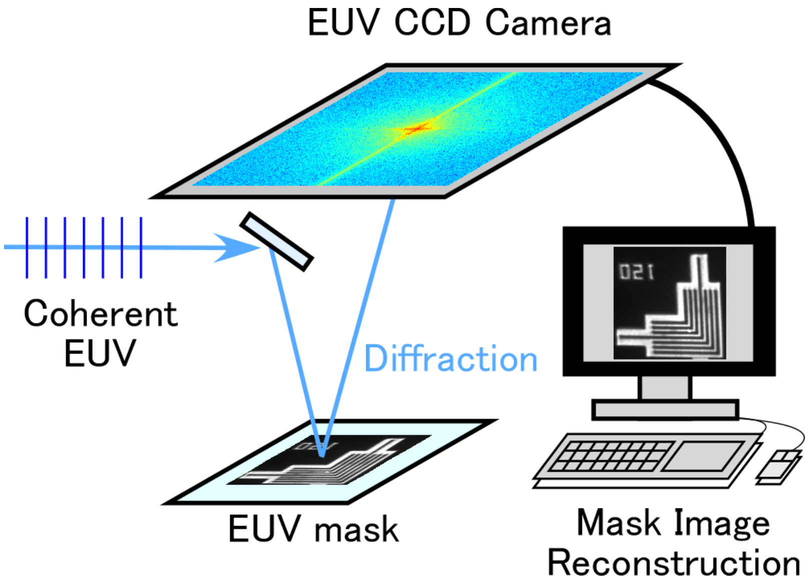
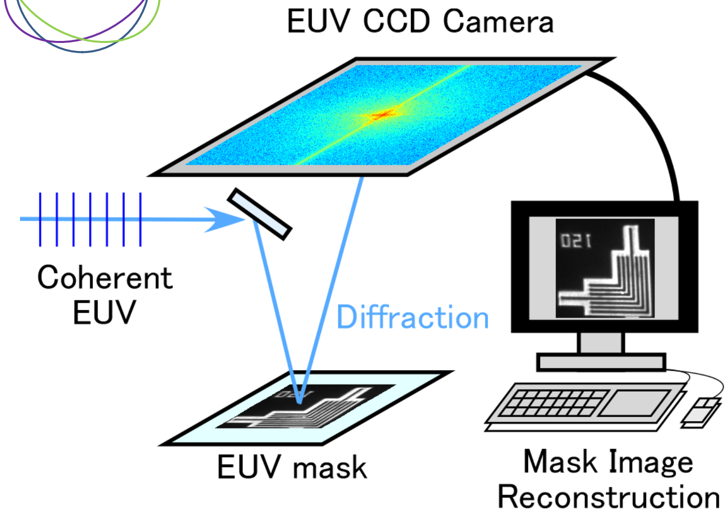
EUVL Workshop in Berkeley 2016.6.13-16

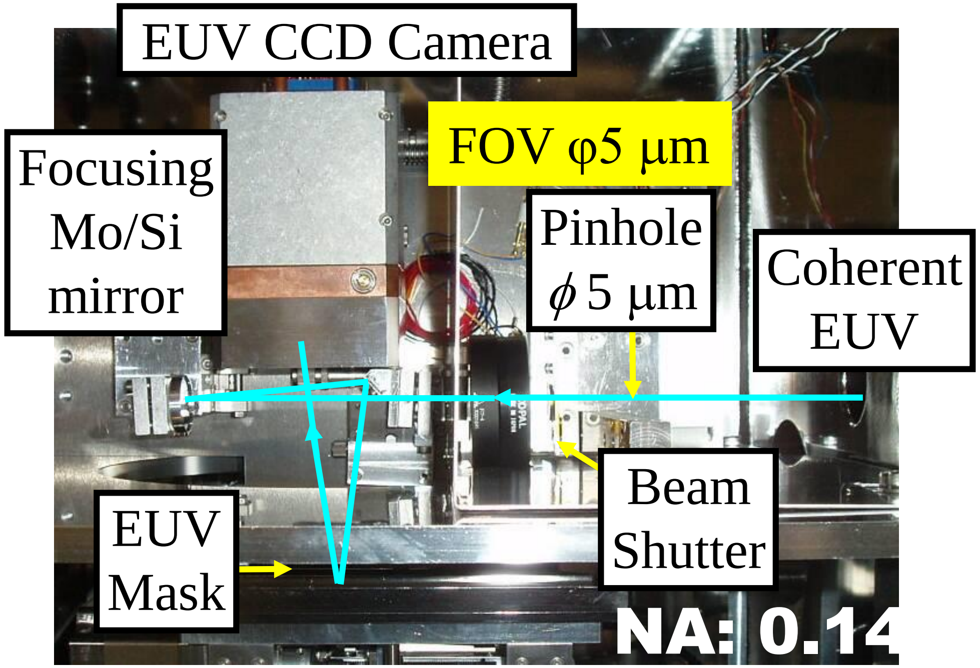
Actinic Mask Inspection System Using Coherent Scatterometry Microscope



University of Hyogo, Riken*
H.Kinoshita, T. Harada, *Y. Nagata,
T. Watanabe and *K. Midorikawa

Coherent EUV Scatterometry Microscope (**CSM**)



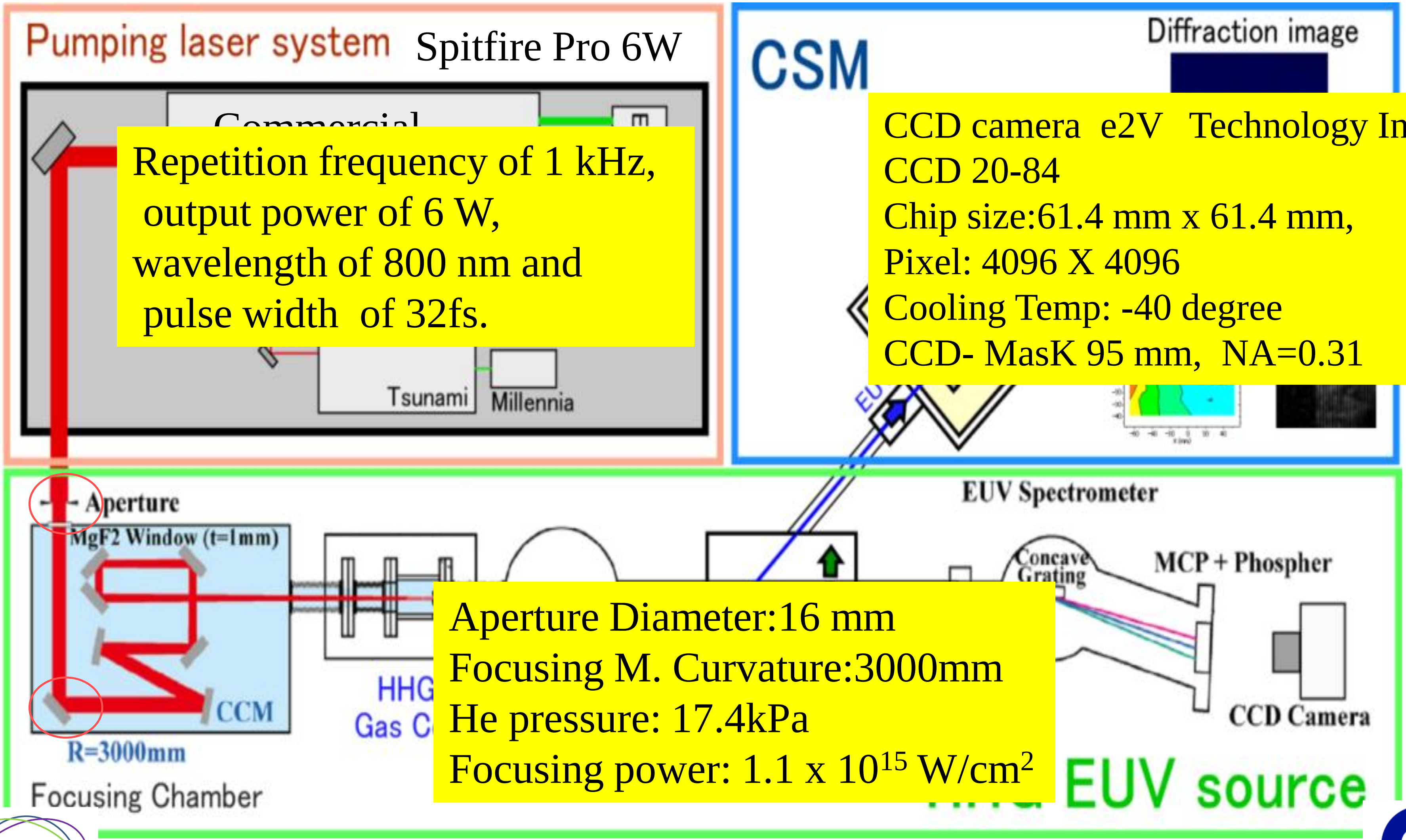


Lensless
Very simple
High resolution

Imaging + **CD metrology**

- Coherent scatterometry microscopy is an ideal form of X-ray phase-contrast imaging, since there is no contrast degradation due to lenses.
- CSM inspect an amplitude defect, phase defect and and measure CD value.
- HHG light source for EUV (λ = 13.5 nm) that employs a femtosecond laser was developed in collaboration with RIKEN.

Schematic structure of HHG-CSM system.



