# EUV Mask Observation Result Using Coherent EUV Scatterometry Microscope with High-Harmonic-Generation EUV Source


**Tetsuo Harada**[1], Takahiro Fujino[1], Yusuke Tanaka[1], Yutaka Nagata[1,2], Takeo Watanabe[1], and Hiroo Kinoshita[1]

1. Center for EUV Lithography, LASTI, University of Hyogo
2. RIKEN

E-mail: harada@lasti.u-hyogo.ac.jp


## Introduction

- An EUV mask should be inspected at-wavelength, because the mask has 3D structure of absorber and Mo/Si multilayer. There are some wavelength- and structure-specific issues of a phase defect, shadowing effect, and absorber phase, for example.
- An EUV microscope is a key tool for EUV mask development.
- We have been developed EUV microscopes for EUV mask evaluation using a synchrotron radiation source of NewSUBARU.
- This poster is about coherent EUV scatterometry microscope (CSM) using coherent diffraction imaging method without objective. The CSM can image phase distribution.
- Since we would like to apply the CSM for industrial use, a laboratory source of high-harmonic-generation (HHG) EUV source has been developed with a laser group in RIKEN.

**Objective**

At-wavelength EUV mask evaluation of 3D effect with laboratory source.

Coherent EUV Scatterometry Microscope (CSM)

\+ PHASE imaging

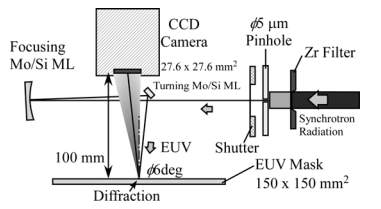
High-harmonic-generation (HHG) EUV source

Laboratory coherent EUV source

## Coherent EUV Scatterometry Microscope (CSM)

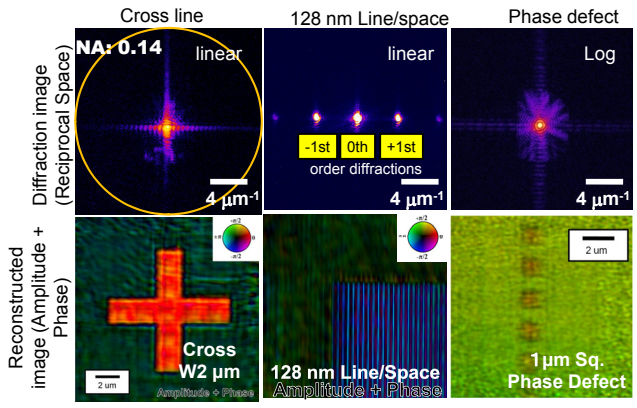
We have developed THREE types of coherent EUV scatterometry microscopes (CSM), which was based on coherent diffraction imaging method. (SR-CSM, Micro-CSM, HHG-CSM)

### 1. SR-CSM



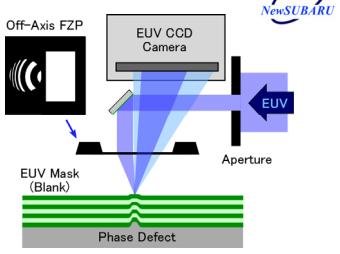

Wavelength: 13.5 nm (EUV)
Source: Synchrotron (NewSUBARU)
Focusing size: Φ5 μm
NA: 0.14

- Sample was exposed with coherent EUV light.
- Diffraction signal is recorded with CCD camera directly.
- Pattern image is reconstructed with iterative calculation with the diffraction image.




- CSM system images phase distribution.
- Absorber phase and shadowing effect in phase were actually observed.
- Quantitative phase value of phase defect was achieved.

### 2. Micro-CSM

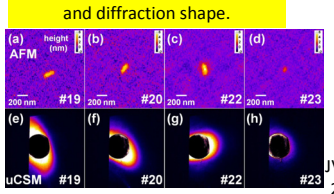



Wavelength: 13.5 nm (EUV)
Source: Synchrotron (NewSUBARU)
Focusing size: Φ230 nm
NA: 0.27

- Illumination EUV is focused using Fresnel zone plate to Φ230 nm.
- For phase defect imaging. (Phase imaging)

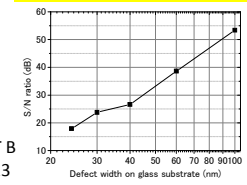
(Phase imaging result will be presented in MNC2014 conference next week.)

