FCMN 2013: Metrology Tools for Photo Mask Repair and Mask Performance Improvement

Klaus Edinger Carl Zeiss SMS
March 28th, 2013
Lithography Roadmap & Key Mask Challenges

Resolution, "Shrink" (nm)

Year

'02 '03 '04 '05 '06 '07 '08 '09 '10 '11 '12 '13 '14 '15

DRAM Logic NAND Flash

Advanced Repair Technology

Actinic/193nm Metrology & Mask Tuning

AIMS™ EUV & advanced Repair

Photomask error budget
Carl Zeiss „Perfect Mask Solutions“

- **Design**
- **Patterning**
- **Metrology**
- **Tuning**
- **Inspection**
- **Repair**
- **Verification**
- **Cleaning**

**In-die Metrology**
Perfect image placement, CD & phase measurement

**Mask Tuning**
Improve registration, overlay and CD performance

**Zero Defect Solutions**
High precision repair and actinic repair verification

- **PROVE**
- **RegC**
- **MeRiT**
- **AIMS™**
Motivation

The current and the near future registration specs are very challenging for mask manufacturers.

Emphasized with the appearance of the Double Patterning (DP) techniques.

### ITRS 2011 – Optical mask requirements

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>DRAM ½ pitch (nm)</td>
<td>36</td>
<td>32</td>
<td>28</td>
<td>25</td>
<td>23</td>
<td>20</td>
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<tr>
<td>Flash ½ pitch (nm)</td>
<td>22</td>
<td>20</td>
<td>18</td>
<td>17</td>
<td>15</td>
<td>14</td>
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<tr>
<td>MPU/ASIC Metal 1(M1) ½ pitch (nm)</td>
<td>38</td>
<td>32</td>
<td>27</td>
<td>24</td>
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**Generic Mask Requirements**

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<tbody>
<tr>
<td>Mask minimum primary feature size</td>
<td>99</td>
<td>88</td>
<td>80</td>
<td>80</td>
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<tr>
<td>CDU isolated lines (nm 3S)</td>
<td>2.3</td>
<td>2.1</td>
<td>1.7</td>
<td>1.5</td>
<td>1.2</td>
<td>1.1</td>
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<tr>
<td>CDU dense lines (nm 3S)</td>
<td>3.0</td>
<td>2.4</td>
<td>1.9</td>
<td>1.5</td>
<td>1.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Image placement* (S/O removed)</td>
<td>4.3</td>
<td>3.8</td>
<td>3.4</td>
<td>3.0</td>
<td>2.7</td>
<td>2.4</td>
</tr>
<tr>
<td>Image placement for double patterning* (S/O removed) **</td>
<td>3.4</td>
<td>3.0</td>
<td>2.7</td>
<td>2.4</td>
<td>2.1</td>
<td>1.9</td>
</tr>
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* Not including pellicle induced errors  
* *ITRS 2010
PROVE®

Tool Overview

Horizontal purge concept with separated zones

Advanced damping concept

External handling area, (SMIF pod)

System electronics

193 nm Laser

Illuminator for reflection

Homogenizer and illuminator for transmission

Precision stage
Flexible illumination for transmission or reflection

Imaging optics $\lambda=193\text{nm}$, NA=0.60, pellicle compatible

Stage actively controlled in 6 dof, ultra precise stage metrology system

Autofocus system

CCD camera

Image processing

Auxiliary optics for coarse alignment

Reticle (face-up)
RegC® Process Concept

- Deformation of the mask bulk on the level of few PPM’s is done by writing special deformation elements utilizing ultra short laser pulses.
- Calibration of the deformation magnitude and direction is done with a special in situ metrology system that determines the induced deformation properties.
RegC® target: Bring all registration errors to a correctable systematic field.

- The RegC® algorithm allows to simulate the best correctable field.
- The RegC® process generates local deformations to compensate for local registration errors.
- The errors magnitude is increased but all are correctable by the scanner.
- After scanner S/O removal the residual registration will be minimized.
Utilizing the full mask area, including the exposure field increases the RegC® efficiency.

By writing RegC® with two modes it is possible to maintain a constant attenuation across the exposure field and thereby maintaining CDU.

