Use of Cross-Platform Metrology Techniques to Investigate the Marvell Nanofabrication Laboratory Etch Quality Monitoring Program

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Outline

• Goals and Objectives
• Plan of Action
• Process Flow and Data
  ▫ Quantifying Measurement Error in Metrology Tools
  ▫ Inspect new Quality Monitoring Etch Mask
  ▫ Implement Quality Monitoring
• Conclusions
• Acknowledgements
Goal and Objectives

• To implement the new Quality Monitor Etch Mask into the Quality Monitor Program
  1. Characterize measurement error in selected metrology tools
  2. Inspect new Etch Mask and validate subsequent photolithography processes
  3. Characterize thin film etch rates and selectivity to photoresist
Plan of Action

1. Quantify Measurement Error
   - Measure standards on selected metrology tools

2. Inspect Etch Mask
   - Characterize elbow and checkerboard features

3. Implement Quality Monitoring
   - Photolithography and etching of SiO$_2$, Al/SiO$_2$, Al/Si$_3$N$_4$, and PolySi
Selected Metrology Tools

- olympus
- keyence
- linewidth1
- nanospec
- nanoduv
- ellipsometer
- dektak

- Measured each pitch (consisting of a space and a line) on 3 VLSI Standards at 5 different locations and found the average
  - Completed on olympus, keyence, linewidth1

\[
\text{percent error} = \left| \frac{\text{measured} - \text{actual}}{\text{actual}} \right| \times 100\%
\]
<table>
<thead>
<tr>
<th>Standard Used</th>
<th>Pitch (µm)</th>
<th>Keyence</th>
<th>Olympus</th>
<th>Linewidth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VLSI Standard 1</td>
<td>10</td>
<td>2.52%</td>
<td>0.430%</td>
<td>0.640%</td>
</tr>
<tr>
<td>Step Height =</td>
<td>20</td>
<td>1.32%</td>
<td>0.425%</td>
<td>0.624%</td>
</tr>
<tr>
<td>9325 Å</td>
<td>50</td>
<td>1.92%</td>
<td>0.523%</td>
<td>0.516%</td>
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<tr>
<td></td>
<td>100</td>
<td>1.56%</td>
<td>0.419%</td>
<td>0.167%</td>
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<tr>
<td>VLSI Standard 2</td>
<td>5</td>
<td>2.00%</td>
<td>0.420%</td>
<td>1.644%</td>
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<tr>
<td>Step Height =</td>
<td>10</td>
<td>3.26%</td>
<td>0.430%</td>
<td>0.640%</td>
</tr>
<tr>
<td>2999 Å</td>
<td>20</td>
<td>1.43%</td>
<td>0.425%</td>
<td>0.632%</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.54%</td>
<td>0.749%</td>
<td>0.274%</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>1.72%</td>
<td>0.454%</td>
<td>0.318%</td>
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<tr>
<td>VLSI Standard 3</td>
<td>10</td>
<td>2.12%</td>
<td>0.430%</td>
<td>0.640%</td>
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<td>Step Height =</td>
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<td>2.09%</td>
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<tr>
<td>502 Å</td>
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<td>0.70%</td>
<td>0.426%</td>
<td>0.134%</td>
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<tr>
<td></td>
<td>100</td>
<td>1.03%</td>
<td>0.203%</td>
<td>0.135%</td>
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# Measurement Challenges

<table>
<thead>
<tr>
<th>Device</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Olympus (100x obj, 1x zoom)</td>
<td>±0.126 µm</td>
</tr>
<tr>
<td>Keyence (1000x)</td>
<td>±0.19 µm</td>
</tr>
<tr>
<td>Linewidth1 (50x obj)</td>
<td>±0.105 µm</td>
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</tbody>
</table>
Optimizing Olympus Measurements

• Intensity or Height?

VLSI Standard – Step Height 2999 Å
5 µm Pitch
Olympus – 100x obj 1x zoom
Summary: Measurement Error

• Made 2650 measurements and got qualified on 7 tools
• Best tool for line width measurements: **olympus** – measurement error < 1.6%
  ▫ Olympus does have trouble measuring photoresist
  ▫ Intensity is *generally* better for measurements, but in some cases, height works just as well (or better)
• **linewidth1** – measurement error < 2.2%
  ▫ Camera resolution is poor, hard to ascertain exactly where edges of features being measured are
• **keyence** – measurement error < 3.3%
  ▫ Easy to use
2. Inspect Quality Etch Mask

- Characterize mask by measuring elbows in 8 locations with keyence, linewidth, and olympus.
Inspect Quality Etch Mask

Mask Elbows (Clear Field Mask) - Olympus

![Graph showing the relationship between Actual CAD Width (µm) and Average Measured Width (µm) with data points for Vertical Lines, Vertical Spaces, Horizontal Lines, and Horizontal Spaces.](image-url)
Inspect Quality Etch Mask

Mask Elbows (Clear Field Mask) - Keyence

Average Measured Width (µm)

Actual CAD Width (µm)