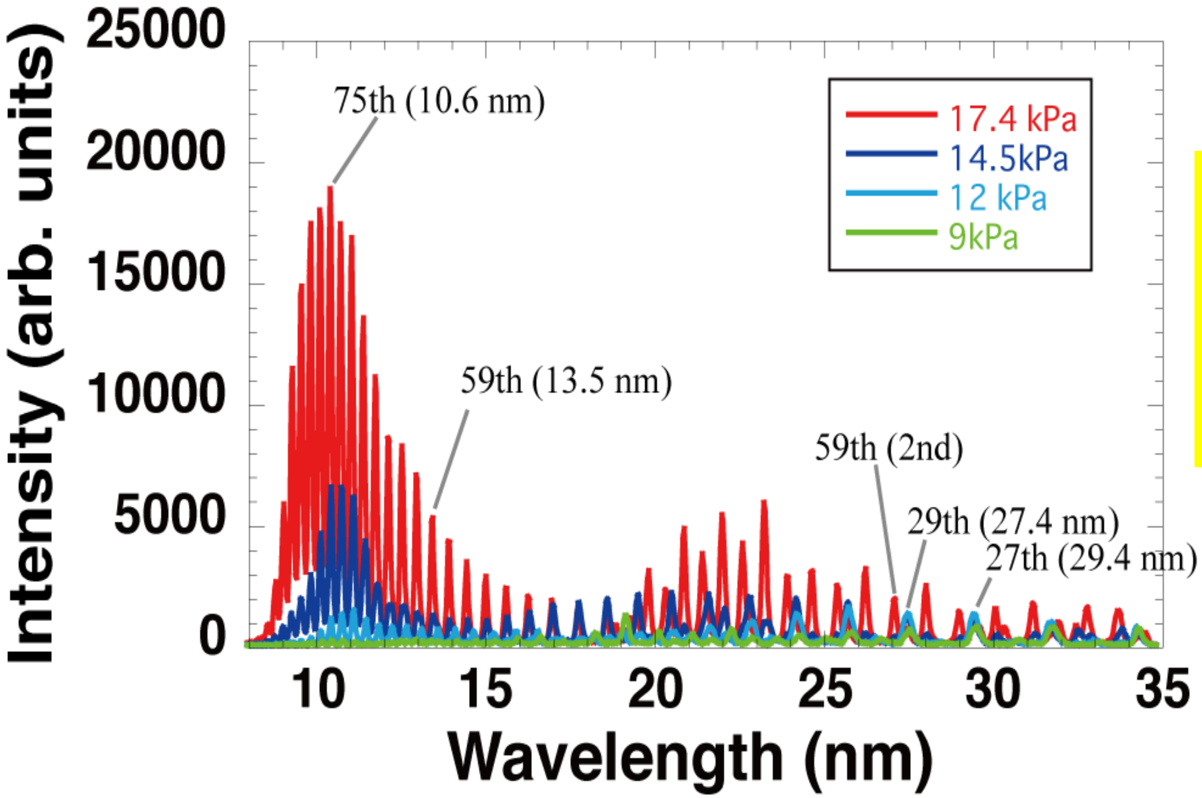
Spitfire Pro 6W

Repetition frequency of 1 kHz,
output power of 6 W,
wavelength of 800 nm and
pulse width of 32fs.

CCD camera e2V Technology Inc.
CCD 20-84
Chip size:61.4 mm x 61.4 mm,
Pixel: 4096 X 4096
Cooling Temp: -40 degree
CCD- MasK 95 mm, NA=0.31

Aperture Diameter:16 mm
Focusing M. Curvature:3000mm
He pressure: 17.4kPa
Focusing power: 1.1 x 10^{15} W/cm^2

Characteristic of HHG EUV light



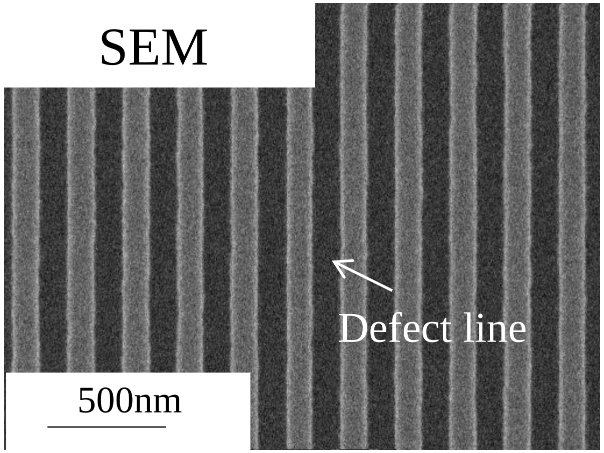
- **Output EUV (59th)**
  1 µW
- **Divergence:**
  0.17 mrad

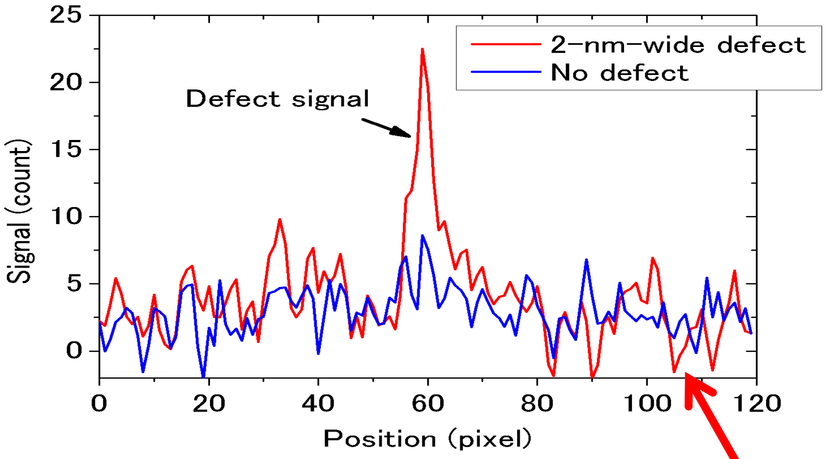
Coherent EUV
power
SR ×1,000

Spectral intensity distribution of He gas pressure.

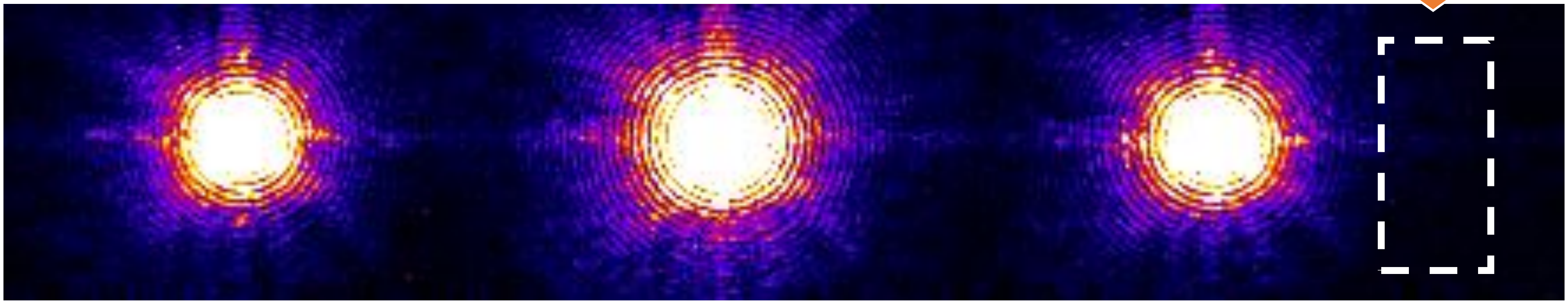
Inspection of downsizing defect

hp 88 nm L/S pattern   2 nm downrsizing defect
Exp. Time: 10 s





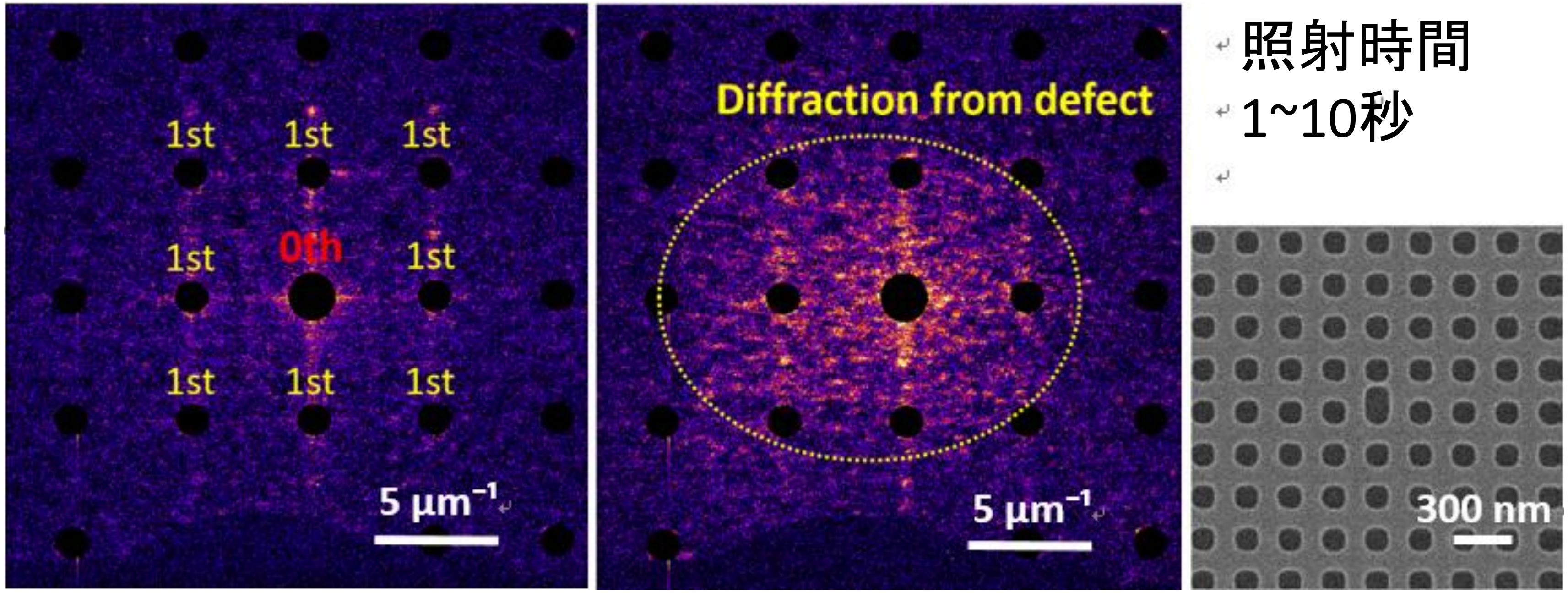
2nm downsizing defect can be observed by HHG system.



