Successful New Chemistry Qualification for a Cost Conscious Industry

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Outline of Presentation

• An Industry Focused on Cost
• BEOL Cu Post-Etch Cleaning Challenges
• DMAC vs. DMEA Formulations
• Qualification Data for DMEA Replacement Chemistry
• Issues and Advantages for DMEA Replacement Chemistry
• The End Result: Cost Improvement with no Yield Reduction
An Industry Focused on Cost

- 2008-2009 global economic downturn provided more focus for cost improvement to increase margins
- Chemical and Gas cost compared to other Wafer Fab Costs
Cost Reduction Goals

• An example of where a factory will focus its resources in terms of cost reduction
Why Focus on Chem/Gas Costs?

• Typically there are several options for chemistries, so pricing leverage is possible
• Dual supplier strategies offer more leverage
• Wafer fabs start with a single supplier, so dual supplier strategies are an improvement project
• Prices and supplier options are a moving target – what worked best in 2005 may not work best in 2011
• Risk in new supplier / chemistry qualification can often be offset by spec or process improvements – competition helps put these options on the table
**BEOL Post-Etch Cleans**

- BEOL Al and Cu are often integrated with a specially formulated chemistry for post-etch/ash cleans rather than a inorganic commodity chemistry (i.e. SPM, SOM, DI-O3 for FEOL post-etch/ash cleans)
  - Chemistries are formulated to maximize polymer removal while protecting the metals and dielectrics exposed with high selectivity
  - Processes are typically very sensitive – what works for customer A may not work for customer B, driving unique formulations and large product lines

- Formulated chemistries are a natural target for cost reduction due to the cost of a custom-blended formulation
  - BEOL Al and Cu formulated chemistries typically cost 3X-10X more than inorganic bulk chemicals
BEOL Cu Post-Etch Clean Process

- Polymer generated in a typical Cu BEOL integration consists of any combination of Cu, Ta, C, F, O, N
BEOL Cu Post-Etch Clean Challenges

• Cu etching must be limited, although removing a post-ash oxidized residue on the Cu is often required
• Dielectric etching must be limited to prevent CD loss
  – Multi-layer stacks require etch rate matching to prevent undercut and profile changes
• Polymer and residue in trenches and vias is difficult to detect with typical inspection and SEM review tools
• Issues with BEOL Cu post-etch cleans can show up:
  – Inline – CD measurement or inline inspection
  – As parametric or probe yield loss
  – Only in reliability testing – Cu migration, outgassing and other phenomena that are typically seen only in high-stress environments
Chemistry Change Strategy

- In 2007-2008, TI’s DMOS6 300mm fab undertook the project of changing its POR BEOL post-etch clean chemistry.
- After a detailed review of product offerings from various suppliers, TI decided on an Air Liquide formulation to test.
- The project goal was to be able to change all BEOL post-etch applications to this new chemistry.
- DMOS6 runs Cu interconnect nodes with a combination of 130 nm, 90 nm, and 65 nm product lines with dielectric layers consisting of OSG, FSG, and TEOS.
- Initial approach was to test the Air Liquide formulation on the highest impact node at the time, then fanout to other nodes.
- Overall project success was gated by several issues, but the overall project objective (cost reduction) was fully realized in 2009.
Why move away from solvents containing DMAC?

- In the past solvents containing DMAC were used to remove residue and particulates remaining after BEOL Cu etch processes.
- DMAC has been banned in European fabs due to its toxicity.
- A DMAC free residue remover is required while maintaining high selectivity to copper and ILD films.