- Vertical Lines
- Vertical Spaces
- Horizontal Lines
- Horizontal Spaces
Summary: Mask Validation

- The pattern generator had difficulty rendering small features
  - Elbow features from 2.5 µm – 12.5 µm did not resolve well
    - 7 - 25% different than CAD design
    - Features can be improved with pattern generator calibration
  - Elbow features bigger than 25 µm turned out better
    - 1 – 3% different than CAD design
3. Implement Quality Monitoring

- Measured film of interest thickness, elbow line widths, and step height
  - Measured wafers before photolithography, post-etch with resist, and post-etch with resist stripped
**Process Flow**

- **svgcoat6**: Rohm Hass positive UV210-0.6 (DUV resist) - Program 2 - 9000 Å thick resist, spin speed = 1480 rpm
  - Soft bake: Program 1 - 130 °C, 60 sec
- **uvbake**: Program U
- **lam6**: 60 second etch, using program 6001_oxide_me
- **lam7**: 25 second etch, using program staff_7001_al_me
- **lam8**: 30 second etch, using program 8001_poly_me

Completed on four different samples:

- **4810 Å Poly Si**
  - SiO₂
  - Si

- **9430 Å SiO₂**
  - Si

- **~4000 Å Al**
  - SiO₂
  - Si

- **Si₃N₄**
  - ~4000 Å Al
  - Si
## Etch Rates and Selectivity

<table>
<thead>
<tr>
<th>Etch rate of photoresist (nm/sec)</th>
<th>Top</th>
<th>Center</th>
<th>Flat</th>
<th>Left</th>
<th>Right</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$/Si</td>
<td>1.765</td>
<td>1.523</td>
<td>1.925</td>
<td>1.902</td>
<td>1.688</td>
<td>1.761</td>
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<tr>
<td>PolySi/SiO$_2$/Si</td>
<td>1.657</td>
<td>1.817</td>
<td>1.840</td>
<td>1.463</td>
<td>1.493</td>
<td>1.654</td>
</tr>
<tr>
<td>Al/SiO$_2$/Si</td>
<td>7.204</td>
<td>6.652</td>
<td>6.968</td>
<td>7.084</td>
<td>7.440</td>
<td>7.070</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Etch rate of material (nm/sec)</th>
<th>Top</th>
<th>Center</th>
<th>Flat</th>
<th>Left</th>
<th>Right</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$/Si</td>
<td>8.260</td>
<td>7.867</td>
<td>8.490</td>
<td>8.400</td>
<td>7.958</td>
<td>8.195</td>
</tr>
<tr>
<td>PolySi/SiO$_2$/Si</td>
<td>4.983</td>
<td>4.823</td>
<td>4.897</td>
<td>4.890</td>
<td>5.000</td>
<td>4.919</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Selectivity (UV 210 Resist)</th>
<th>Top</th>
<th>Center</th>
<th>Flat</th>
<th>Left</th>
<th>Right</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$/Si</td>
<td>4.680</td>
<td>5.164</td>
<td>4.410</td>
<td>4.417</td>
<td>4.714</td>
<td>4.677</td>
</tr>
<tr>
<td>PolySi/SiO$_2$/Si</td>
<td>3.008</td>
<td>2.655</td>
<td>2.661</td>
<td>3.342</td>
<td>3.348</td>
<td>3.003</td>
</tr>
<tr>
<td>Al/Si$_3$N$_4$/Si</td>
<td>2.054</td>
<td>2.037</td>
<td>2.027</td>
<td>2.020</td>
<td>2.007</td>
<td>2.029</td>
</tr>
<tr>
<td>Al/SiO$_2$/Si</td>
<td>1.913</td>
<td>2.034</td>
<td>2.002</td>
<td>1.968</td>
<td>1.867</td>
<td>1.957</td>
</tr>
</tbody>
</table>
Selectivity Uniformity Across the Wafer

Selectivity Uniformity

- **SiO2/Si**
- **PolySi/SiO2/Si**
- **Al/Si3N4/Si**
- **Al/SiO2/Si**

Location on Wafer:
- Top
- Center
- Flat
- Left
- Right
Summary: Quality Monitoring Implementation

• Learned the basics of photolithography
  ▫ Patterned 17 wafers and ran a focus exposure matrix
• Determined the etch rate of SiO₂, PolySi/SiO₂, Al/Si₃N₄, and Al/SiO₂ to be 8.195, 4.919, 12.982, 13.817
• Determined the selectively of photoresist and SiO₂, PolySi/SiO₂, Al/Si₃N₄, and Al/SiO₂ to be 4.677, 3.003, 2.029, 1.957
Conclusion

- Measurement error for olympus, linewidth, and keyence are less than 1.6%, 2.2%, and 3.3% respectively
- Inspection of the Quality Monitor Etch Mask discovered discrepancies in small features from the CAD layout
- Determined the selectivity and etch rates of SiO$_2$, PolySi/SiO$_2$, Al/Si$_3$N$_4$, and Al/SiO$_2$
Acknowledgements

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