Advanced Mask Inspection and Metrology

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*MIRAI – ASET(Association of Super- Advanced Electronics Technologies)

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Outline

• Introduction
• Requirements of photomask for resolution enhancement
• Defect inspection for photomask
• Metrology for Photomask
• Activity of Inspection for NGL mask
• Summary
• **Introduction**
• Requirements of photomask for resolution enhancement
• Defect inspection for photomask
• Metrology for Photomask
• Activity of Inspection for NGL mask
• Summary
Wavelength Gap

- Lithography wavelength
- Minimum feature size
- g-line
- i-line
- 555nm
- 488nm
- 364nm
- 257nm
- 266nm
- 198nm
- 257nm
- 198nm
- KrF
- ArF
- F2

Year:
- 1980
- 1990
- 2000
- 2010

Inspection wavelength 1
Inspection wavelength 2

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Quality specifications Items of photomask

Pattern film
Pellicle
Quartz Sub.

Binary mask
Pattern stricture
Cr
Quartz

Phase shift mask
Attenuated
MoSiON
Quartz
Phase shift (Deg) and Transparency (%)

Alternative
Cr
Quartz
Phase shift (Deg)

Defect
CD
# Roadmap for Photo Mask Technology

## ITRS - 2002 Update

### Optical Mask Requirements

<table>
<thead>
<tr>
<th>Year</th>
<th>Lithography technology</th>
<th>Magnification</th>
<th>Mask minimum image size (nm)</th>
<th>Mask OPC feature size (nm)</th>
<th>Image placement (nm, multi-point)</th>
<th>CD uniformity (nm, 3σ)</th>
<th>Defect size (nm)</th>
<th>Data volume (GB)</th>
<th>Mask design grid (nm)</th>
<th>Att. PSM trans. Mean dev. (+/-% target)</th>
<th>Att. PSM trans. Uniformity (+/-% target)</th>
<th>Att. PSM phase Mean dev. (+/-deg.)</th>
<th>ALT. PSM phase Mean dev. (+/-deg.)</th>
<th>ALT. PSM phase Uniformity (+/-deg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>Optical</td>
<td>4</td>
<td>360</td>
<td>180</td>
<td>27</td>
<td>7.4</td>
<td>104</td>
<td>64</td>
<td>8</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2003</td>
<td>Optical</td>
<td>4</td>
<td>260</td>
<td>130</td>
<td>21</td>
<td>5.1</td>
<td>80</td>
<td>144</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2004</td>
<td>Optical</td>
<td>4</td>
<td>212</td>
<td>106</td>
<td>19</td>
<td>4.2</td>
<td>72</td>
<td>216</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2006</td>
<td>Optical</td>
<td>4</td>
<td>160</td>
<td>80</td>
<td>15</td>
<td>3.4</td>
<td>56</td>
<td>486</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2007</td>
<td>Optical</td>
<td>4</td>
<td>140</td>
<td>70</td>
<td>14</td>
<td>2.5</td>
<td>52</td>
<td>729</td>
<td>729</td>
<td>729</td>
<td>729</td>
<td>729</td>
<td>729</td>
<td>729</td>
</tr>
</tbody>
</table>
• Introduction

• **Requirements of photomask for resolution enhancement**

• Defect inspection for photomask

• Metrology for Photomask

• Activity of Inspection for NGL mask

• Summary
Defect Printability as Defect Positions

• Defects in assist bar area shows low printability

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Effect of Contact Hole Size & Serif Variations

OPC helps defect printability

Serif defect itself is not so important
Increase of Aggressiveness in OPC Technology

- Rule Based → Model Based → Rule + Model Based
- Aggressive OPC is inevitable option in low k1 lithography
• Introduction
• Requirements of photomask for resolution enhancement

**Defect inspection for photomask**
• Metrology for Photomask
• Activity of Inspection for NGL mask
• Summary
## Revised Reticle Defect Size in ArF Lithography

