Roughness Metrology
The next Dimension

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Agenda

- Challenges in Roughness Metrology
- Roughness Metrology Requirements
- Suggested Approach for Roughness Measurement
- Line Roughness Definitions
  - Line Edge Roughness (LER)
  - Line Width Roughness (LWR)
  - Autocorrelation
  - Case Study
- Contact Edge Roughness (CER)
  - Definitions
  - Case Study
- Summary
Line Roughness Key Metrology Challenges (CD-SEM Perspective)

- SEM resolution for clear identification of edge roughness
- Measurement accuracy to enable the separation of roughness attributes from SEM artifacts (charging)
- Ability to differentiate SEM noise from real roughness
- All above over sensitive resists and other advanced materials
**ITRS Roughness Requirements**

- **LER** – Local line width variation (3σ total, all frequency components included, both edges)
- **LWR** for non correlated line edge roughness \( LWR = \sqrt{2*LER} \)
- **LER control**
  - 90nm – 3 nm
  - 65nm – 2 nm
- **LER Precision (P/T=0.2)**
  - 90nm – 0.6nm
  - 65nm – 0.4nm
- **Measurement tool performance needs to be independent of target shape, material, and density**

<table>
<thead>
<tr>
<th>Year of Production</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
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<tbody>
<tr>
<td>Technology Node</td>
<td>h90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>hp65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRAM λ/2 Pitch (nm)</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>65</td>
<td>57</td>
<td>50</td>
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<tr>
<td>Wafer CD metrology tool precision (nm) * (P/T=2) for LWR***</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.3</td>
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<tr>
<td>Line width roughness (nm, 3σ) &lt;8% of CD ***</td>
<td>3.6</td>
<td>3</td>
<td>2.6</td>
<td>2.2</td>
<td>2</td>
<td>1.8</td>
<td>1.6</td>
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</table>
Introduction to Edge Roughness Solutions

**VeritySEM Technology**

- **FOV 1µm**
- High resolution & low distortion in large field-of-view scanning

**LER/LWR Characterization**

- Roughness in tilt for discriminating bottom roughness
- Wavelength analysis

Enabling edge roughness based process control
VeritySEM Approach for Roughness Measurement

- **Line and Contact Roughness should be measured with the following recommended conditions**
  - Long Measurement Box of 20 times the technology node or fit several CH in single analysis
  - Small pixel size for High resolution in scan direction and edge direction for optimal roughness curvature identification
  - MacroCD analysis of Large Number of adjacent edges in order to improve statistic validity
  - Frequency range filtering to screen high frequency (noise) and low frequency (3 times the technology node)
Spatial Frequency: High Sensitivity to Amplitude

nominal amplitude (nominal periodicity constant at 100nm) detection of main frequency even for small LER (down to 5nm)

Thomas Marchner, Infineon SPIE 2003
Spatial Frequency: High sensitivity to Frequency

- Nominal periodicity (nominal amplitude constant at 50nm) shift of peak position increase of line-width of main peak as expected theoretically

Infineon, SPIE 2003
LER Precision

\[
LER = 3 \times \sqrt{\frac{\sum_{i=1}^{n}(X_i - \hat{X}_i)^2}{n-2}}
\]

<table>
<thead>
<tr>
<th>LER Precision &lt; 0.5nm</th>
<th>Meeting 70nm Requirements</th>
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<tbody>
<tr>
<td>LER [nm]</td>
<td>3 sigma LER [nm]</td>
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<tr>
<td>110nm L/S Litho</td>
<td>8.8</td>
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<tr>
<td>110nm L/S Etch</td>
<td>5</td>
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<tr>
<td>Intentional LER</td>
<td></td>
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<tr>
<td>Amplitude / Periodicity</td>
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</tr>
<tr>
<td>20nm / 100nm</td>
<td>6.4</td>
</tr>
<tr>
<td>50nm / 100nm</td>
<td>9.2</td>
</tr>
<tr>
<td>130nm / 100nm</td>
<td>27.8</td>
</tr>
<tr>
<td>50nm / 200nm</td>
<td>20</td>
</tr>
<tr>
<td>50nm / 600nm</td>
<td>27.8</td>
</tr>
</tbody>
</table>

Infineon, SPIE 2003
CER Introduction

Slide Removed
Contact Process Change

Resist thickness change made:

- No Photo CD impact
- Slight Etch CD impact
- Major impact to Breakdown Voltage from contact to unrelated metal

Contact Hole Edge Roughness
Andrew Habermas, Cypress Semiconductor
SPIE Technical Forum, March 2004
The problem addressed was to develop and evaluate algorithms capable of quantifying the roughness differences for these two contact processes. Other algorithm goals were scalability and integration.
Conclusions

✧ Contact Edge Roughness (CER) & CL distinguished between four sets of contact samples
✧ CER can explain the observed electrical breakdown failures in a 0.13μm SRAM process
Summary

- Approach for LER metrology was presented
- and its implementation in CD-SEM discussed
- CD-SEM is capable of measuring LER/LWR and CER with performance meeting ITRS requirements
- Roughness measurement can be utilized in production for quantified process monitoring (SPC)
- Roughness change in production environment need to be studied and control limits established
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