Electron Multi-Beam Technology for Mask and Wafer Direct Write

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IMS Nanofabrication AG

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Contents

- Motivation for Multi-Beam Mask Writer (MBMW)
- MBMW Tool Principles and Architecture
- MBMW Performance
- MBMW Roadmap
- Multi-Beam Technology for Wafer Direct Write
- Conclusions
The Mask Writer: Key for the SC Industry

Sources:
Gartner / EETimes July 8, 2015
Semico Research / EETimes July 6, 2015
SEMI / EETimes April 14, 2015

Semiconductor Market
$348B

Semiconductor Equipment Market
$68B

Photomask Market
$3.3B

Mask Writer Market
$0.5B → $1B
## Increasing Mask Pattern Complexity

<table>
<thead>
<tr>
<th>Optical Proximity Correction</th>
<th>Inverse Lithography Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 nm node without OPC</td>
<td>14 nm node normal ILT</td>
</tr>
<tr>
<td>28 nm node normal OPC</td>
<td>7 nm node ideal ILT</td>
</tr>
</tbody>
</table>

Source: adopted from Jin Choi et al., Samsung, Photomask Japan 2009
Dramatically increased shot number

Using 193i (193nm immersion) optical lithography for sub-20nm nodes, there is the need to realize strong OPC mask patterns, thus achieving improved DOF (Depth of Focus) for Silicon wafer exposures.

For the 14nm technology node, and below, there is the need to implement Inverse Lithography Technology (ILT), starting from the desired pattern on the wafer and calculating the mask pattern as needed.

Electron VSB (Variable Shaped Beam) mask writers suffer from mask write time explosion, in particular for 10nm and 7nm nodes, and below.
Demand: < 1 day Mask Write Time

**VSB**
Variable Shaped Beam mask writer
one beam of variable shape

- # shots  
- Average shot size  
- Exposure Dose

⇒ Use of multi-beam solution is mandatory for future nodes!

**MBMW**
Multi-Beam Mask Writer
262-thousand programmable beams of equal small shape

- Small Beam Shape: 20nm, 10nm  
- Designed for high resist dose to ensure small line edge roughness  
- Write time independent of pattern complexity, incl. Non-Manhattan curvilinear patterns
Multi-Beam Mask Writer: needed for 193i, EUV, imprint and DSA lithography

- Photomasks with strong OPC and non-Manhattan curvilinear ILT patterns are needed for 193nm immersion lithography (193i) at 10nm and 7nm nodes, and below.

- Complex masks with very high data volume are needed for 13.5nm based Extreme Ultra-Violet Lithography (EUVL) at 7nm and 5nm nodes, and below.

- Master templates with 1:1 patterns with very low line edge roughness are needed for nano-imprint lithography (NIL).

- Masks with precise curvilinear guiding patterns are needed for Directed Self-Assembly (DSA) nanofabrication.
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MBMW Tool Principles

APS
programmable Aperture Plate System

Electrostatic Multi-Electrode Accelerating Lens
1st Magnetic Lens
Stopping Plate at 2nd Cross-Over
Beam Steering Multipole
2nd Magnetic Lens

Electron Source
Electrostatic Multi-Electrode Condenser Optics

Aperture Array Plate
Deflection Array Plate with integrated CMOS electronics

Projection Optics with 200x reduction
Deflected beams filtered out at Stopping Plate

resist coated 6" Mask Blank

Scanning Stage
IMS production facility
at Brunn am Gebirge, near border of Vienna, Austria

- 450 m² clean room area, 550 m² presently being added
Multi-Beam Mask Writer Alpha Tool

Multi-Beam Column on air-bearing Stage Platform
1st full field mask exposure (Feb 2014)

Exposure of 128mm x 104mm field on 6” mask blank (scanning stage)

- Stripe length: 128 mm
- Stripe width: 80 µm
- # of stripes: 1300
- Stage velocity: 3.5 mm/s

⇒ Write time: 13.2 h

30nm ILT
## Multi-Beam Mask Writer Corrections

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PEC</strong> Proximity Effect Corrections</td>
<td>fully implemented</td>
</tr>
<tr>
<td><strong>FEC</strong> Fogging Effect Corrections</td>
<td>fully implemented</td>
</tr>
<tr>
<td><strong>LEC</strong> Loading Effect Corrections</td>
<td>fully implemented</td>
</tr>
<tr>
<td><strong>GMC</strong> Grid Matching Corrections</td>
<td>fully implemented</td>
</tr>
<tr>
<td><strong>GCD</strong> Global CD Corrections</td>
<td>fully implemented</td>
</tr>
<tr>
<td><strong>CEC</strong> Charging Effect Corrections</td>
<td>available, tests ongoing</td>
</tr>
<tr>
<td>Defective Beam Corrections</td>
<td>fully implemented</td>
</tr>
<tr>
<td>Stripe Butting Corrections</td>
<td>fully implemented</td>
</tr>
<tr>
<td>Drift Corrections (auto calibration)</td>
<td>fully implemented</td>
</tr>
<tr>
<td>More…</td>
<td></td>
</tr>
</tbody>
</table>
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MBMW exposure in negative resist

32nm half-pitch & iso line
nCAR (negative chemically amplified resist)
exposure dose: 80 µC/cm²

with multi-beam proximity effect and fogging effect corrections
MBMW exposure in positive resist

32nm & 30nm half-pitch & iso lines
pCAR (positive chemically amplified resist)
exposure dose: 100 µC/cm²