<table>
<thead>
<tr>
<th>Year of Production</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100nm</td>
<td>90nm</td>
<td>80nm</td>
<td>70nm</td>
</tr>
<tr>
<td>Wafer minimum half pitch (nm)</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>Mask minimum image size (nm)</td>
<td>260</td>
<td>212</td>
<td>180</td>
<td>160</td>
</tr>
<tr>
<td>Mask OPC feature size (nm) Opaque</td>
<td>130</td>
<td>106</td>
<td>90</td>
<td>80</td>
</tr>
<tr>
<td>CD uniformity: Isolated lines (MPU gates) Binary</td>
<td>5.1</td>
<td>4.2</td>
<td>3.7</td>
<td>3.4</td>
</tr>
<tr>
<td>CD uniformity: Dense lines DRAM half pitch)</td>
<td>8.0</td>
<td>7.2</td>
<td>6.4</td>
<td>5.6</td>
</tr>
<tr>
<td>Defect size of ITRS (nm)</td>
<td>80</td>
<td>72</td>
<td>64</td>
<td>56</td>
</tr>
<tr>
<td>Cr dot (nm)</td>
<td>1:1 pitch</td>
<td>103</td>
<td>96</td>
<td>91</td>
</tr>
<tr>
<td>Cr extension (nm)</td>
<td>1:2 pitch</td>
<td>109</td>
<td>100</td>
<td>93</td>
</tr>
<tr>
<td>Oversize defect (nm)</td>
<td>1:1 pitch</td>
<td>80</td>
<td>76</td>
<td>65</td>
</tr>
<tr>
<td>Undersize defect (nm)</td>
<td>1:2 pitch</td>
<td>85</td>
<td>89</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>1:1 pitch</td>
<td>35</td>
<td>29</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>1:2 pitch</td>
<td>40</td>
<td>36</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>1:1 pitch</td>
<td>25</td>
<td>21</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>1:2 pitch</td>
<td>30</td>
<td>27</td>
<td>23</td>
</tr>
</tbody>
</table>
Inspection Image in Various Wavelength

<table>
<thead>
<tr>
<th>Mask apertures</th>
<th>Detected images</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>364nm</td>
</tr>
<tr>
<td></td>
<td>266nm</td>
</tr>
<tr>
<td></td>
<td>198nm</td>
</tr>
</tbody>
</table>

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Requirement of mask defect inspection

Inspection wavelength

Mask defect sensitivity

Sensor

Source

Optics

Mask

Optics

Image

Sensor

Lithography

KrF

ArF

F2

EUV

EPL

Dimension (nm)

Technology node (nm)

266 nm, 257 nm

200 nm

160 nm

13 nm

KrF ArF F2 EUV

EPL EBDW

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# Requirements and Issues for Photomask Inspection

<table>
<thead>
<tr>
<th>Technology node</th>
<th>130 nm</th>
<th>90 nm</th>
<th>65 nm</th>
<th>45 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection sensitivity (D) *</td>
<td>104 nm</td>
<td>72 nm</td>
<td>52 nm</td>
<td>35 nm</td>
</tr>
<tr>
<td>Inspection wavelength (l)</td>
<td>257 nm</td>
<td>365 nm</td>
<td>257 nm</td>
<td>200 nm</td>
</tr>
<tr>
<td>Numerical Aperture</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Nominal resolution (R) **</td>
<td>209 nm</td>
<td>296 nm</td>
<td>209 nm</td>
<td>163 nm</td>
</tr>
<tr>
<td>Ratio of sensitivity and resolution (D/R)</td>
<td>0.5</td>
<td>0.35</td>
<td>0.34</td>
<td>0.32</td>
</tr>
</tbody>
</table>

*Minimum defect size which can be detected

**Rayleigh Limit : 0.61 l /NA
266nm wavelength Defect Inspection Tool

- Development by joint with Selete and NEC

Target Spec.

