EUV Interference Lithography in NewSUBARU

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1. Introduction
2. Design concept of EUV-IL beamline
3. Setup and spatial coherence length measurement using double slit
4. Fabrication of transparent grating
5. Replicated resist patterns of L/S and dot patterns
6. Conclusion
### Requirement of the resist line control in ITRS roadmap 2007

Line control size with nanometer level is required in 32 nm node below !!

Line control size has to be smaller than the molecule size of the base polymer !!

<table>
<thead>
<tr>
<th>Year 2000+</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>20</th>
<th>21</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAM HP (nm)</td>
<td>32</td>
<td>28</td>
<td>25</td>
<td>23</td>
<td>20</td>
<td>18</td>
<td>16</td>
<td>14</td>
<td>13</td>
<td>11</td>
</tr>
<tr>
<td>LWR 3σ (nm)</td>
<td>1.7</td>
<td>1.5</td>
<td>1.3</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
<td>0.8</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Sensitivity (EUV) mJ/cm²</td>
<td>5-15</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Outgassing (molecules/cm²/s)</td>
<td>(5 \times 10^{13})</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Necessity of EUV interference lithography

Line control with sub nanometer is required!!

Conventional EUV optics have aberration and flare.

Low LWR of EUV resist is difficult to achieve.

There is no aberration and no flare in EUV interference lithography. Thus, to achieve low LWR, EUV-IL is powerful for the evaluation of EUV resist in 22 nm node and below.
Principle of EUV-IL

Pattern is appeared !!

Pattern Pitch = Grating Pitch / 2
Brilliance of long undulator and bending magnet

- **NewSUBARU**
  - $I = 220 \text{mA}$
  - $\Delta E/E = 0.00072$
  - $\varepsilon_x = 40 \text{nm} \quad \varepsilon_y = 4 \text{nm}$

- **SPring-8**
  - 1st
  - 1st
  - 5th
  - 5th/1.5GeV

- **Optical Klystron**
  - $\lambda_u = 32 \text{cm} \quad N = 32$

- **The sun**
  - $\varepsilon_x = 67 \text{nm} \quad \varepsilon_y = 6.7 \text{nm}$

- **Banding magnet-1.5GeV**
  - $\varepsilon_x = 40 \text{nm} \quad \varepsilon_y = 4 \text{nm}$

- **Banding magnet-1.0GeV**

- **Long Undulator**

- **Short Undulator**

- **Photon Energy (eV)**
EUVL beamlines in NewSUBARU

- 11m Long Undulator
- PDI Experiment (Nikon & Canon)
- Interference Lithography for 22nm and below
- Bending Monochrometer
- Reflectometer
- Resist absorption & Transmittance
- Mask Inspection
- Resist characteristics
- Mask CD Measurement
- Contamination
- Mark 8
- ICP Dry Etcher
- Nanometorics
- FT-IR
- Clean Draft Chamber
- SEM, AFM

High power source and long coherence length

BL10
Bending Monochrometer
BL9
11m Long Undulator
BL3
Bending Magnet
Clean Room
Mark 8
ICP Dry Etcher
Nanometorics
FT-IR
Clean Draft Chamber
SEM, AFM
Beamline setup for EUV-IL in NewSUBARU

Light Source: 11-m Long Undulator

Top View

Side View

Focusing on the pinhole
Beam size $\sim 10\,\mu m$ (V)
Light spectrum of the LU light source

Electron storage current : 230 mA

LU gap of 34.8 mm

![Graph showing light spectrum with peak at 398.5 nA at 13.38 nm and 61.4 nA at 7.24 nm.]

 Photodiode Current (nA) vs. Wavelength (nm)
EUV-IL beamline in NewSUBARU
Experimental setup for the coherence measurement

- Pinhole~Double slit (DS):
  - L = 0.9 m
- DS~Exp. Chamber:
  - L = 2.4 m

- Single slit:
  - 3 mm (H) x 50 μm (V)
  - 3 mm (H) x 25 μm (V)
  - 3 mm (H) x 10 μm (V)

- Double slit:
  - 2 mm (H) x 2 μm (V)

Slit separation (μm):
- 10, 20, 40, 80, 160, 320, 640, 1280
Calculation of the coherence length

- Fringe visibility (V):

\[
Contrast = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}}
\]

- \(I_{\text{max}}\) : maximum PD current
- \(I_{\text{min}}\) : minimum PD current

- Fringe visibility of Gaussian beam:

\[
Contrast = \exp\left(\frac{-d_s^2}{2R_c^2}\right)
\]

- \(R_c\) : coherence radius (\(R_c=2L_c\))
- \(d_s\) : double slit separation
- \(l_c\) : spatial coherence at the DBL slit position

- Spatial coherence is defined: \(Contrast = \exp(-1/8) = 0.88\)

- Spatial coherence at double slit position: \(l_c = d_s\)

- Spatial coherence length at transmission grating:

\[
L_c = (DBL - Grating)/(SLIT - DBL) \times l_c = 2.4m / 0.9m \times l_c
\]
Examples of light intensity measurement at the grating position

Slit width 25 \( \mu m \)
Double slit separation 320 \( \mu m \)

Slit width 10 \( \mu m \)
Double slit separation 640 \( \mu m \)
Results of the spatial coherence length measurement

- LU gap: 34.8 mm
- Storage ring current: 230 mA
- Distance slit-DS: 0.9 m
- Distance slit-grating: 2.4 m

<table>
<thead>
<tr>
<th>Position</th>
<th>25 μm slit</th>
<th>10 μm slit</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS</td>
<td>204 μm</td>
<td>440 μm</td>
</tr>
<tr>
<td>Grating</td>
<td>544 μm</td>
<td>1173 μm</td>
</tr>
</tbody>
</table>
EUV-IL exposure tool in NewSUBARU

- Wafer stage
- Grating stage

$\lambda = 13.5$ nm
Replicated L/S pattern by EUV interference lithography

Resist pattern of 25 nm hp (34 nm line and 16 nm space)
Resist: ZEP520A
Resist thickness: 50 nm

Dot dense pattern
Dot pattern width 71 nm
ZEP520A 50 nm\textsuperscript{t}
Fabrication process of novel transmission grating

40 nm HP and 30 nm HP grating patterns require high etching durability.

Si$_3$N$_4$ Coated on Si substrate

Deposition of TaN and SiO$_2$

Coating ZEP520A resist

Electron beam exposure

Dry etching by Cl$_2$ gas

Dry etching by CF$_4$ gas

Dry etching by CF$_4$ gas

Wet etching by KOHaq

Completion
Fabricated novel transmission grating

The detail of the novel transmission grating and the exposure results using this novel grating will be presented at EUVL symposium 2009 and MNC2009.
Conclusions

1. EUV-IL beamline with 11-m long undulator was constructed at the BL9 beamline in NewSUBARU.

2. It was confirmed that spatial coherence length of more than 1.0 mm by Young’s double slit experiment.

3. 25-nm HP dense resist pattern and 71-nm-width dot dense pattern were replicated using EUV-IL.

4. A two-window transparent grating was succeeded to fabricated in our lab.
Acknowledgement

I would like to thank to each person who support our experiment.