Difraction signal

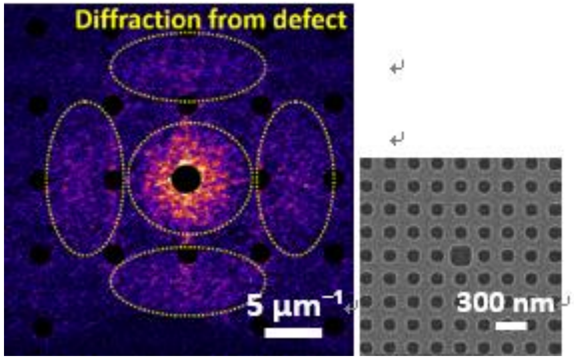
Die to die inspection

Line-end-oversize defect

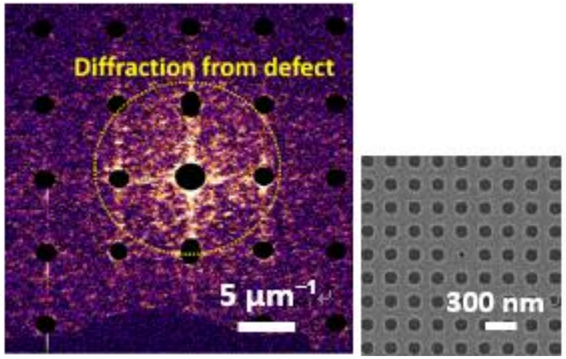


照射時間
1~10秒

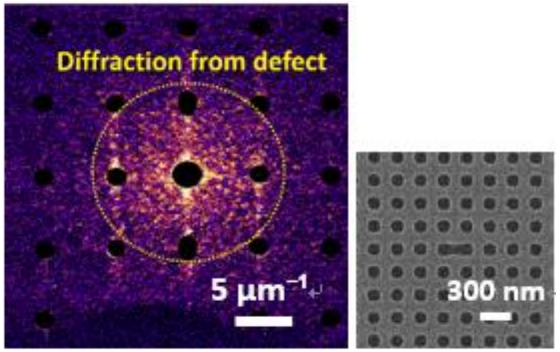
Oversize defect



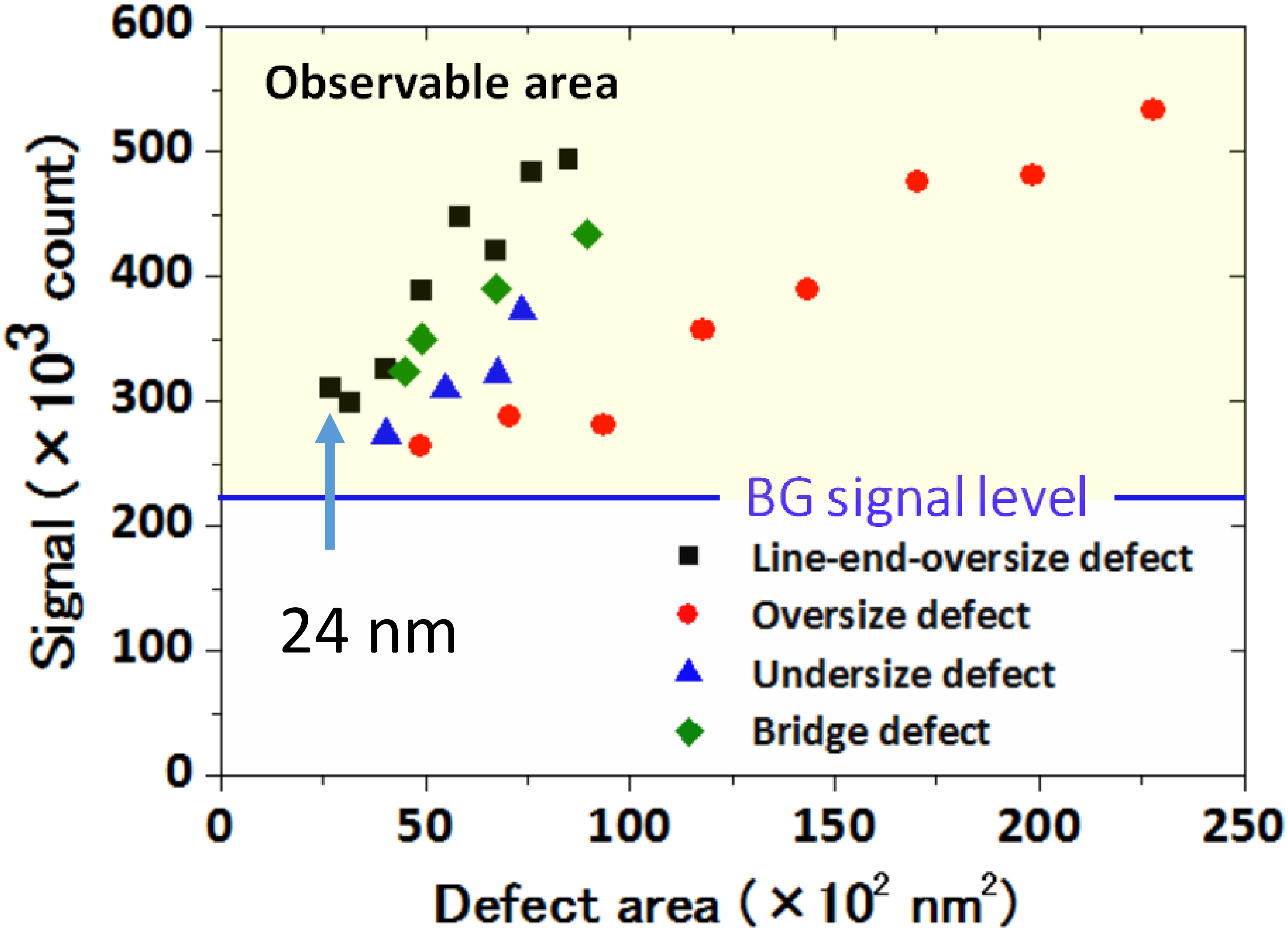
Undersize defect



Bridge defect

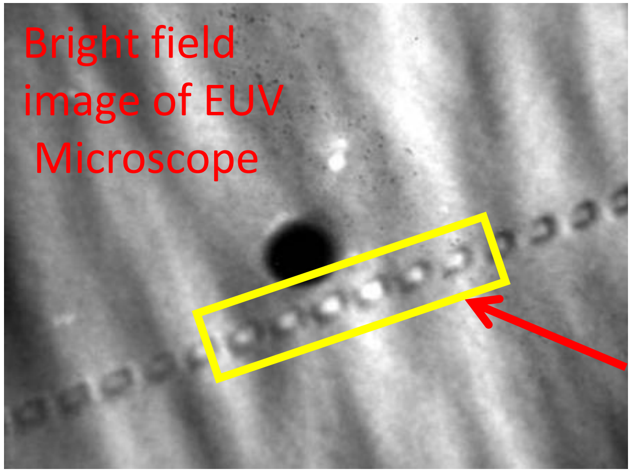


Minimum feature size for various defects

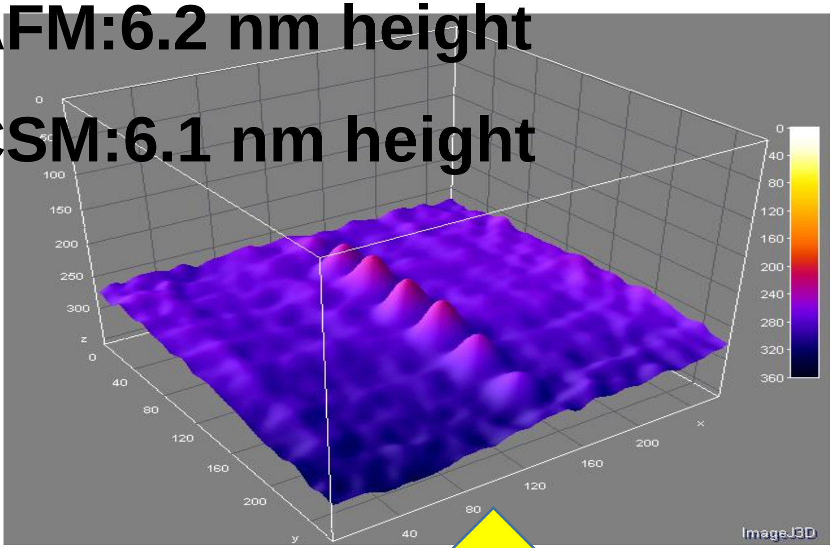


Phase defects observation by CSM

JST CREST . 2002～2007

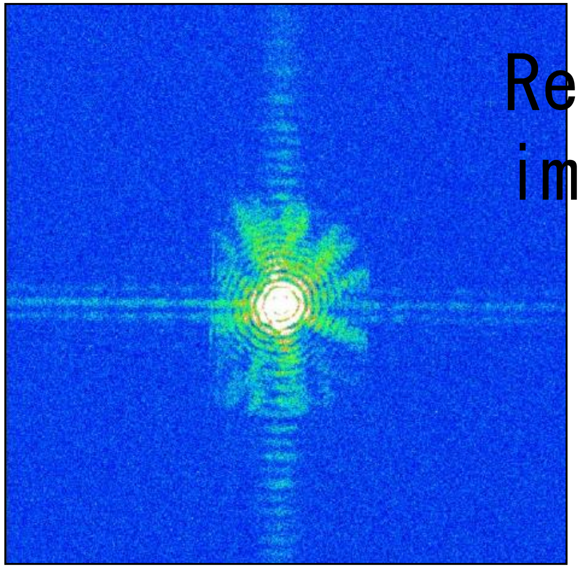

Bright field image of EUV Microscope

Programmed Phase defect

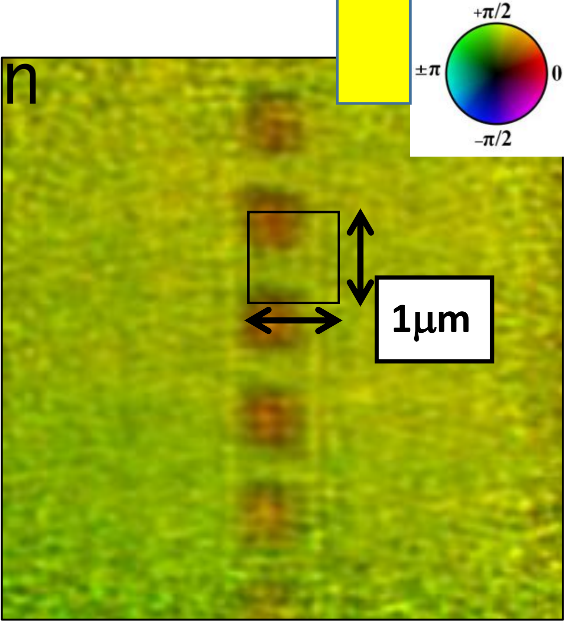

AFM:6.2 nm height

CSM:6.1 nm height

