Substrate Preparation for EUV Mask Blank Production

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Defect Distribution on a Typical Mask Blank

Substrate:
Total defects = 11 @ 42 nm +

ML Blank:
Particles = 9 @ 50 nm +
Total defects = 59 @ 50 nm +

Defects on Champion mask blank: 2011
Substrate Preparation and ML Deposition Process

- CMP
- Post CMP Cleaning
- Handling
- Storage
- Shipping

- Handling
- Inspection
- Cleaning
- Inspection
- Storage

- ML deposition
- Inspection
- Storage

Potential Particle Adders, easy to remove
Potential Pit and particle Adders
Potential Particle, Pit and Scratch Adders
No Adders
Adders from CMP Process

**Inspection of incoming substrates**

- **M1350**: Inspection at 70 nm+ does not reveal substrate issues
- **M7360**: Pits, particles and scratches detected at 42 nm+
- **EDX of CMP particles**

**CMP induced defects depend on**
- Substrate supplier (polishing parameters)
- Substrate material (substrate properties)
  - Hardness, roughness, type
Effect of CMP Scratches on Post CMP Cleaning

Substrates after cleaning, defects @ 42 nm+

Remaining pits and particles > 42 nm

Particles
Pits
Scratches

Number of particles and pits added on substrate by cleaning depends on initial scratch count
Scratches act as pockets for cleaning induced adder particles
Weaker material around scratch form pits by cleaning chemicals and megasonics
Reducing CMP Added Defects

• Substrate quality can be improved*
  – If polishing process is optimized
• However
  – Requires knowledge of defects generated by polishing processes
  – Requires inspection that can detect defects
• SEMATECH working with supplier has enabled to improve substrate quality

*SEMATECH is evaluating various polishing techniques to improve substrate quality
Cleaning of Quality Substrates for ML Deposition

• Ideal cleaning process
  – Should remove
    • CMP, post CMP, handling, and storage added particles
  – Should not add particles or pits by cleaning process or chemicals
  – Should not enlarge pits or scratches by chemical etching
  – Should have high yield
    • provide zero defect substrates for deposition consistently

• Factors affecting Cleaning yield
  • material properties, scratches and pits
  • Embedded particles from CMP process
  • Megasonics cleaning
  • Particle adders from cleaning

Particle Removal Efficiency (PRE)
  Ratio of particles removed by cleaning to particles before cleaning

Particle Cleaning Efficiency (PCE)
  Ratio of total particles after cleaning to before cleaning
  (includes particle adders from cleaning processes)

Total Cleaning Efficiency (TCE)
  Ratio of total defects (pits and particles) after cleaning to before cleaning

Cleaning Yield
  Ratio of number of zero defect substrates at certain size to the number of substrates cleaned

Added Pit Count
  Number of pits added by cleaning process
Cleaning Process Induced Detectable Adders at 42 nm+

**Substrate 1:**
- **Pre Cleaning:** 20 pits, 1 particle
- **Added:** 11 pits, 4 particles
- **Post Cleaning:** 31 pits, 7 particles

**Substrate 2:**
- **Pre Cleaning:** 12 pits, 77 particles
- **Post Cleaning:** 58 pits, 11 particles, 7 Scratches
- **Added:** 46 pits, 8 particles, 7 Scratches
Cleaning Process Induced Adders Below Current Detection Limit

- Compared ML deposition added defects on substrates cleaned with substrates not cleaned before deposition

2x more pits, 1.4 x more particles, and 4.5 x more scratches detected on blanks deposited on cleaned substrates!