Relation with phase defect shape and diffraction shape.




JVST B 2013

Detection limit of phase defect 25 nm, D1.4 nm

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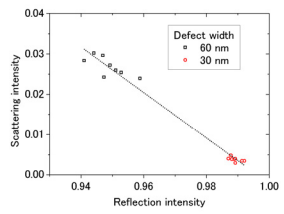
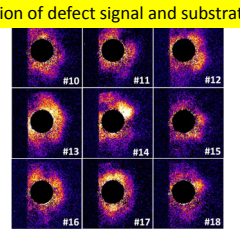
Defect signal variation




JJAP 2014

Relation of defect signal and substrate speckle

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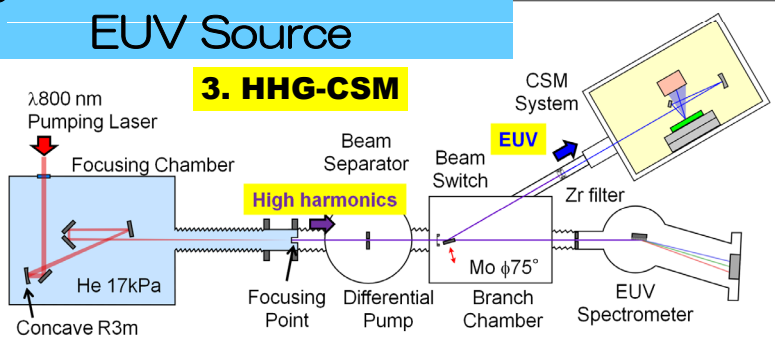
## High Harmonic Generation EUV Source

### 3. HHG-CSM

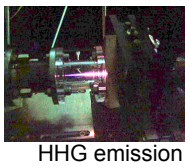



**Specification**

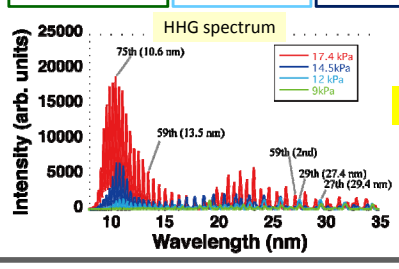
Wavelength: 13.5 nm (EUV)
Source: HHG EUV source
Focusing size: Φ4.3 μm
NA: 0.14

- High-harmonic-generation (HHG) source emits coherent EUV light.
- The brilliance of the HHG is higher than the NS synchrotron (Bending) light.
- The source is LAB SCALE source, which can apply industrial tool.

| Pumping laser | Focusing optics | HHG gas cell | EUV Output |
|---|---|---|---|
| Wavelength: 800 nm Near Infrared | R3 m Concave ϕ85 μm focus | Helium gas ~ 17 kPa | 59th wavelength conversion 800/59 ~ 13.5 nm |
| 6 mJ/pulse 30 fs duration → 0.2 TW | $10^{15}$ W/cm² | Non-linear Interaction | |



HHG emission

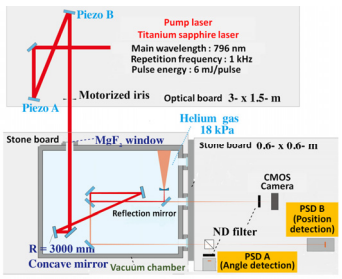


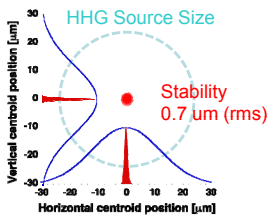

HHG Performance (Current status)
200 nW, ϕ48 μm, 0.18 mrad, δλ 0.1 nm

**Brilliance** photons/sec/0.1%BW/mm²/mrad²

| | |
|---|---|
| HHG (13.5 nm) | $1.3 \times 10^{14}$ |
| NewSUBARU Bending | $6 \times 10^{12}$ |
| NewSUBARU Undulator | $6 \times 10^{17}$ |

Position Stability Improvement (New)

