Comparative Study of Binary Intensity Mask and Attenuated Phase Shift Mask using Hyper-NA Immersion Lithography for Sub-45nm Era

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Hynix Semiconductor Inc.

Outline

1. Characterization of Hyper NA Polarized Imaging
   a. Merit of Polarization
   b. Transmittance Change for Polarization State
   c. Comparison of Att.PSM and BIM

2. Experimental Results
   a. Simulation & Experimental Set up
   b. Comparison of Image Contrast for Mask Structure
   c. Experimental Verification for 3 Dimensional Mask Effect
   d. 1.35NA Polarized Imaging of 44nm DRAM Cell for several Mask Structure (Isolation Pattern & Contact Hole Pattern)
   e. OPE Change by Pellicle Interference Effect

3. Conclusion
Limit of conventional lithography

- From 32nm node, completely new technology should be required such as EUV and DPT
- Water immersion ArF, the last conventional lithography technology standing, will have max. 1.35NA tool
- Hence, capability of 1.35NA ArF will decide the limit for conventional lithography

<table>
<thead>
<tr>
<th>Litho $k_1$ criteria</th>
<th>Resolution Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.27</td>
<td>38.6</td>
</tr>
<tr>
<td>0.28</td>
<td>40.0</td>
</tr>
<tr>
<td>0.29</td>
<td>41.5</td>
</tr>
<tr>
<td>0.30</td>
<td>42.9</td>
</tr>
<tr>
<td>0.31</td>
<td>44.3</td>
</tr>
<tr>
<td>0.32</td>
<td>45.7</td>
</tr>
</tbody>
</table>

How much the Polarization Helps

- Unpolarized vs. Polarized Lithography

> Polarized illumination can guarantee better image contrast
Mask 3D effect should be considered

As pattern size on mask decreases to the level of \( \lambda \), Mask 3D effect gets significant.

Mask Structure Effect on Polarization

As pattern size on mask decreases to the level of \( \lambda \), specific polarization direction gets transmitted higher than others. Preferred polarization direction is different by different mask stacks used.
**Degree of Polarization (PSM vs. BIM)**

- Simulation w/ G-Solver
- Incident Angle 18° (1.35NA Immersion)

Oblique incidence gives different DOP behavior to normal incidence and 1st order diffraction is different from 0th order.

**Image Contrast considering Polarization**

Amplitude of 0th and 1st order diffracted light; $A_0$ and $A_1$

- Crosspole
  - $A_c = \left[ \text{Mag} \left| \text{cross-pole} \right| \right] = \left| 1 + \sqrt{T} \right| \left| \sin(\pi p) \right| / \pi$
  - $A_i = \left[ \text{Mag} \left| \text{in-order} \right| \right] = \left| 1 + \sqrt{T} \right| \left| \sin(\pi p) \right| / \pi$

- Dipole

$T$ : Transmittance of Pattern
$s$ : space size, $p$ : pitch size
$r$ : ratio of captured 1st order (1st order efficiency)

**Unpolarized Case** → Scalar model

- Contrast $= \frac{2rA_h A_i}{A_h^2 + rA_i^2}$

**Polarized Case** → Vector model

- **Crosspole**
  - Contrast $= \frac{2rA_h A_{1r} \cdot A_{1r}}{A_{1r}^2 + A_{1r}^2 + rA_{1r}^2}$

- **Dipole**
  - Contrast $= \frac{2rA_h A_{1r} \cdot A_{1r}}{A_{1r}^2 + rA_{1r}^2}$
### Experimental

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>ArF 1.35NA Immersion Scanner</td>
</tr>
<tr>
<td>Illumination</td>
<td>Crosspole and Dipole w/ Polarization</td>
</tr>
<tr>
<td>Resist</td>
<td>ArF 0.10 μm thickness on Organic BARC</td>
</tr>
<tr>
<td>Mask</td>
<td>6% Att.PSM and 3 Types of BIM</td>
</tr>
<tr>
<td>Simulation</td>
<td>HOST (Diffused Aerial Image Model) EM-Suite (rigorous EMF Simulation)</td>
</tr>
<tr>
<td>Pattern Size</td>
<td>38nm ~ 50nm Line &amp; Space</td>
</tr>
<tr>
<td></td>
<td>44nm DRAM Isolation &amp; Contact Hole Patterns</td>
</tr>
</tbody>
</table>

### Mask Structure for Experiment

- **(a) ArF Att.PSM**
  - Shifter (MoSi) : 680 Å

- **(b) Thick Cr BIM**
  - Cr : 1030 Å

- **(c) Thin Cr BIM**
  - Cr : 590 Å

- **(d) Multi Layer BIM**
  - Cr : 740 Å/MoSi : 930 Å
Image Contrast on Mask Bias

- 40nm Half Pitch
- 44nm Half Pitch
- 48nm Half Pitch

Simulation w/ EM-Suite (Panoramic)
N.A. / 1.35, λ / 193nm, Dipole Illumination

DOP for Mask Structure

- 0th Diffraction Order
- 1st Diffraction Order

First and zero diffraction order polarization are shown to be influenced by the structure of masking film.
As half-pitch of pattern decreased, NILS of MoSi decreases significantly while those of thick Cr and Multi layer BIM are not much varied.