- Defect Sensitivity: 80nm
- Inspection mode: Die-Die, Die-Data
- Inspection Optical: 2 Beams Scan
- Inspection Wavelength: 266nm

Present Progress Data

<table>
<thead>
<tr>
<th>Defect type</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75nm</td>
</tr>
<tr>
<td></td>
<td>70nm</td>
</tr>
<tr>
<td></td>
<td>70nm</td>
</tr>
<tr>
<td></td>
<td>60nm</td>
</tr>
</tbody>
</table>
Development of 198.5nm laser for mask inspection tool

1064 nm laser → 1064nm resonant cavity → 198.5nm

CLBO

(a) Optical schematic of sum-frequency generation cavity

(b) Experimental Set up

(c) 50 mW power

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# Deep UV sensitive CCD Architecture

<table>
<thead>
<tr>
<th>Phosphor Coating</th>
<th>Virtual Phase</th>
<th>Poly Hole Gate</th>
<th>Backside Illumination</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Phosphor Coating Diagram" /></td>
<td><img src="image2.png" alt="Virtual Phase Diagram" /></td>
<td><img src="image3.png" alt="Poly Hole Gate Diagram" /></td>
<td><img src="image4.png" alt="Backside Illumination Diagram" /></td>
</tr>
<tr>
<td>UV light down converts UV light to visible light by phosphor</td>
<td>Substitute poly gate with virtual gate</td>
<td>Make hole in poly gate which absorbs UV light</td>
<td>Illuminate from the backside of CCD thinned to about 10µm</td>
</tr>
</tbody>
</table>

**Legend:**
- UV light
- Visible light
- Poly gate
- Virtual gate
- Hole
- Potential

**Note:**
- CCD thinned to about 10µm
- Poly gate thickness 10µm
- UV light illumination from the backside
Development of 198.5nm wavelength mask inspection tool

- Joint development with Selete, NEC and Toshiba
- Development of new platform system for 65nm node

Target Spec.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Defect Sensitivity</td>
<td>60nm</td>
</tr>
<tr>
<td>Inspection mode</td>
<td>Die-Die, Die-Data</td>
</tr>
<tr>
<td>Inspection Optical</td>
<td>Projection</td>
</tr>
<tr>
<td>Inspection Wavelength</td>
<td>198.5nm</td>
</tr>
</tbody>
</table>
• Introduction
• Requirements of photomask for resolution enhancement
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**Metrology for Photomask**

• Activity of Inspection for NGL mask
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# Requirements and Issues for Photomask Metrology

<table>
<thead>
<tr>
<th>Year of production</th>
<th>2003 100 nm</th>
<th>2004 90 nm</th>
<th>2007 65 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mask minimum image size (at 4X, nm)</td>
<td>260</td>
<td>220</td>
<td>160</td>
</tr>
<tr>
<td>Minimum OPC size (opaque 4X, nm)</td>
<td>130</td>
<td>110</td>
<td>80</td>
</tr>
<tr>
<td>Mask image placement technology</td>
<td>21</td>
<td>19</td>
<td>16</td>
</tr>
<tr>
<td>Mask CD metrology tool precision (P/T=0.2 for isolated lines, binary)</td>
<td>1.3</td>
<td>1.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Mask CD metrology tool precision (P/T=0.2 for isolated lines, alternated)</td>
<td>1.75</td>
<td>1.6</td>
<td>1.15</td>
</tr>
<tr>
<td>Mask CD metrology tool precision (P/T=0.2 for dense lines, binary)</td>
<td>1.6</td>
<td>1.45</td>
<td>0.85</td>
</tr>
<tr>
<td>Mask CD metrology tool precision (P/T=0.2 for contact/vias)</td>
<td>1.2</td>
<td>1.05</td>
<td>0.65</td>
</tr>
<tr>
<td>Phase metrology precision (P/T=0.2)</td>
<td>0.4</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>
157nm Wavelength Aerial Image Measurement System
Zeiss AIMS157

AIMS157 beta-tool
157nm Wavelength Mask Phase Measurement

Lasertec MPM157

Att. PSM

Quartz

Wavelength: 157.6nm

I₀

I

P₀

P

Alt. PSM

Cr Oxide/Metal Cr

Quartz

P₀

P

Phase Sift = P - P₀, \[ T\% = \frac{I}{I₀} \]