JST CREST . 2008～2013

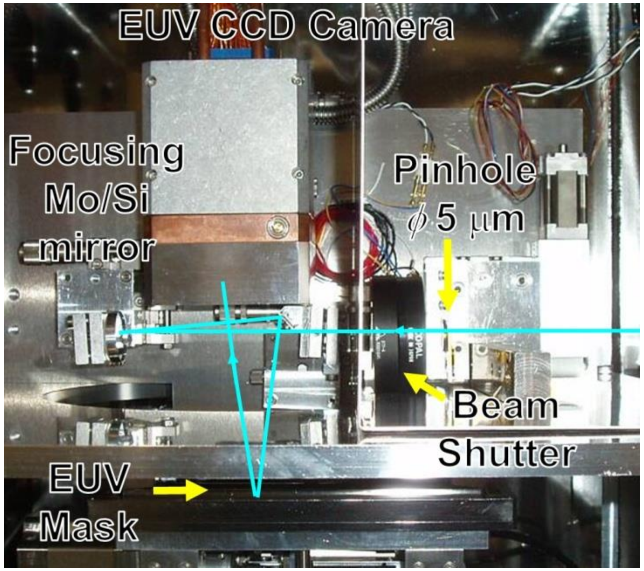

Diffraction pattern of phase defects

Reconstruction image



Intensity + Phase

Observation of phase defect by CSM



Lensless Actinic Microscope

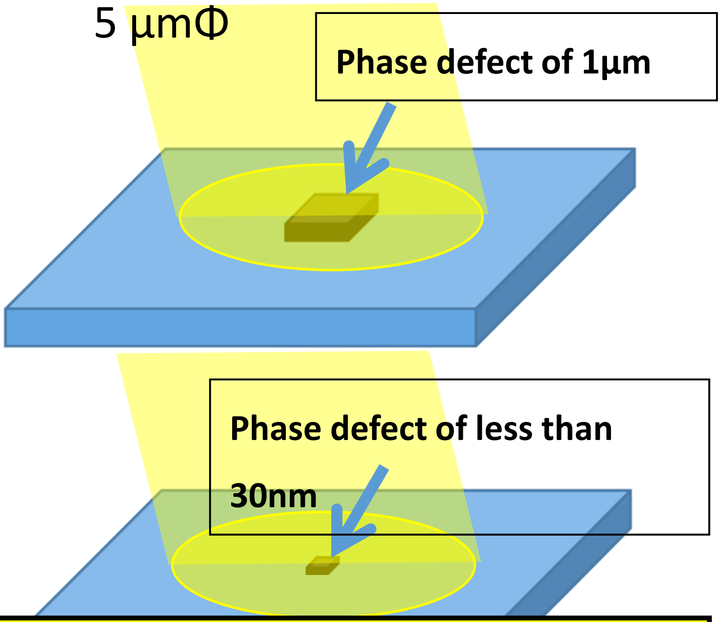
Coherent Scatterometry Microscope

JST CREST 2008～2013

Demonstrate the phase defect of 1 μm square.

Target resolution of phase defect was less than 30 nm.

Improve the defect signal

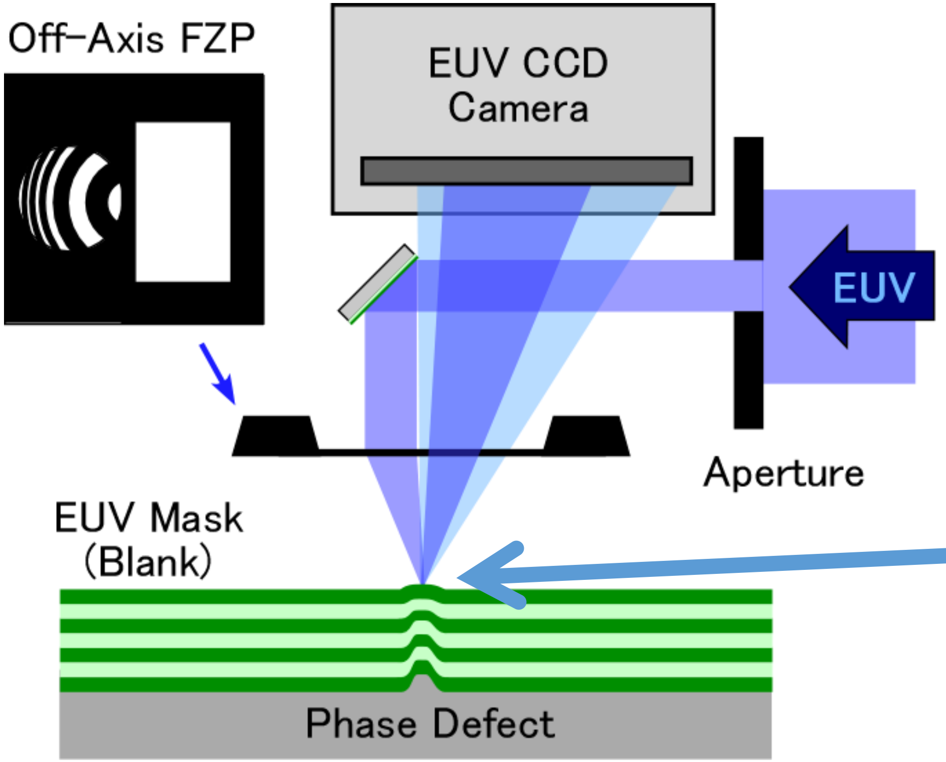


Defect signal become to be so low.

Principle of μCSM

2011~

NewSUBARU BL-10



Vacuum cond. : 10^{-5} Pa
NA of FZP : 0.08
NA to CCD camera : Max. 0.27
Number of pixel : 2048 x 2048 pixel