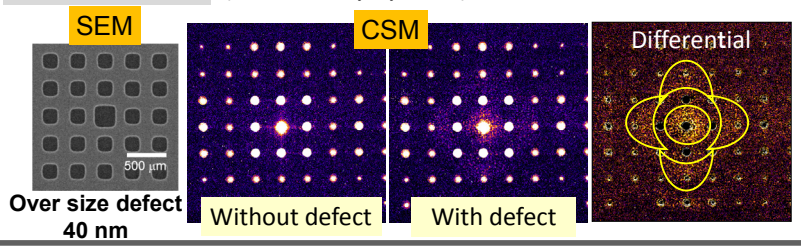



HHG position stability (1hr)

- Feedback system corrects the beam position. (Piezo Mirror x 2, PSD x 2)
- Position stability is very high of 0.7 μm (rms) in an hour.
- We upgraded relay optics to "single relay" system. The source image was directly relayed on the mask surface using a concave mirror.
- Previous system used two concave, and a pinhole. (Twice RELAY)

**Previous Result** (Twice relay system)




Over size defect 40 nm

HP 45 nm (180 nm on Mask) hole pattern array
Center hole is bigger than other.
EXP.time: 1,000s
too long time for detection

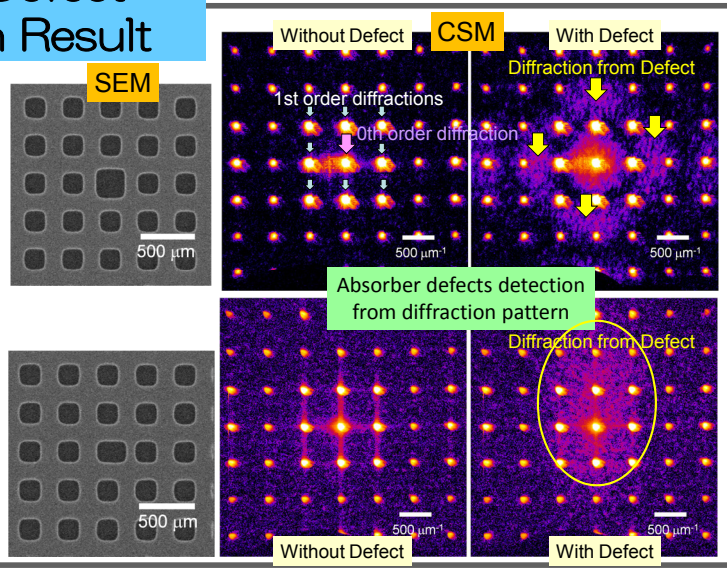
## Absorber Defect Observation Result

HP 45 nm (180 nm on Mask) hole pattern array

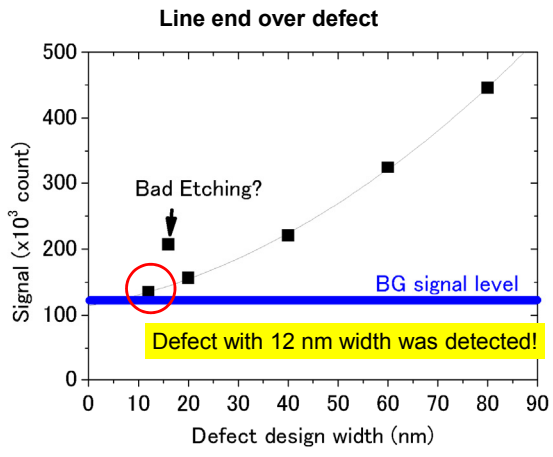
Over size defect 40 nm

EXP.time: 10 s

Line end over defect 80 nm




Defect signals from various size




- Absorber defects in hp 45 nm hole pattern (180 nm on mask) were detected using HHG-CSM.
- This experiment is for detection-limit evaluation.
- Exposure time was dramatically improved to 10 s compared to previous result.
- Various type of defects were detected.
- Detection limit of the defect was 12-nm line-end over size, which area was 2,160 nm². This area was equivalent to the square defect with area of 46 x 46 nm².

## Summary

- We have developed CSM with HHG EUV source. This HHG-CSM is for at-wavelength EUV mask evaluation of 3D effect with laboratory source.
- The beam position was stabilized to 0.7 μm (rms) in an hour using feedback system. Thus, we upgraded the relay optics from twice relay to single relay system.
- Exposure time and the detection size limit were dramatically improved to 10 s and 12-nm with line –end over defect. This defect area size of 2,160 nm² was equivalent to the square defect with area of 46 x 46 nm².
- The CSM system has high capability to evaluate small structure. We will continuously evaluate the EUV mask structure with amplitude and "PHASE image".