Additional pits and scratches were not detected at substrate level
1 MHz megasonics used for particle removal is the major source of pit and particle adders.
Reducing Cleaning Induced Adders by Increasing Megasonic Frequency

Added pits on substrate cleaned multiple times

Active area of megasonics

Experimental observation of cavitation collapse

Resonant bubble size with Acoustic Frequency

Boundary Layer Change with Acoustic Frequency

Inertial Radius

- Radius (m)
- Frequency (Hz)
- Boundary Layer Thickness (m)
- Bubble Radius (m)
- Pressure Ratio ($P/P_0$)
Adder Reduction by Higher Frequency Megasonic Processes

Processes where evaluated on LTEM which is more challenging to clean
Zero Pit Generation Using 3 MHz Processes

Zero pit generation cleaning is proven for LTEM from both suppliers.
Reduction in Pit and Scratch Enlargement

- Pits and scratches are enlarged by chemical etching

**H$_2$SO$_4$/H$_2$O$_2$**
Oxidation/organic removal

**NH$_4$OH/H$_2$O$_2$**
Oxidize/etch/particle removal

**VUV @172 nm**
Reduce time & Optimize

Eliminate redundancies, optimize critical steps

Zero pits, zero particles, zero scratch adders @ 42 nm +
Substrate Storage After Cleaning

- Substrate Storage after cleaning resulted in progressive contamination

Storage contamination not detected at substrate level
Contamination affected deposition yield, experiments, and total defectivity on blanks
Cleaning Recipe Optimization for Complete Removal of Chemical Residues

Progressive contamination was not observed in any environment for several days on substrates cleaned with modified recipes.
Improvement in Cleaning Yield using Modified Processes

Demonstrated continuous improvement in substrate cleaning yield with improved processes
Improvement in Blank Yield

Blank Defect Trend

- Previous Marathons
- Current Marathon (M16)
- M16: M7360@50nm+
Improvement in Blank Defectivity and New Champion Blanks

@50 nm+

17 Defects

18 Defects

19 Defects

@50 nm+

19 Defects

22 Defects

22 Defects

@70 nm+

11 defects

14 defects

12 defects

M15: ML Defects; 1350-7360 comparison

M16: ML Defects; 1350-7360 comparison
Mask Blank Champion Data

Absence of small substrate defects from 40 – 70 nm

M16 Champion @50 nm+

Previous champion @50 nm+

25 x reduction in small defects

Average# of defects (M1350)

Absence of small substrate defects from 40 – 70 nm
Conclusions

• Pits and scratches were identified as major source of blank defects @ 50 nm+
  – Substrate defects decorated by multilayer deposition

• Cleaning induced adders and post cleaning storage adders were identified as major source of substrate defects from 40 nm – 70 nm
  – Small pit and particle adders from megasonics
  – CMP scratch and pit enlargement by chemical etching
  – Progressive contamination buildup from chemical residues

• Substrate cleaning processes and tool components were modified to suit the requirements of EUV blank defect reduction
  – 1 MHz particle removal process was replaced by 3 MHz process
  – Chemical usage and time of exposure was reduced to prevent over etching
  – Cleaning residues were completely eliminated

• Lower defect levels were achieved on blanks with improved substrate preparation
  – Demonstrated by champion blanks
  – Demonstrated by improved blank production yield
  – Absence of small defects from 40 nm – 70 nm
Backup
Cleaning Tool Induced Adders

Substrates after cleaning, defects @ 42 nm+

Cleaning tool issues prevent achieving high yield for zero defect substrates
Achieved > 90% PRE (target spec) on 3 MHz cleaning process

<table>
<thead>
<tr>
<th>PRE (%)</th>
<th>Particle Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>Handling particles</td>
</tr>
<tr>
<td>90</td>
<td>Particles from chemicals</td>
</tr>
</tbody>
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- Achieved PRE and Met/ exceed target spec (90%)
Achieved 100% PRE on Quartz and LTEM Substrates

PRE of substrates from supplier B is influenced by incoming substrate quality
Average Particles Remaining After Cleaning on substrates from Supplier B

- Higher number of particles remained on substrates from Supplier B affecting PRE, PCE and yield
Higher Frequency Megasonic (3MHz) Processes has better PRE and PCE yield

- Higher total cleaning efficiency for 3 MHz process is achieved due to reduction in pit and particle adders
- Easy to remove particles
  - Particles added by handling
- Hard to remove particles
  - Particles added from cleaning chemicals

![Easy to Remove Particles](chart1.png)

![Hard to Remove Particles](chart2.png)