Development of Actinic Mask Inspection

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Introduction: Center for EUV Lithography

NewSUBARU Synchrotron Radiation Facility

Reflectometer (BL10)  
Interference Lithography & New Resist evaluation system (BL9)
The SEMATECH Berkeley Actinic Inspection Tool (AIT)

λ: 13.2–13.6 nm
NA (4x): 0.25–0.35, θ 6°
Mag: 907x

CCD

The SEMATECH Berkeley Actinic Inspection Tool (AIT)

Photocathode
(CsI)

Electromagnetic lens
(10–200X)

MCP

CCD camera
(6 µm/pixel)

X-ray zooming tube

Turning mirror

Schwarzschild objective
(NA 0.3, 30X)

Mask

SR (EUV) →

EUVL

EUVM

CSM

ABI
## Comparison of Actinic Inspection System

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<th>ABI</th>
<th>EUVM</th>
<th>CSM</th>
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<td><strong>Source</strong></td>
<td>SR</td>
<td>DPP</td>
<td>SR</td>
<td>HHG</td>
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<tr>
<td><strong>Object</strong></td>
<td>Finished Mask Pattern</td>
<td>Blanks Phase Defect</td>
<td>Finished Mask Pattern &amp; phase defect</td>
<td>Finished Mask Pattern defect &amp; CD</td>
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<tr>
<td><strong>Resolution</strong></td>
<td>60 nm</td>
<td>W40nm,H1nm</td>
<td>100nm W20H1nm</td>
<td>2nm downsizing defect</td>
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<tr>
<td><strong>Speed</strong></td>
<td>N/A</td>
<td>4 hours/mask</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td><strong>Bright field / Dark</strong></td>
<td>Bright field</td>
<td>Dark field</td>
<td>Bright field</td>
<td>Bright field</td>
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EUV Microscope (EUVM)

- **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
Elbow pattern 100 nm Lines and spaces
Confirmation of the magnification enhancement

Intermediate image \( (m=30) \)
- Exp. time: 0.25 sec.

Final image \( (m=1460) \)
- Line width: 240nm (60nm)
- Exp. time: 36 sec.

EUV-CCD camera: pixel size 13.5μm, 2048 × 2048 pixels
Resolution measurement with L/S patterns

High magnification images \((m=1460)\)

Line width: 225nm (56nm)
Exp. time: 10s

Line width: 88nm (22nm)
Exp. time: 100s
88nm-width L/S pattern was clearly observed.

⇒ The capability of inspecting 22nm-node masks.
Coherent EUV Scatterometry Microscope (CSM)

- **EUV ACTINIC** observation
- **LENSLESS** system (Diffraction & Scattering)
- Real space image (pattern image) & CD values are calculated with the diffraction image.
- **COHERENT EUV light** is required. (SR source)

Very Simple

**CD on resist Evaluation** + **Defect Inspection of Absorber pattern & Phase defect**
Measurement principle

**CSM**
Detects the size of Mo/Si multilayer.

**SEM**
Detects the secondary electron of the top of absorber.

The case of a side wall has the inclination, the measure of the SEM will be smaller than the measure of the CSM.
- EUVL is going to the HVM stage.
- EUV mask should be evaluated at the factory using **standalone system**.
- **High-Harmonic-Generation** (HHG) EUV source is standalone and coherent EUV source.

Laboratory scale system
Laser table: $3 \times 1.5 \, m^2$
Room size: $8 \times 4 \, m^2$

Carbolated work with RIKEN
CSM with high harmonic generation (HHG)

Schematic structure of HHG-CSM system.

Carbolated work with RIKEN
HHG EUV light output

- Spatial COHERENT
- Ultra short pulse

- Output EUV (59\textsuperscript{th})
  - 1 uW
- Divergence:
  - 0.17 mrad

Intensity profile with two He pressure conditions.

Coherent EUV power
SR $\times$ 1,000
Result using the HHG-CSM system

First light of HHG EUV

Shown in log scale
Diffraction image without pattern
(Blank region)

High contrast, low speckle noise

Only 59th generation is recorded.

Diffraction angle with
88 nm L/S, λ13.5 nm

-1st  0th  +1st

order diffractions
Defect inspection by HHG-CSM system

Sample:
30-nm-wide defect in 88 nm L/S pattern (Programmed defect)

CCD image

Defect Signal

-1st 0th +1st
order diffractions

HHG-CSM

SR-CSM

Defect signal was clearly detected using HHG-CSM
Detection limit of HHG-CSM system

Sample:
2-nm-wide defect in 88 nm L/S pattern (Programmed defect)

Detection limit at SR-CSM: 10 nm

Detection limit is improved to 2 nm with the HHG-CSM system.
Summary

• We developed the CSMs for EUV mask evaluation.

• We developed the algorithms to reconstruct the pattern, to detect the defect, and to evaluate the CD values.

• HHG EUV source was developed for standalone CSM system.

• Using the HHG-CSM system, the detection limit of defect size was improved from 10 nm with SR-CSM system to 2 nm.

• EUV Microscope attached a magnified optics improved the pattern resolution.