Thick and thin Cr BIM show better MEF value than others. But MEF is not matched with NILS result in case of thin Cr BIM.
### Comparison of Exposure Latitude

- **L/S Pattern with Dipole 35° Illumination @ 1.35NA**

<table>
<thead>
<tr>
<th>Half Pitch</th>
<th>Att.PSM</th>
<th>Thick Cr BIM</th>
<th>Thin Cr BIM</th>
<th>Multi Layer BIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>40nm</td>
<td>14.7 %</td>
<td>17.4 %</td>
<td>13.2 %</td>
<td>13.3 %</td>
</tr>
<tr>
<td>44nm</td>
<td>15.0 %</td>
<td>18.2 %</td>
<td>17.5 %</td>
<td>16.8 %</td>
</tr>
<tr>
<td>48nm</td>
<td>14.5 %</td>
<td>18.4 %</td>
<td>18.8 %</td>
<td>17.6 %</td>
</tr>
</tbody>
</table>

### Comparison of DOF

- **L/S Pattern with Dipole 35° Illumination @ 1.35NA**

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<tr>
<th>Half Pitch</th>
<th>Att.PSM</th>
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<th>Thin Cr BIM</th>
<th>Multi Layer BIM</th>
</tr>
</thead>
<tbody>
<tr>
<td>40nm</td>
<td>0.15 μm</td>
<td>0.12 μm</td>
<td>0.08 μm</td>
<td>0.15 μm</td>
</tr>
<tr>
<td>44nm</td>
<td>0.12 μm</td>
<td>0.15 μm</td>
<td>0.15 μm</td>
<td>0.16 μm</td>
</tr>
<tr>
<td>48nm</td>
<td>0.08 μm</td>
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</table>
**SEM for L/S Pattern**

<table>
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<tr>
<th>38nm</th>
<th>40nm</th>
<th>44nm</th>
<th>48nm</th>
</tr>
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<td>Att.PSM</td>
<td>Thick Cr BIM</td>
<td>Thin Cr BIM</td>
<td>Multi Layer BIM</td>
</tr>
</tbody>
</table>

**DRAM Isolation Pattern**

**Crosspole Illumination @ 1.35NA 44nm Half Pitch Isolation Pattern**

<table>
<thead>
<tr>
<th>Mask Type</th>
<th>EL</th>
<th>DOF</th>
<th>Eop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Att.PSM</td>
<td>8.07 %</td>
<td>0.04 μm</td>
<td>43.21 mJ</td>
</tr>
<tr>
<td>Thick Cr BIM</td>
<td>6.66 %</td>
<td>0.06 μm</td>
<td>45.09 mJ</td>
</tr>
<tr>
<td>Thin Cr BIM</td>
<td>6.44 %</td>
<td>0.06 μm</td>
<td>44.46 mJ</td>
</tr>
<tr>
<td>Multi Layer BIM</td>
<td>15.37 %</td>
<td>0.04 μm</td>
<td>43.37 mJ</td>
</tr>
</tbody>
</table>

Similar dose to size for different mask structures contrary to 1D L/S means polarization dependent transmittance behavior is Different in 2D BW pattern. Peak EL in multilayer BIM needs to be examined again!
**Diffraction vs. Polarization in 2D BW**

Incidence angle 17°, 45nm Brick Wall pattern

In 2D BW pattern, att.PSM shows no TM preference to TE in 0th and even higher intensity of 1st order diffraction in TE polarization contrary to 1D L/S case while similar behavior in thin Cr Mask show

**DRAM Contact Hole Pattern**

Crosspole Illumination @ 1.35NA 44nm Half Pitch Hole Pattern

Similar E/L and dose to size for 2D contact array patterns regardless of mask structures except for eccentric low dose to size behavior in multi-layer BIM.
Pattern Fidelity for Contact Hole

Crosspole Illumination @ 1.35NA  44nm Half Pitch Hole Pattern

Pattern fidelity of the hole pattern is similar to all mask structure.

Pellicle Effect on Hyper NA

Transmittance of pellicle is changed by the incident angle according to NA. Thickness of pellicle should be optimized to minimize the transmission loss as NA gets higher.
**Experimental Verification for Pellicle Effect**

1.2NA, Dipole – Y Open Angle 90, 0.97/0.82 INNER/OUTER \( \sigma \), x-polarization

![Graph showing CD difference (nm) with and without pellicle](image)

- **Horizontal Pattern**
- **Vertical Pattern**

Pellicle can change optical proximity effect by transmittance change.

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**Summary**

- Technical issues of polarized illumination in hyper NA imaging were studied through experiment and simulation.
  - How much merit by Polarization on through pitch
  - Light interaction with mask structure is significant in Hyper NA
- Effect of 3D mask structure is studied through simulation and experiment.
  - 4 types of mask were made for this experiment such as att. PSM, Thick Cr BIM, Thin Cr BIM and multi layer BIM
  - The image contrast is strongly dependent on mask bias, need to be taken into account for comparison of att.PSM and BIM
  - BIM shows better performance than att.PSM below 44nm half pitch L/S pattern. But MEF is not matched well to simulation result because of incomplete optimization on mask bias.
  - In case of 2D pattern, it is difficult to find the advantage of BIM for sub-45nm. It needs further study for 2D pattern
  - Pellicle transmittance is changed by thin film interference effect and should be corrected through the optimization of pellicle thickness