Automated (S)TEM Workflow for Process Control

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Outline

• Introduction
• Experimental Setup
• (S)TEM Process Control
• Conclusions
Introduction
Metrology Challenges in the Fab

Precise Metrology

More sampling

3D Metrology

Imaging of HAR contact hole along its depth

Measurement of Fin width across the Fin height

Measurement of sidewall angle

Measurement of capacitor width

Precise Fin height control

14nm-class FinFET transistor


Memory

Logic
Introduction

Most commonly used Metrology techniques

OCD
- CD, Profile
- Depth limited
- Fastest & Statistics
- Requires Calibration
- Needs modelling

CDSEM
- CD, LWR
- Top Down View
- Fast & Statistics
- Requires Calibration
- Limited resolution

(S)TEM
- CD, Profile, LWR, any
- Any structure
- Slow & No Statistics
- Accurate
- Destructive

Legend:
- Green: Advantage
- Orange: Average
- Red: Disadvantage
Introduction

(S)TEM Metrology

• Highest Resolution
• Accurate [1% Si Lattice]
• Cross-Section or Plan View CD
• Visual / No modeling

• Slow
• No Statistical data
• Not precise

Automation

• Fast
• Statistical Data
• Precision
Experimental
Automated ETM Workflow

- **ExSolve 2**: Automated Sample Prep
- **TEMLink**: Semi-Automated Plucking
- **Metrios DX**: Automated (S)TEM (TEM/STEM/EDS/Metrology)

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![ExSolve 2](image1.jpg)

![TEMLink](image2.jpg)

![Metrios DX](image3.jpg)

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<table>
<thead>
<tr>
<th>Row Labels</th>
<th>Distance (nm)</th>
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<td>FinHeight</td>
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<td>LeftOxideWidth50Percent</td>
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<td>RightOxideWidth50Percent</td>
<td>1.6</td>
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<td>TopOxideWidth</td>
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Experimental Tool Precision

Not Precise Maybe accurate

Precise (repeatable)

Accurate (real size)

<0.3nm 3σ Precision
<1% Accuracy Error

70% Precision improvement

STEM Metrology Dynamic Precision

- TopWidth
- MiddleWidth
- BottomWidth
- HeightSiOC
- HeightSi
- Pitch

STEM Precision 3σ (nm)

Manual Metrology

Height from SiOC: 34.3nm
Top Width: 25.9nm
Middle Width: 25.8nm
Bottom Width: 30.5nm
Angle: 77.9°
Height from Si: 57.3nm
Experimental

<table>
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<tr>
<th>Wafer</th>
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<td>EUV Resist A</td>
<td>Increases Left to Right</td>
<td>Constant</td>
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<tr>
<td>Wafer 16</td>
<td>EUV Resist B</td>
<td>Increases Left to Right</td>
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</tbody>
</table>

- 2 wafers
- 21 samples/wafer
- 6 images/sample
- 45 devices/sample
- 7 CDs/device

~13,000 Data Points!

Total time (42 samples): 21 hours [Automated]
Total time (42 samples): 58 hours [Manual] + overhead
Limited amount of data from Manual (S)TEM workflow may lead to erroneous decisions in production.
(S)TEM Process Control

Process Variation

Tool Precision:

Dynamic Precision: <0.3nm 3σ <1% Nominal CD

Process Variation >6nm due to large LWR
Tool Measurement Variation <0.3nm
Conclusions

• (S)TEM metrology provides precise and accurate measurements for 3D CD.
  – <1% Accuracy, <0.3nm 3σ Precision
• ETM Workflow allows fully automated (S)TEM metrology in the fab
• Statistically relevant (S)TEM data with high throughput provides new solutions for process control of 3D devices
• Fast and large amounts of data from ETM workflow improves the accuracy of OCD modeling.
Acknowledgements

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• Anne Kenslea
• IMEC – For providing the wafers
• More details on OCD, LWR and (S)TEM

H. Johanesen et al., “CD metrology for EUV lithography and etch” Advanced Semiconductor Manufacturing Conference (ASMC), 2015 26th Annual SEMI
Thank You