Effect of Pump Induced Particle Agglomeration On CMP of Ultra Low k Dielectrics

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Outline

- Introduction and Challenges
- Objectives
- Experimental Design
- Results and Discussion
  - Particle Oversize- Pump Variable Correlations
  - Defectivity Measurements
  - Correlation Defectivity- Oversize
- Conclusions
## Back-end ITRS Roadmap

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Technology Node (nm)</td>
<td>90</td>
<td>65</td>
<td>45</td>
</tr>
<tr>
<td># of Metal levels</td>
<td>10</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Average dielectric constant</td>
<td>3.1-3.6</td>
<td>2.7-3.0</td>
<td>2.3-2.6</td>
</tr>
<tr>
<td>Dishing Planarity (nm)</td>
<td>30</td>
<td>19</td>
<td>14</td>
</tr>
<tr>
<td>Min. defect particle size (nm)</td>
<td>50</td>
<td>32.5</td>
<td>22.5</td>
</tr>
</tbody>
</table>

### Grand Challenges ≥ 45 nm/Through 2010

<table>
<thead>
<tr>
<th>Grand Challenges ≥ 45 nm/Through 2010</th>
<th>Summary of Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction of new materials to meet conductivity requirements</td>
<td>Creates integration and material characterization challenges.</td>
</tr>
<tr>
<td>Engineering manufacturable interconnect compatible with new materials and processes</td>
<td>Integration complexity, CMP damage, resist poisoning, dielectric constant degradation.</td>
</tr>
</tbody>
</table>

More Complicated and Lower Defect Based CMP Processing
Particle Challenges in Cu/ULK CMP

- Integration of Ultra low K (ULK) Dielectrics
  - Low Stress Polishing of fragile materials
- Process Simplification
  - Easy Handling (High Stability)
- Enhanced Performance
  - Reduced Defectivity

>> Particle Size/Size Distribution and Oversize Affects CMP Performance
Polishing of Fragile materials

- **Hardness of Low k materials**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Dielectric constant (k)</th>
<th>Hardness (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td>4.1</td>
<td>~ 8</td>
</tr>
<tr>
<td>Silicon-oxycarbide</td>
<td>3.3</td>
<td>~ 4</td>
</tr>
<tr>
<td>Porous SiLK (Dow Chemical)</td>
<td>2.2-2.7</td>
<td>~ 0.4</td>
</tr>
<tr>
<td>Porous Silica</td>
<td>1.9-2.2</td>
<td>0.29 – 0.47</td>
</tr>
</tbody>
</table>

- **New materials are mechanically fragile and exhibit poor adhesion with substrate**
Particle Size Distribution Effects

- Polishing Rate
- Defectivity

Concentration

Particle Size
Large Particle Defectivity

$$\delta = \frac{3}{4} \phi \left( \frac{P_{\text{app}}}{2KE} \right)^{2/3}$$

$\phi$ = Particle Size
$E$ = Young’s Modulus
$P$ = Applied Load
Large Particle Settling Effects

Increased Defectivity Due to Settling
Proposed Adoption of Low K Dielectrics for Various Editions of ITRS Roadmaps

Push out in low k integration due to integration challenges
Pump Effects on CMP Slurries

- Pumps for Slurry Handling Can Significantly Affect Particle Characteristics
  - Particle Size Distribution
  - Oversize Particle Production
  - Critical in Polishing of copper/low k dielectric (more susceptible to scratches)
Pump Based Particle Agglomeration

- **Pumps (Types)**
  - Bellows, Diaphragm, Centrifugal
  - Typically bellows/diaphragm pumps are used have shown significant agglomeration in silica based slurries. (CT Associates)
  - Agglomeration attributed to high shear stress in partial sample volumes.
  - Magnetically levitated centrifugal pumps have shown considerable less agglomeration. (attributed to low shear rates/cavitation effect)
Objectives

- Role of Oversize Particles in Defectivity Generation in Low K/ ultra low k Polishing (most sensitive to oversize particles).
- Evaluation of Agglomeration-free pumping systems (Centrifugal Pumps) for low k/ ultra low K polishing
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Experimental Details – Slurry Loop