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• **Activity of Inspection for NGL mask**
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EPL mask defect inspection

<table>
<thead>
<tr>
<th>Magnification</th>
<th>Photo mask</th>
<th>EPL Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 x</td>
<td>4 x</td>
<td></td>
</tr>
</tbody>
</table>

| Pattern Thickness | 100 nm | 2000 nm |

| Pattern Aspect Ratio * | Low (0.5) | High (7) |

| Structure | 2 Dimensional | 3 Dimensional |

| Substrate | Thick and Firm | Thin and Fragile |

| Pattern Material | Metal (Cr) | Si |

| Pattern Support | Exist (Quartz) | None (Strut) |

*: 260nm (4x)
Inspection image for EPL mask
(Optical vs SEM)

Reflection
Transmission
Transmission

DUV Optical Microscope (Wavelength : 266nm)
SEM (HOLON EST-100)
**EB inspection system for EPL mask**

**EB Scanner**

- Signal Processing Unit
- Control Unit
- Image Processing Unit
- TDI CCD Sensor
- Stage Drive
- Electron Gun
- Mask
- Projection Optics
- Illumination Optics
- EB Column (Projection)
- High Speed Camera
- Mask Stage
- Stage
- Mask
- E-Beam Column (Illumination)

**Machine Specification**

<table>
<thead>
<tr>
<th></th>
<th>Stencil mask</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mask</strong></td>
<td>Stencil mask</td>
</tr>
<tr>
<td><strong>Scan</strong></td>
<td>Stage Scan</td>
</tr>
<tr>
<td><strong>Alignment</strong></td>
<td>Optical &amp; EB</td>
</tr>
<tr>
<td><strong>Mask Loading</strong></td>
<td>Palette</td>
</tr>
<tr>
<td><strong>Inspection Mode</strong></td>
<td>Die to Database &amp; Die to Die</td>
</tr>
<tr>
<td><strong>Pixel Size</strong></td>
<td>50 nm</td>
</tr>
<tr>
<td><strong>Acceleration Voltage</strong></td>
<td>5 kV</td>
</tr>
<tr>
<td><strong>Throughput</strong></td>
<td>4.6 h (200-nm EPL mask)</td>
</tr>
</tbody>
</table>
TDI-CCD Image with EB inspection system

70-nm node logic pattern

Design: 280 nm on mask
TDI-CCD Image with EB inspection system

100-nm node DRAM pattern

Design: 360 nm on mask
EUV mask & process

1: Substrate clean

2: Multilayer (Si/Mo) Deposition

3: Buffer layer / Absorber layer Deposition

EUV microscope, EUV defect detection tool?

4: Pattern Write / Absorber etch

EUV Aim

5: Repair / Buffer layer etch

Possible market for actinic (at-wavelength) inspection
EUV mask phase defect inspection

- LPP EUV source
- Schwarzschild Optics
- Dark field imaging
- Mask blanks
- CCD

Defect size (nm)
- 02 0 4 0 6 0 8 00

Defect height (nm)
- Dense lines
- Isolated lines
- Non-critical
- Critical

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Summary

- The minimum feature size of ULSI devices becomes smaller than wavelength of exposure light used in optical lithography.

- The mask technology such as OPC and PSM with the current large NA projection exposure tool provides the fine features with approximately a half of exposure wavelength. Since a mask is the original edition of semiconductor patterns, precise control of the mask aperture size becomes critical.

- The requirements of mask pattern defects also becomes critical. In order to achieve the higher defect sensitivity, the defect inspection tools with UV(266nm) / DUV(198nm) laser are developed.

- CW-deep UV laser source for mask inspection tool has been developed.

- As 157nm mask metrology tool, aerial image monitor tool and phase measurement tool are developed.

- Inspection technologies for EPL and EUVL mask are under development.
  - EPL mask: EB imaging system
  - EUV mask: At-wavelength phase defect detection system.