Step 1, X-axis + Step 2, Y-axis = Sum of steps 1&2

Transmission uniformity in the exposure field is maintained >> CDU unchanged

Exposure Field
Fixed light attenuation
104 X 132 mm
RegC® CDU Neutral – Results

Pre RegC® Scale/Ortho removed

Post RegC® Scale/Ortho removed

Systematic residuals

Reduced systematic residuals

<table>
<thead>
<tr>
<th>3S (S/O removed)</th>
<th>Improvement</th>
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<tbody>
<tr>
<td>Pre [nm]</td>
<td>Post [nm]</td>
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<tr>
<td>X</td>
<td>8.21</td>
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<tr>
<td>Y</td>
<td>8.55</td>
</tr>
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Enables double patterning specifications !!!
Mask Metrology: WLCD – CD Metrology based on proven Aerial Image Technology

- WLCD is based on proven Aerial Image Technology
- WLCD measures under the same conditions as the scanner
- WLCD captures OPC and optical MEEF effects
- Simplifies measurement for complex 2D features
- FreeForm Illumination supports SMO technology
- Applied illumination conditions: same as for wafer print

Equivalent image formation for Scanner and WLCD
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**PROVE®**

**RegC®**

**MeRiT®**

**AIMS™**

**WLCD**

**CDC**
Focused electron beam based mask repair

Real defect

Repair shape(s)

→ Computer-assisted shape generation, modification and placement
Electron beam induced deposition and etching

Adsorption of precursor molecules:

- Exposure with electron beam
- Reaction and immobilization of precursor $\Rightarrow$ **Deposition**
- Reaction with substrate and volatilization $\Rightarrow$ **Etching**
State-of-the-art achievements with the MeRiT

Statistics over 2 months at a customer’s site:
• 74% yield on 1st attempt;
• 24% increase on further attempts

A. Garetto et al., Proc. SPIE (2009)
Optical repair qualification by aerial imaging

No wafer stepper in the mask-shop

→ 193 nm CCD exposure with „Aerial Imaging Metrology System“ (AIMSTM)

→ Detailed phase & intensity information on 10 x 10 µm areas
AIMS: Process window evaluation
EUV absorber e-beam repair
25 nm real defects

<table>
<thead>
<tr>
<th>Mask SEM</th>
<th>NXE: 3100</th>
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<tr>
<td><img src="image1" alt="Mask SEM 1" /></td>
<td><img src="image2" alt="NXE: 3100 1" /></td>
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<tr>
<td><img src="image3" alt="Mask SEM 2" /></td>
<td><img src="image4" alt="NXE: 3100 2" /></td>
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<tr>
<td><img src="image5" alt="Mask SEM 3" /></td>
<td><img src="image6" alt="NXE: 3100 3" /></td>
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<tr>
<td><img src="image1" alt="Mask SEM 1" /></td>
<td><img src="image2" alt="NXE: 3100 1" /></td>
<td>Complex OK</td>
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<tr>
<td><img src="image3" alt="Mask SEM 2" /></td>
<td><img src="image4" alt="NXE: 3100 2" /></td>
<td>Half height OK</td>
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<tr>
<td><img src="image5" alt="Mask SEM 3" /></td>
<td><img src="image6" alt="NXE: 3100 3" /></td>
<td>Multiline OK</td>
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→ Repair success on real defects validated on NXE:3100 scanner
EUV multilayer defect

Cross-sectional profile

Simulated aerial image

Dose to size
EUV multilayer defect
Compensational repair simulation

LS pattern with bump

Aerial image

Line
Space
Distorsion

Dose to size
EUV multilayer defect
Compensational repair simulation

LS pattern with bump

Aerial image

Line Space Distorsion

Dose to size
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Note: Printability of ML defects is strongly focus dependent
EUV multilayer defect

ML bump: reticle cross-section

Simulated aerial image

SEM
5 nm „bump”

SEM
3 nm „pit“

→ Problem: Many mirror distortions that print are invisible in SEM!
EUV multilayer defect: Detection by integrated AFM

ML bump: reticle cross-section

Simulated aerial image

But: All ML defects found so far by wafer printing could be successfully visualized by AFM!
Integrated AFM system

- Dual head AFM system
  - Faster turnaround since mask stays in vacuum
  - Closed loop with repair software

- Automated tip exchange system
  - Tip exchange < 120 min

- Applications
  - Fast process tuning
  - 3D defect repair shape generation
  - EUV compensational repair
Compensational repair: “Bump defect”

AFM: 3 nm „bump“

Compensated

SEM

BF -100 nm  BF -50 nm  BF  BF +50 nm  BF +100 nm

Wafer before repair

Wafer after repair

40 nm HP performed on the ASML Alpha Demo Tool
Compensational repair: „Pit defect“

Propagating ML pit simulation

Through-focus ML pit compensation repair (see R. Jonckheere et al., Proc. SPIE 8166, 81661G (2011))
The extension of optical lithography has strongly increased the demands on advanced photo masks

Carl Zeiss SMS has developed dedicated tools sets to improve photo mask registration, overlay and CD uniformity based on femto second laser writing in two closed loop applications with registration and wafer level CD measurements.

MeRiT® e-beam mask repair ready for 32 nm, 27nm and 25nm EUV absorber defects

MeRiT® e-beam mask repair is capable for ML defect repair utilizing data of an integrated AFM for placement and compensational shape generation

Compensational repair has its limits. Defect reduction during blank manufacturing is strongly recommended
We make it visible.