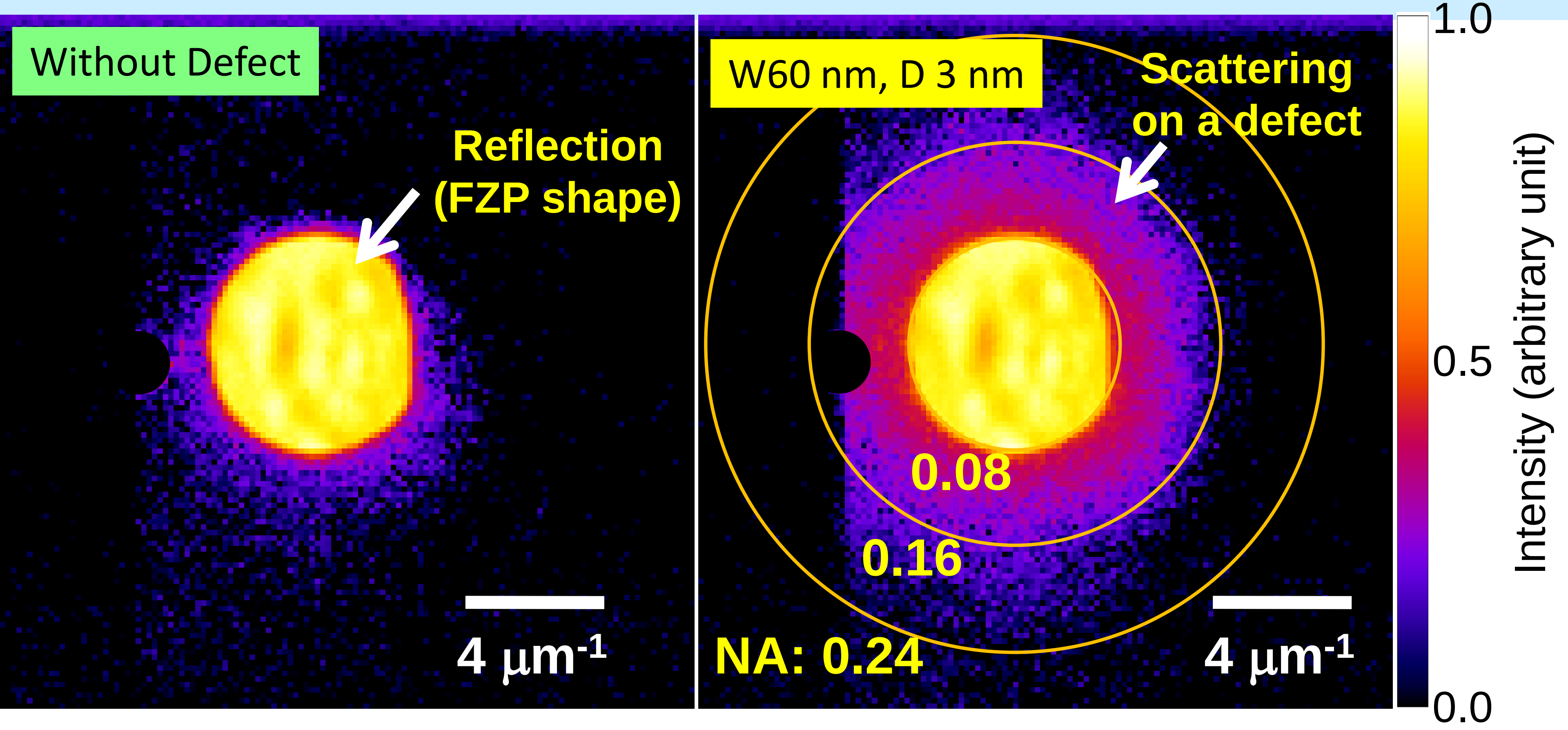
Focus size of ϕ200 nm

Off-Axis FZP focused the SR beam and the intensity of the diffraction signal was improved enough to detect the fine phase defects.

EUVL

EIDEC

Diffraction pattern by μCSM

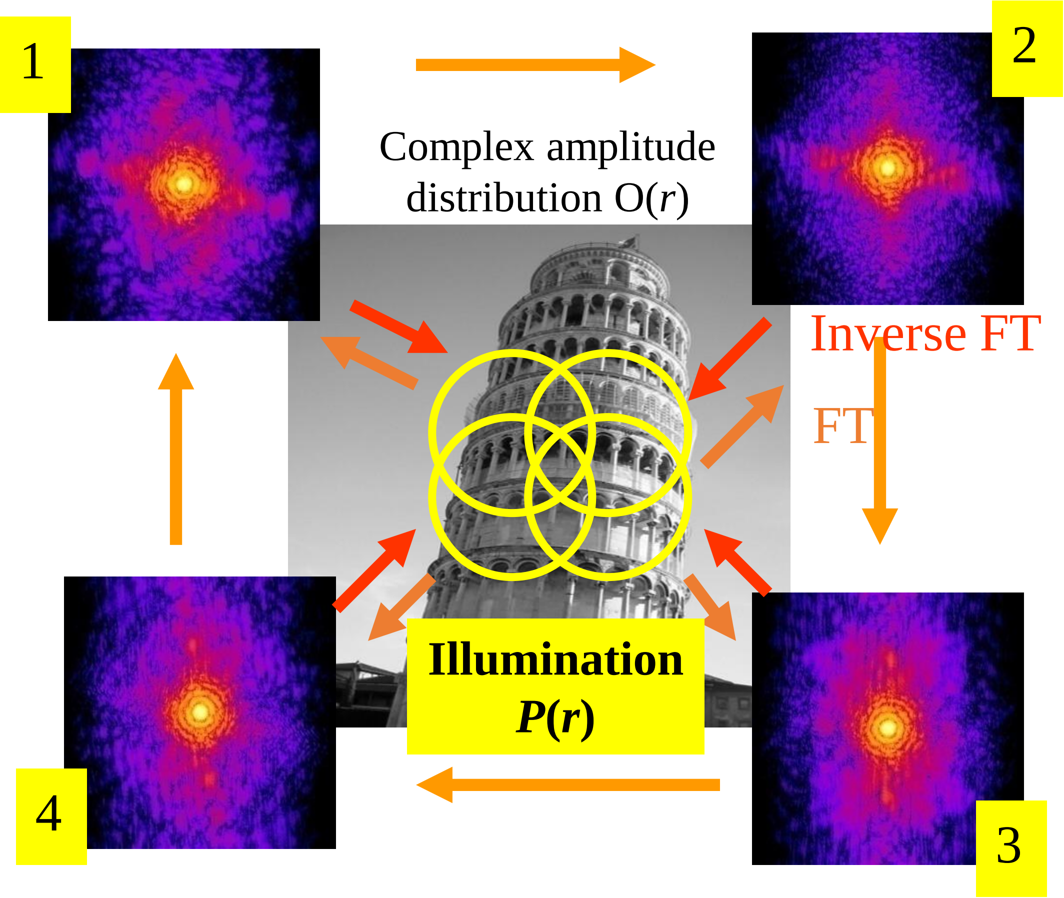


Micro-CSM images without and with a defect.
(CCD camera images)

Resolution
35 nm (X), 28 nm (Y)

Reconstruction Algorithm: **Ptychography**

The diffracted light intensity are recorded by shifting the irradiated region of the sample little by little.



1

2

Complex amplitude distribution O(*r*)

Inverse FT

FT

Illumination *P*(*r*)

4

3

Ex.) 4 exposed area, 4 diffraction intensity

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

Constraint

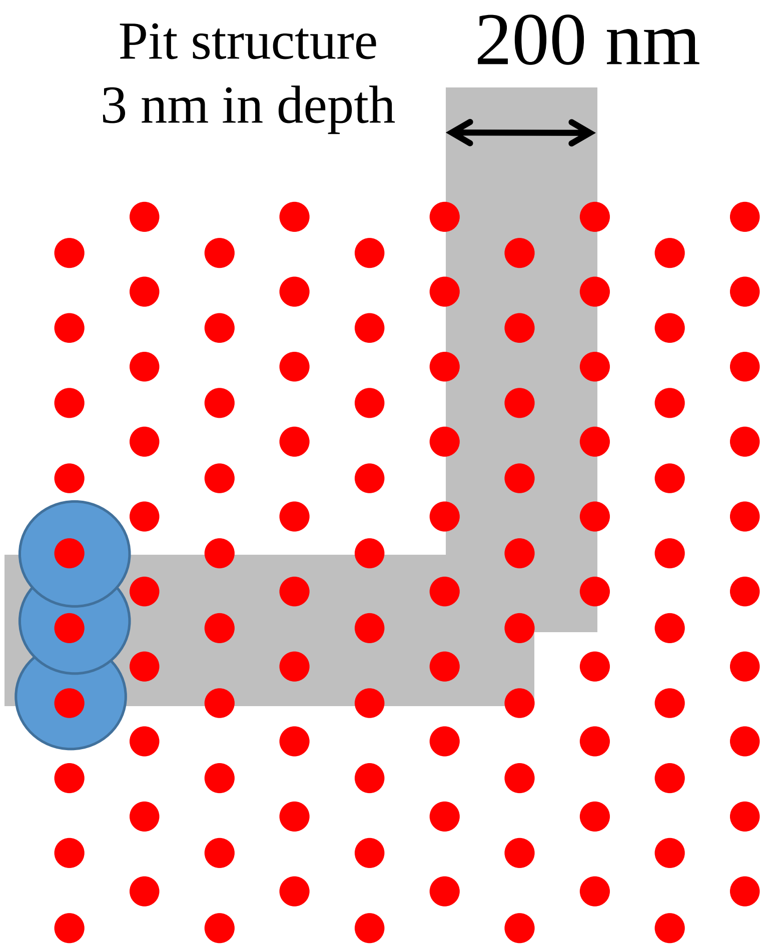
Illuminated areas are overlapped. Several diffraction intensities have same sample area information.

