Etching of SiLK - an Organic Low-k Material

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Outline

• Principles of Etching SiLK
  – SiLK - Basic Material Properties
  – Chemistry for SiLK Etching
  – Process Characterization and Trends

• Etch Challenges and Solutions

• Etching Porous SiLK

• Summary
Principles of Etching SiLK
SiLK - Organic, Spin-on, Low-k Dielectric Film. Basic Material Properties

- **SiLK**: Aromatic Hydrocarbon -- Pure Organic
  - No Fluorine, no Silicon -- C, H, O, ...
- **$K < 2.65$**
- **Coat and Cure**
  - Coating is spin-on. Curing is needed.
  - SiLK J has 3.25% adhesion promoter which contains Si
  - Porous SiLK is based on SiLK I.

<table>
<thead>
<tr>
<th>Process Step</th>
<th>SiLK I</th>
<th>SiLK J</th>
<th>Porous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispense Promoter</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Bake Promoter @ 185C for 60 secs</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Dispense SiLK</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bake SiLK @ 325C for 90 secs</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cure SiLK on hot plate or furnace</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Adhesion Promoter</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
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</table>

Ref. Scott Cummings - Dow Chemical ; PEUG March 2001
SiLK Properties:
Dielectric Constant and Resistance to Stress

Ref. Scott Cummings - Dow Chemical; PEUG March 2001
SiLK Etch ---- Reaction of SiLK with H₂, O₂, N₂

- SiLK + H₂ ⇌ C₂H₂, C₂H₄, *C₃H₂⁺, H₂O, OH⁺, ...
- (CₓHᵧOᵦ) + O₂ ⇌ CO₂, CO, H₂O, OH⁺, ...
- + N₂ ⇌ *C₃H₂N⁺, CO, NO, NCO, NH⁺.

Graphitized SiLK (Carbon Skeleton)

* Polymer Precursors: Large Molecules or Radicals or Ions formed & decomposed, … yielding less or non-volatile products.
Chemistry for SiLK Etch - SiLK Etch Rate (Blanket)*

- Conclusions:
  1). N\textsubscript{2}: More physical etching (compared to H\textsubscript{2})
  2). H\textsubscript{2}: More chemical Etching
  3). O\textsubscript{2}: Chemical and Physical Etching (ER: O\textsubscript{2} > N\textsubscript{2} > H\textsubscript{2})

Process Characterization - Plasma Optical Signal Detection during SiLK Etch

387 nm (CN)
Increasing N/H ratio and/or total flow does not strongly influence ER but improves ER uniformity.
Higher 27/2 RF power ratio and higher total power increases ER and improves uniformity
Etch Challenges and Solutions

- *Single Damascene*
- *Dual Damascene*
- *Integration Schemes*
- *Process Challenges*
- *Lam Solutions for Integrated SiLK Etch*
Dual-HM SiLK Single Damascene Trench Etch

Pre-etch Structure

1. ARC/Mask Open
   - CD Bias <10nm

2. SiLK Trench Etch
   - No bowing

3. Barrier Open
   - Low Facet and Mask Erosion
   - No undercut
Dual-Hard Mask SiLK Etch - Trench pattern definition for DD scheme

1. ARC/Oxide Mask Open
   - CD Bias <10nm

2. PR Strip
   - CD Bias <10nm

3. Arc Deposition
4. PR Deposition
5. Via Lithography

- Ready for DD
Dual Hard Mask DD SiLK Etch without Stop Layer

Pre-etch Structure

1. ARC/Via Mask Open
- CD Bias < 10 nm
- No bowing

2. SiLK Via Etch
- ~100 nm
Dual Hardmask DD SiLK Etch without Stop Layer - continued

3. Trench Mask Open
- Minimal mask facet
- No mask undercut

4. SiLK Trench Etch
- No microtrenching
- No residues

5. Finish Etch
- Minimal mask facet
- No mask undercut
Dual Hardmask DD SiLK Etch Steps with Stop Layer

Pre-etch Structure

1. ARC/Via Mask Open

2. SiLK Via Etch

- CD Bias < 10nm
- No bowing
Dual Hardmask DD SiLK Etch Steps with Stop Layer
-continued

