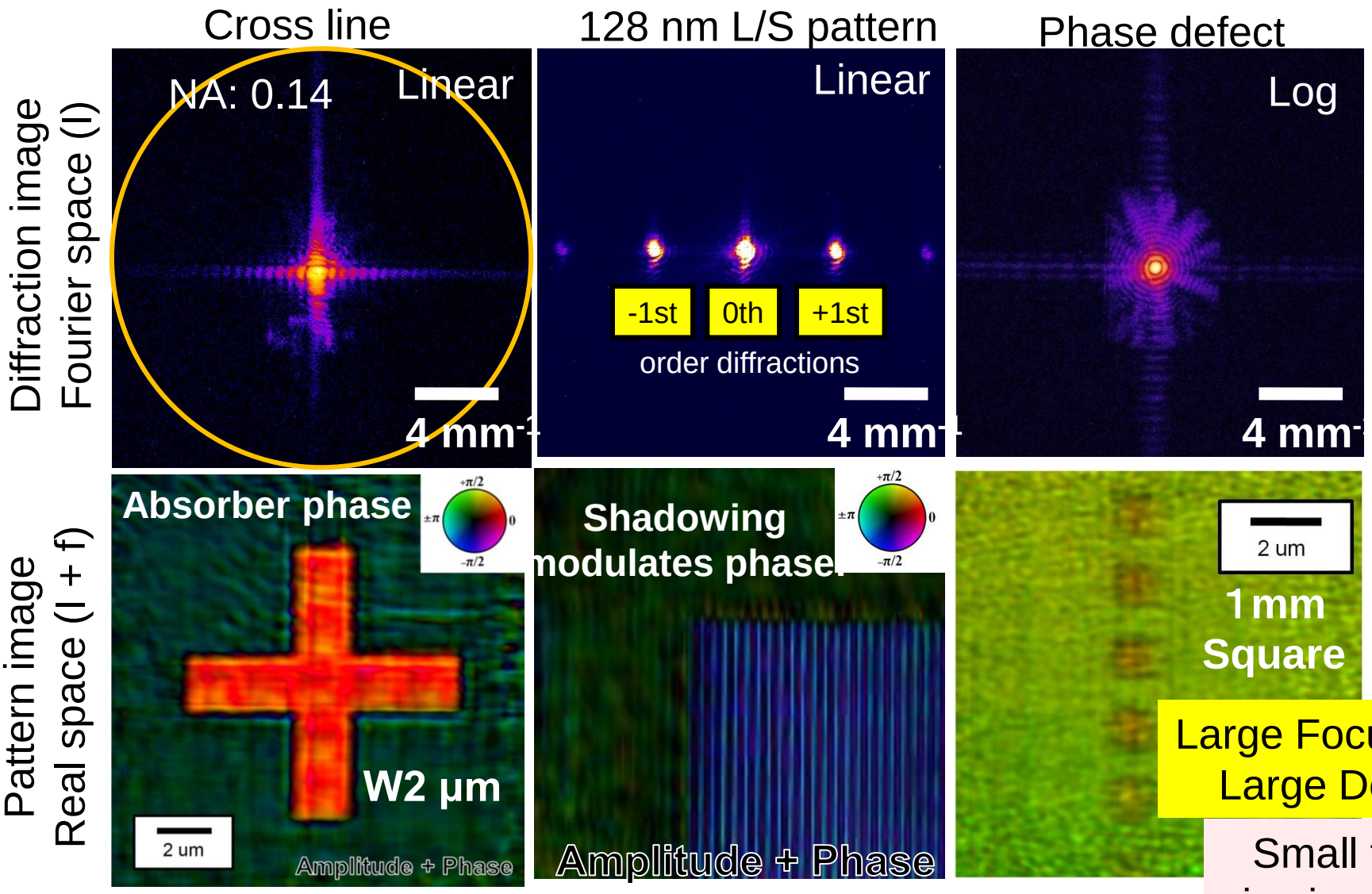
For the Micro-CSM, this work was partially supported by NEDO through EIDEC.

