Contamination Removal of EUVL masks and optics using 13.5-nm and 172-nm radiation

Takeo Watanabe, Kazuhiro Hamamoto and Hiroo Kinoshita

University of Hyogo

IEUVI Resist & Contamination TWG Oct.19, 2006 in Barcelona
Method of contamination removal

(1) Cleaning of EUVL imaging optics
   (The optics used for EUVL has been aligned in high accuracy. So the cleaning of imaging optics requires in-situ process.)

   ⇒ In-situ contamination removal by synchrotron radiation without heating

(2) Cleaning of EUVL masks
   (Both large cleaning area and high speed are required.)

   ⇒ Contamination removal by 172-nm-wavelength.

Evaluation between before and after removal

- Contamination thickness → Optical thickness measuring system
- Surface roughness → AFM
- Reflectivity → Reflectometer (NewSUBARU BL-10)
Online contamination removal by a wavelength of 13.5 nm
Contamination adhesion in ETS-1 exposure system

Sample of the multilayer is set on the mask stage, and EUV is irradiated.

Total pressure: $1 \times 10^{-5}$ Pa
Thickness of contamination

Electron beam current: 200 mA

Deposition rate: 7.5 nm/hr (0.125 nm/min)
Reflectivity of multilayer

Multilayer reflectivity of 10% decreased by 4 hours irradiation
Surface roughness of multilayer

![Graph showing the relationship between surface roughness and irradiation time.](image)
The ratio of C to O is 96:4
Experimental setup of SR cleaning

- Storage ring
- M1 mirror
- M2 mirror (Branch)
- M3 mirror
- ETS-1
- Contamination testing chamber
- Photodiode (GaAsP)
- Incident angle: 10°
- Mask sample
- SR
- TMP
- Oxygen
- Back pressure: 5.0×10^{-5} Pa
- Adding O₂ during SR irradiation
- Pressure: 5.0×10^{-2} Pa
Experimental results

Pressure: $5.0 \times 10^{-2}$ Pa
Electron beam current: 130 mA
Irradiation: 7 hr

Contamination of 0.1-μm-thick was removed.
Reduction of contamination thickness

Electron beam current: 130 mA

Removal rate: 0.24 nm/min

Graph showing the relationship between reduction in thickness (nm) and exposure dose (mAs). The graph indicates a removal rate of 0.24 nm/min over 7 hours. The electron beam current is specified as 130 mA.
Reflectivity of multilayer (measurement: NS-BL10)

Before cleaning

contamination

multilayer

absorber

After cleaning

absorber

multilayer

absorber

Reflectivity

Wavelength (nm)

12.0 13.0 14.0 15.0

Before cleaning:

Reflectivity

Wavelength (nm)

12.0 13.0 14.0 15.0

After cleaning:

Reflectivity

Wavelength (nm)

12.0 13.0 14.0 15.0
Offline contamination removal by a wavelength of 172 nm
The absorption coefficient to the oxygen molecule at the wavelength of 172 nm is 20 times larger than that at the wavelength of 185 nm of the low-pressure mercury lamp.

⇒ A high density active oxygen species can be generated.
Experimental setup of 172 nm cleaning

Intensity 20 mW/cm²
Distance 1 mm
Sample size 8-inch
Temperature 25°C
Environment in the air / in O₂-rich vacuum

O₂-rich vacuum environment:
The initial back pressure of the chamber was 500 Pa by scroll pump, and an O₂ flow kept the pressure at 2×10³ Pa.
Results of mask cleaning using 172 nm-excimer lamp

(1) Reduction of contamination thickness

- In vacuum: rate 2 nm/min.
- In the air: rate 0.53 nm/min.
Results of mask cleaning using 172 nm-excimer lamp
(2) Reflectivity of multilayer

Before cleaning

After cleaning

Reflectivity

Wavelength (nm)
Summary

(1) From the result of AES, it has been understood that the element of contamination is almost carbon.

(2) The effectiveness of the contamination removal for EUVL imaging optics using both in-situ and non-heating method by EUV irradiation in the oxygen atmosphere is confirmed.

(3) The effectiveness of the contamination removal for the finished EUVL mask in off-line process using the 172 nm-excimer lamp in the O₂-rich vacuum atmosphere at the room temperature is confirmed.
Thank you for your attention!!
Outgassing Measurement in University of Hyogo

-Short summary-

Takeo Watanabe, Hiroo Kinoshita
University of Hyogo

IEUVI Resist & Contamination TWG Oct.19, 2006 in Barcelona
Setup of novel resist evaluation system

1) Measurements of sensitivity
2) Outgas characteristics
3) Chemical reaction analysis

Simulating six-mirror optics

Practical exposure spectrum

PC controlled fast speed shutter ($\Delta t=11$ ms)

High-sensitive ion counting type Q-mass spectrometer

Model HAL/3F/PIC 501 RC, Hiden Analytical, Ltd.

Distance 30 mm

Mo/Si MLs
Concave Mirror

Mo/Si MLs Two Plane Mirrors

Sample
Setup of novel resist evaluation system

- Mirror chamber: TMP 700L/s
- Loadlock chamber: TMP 300L/s
- Sample insertion rod
- Gate valve
- Sample chamber: TMP 300L/s
- Shutter chamber
- SR
- Differential pumping
<table>
<thead>
<tr>
<th>Institute</th>
<th>Method</th>
<th>Results</th>
<th>Estimate Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Molecules/cm² @5.6 mJ/cm² dose</td>
<td>Molecules/cm²/s @each intensity condition</td>
</tr>
<tr>
<td>Intel</td>
<td>Synchrotron</td>
<td>4.37×10¹¹</td>
<td>7.3×10⁹ 0.09 mW/cm²</td>
</tr>
<tr>
<td></td>
<td>GC/MS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.3×10¹³</td>
</tr>
<tr>
<td>SEMATECH</td>
<td>Synchrotron</td>
<td>3.9×10¹³</td>
<td>2.6×10¹² 0.37 mW/cm²</td>
</tr>
<tr>
<td></td>
<td>GC/MS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.1×10¹⁵</td>
</tr>
<tr>
<td>ASET</td>
<td>Synchrotron</td>
<td>1.9×10¹⁴</td>
<td>4.5×10¹² 0.13 mW/cm²</td>
</tr>
<tr>
<td></td>
<td>Online QMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.7×10¹⁵</td>
</tr>
<tr>
<td>BOC Edwards</td>
<td>Stand-alone source</td>
<td>2.8×10¹⁴</td>
<td>5×10¹³ 1 mW/cm²</td>
</tr>
<tr>
<td></td>
<td>Online QMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8.3×10¹⁵</td>
</tr>
<tr>
<td>Univ. of Hyogo</td>
<td>Synchrotron</td>
<td>7.1×10¹⁵</td>
<td>3.4×10¹⁴ 0.27 mW/cm²</td>
</tr>
<tr>
<td></td>
<td>Online QMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.9×10¹⁷</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.4×10¹⁴ 35-200 amu</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>35-200 amu</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.3×10¹⁴ 35-200 amu</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.3×10¹⁴ 35-200 amu</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.1×10¹³ 35-200 amu</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.1×10¹⁶ 35-200 amu</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Excluding 44 amu</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Excluding 44 amu</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Excluding 44 amu</td>
</tr>
</tbody>
</table>