3. Trench Mask Etch

- Minimal mask facet
- No mask undercut

4. SiLK Trench Etch

- No microtrenching
- No residues

5. Finish Etch

- Minimal mask facet
- No mask undercut
Other possible SiLK DD Integration Schemes:

- Self Aligned
- Trench First Via Last
- Via First Trench Last
Etching Challenges and Solutions

• **CD/Profile control**
  - Pressure -- change in process regime
  - Pressure -- Neutral/ion ratio
  - Temperature -- sticking coefficient
  - Additives -- Polymer precursors

  ![High Press.](image1)
  ![High T](image2)
  ![Optimized: Vertical profile with good CD and facet control](image3)

• **Microtrenching**
  - Bias power
  - Pressure
  - Temperature
  - Polymer addition

  ![Low Pressure](image4)
  ![Low T](image5)
  ![High CHxFy & high Pressure](image6)
  ![Optimized: Vertical profile with no bowing, no residue, and no microtrenching.](image7)
Etching Challenges and Solutions:

**Facet:**
Knobs:
- 2 MHz Power (W)
- ESC Temperature

- 500 W (2 MHz) / 40 °C
- 0 W (2 MHz) / 0 °C

**Via CD:**
Knobs:
- 2 MHz Power (W)
- ESC Temperature

- 0 W (2 MHz)/0 °C
- 500 W (2 MHz)/40 °C
Dual HM SiLK Etch

• Etch Performance
  – Vertical profile
  – Minimum HM facet
  – Residue-free
  – No under cut, no bow
  – Flat and smooth trench etch front
  – No residue/ grass/ pitting, no microtrenching
  – Etch rate
  – Good profile (No bowing)
  – Maintain critical dimensions (CD)
Etching of Porous SiLK
Porous Low-k Etch Integration: Similar Integration Schemes as Non-Porous Materials

Typical Film Stack for DD Porous or Non-porous SiLK:

- 100-150 nm SiO$_2$
- 40-60 nm SiN
- 300-700 nm Porous SiLK
- 40-100 nm SiN
- Silicon
- Cu

Not very large pores for protection against shorts
Uniform Pore Distribution for mechanical integrity and performance
Closed Pores. Channels can trap chemicals

Ref. Scott Cummings - Dow Chemical ; PEUG March 2001
### Dense and Porous SiLK Etch - SD Via Comparison

<table>
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<th>SiLK</th>
<th>Porous SiLK</th>
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- Similar results obtained using the same process
- 10 to 30% higher etch rate for porous SiLK
Single Damascene processing with porous materials

Etch front roughness is eliminated when encountering a stop layer

Etch Front Progression
Etch rate Comparison

<table>
<thead>
<tr>
<th></th>
<th>SiLk ER (A/min)</th>
<th>OSG ER (A/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Porous</td>
<td>2250</td>
<td>2437</td>
</tr>
<tr>
<td>Porous</td>
<td>2970</td>
<td>3286</td>
</tr>
<tr>
<td>ER Ratio</td>
<td>1.32</td>
<td>1.35</td>
</tr>
</tbody>
</table>

- Porous low-k etch rates are typically 20-30% higher than the non-porous film
Dense and Porous DD SiLK Etch - Comparison

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<th>Porous SiLK</th>
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<tr>
<td>Dense and Porous SiLK: similar etch behavior: Etch Process recipe can be easily transferred from dense SiLK</td>
<td></td>
</tr>
<tr>
<td>Higher Etch Rates for porous material</td>
<td></td>
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<tr>
<td>Similar Integration</td>
<td></td>
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<tr>
<td>For porous SiLK, rough etch front might require stop layer</td>
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</tbody>
</table>
Dense and Porous SiLK Etch - Summary

- Optimized SiLK etch process for Single and Dual Damascene applications have been developed on Lam Research dielectric etch systems, down to 130 nm feature CD.

- Different chemistries (reducing or oxidizing) can be used to etch SiLK.

- SiLK profile and microtrenching can be improved by gas additives and/or optimizing pressure, ESC temperature, and RF power.

- Responses such as HM facet, bowing and CD can be finely controlled using gas flows, 27 MHz power, 2 MHz power and pressure as factors. Process factors with the greatest effect on process performance vary with feature dimension.

- Dense and Porous SiLK etching display similar process trends, making processes transferable from dense to porous SiLK with ease. An porous SiLK DD integrated scheme has been demonstrated.
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