<table>
<thead>
<tr>
<th>Component</th>
<th>POR Chemistry (DMAC)</th>
<th>New Chemistry (DMEA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic Acid (glacial)</td>
<td>10-20%</td>
<td>3-6%</td>
</tr>
<tr>
<td>Ammonium Acetate</td>
<td>10-20%</td>
<td>N/A</td>
</tr>
<tr>
<td>DMAC</td>
<td>50-60%</td>
<td>N/A</td>
</tr>
<tr>
<td>Ammonium Fluoride (40%)</td>
<td>1-5%</td>
<td>10-15%</td>
</tr>
<tr>
<td>Water</td>
<td>10-20%</td>
<td>60-70%</td>
</tr>
<tr>
<td>DMEA</td>
<td>N/A</td>
<td>10-15%</td>
</tr>
<tr>
<td>pH</td>
<td>4-5</td>
<td>8-9</td>
</tr>
</tbody>
</table>
How it works

• The DMEA formulation has >60% water which assists in removing inorganic salts including Fluoride salts formed by interaction of the F in the strippers with the inorganic residue
  
• A result of the POR DMAC chemistry’s low water content is that it does not remove the fluoride salts well
  – A typical process recipe requires cycling of chemistry with intermittent rinsing to refresh the surface
  – DMEA formulation does not require recipe cycling

• The DMEA formulation’s higher pH is better at dissolving salts into solution
  – In combination with higher water content, the DMEA formulation has much higher capacity for dissolving and holding in solution the mostly inorganic salt residue
  – This higher capacity should also translate into less particle deposition on wafer surface

• The DMEA formulation’s disposal is easier and less costly than the DMAC formulation since it contains more water with an amine and no DMAC
**Chemistry Comparison (DMAC vs. DMEA)**

<table>
<thead>
<tr>
<th>DMAC containing Products</th>
<th>New Chemistry without DMAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expensive</td>
<td>Less Expensive</td>
</tr>
<tr>
<td>RT with DIW rinsing</td>
<td>RT with DIW rinsing</td>
</tr>
<tr>
<td>Etch Rates (A/min)</td>
<td>Etch Rates (A/min)</td>
</tr>
<tr>
<td>FSG – 4</td>
<td>FSG – 1</td>
</tr>
<tr>
<td>TEOS – 8</td>
<td>TEOS – 1</td>
</tr>
<tr>
<td>SiC – 0.5</td>
<td>SiC – 0.1</td>
</tr>
<tr>
<td>Al – 5</td>
<td>Al – 2</td>
</tr>
<tr>
<td>Cu – &gt;1</td>
<td>Cu – &lt;1</td>
</tr>
<tr>
<td>Ta – &gt;1</td>
<td>Ta – &lt;1</td>
</tr>
</tbody>
</table>

- Surface roughness changes very little when using the DMEA formulation due to low etch rates
- CD’s and profile change very little when using DMEA formulation due to low etch rates
POR vs. Air Liquide (AL) Chemistry – Probe Yield

**Trench etch clean levels**

**Via etch clean levels**
POR vs. Air Liquide Chemistry – Probe Yield

- Probe yield plotted by number of passes (levels) through new AL chemistry
- Increasing passes through new chemistry may improve yield
- 0 passes indicates all POR chemistry
- Comparison data plotted against number of passes is critical in determining risk of multi-level chemistry qualification
- Count is for statistics – significant data exists for up to 5 or 6 passes, not more
Issues with Air Liquide Chemistry

• Smaller CD’s causing yield loss on several nodes investigated – not implemented
• Wafer-level reliability failures on one node where yield loss was nominal – not implemented
• Reduced pump efficiency over time due to filter loading, compensated by Levitronix pump flow control
  – This is a non-issue for the toolset due to the pump reliability – speed increases periodically until the filter needs to be changed and resets the pump speed
Advantages of Air Liquide Chemistry over POR

- Better compatibility with toolset materials
- Improved particle performance
- Resistance to an inline defect excursion (unexpected)
  - Without this chemistry already being in qual at the time of the excursion, the upstream ash operation would be severely restricted
  - Air Liquide chemistry changed the surface state to remove susceptibility to this defect
- Equal or better probe yield on the technologies where implemented
- Location – Chemistry is domestically produced with rapid technical expertise local to the fab site
- Engineering – TI continues to pursue chemical opportunities with Air Liquide
- COST!!! All of the above advantages come with the original goal of cost reduction
  - New chemistry also provides cost leverage for POR material
Acknowledgements

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