Status and Challenges in EUV Mask Cleaning

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Outline

- Technology landscape
- Various wet cleaning processes
- Focus areas to extend capability
  - Cleaning efficiency – adders
  - Surface damage - Chemistry
  - Pattern damage – Megasonic/spray

- Summary
Technology Landscape

- Need breakthrough/progress in alternative technology
- Wet clean extendability: CE (PRE, adders) and damage

<table>
<thead>
<tr>
<th></th>
<th>Wet clean</th>
<th>VUV/O</th>
<th>Cryogenic</th>
<th>PACE</th>
<th>EBIE</th>
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<tbody>
<tr>
<td>Organic removal</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Surface damage</td>
<td>?</td>
<td>✓</td>
<td></td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Pattern damage</td>
<td>?</td>
<td>✓</td>
<td></td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Particulate CE</td>
<td>?</td>
<td></td>
<td></td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Local or Global</td>
<td>Global</td>
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<td>Both</td>
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<td>Local</td>
</tr>
<tr>
<td>Blank clean</td>
<td>✓</td>
<td>✓</td>
<td></td>
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<tr>
<td>Final clean</td>
<td>?</td>
<td></td>
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</tr>
</tbody>
</table>

Scales
- Better: ✓ - capable; ? – marginal extendability
- Potential - need convincing data (important for R&D)
- Worse or no data

CE – cleaning efficiency
PRE – particle removal efficiency

2007 EUVL Symposium, Sapporo, Japan
<table>
<thead>
<tr>
<th></th>
<th>DIH2</th>
<th>DI03</th>
<th>SC1+NS</th>
<th>SC1+MS</th>
<th>SPM</th>
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<tbody>
<tr>
<td>Organic/residue removal</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Particulate removal</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Pattern damage</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Surface damage</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Adders</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

**Process marginality**

- Narrow MS margin
- Low PRE?
- Surface damage
- Adders
- PRE/Pattern damage
- PID (post clean environment)

**Relative scale**

- Better
- Worse

- Identify key focus areas

**Assessment of Wet Clean Processes**

- Better
- Worse

**Relative scale**

- Identify key focus areas

- Better
- Worse

- Organic/residue removal
- Particulate removal
- Pattern damage
- Surface damage
- Adders
- PRE/Pattern damage
- PID (post clean environment)
Extendability Issues with SPM

- SPM (Sulfuric acid and hydrogen peroxide mixture) chemistry is robust for removing organic contaminations
- SPM contains relatively high level of particulates
- There are two issues
  - Particulates in SPM remain on surface after clean cycle – adders
  - Haze/PID (photo-induced defect) formation from residual \( SO_4^{2-} \) ions – relatively manageable
Extendability Issues with SPM

- Adder level depends on type of surface
  - Different adhesion
- Quartz surface is ‘immune’ – low adhesion and removable
- AR-Cr surface retain low adders – min. imaging impact
  - Removable with rinse and SC1+MS
- EUV Ru-ML surface retains more adders – absorbs EUV
  - Difficult to remove

Qtz: 0 adders > 60nm (1X)
AR-Cr: 18 adders > 60nm (1X)
Ru-ML: 28 adders > 60nm (1X)
Ru-ML: 51 adders > 60nm (5X)
Adder Morphology

- AFM images (Heights on Ru-ML)

88nm

63nm

9nm

13nm

10nm

6nm
Most Are C-containing

- Micro-AES analysis

Reference Spectrum

Ru (symmetric line)

On defect

C (overlap with Ru, asymmetric line)

13nm
Adder Elimination

- Adder elimination in SPM chemistry is required to meet future defect specs
  - Tighter soft defect control for 193nm mask
  - Challenges in EUV mask cleaning
- Eliminate at the source
  - Improve filtration for bulk chemicals
  - Filters with smaller pore sizes – advances in Si cleaning
- Adder removal from the surface
  - Many adders are un-removable with additional SPM
  - Some are removable by UV/O oxidation
  - DIO3 (Ozonated DI water) is effective
DIO3 Process – Extremely Low Adders

- Zero adder is possible on Ru-ML

2 adders >60nm

1 adders >60nm
DIO3 Effective for Organic Removal

- DIO3 process is in limited use for cleaning
  - More widely use for resist strip on Si
- DIO3 is very effective in removing organic residues
  - Even in low concentration

![Cleaning Efficiency (%) vs. DIO3 Concentration](chart.png)

Organic Particulates

Partice Sizes (Bin)

- All > Bin3
- 5
- 7
- 10
- 20
- > 40

Cleaning Efficiency (%): 0 ppm, 10 ppm, 30 ppm, 50 ppm
Surface Damage Issue with DIO3

- Damage to ‘metallic’ surface a key limiter for wide adaptation of DIO3 process
  - Oxidation of Cr and Ru
- Surface roughness

AR-Cr: 20ppm DIO3 20min. → 2x rms
Ru-ML: 20ppm DIO3 50min. → 3.5x rms
Extendability of SC1+MS

- **SC1 + MS** (megasonic spray) ‘marginally’ meets the demand for particle removal
  - Works well for fall-on/contaminations
  - Performs to the limit of current inspection capabilities

- **Structure damage limits to MS** higher frequency and low power
  - Shock waves from cavitation

- **Reducing damage requires mechanistic understanding of MS in a spray system**
  - Dynamic pressure vs. cavitation to implosion
  - Probes for ‘direct’ measurements of cavitation distribution at POU

- ‘Fine’ and uniform cavitation in megasonic spray is critical in reducing pattern damage and maintaining PRE
Alternatives to MS

- Different forms of ‘Nano-spray’ have been advocated
  - Potential for reducing pattern damage
- Further demonstration for PRE
  - Is pressure alone enough?
- Adhesion, pattern fracture, pressure

<table>
<thead>
<tr>
<th>Property</th>
<th>Pattern fracture</th>
<th>Rolling a 2μm particle/SC1</th>
<th>Integ. MS pressure</th>
<th>Spray</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Value</td>
<td>0.1-1 GPa</td>
<td>~1-10MPa</td>
<td>&lt;1MPa</td>
<td>0.5MPa?</td>
</tr>
</tbody>
</table>
Summary

● Wet clean platform will stay, but with various forms
  – Extend existing capability – SPM, SC1
  – Enable new capability – functional water DIO3, DIH2

● Adder elimination is critical for extending the use of SPM
  – EUV mask is more sensitive to adder adhesion
  – Tighter soft defect spec for future 193nm masks

● Surface damage is a key issue to resolve in DIO3 chemistries
  – Complement or even replace SPM

● Understanding and controlling cavitation in megasonic system is critical
  – Maintain PRE while limiting pattern damage