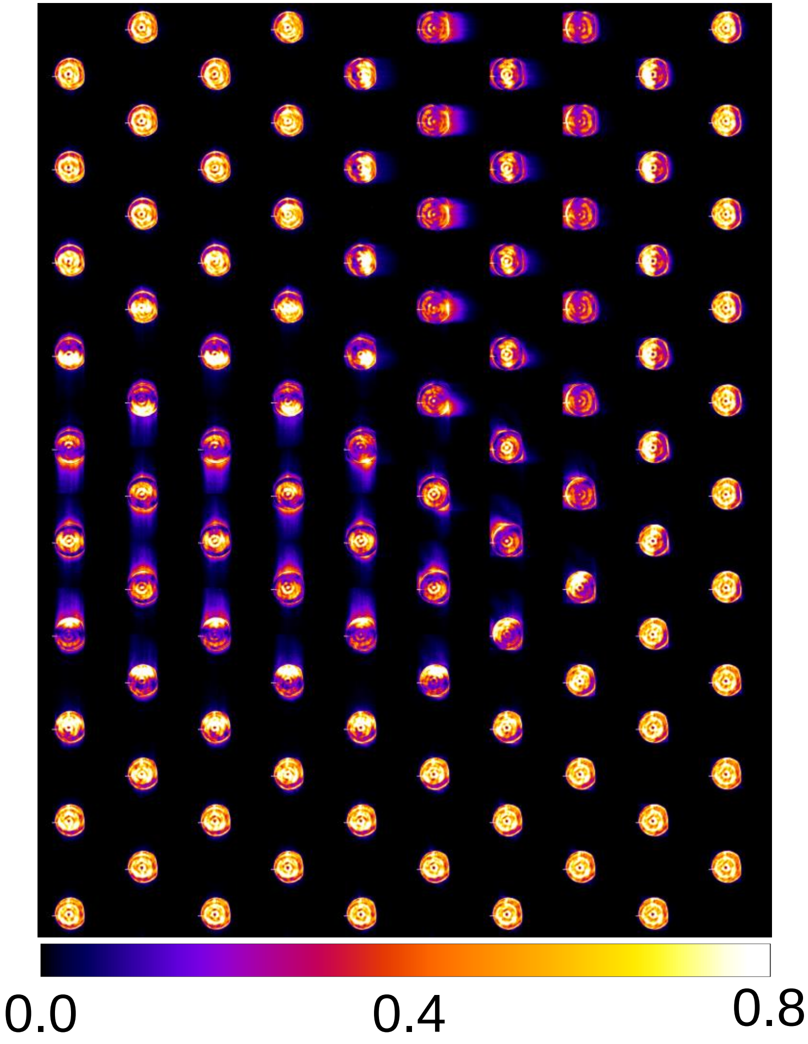
Note: Requirement

- Illumination profile
- Preciously control of the shift position

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

Image Reconstruction Process

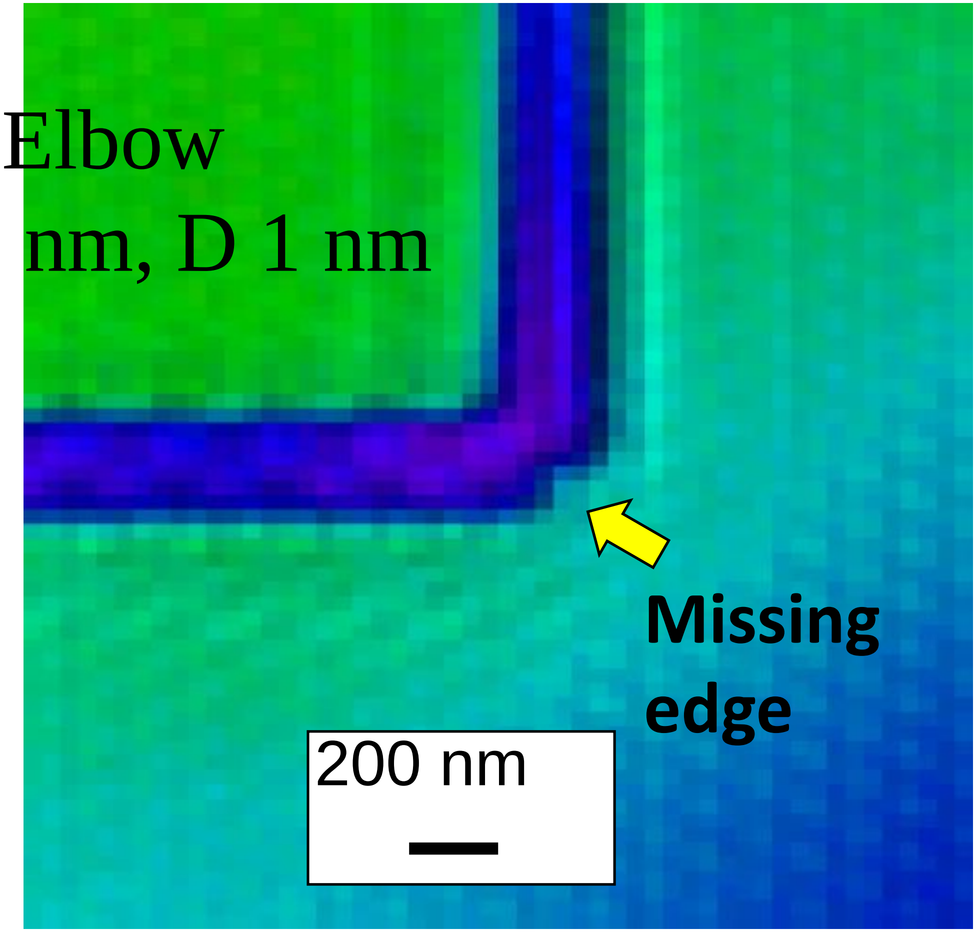




(iterative calculation of ptychography)

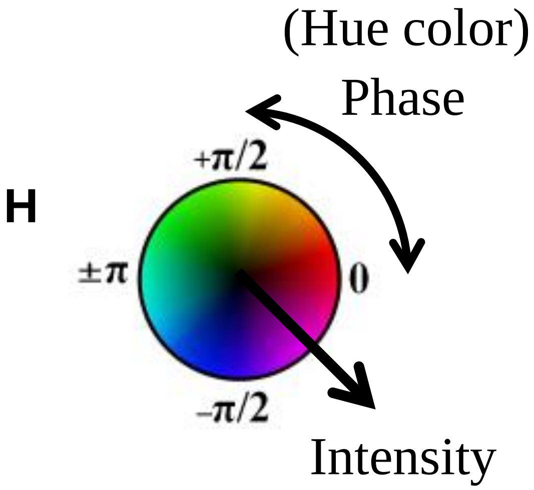
measurement points 10 × 10 = 100 points
Exposure time 5 s at each position. (total 10 min)

Observation Result of Programmed Phase Defect



Elbow

W200 nm, D 1 nm



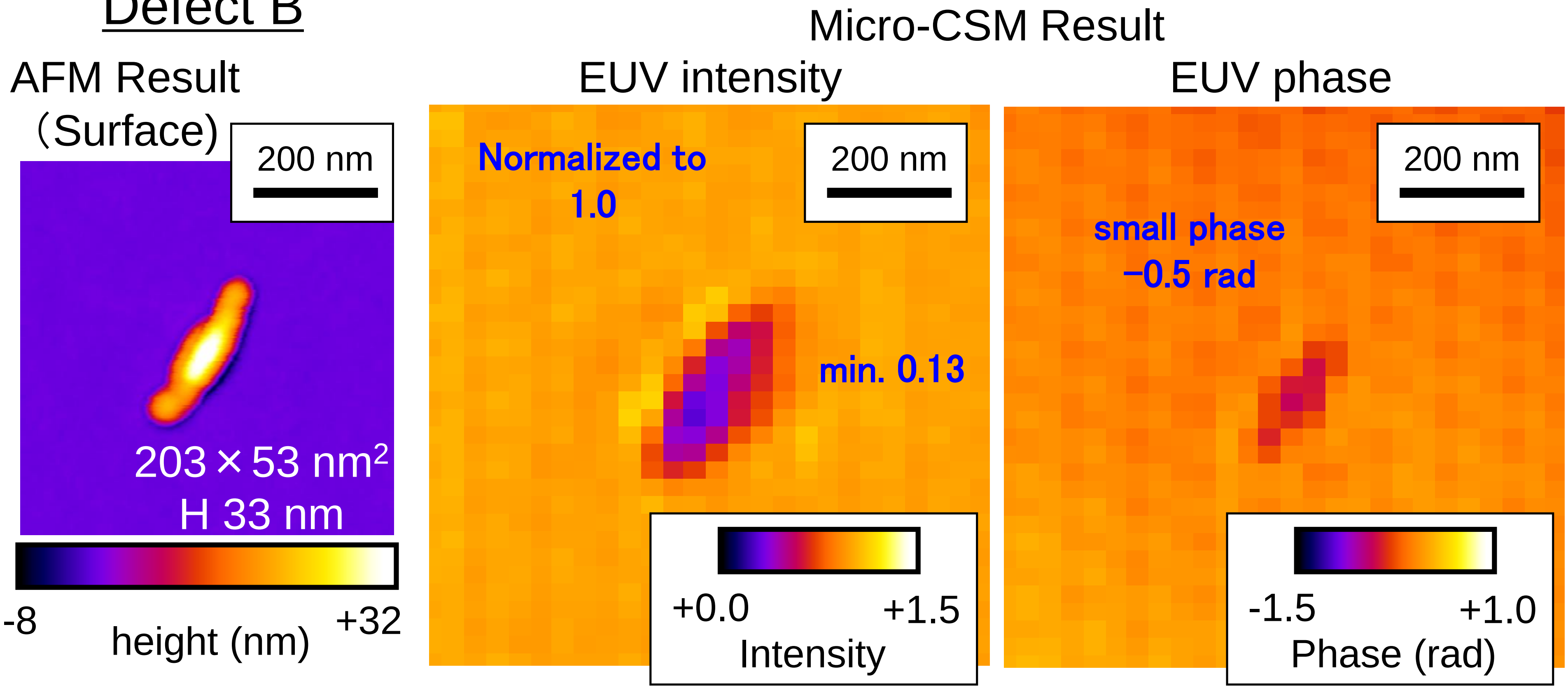
Resolution
30 nm

The actual defect should have different shape and phase distribution.

⇨ We did Actual Defect observation.

Actual defect observation Result：Absorber Defect

Defect B

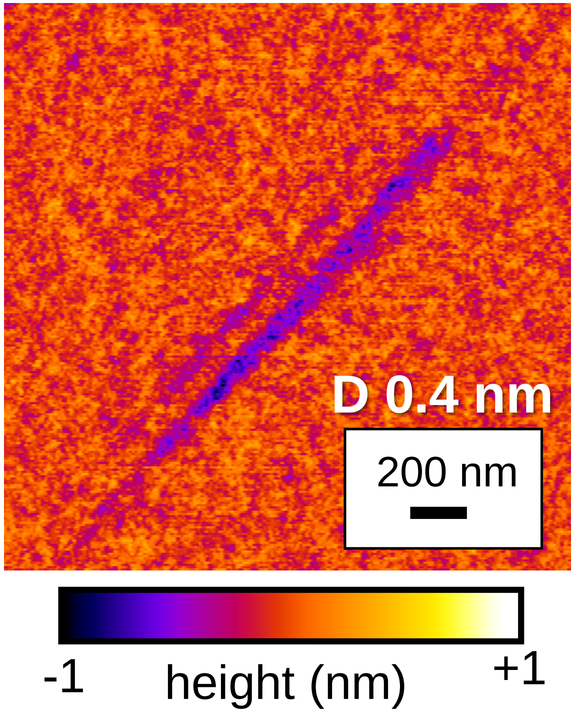


Defect shape was narrow, which corresponded with the AFM result.
This defect was estimated to be **an amplitude defect** (particle), because the phase value was small. (n = 0.98 , Aluminum particle?)

