Recent Activities of the Actinic Mask Inspection using the EUV microscope at Center for EUVL

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Outline

1) EUV actinic mask inspection using EUV Microscope

2) EUV Microscope using a high-magnification objective with three multilayer mirrors
EUV actinic mask inspection using EUV Microscope

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Outline

1) EUV microscope
2) Phase defect observation
3) Defect repairing using FIB and its observation
4) Conclusions
Total 11 sets of the commercial steppers for EUV Lithography will be delivered in 2013 ~ 2014.

EUV mask repair and the mask inspection for the repaired mask is required
Mask inspection method

Inspection by exposure wavelength

**EUV Mask Defect**
- Amplitude defect
- Phase defect

Glass

Affected with Intensity profile

Pit and bump defects of 1-nm-depth are printable.

Difficult to inspect using DUV and SEM.

EUV mask defect inspection tool

**EUV mask**

ALS Zone Plate型

NewSUBARU Schwarzschild型

hp100 nm

hp150 nm

Difficult to inspect using DUV and SEM.
Specification of EUV Microscope

Schwarzschild optics
Magnification: 30X
Numerical aperture: 0.3

- Light source: Bending magnet
- Total magnification: 300〜6000x
- Resolution: 10 nm
- Method: Bright field
- Defect observation: Amplitude and phase defects
Mask defect inspection by EUVM

150nm L/S

Absorber

Mo/Si ML

ULE Substrate

Finished mask

Contamination

1um Dot

Dark area

Amplitude

Phase

Blanks
Resolution of mask defect by EUVM

Isolated line of 300 nm width

Pattern edge profile of light intensity

By 25% and 75% of maximum light intensity light for the absorber edge pattern, the resolution of 50nm is obtained.
Printability of Mask Defect

Printability of phase defect under the absorber pattern

400 nm L/S, programmed defect height of 12 nm

The printability depends on the position of the programmed defect.

Controlled the width and height of the programmed defect.

Depth: 1～4 nm
Width: 20～140 nm

The printability criteria was clarified using EUVM.

Printability of point and line programmed defects
Repair of clear defect

SEM image

Clear defect (Reflected region)

ML

Absorber

Lack of absorber

Resist image

EUVM image

Lack of circuit pattern

Clear defect
Conventional repairing method of clear defect by CVD

Demerrit:
- CVD layer contains carbon.
- Thickness loss by cleaning.
- CVD layer has to be large height.
- Affected with shadowing effect
Mask defect repair using FIB

By removing of the ML under the Clear defect by the Ga ion beam of FIB, the EUV light will not be reflected.
Pattern inspection by EUVM for the repaired clear defect by FIB

225 nm L/S

FIB irradiation area

Narrow width

Wide width

SEM image

ML removal area

EUVM像

Clear defect

Not completely removed

Completely removed

Narrow width for repairing
Pattern inspection by EUVM for the repaired clear defect by FIB

The clear defect which was repaired by FIB was observed using EUVM.
Conclusions

1) Printability criteria of the programmed defect width and height was obtained using EUVM mask defect inspection.

2) It is confirmed that the clear defect repairing by FIB is found to be usable using the EUVM observation.
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EUV Microscope using a high-magnification objective with three multilayer mirrors

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1. Motivation
   Early studies and technical issues
2. Experimental
   Innovative optics utilizing high-magnification
3. Highlight data
   EUVL mask images with improved resolution
4. Summary and future plans
1. Motivation
Benefit of using high-magnification mirror as an objective

In the x-ray zooming tube, CsI thin film was utilized as the photoelectric conversion element.

However, the grain size of the CsI affected with the resolution of the EUVM imaging.

Thus the high-magnification-mirror objective is selected for the EUVM imaging.
At-wavelength inspection of EUVL mask

Requirements for an inspection tool

✓ At-wavelength observation (λ=13.5nm)
✓ High spatial resolution (δ<40nm)
✓ Wide field of view for a rapid whole mask inspection
Early study: EUV Microscope on NewSUBARU

SR EUV light

Schwarzschild objective (30x)
NA=0.3

EUV zooming tube (200x)
photo cathode

mask sample
electron lens

EUV $\Rightarrow$ electron
✓ Bright field image at $\lambda=13.5$ nm
✓ Rayleigh’s limit $\delta=30$ nm
Field of view $\Phi=20\mu m$
Actual resolution $\delta>100$ nm

Line width 480nm (120nm on wafer)

Technical issues of the EUV Microscope

✓ **Degraded resolution** resulting from *aberrations of Schwarzschild objective*.
✓ **Small field of view**
  limited by an electron lens of the zooming tube.

**Aim of this work**
Innovative EUV imaging facility realizing both
✓ **high spatial resolution** for 22-nm node mask,
✓ **wider field of view** for practical inspection time.
2. Experimental
Two-stage imaging system for high magnification

1st stage
- Sample
- Rayleigh's limit $\delta = 33nm$
- NA = 0.25
- $m = 30$

CCD camera
- $\delta = 40\mu m$
- Intermediate image $\delta = 1\mu m$

2nd stage
- NA = 0.01
- $m = 40$


- Higher magnification ($m > 1200$)
  $\Rightarrow$ 30nm resolution with EUV-CCD camera
- Good correction of off-axis aberrations
  $\Rightarrow$ Large field of view over $\Phi > 160\mu m$
Experimental setup of the novel facility

- NewSUBARU BL3
- Schwarzschild objective
- Illumination optics
  - SR EUV
  - CCD camera
- 2nd stage mirror
- Intermediate image
- Turning mirror
- EUVL mask
- Load-lock system
✓ Substrates (5 sets) were polished in IMRAM.
✓ Mo/Si multilayer was coated with IBS.
✓ Mirrors were aligned using Zygo interferometer.

⇒ Wavefront error $W=2.2 \text{ nm rms. (on-axis)}$
3. Highlight data
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
Resolution measurement with L/S patterns

- 88nm-width L/S pattern was clearly observed.
  ⇒ The capability of inspecting 22nm-node masks.
Conclusions

1) High-magnification of 1460x was achieved using three-mirror objective.

2) High-magnification enhancement was confirmed by the observation of the actinic EUV mask.

3) 88 nm mask pattern was observed using high-magnification objective in EUVM.
1) Printability criteria of the programmed defect was confirmed by EUVM.

2) The benefit of the clear defect repairing method using FIB was confirmed by EUVM.

3) 88 nm mask pattern was observed using high-magnification objective in EUVM.