ACKNOWLEDGEMENTS



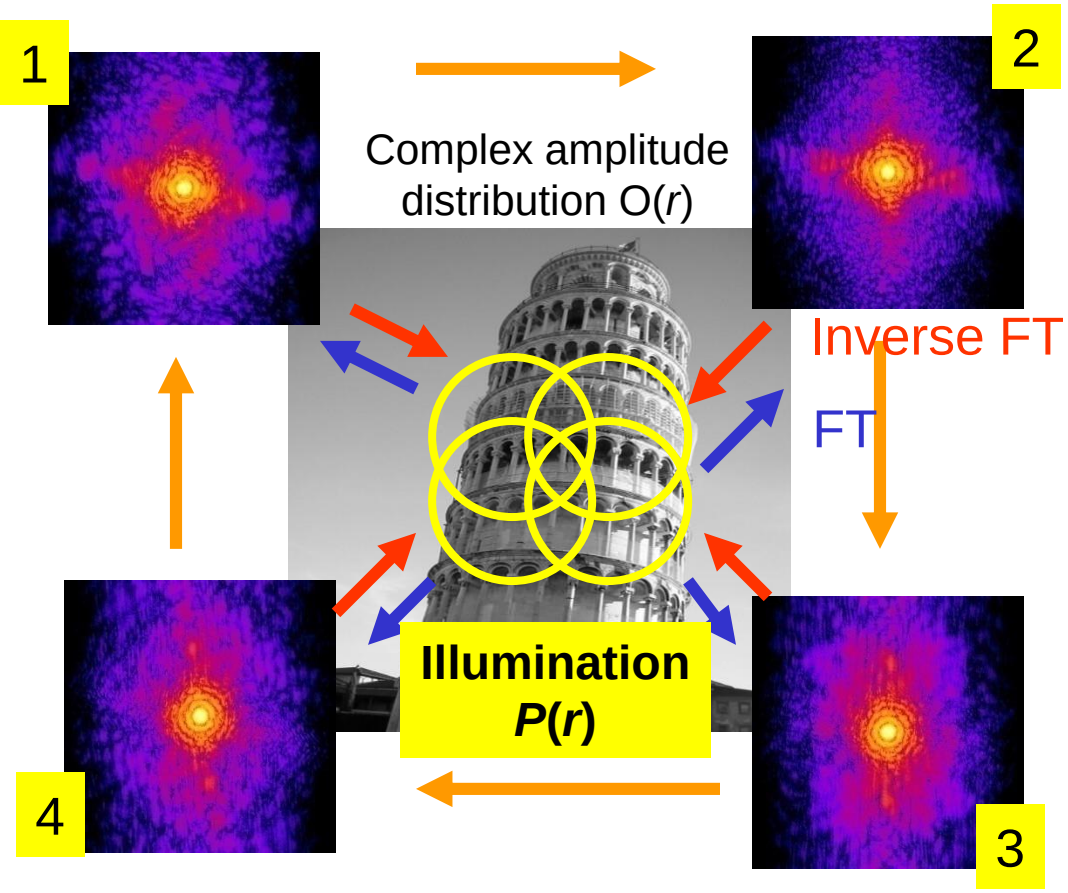
Thank you for your attention!

Observation of Mask Patterns (CSM)



CSM captured phase images that modulated by the 3D structure. The phase value is **quantitative** because CSM records **interference**.

Reconstruction Algorithm: Ptychography



Ex.) 4 exposed area, 4 diffraction intensity

Iterative calculation of Fourier transform and inverse Fourier transform **with shifting illumination.**

Constraint

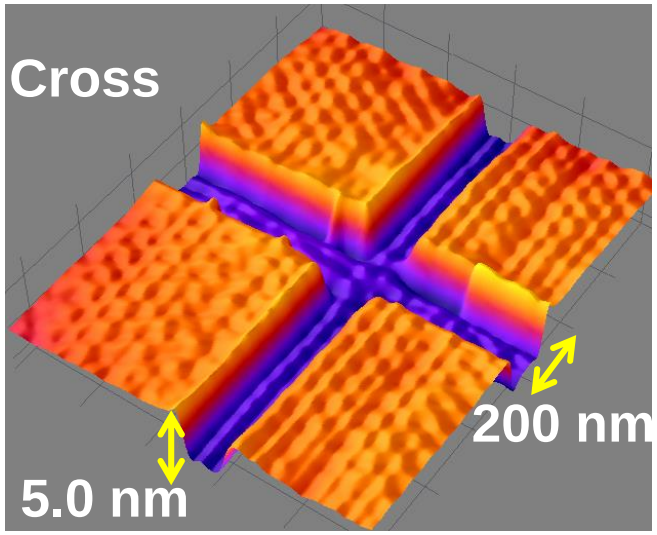
Illuminated areas are overlapped.
Several diffraction intensities have same sample area
inf

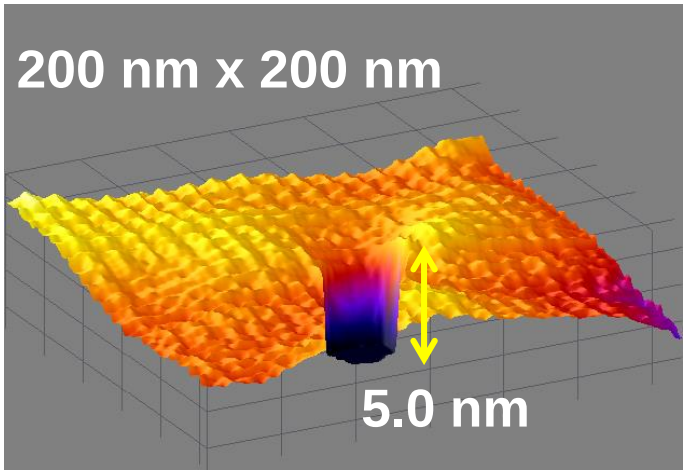
Note: Requirement

- Illumination profile
- Preciously control of the shift position

J. M. Rodenburg *et. al*., Appl. Phys. Lett. **85** (2004) 479.

3D Image of the Reconstructed Patterns





-2.0 Phase (rad) +1.6

AFM 4.6 nm

-2.0 Phase (rad) +0.5

AFM 4.6 nm

- The defects are shown in 3D image.
- Micro-CSM measured the 3D structure of phase defect.
- AFM value is on the multilayer surface. Micro-CSM measures the phase value at EUV wavelength quantitatively.