- Particle Measurements
  - Dynamic Light Scattering – Average Particle Size
  - Accusizer Optical Particle Counter – Oversize Tail
Experimental Details – CMP

- Polishing Systems
  - IPEC 372 M 8 inch wafers
  - Struers Table Top Polisher

- Wafers
  - TEOS
  - BD1 low k (k = 3.0),
  - LKD 5109 (JSR) ULK (k = 2.2)

- Slurries
  - Planar Solutions – Step II Slurry – Cu 10 K Series

- Metrology
  - Optical Scattering
  - AFM : RMS and R max
  - Optical Microscopy
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Average Particle Size Vs Slurry turnovers

- Average particle size remains constant for all pumps
- Independent of number of slurry turnovers
Oversize Distribution

- **Bellows (12lit/min)**
  - Significant increase in particle tail in Bellows & Diaphragm pumps
- **Diaphragm (12lit/min)**
  - Insignificant change in particle tail in Centrifugal pump
Normalized Oversize Distribution

- Insignificant increase in oversize particles for centrifugal pump
Oversize Increase Vs Pump Speed

- Centrifugal pump shows least oversize increase
Oversize Increase Vs Turnovers

- Centrifugal pump has least oversize increase in different turnovers and pump speeds
Oversize
[significant change for positive displacement pumps]

Average Size
(no change)
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## Diaphragm Pump
(12 lit/min-1000 turnovers)

<table>
<thead>
<tr>
<th>Material</th>
<th>Image 1</th>
<th>Image 2</th>
<th>Image 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD1 Wafer</td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
</tr>
<tr>
<td>ULK Wafer</td>
<td><img src="#" alt="Image" /></td>
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## Centrifugal Pump
(12 lit/min-1000 turnovers)

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AFM
Defectivity vs. Pump Speed

- Increased defectivity with high pump speed
- Centrifugal pump has least defectivity
Defectivity vs. Turnovers

• Increased defectivity with high turnovers for Diaphragm
RMS-Roughness vs. Pump types

- Least roughness observed in Centrifugal pump

BD1 Wafer

<table>
<thead>
<tr>
<th>Pump Type</th>
<th>Rms (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrifugal-1000 turnover</td>
<td>0.05</td>
</tr>
<tr>
<td>Diaphragm-1000 turnover</td>
<td>0.20</td>
</tr>
<tr>
<td>Bellows-1000 turnover</td>
<td>0.15</td>
</tr>
</tbody>
</table>

- 9 liters/min
- 12 liters/min
Surface Damage & Pump Speed

R Max (nm)

Centrifugal-1000 turnover
Diaphragm-1000 turnover
Bellows-1000 turnover

AFM-Centrifugal
12 liters/min

AFM-Diaphragm
12 liters/min

AFM-Bellows
12 liters/min

Legend:
- 9 liters/min
- 12 liters/min
Surface Roughness Vs number of Turnovers

BD1 Wafer-12 liters/min

Rms (nm)

Centrifugal

Diaphragm

AFM-Centrifugal

AFM-Diaphragm

AFM-Centrifugal

AFM-Diaphragm
Oversize Distribution

- Significant increase in particle tail in Bellows & Diaphragm pumps
- Insignificant change in particle tail in Centrifugal pump
Oversize increase Vs Defectivity

- Excellent Correlation between oversize particle increase with RMS roughness and scratch density.
Conclusions

- Bellows and diaphragm pumping systems result in significant agglomeration (oversize particles) of low k slurries. The degree of agglomeration depends on slurry turnovers and pump speed.
- Centrifugal pumps based on magnetic levitation did not show appreciable particle agglomeration in low k slurries.
- Significant Increase in Defectivity (scratches, roughness, particle deposition) were observed in conventional pump processed slurries.
- Least Defectivity observed for Centrifugal pump processed slurries.
- Excellent Correlation between roughness/defect density and the degree of agglomeration.
Acknowledgements

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