Actual defect observation Result：Absorber Defect

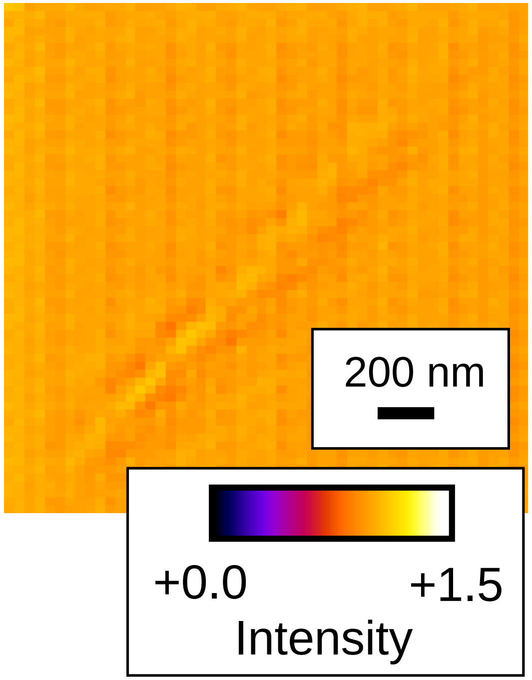
Defect C

AFM Result（Surface)

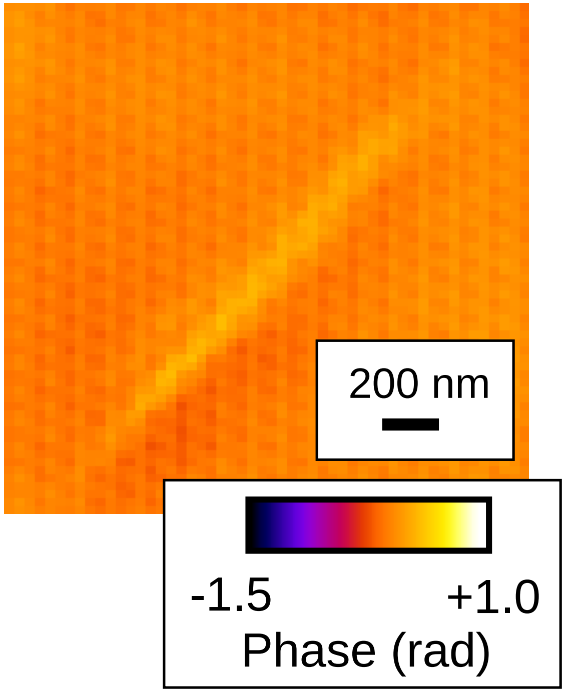


Micro-CSM Result

EUV intensity



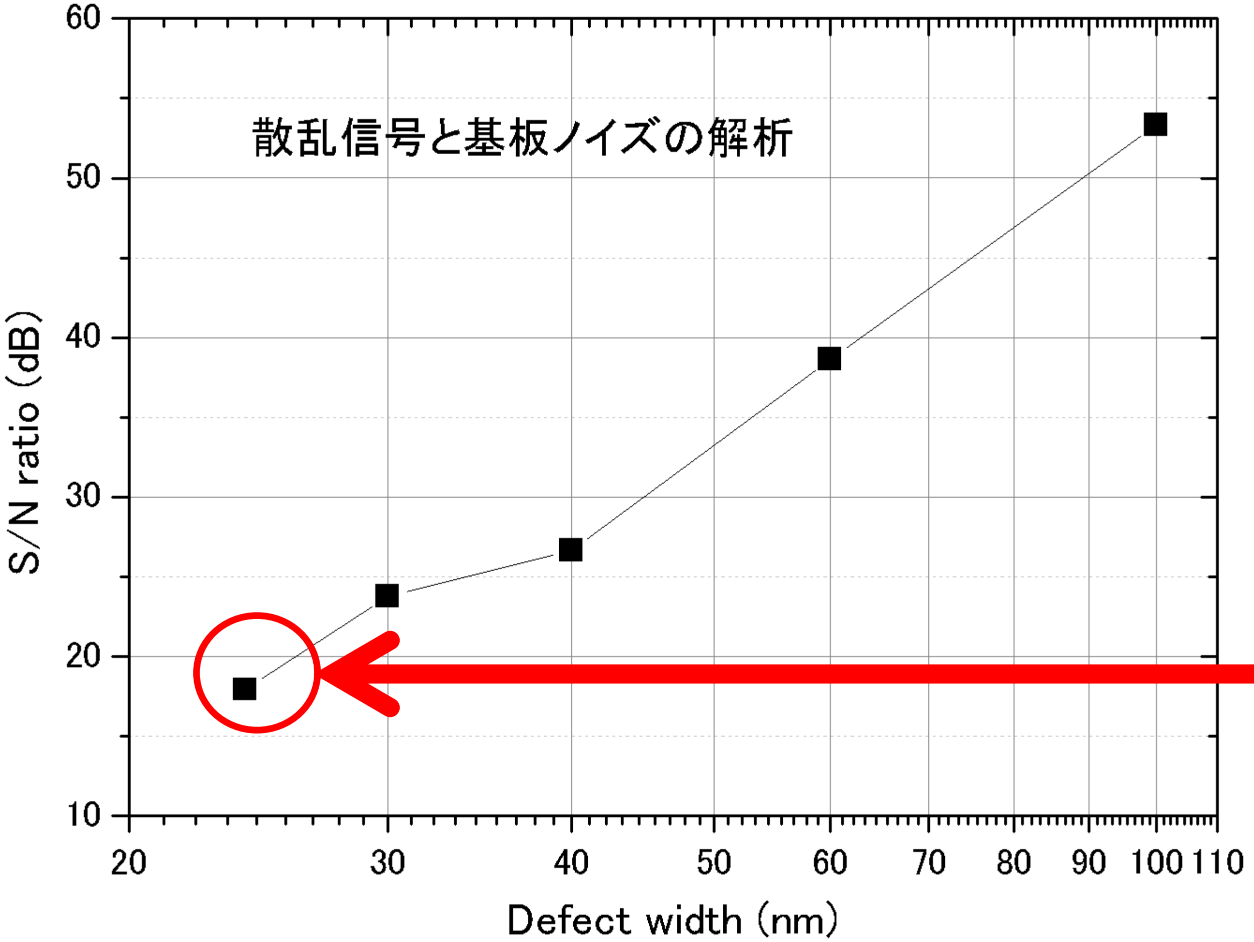
EUV phase



Scratch shaped defect was observed.

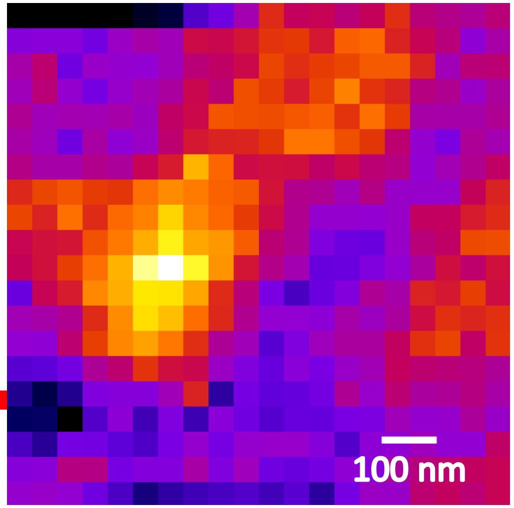
This defect was estimated to be **an phase defect** (scratch on the substrate).

Resolution of phase defect inspection



The relation between S/N and defect size

Defect image



Mapping image

Up to now, defect size of 25.5 nm width and 1.4 nm height was detected.

3-D image reconstruction by the diffraction signal

CSM

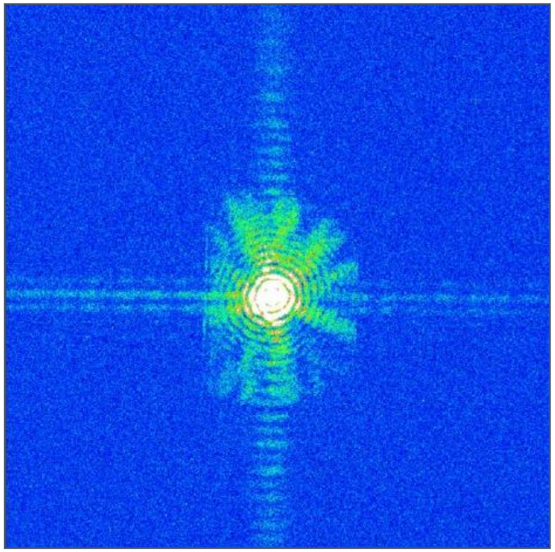
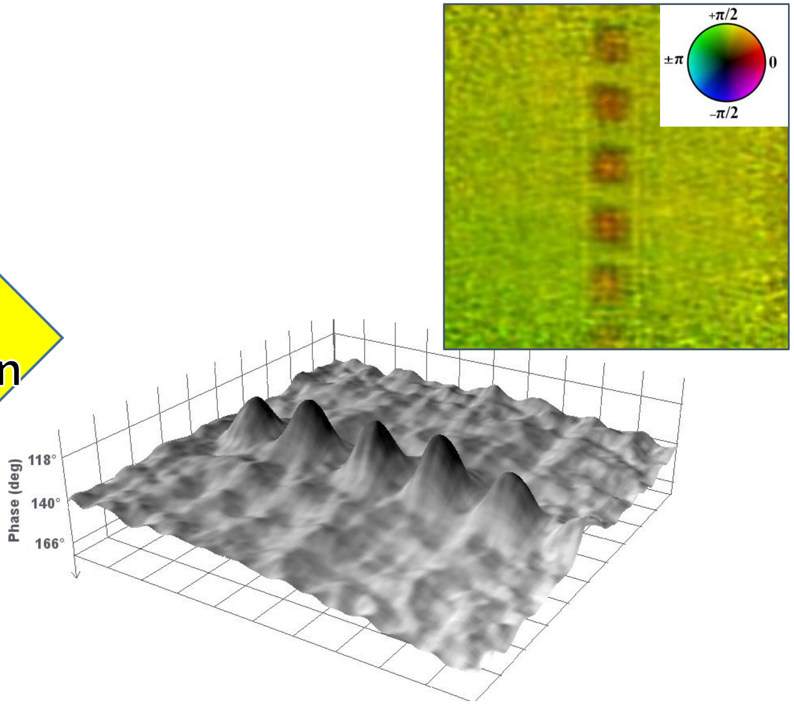