24nm iso line
in Non-CAR (ZEP520A)
exposure dose: 170 µC/cm²

etched into MoSi
## Multi-Beam Mask Writer Performance

### Important Parameters:

<table>
<thead>
<tr>
<th>Metric</th>
<th>Explanation</th>
<th>Status Aug 2015</th>
<th>ITRS Roadmap: needed for 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mask minimum Primary Feature Size</td>
<td>Resolution lines and spaces</td>
<td>30 nm</td>
<td>44 nm</td>
</tr>
<tr>
<td>LCDU 3sigma</td>
<td>Local (beam array field) Critical Dimension Uniformity</td>
<td>0.6 nm</td>
<td></td>
</tr>
<tr>
<td>GCDU 3sigma</td>
<td>Global (130mm x 130mm) Critical Dimension Uniformity</td>
<td>1.1 nm</td>
<td>1.8 nm</td>
</tr>
<tr>
<td>Local Registration 3sigma</td>
<td>Local (beam array field) Placement Accuracy</td>
<td>0.9 nm</td>
<td></td>
</tr>
<tr>
<td>Global Registration 3sigma (wo scale &amp; ortho)</td>
<td>Global (130mm x 130mm) Placement Accuracy</td>
<td>1.5 nm</td>
<td>2.2 nm</td>
</tr>
</tbody>
</table>
1.5nm 3sigma Registration Repeatability

3 pattern runs on same plate

Run 1 vs. Run 2

\[
\begin{array}{cc}
\text{Mean} & \text{Max 3 S.D.} \\
X \text{ } \text{[nm]} & 0.00 & 1.99 \\
Y \text{ } \text{[nm]} & -0.00 & 1.82
\end{array}
\]

Run 1 vs. Run 3

\[
\begin{array}{cc}
\text{Mean} & \text{Max 3 S.D.} \\
X \text{ } \text{[nm]} & -0.00 & 1.50 \\
Y \text{ } \text{[nm]} & 0.00 & 1.50
\end{array}
\]

Run 2 vs. Run 3

\[
\begin{array}{cc}
\text{Mean} & \text{Max 3 S.D.} \\
X \text{ } \text{[nm]} & -0.00 & 1.33 \\
Y \text{ } \text{[nm]} & 0.00 & 1.34
\end{array}
\]

\(\text{X: 1.4nm / Y: 1.5nm 3sigma}\)

\(\text{X: 1.5nm / Y: 1.5nm 3sigma}\)

\(\text{X: 1.3nm / Y: 1.3nm 3sigma}\)

measured on KLA-Tencor IPRO5
< 1nm 3sigma 10h-run Beam-Stability

- In-situ beam position measurement every 2min
- no repositioning

<table>
<thead>
<tr>
<th>@ 10 hours</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>3sigma Drift</td>
<td>0.54 nm</td>
<td>0.75 nm</td>
</tr>
</tbody>
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# Multi-Beam Mask Writer Roadmap

<table>
<thead>
<tr>
<th></th>
<th>POC</th>
<th>ALPHA</th>
<th>BETA</th>
<th>HVM</th>
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</thead>
<tbody>
<tr>
<td>Test 7nm Logic (11nm HP)</td>
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<tr>
<td>7nm Logic (11nm HP)</td>
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<tr>
<td>7nm Logic (11nm HP)</td>
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<tr>
<td><strong>Beam Array Field</strong></td>
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<tr>
<td>82µm x 82µm</td>
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<tr>
<td>82µm x 82µm</td>
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<tr>
<td><strong># programmable Beams</strong></td>
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<tr>
<td>262,144 (512 x 512)</td>
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<td>262,144 (512 x 512)</td>
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<tr>
<td>262,144 (512 x 512)</td>
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<td></td>
</tr>
<tr>
<td><strong>max Current (all beams “on”)</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>0.1 µA</td>
<td></td>
<td>0.1 - 0.25 µA</td>
<td>0.25 - 1 µA</td>
<td>1 µA</td>
</tr>
<tr>
<td>IMS platform with Philips piezo test stage</td>
<td></td>
<td>JEOL platform with air-bearing vacuum stage</td>
<td>JEOL platform with air-bearing vacuum stage</td>
<td>JEOL platform with air-bearing vacuum stage</td>
</tr>
<tr>
<td><strong>6” Mask Platform</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Mask Write Time (Dose ≥ 100 µC/cm²)</td>
<td></td>
<td>15h / mask (*)</td>
<td>10h / mask</td>
<td>10h / mask</td>
</tr>
<tr>
<td>10 cm²/h</td>
<td></td>
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(*) area 128mmx104mm
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Multi-Beam Direct Write: 100-200 WPH

Small Diameter Column

Multi-Axis Multi-Beam Direct Write Tool

Cluster of Multiple Multi-Axis Direct Write Tools

3 µA

150 µA

1.5 - 3 mA (all beams “on“)

谔 Technical Potential: Realization needs high investments and substantial efforts!
Multi-Beam Direct Write Tool Concept

49 Sub-Columns to write 98 Die Fields on a 300 mm Wafer

One Sub-Column to write two 26mm x 33mm Die Fields:
Wafer Movement < ± 35 mm

Small Diameter Sub-Column

26mm x 33mm Die Field

TPT incl. 25% overheads 5 - 10 WPH
Conclusions

- The overall writing architecture works well – **multi-beam is real**!

- The multi-beam mask writer lithography results obtained so far look promising, further improvements are in progress.

- Beam and platform stability are generally good, more automation will help user friendliness and fab integration.

- The main advantages of the multi-beam mask writer come from complex patterns, small feature sizes, and high dose.

- Using 10nm beam size, there is the potential to adapt the IMS multi-beam technology for wafer direct write applications.
The world’s 1st Electron Multi-Beam Mask Writer

30nm HP & iso

pCAR 100 μC/cm²

Thank You for Your Attention!