Image Reconstruction



Micro CSM

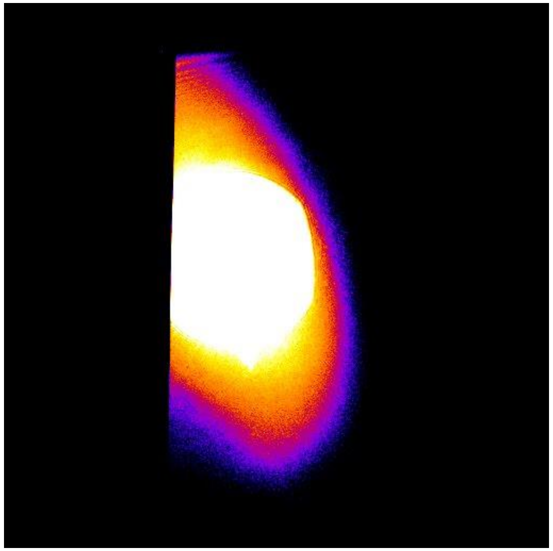
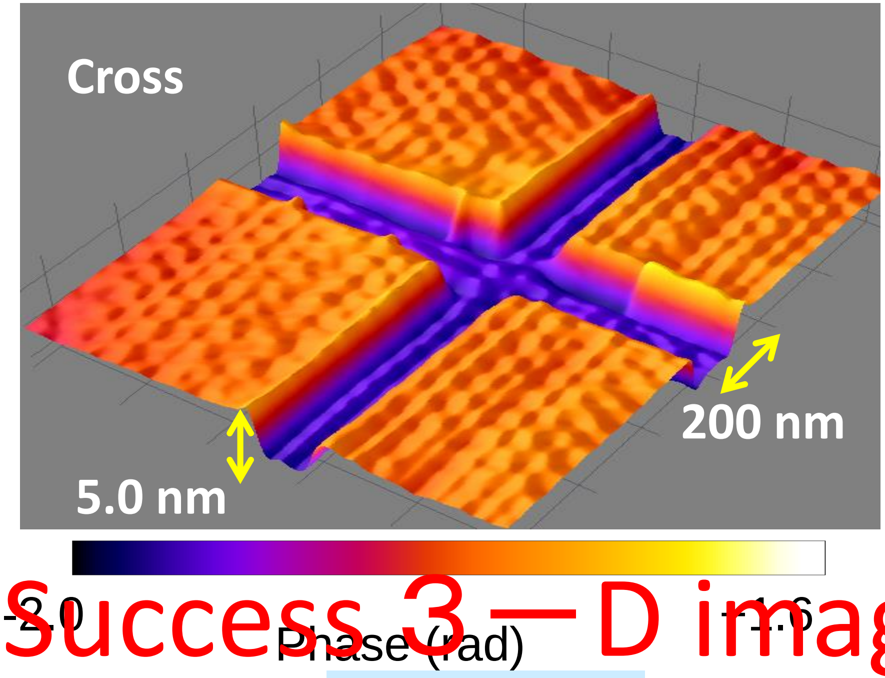


Image Reconstruction

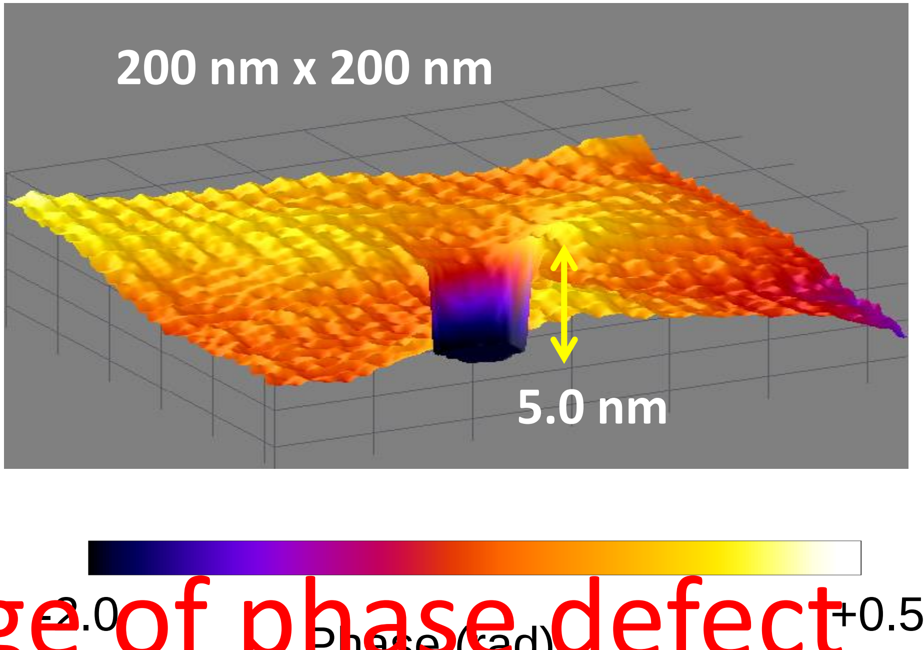
?

Intensity + Phase

3D image of the Phase defect



AFM 4.6 nm



AFM 4.6 nm

Success 3—D image of phase defect

- 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.

Summary

- **CSM** systems have developed for characterization of a small absorber defect with high **resolution of 24 nm**.
- **Micro-CSM** systems have developed for characterization of a small phase defect with with high **resolution of 25 nm**.
- **Actual** (amplitude and phase type) **defects** on the actual EUV mask were characterized with intensity and phase contrast.
- We want to develop the practical system with high harmonic generation EUV source.

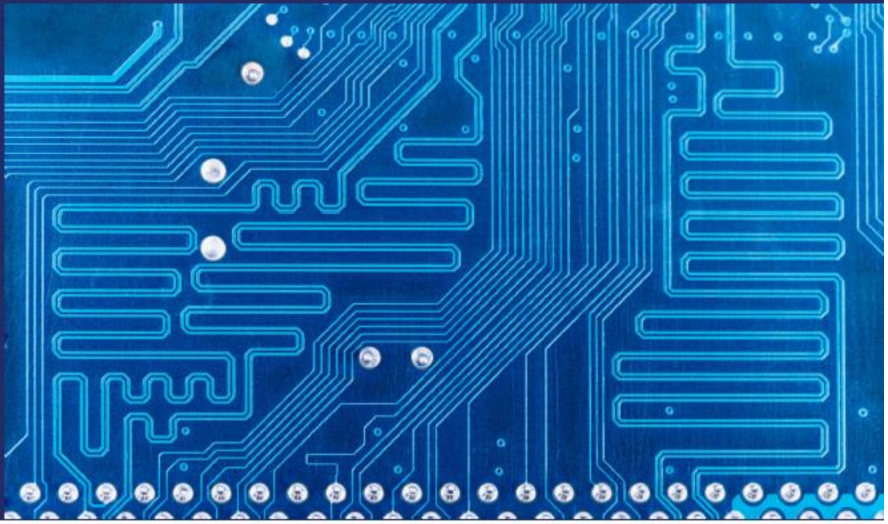
This book describes the principles and basic technologies of extreme ultraviolet lithography (EUVL). The topics include why research on EUVL was begun and why an exposure wavelength of 13.5 nm was selected; the design of the optical system, which employs reflective mirrors; the use of a multilayer film to make a reflective-type mask and how masks are inspected; an historical overview of the development of light sources; resist materials; and the recent performance of lithographic tools for mass production. Three innovations were key to the development: of Mo/Si multilayer films with a high reflectivity and to the shaping and metrology of aspherical mirrors with a precision of less than 0.1 nm. The technology for measuring figure error and the fabrication technology now meet the performance targets. Thus, EUVL has become the most promising lithographic technology for device fabrication at the 7-nm node.

Hiroo Kinoshita is an expert with over 40 year's experience in lithography. He worked for NTT and University of Hyogo, where he developed an EUVL experimental system. He has authored over 170 technical paper on EUVL. He is a fellow of The Optical Society. And he won the Joseph Fraunhofer Award/Robert M. Burley Prize from the Optical Society in 2012

978-3-659-82740-2

Extreme Ultraviolet Lithography

Kinoshita



Hiroo Kinoshita

Extreme Ultraviolet Lithography

Principles and Basic Technologies

LAP LAMBERT Academic Publishing

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