Key Factors that Influence Step Height Reduction Efficiency and Defectivity during Metal CMP

Yuzhuo Li
Center for Advanced Materials Processing
Department of Chemistry
Clarkson University
Potsdam, NY 13699

Levitronix CMP Users' Conference 2006
Presentation Outline

- Overview
  - Step Height Reduction Efficiency
- Some case studies
  - Effective BTA concentrations
  - Caged in supramolecular structures
  - Slurry viscosity and SHRE
  - Organic abrasives
  - Edge over Erosion
- Summary
CMP Slurry Performance Metrics

- Step Height Reduction Efficiency and planarization length
  - Static Etch Rate (SER)
  - Material Removal Rate (MRR)
  - MRR/SER Ratio

- Over polishing window
  - Within Wafer Non-uniformity (WIWNU)
  - Wafer to Wafer Non-uniformity (WTWNU)
  - MRR selectivity

- Surface quality
  - Chemical and mechanical balance
  - Surface scratch and polishing debris
  - Delamination and coefficient of friction (COF)
Planarization Efficiency Requirement

A^b = Up thickness before CMP = ca. 10,000 A (7,000 A for new testing wafers)
S^b = copper step height before CMP = ca. 6,000 A (5,000 A)
S = copper step height after CMP = ca. 0
Initial copper WIWNU = ca. 5%
Copper removal rate WIWNU = ca. 5%
A = Up thickness after CMP = at least 1,000A across the wafer with no step height left
Minimum planarization efficiency required?
Correlation Between MRR/SER Ratio and Step Height Reduction Efficiency (SHRE)

No abrasive, a solution gives high MRR and low SER

No abrasive, a solution gives high MRR and high SER

MRR/SER > 25
SHRE > 85%

MRR/SER < 10
SHRE < 40%

MRR = Materials Removal Rate, SER = Static Etch Rate
Key Factors that Influence MRR/SER Ratio:
Complexing/passivating System such as Glycine/BTA

Note: SER is in the same trend as MRR
What about particles?

At pH = 5

It will be a different picture
For Alumina
Impact on passivation

BTA-copper complex has stronger tendency to adsorb onto silica
Static Etch Rates of Three Slurries before CMP

- Particle A
- Particle B
- Particle C

Static Etch Rate (nm/min) vs. % Particles
Static Etch Rate Before and After Polishing

Why?
Post CMP Static Etch Rate vs MRR

Material removal rate (A/min)

Increase in SER after CMP (nm/min)

- Alumina
- Silica A
- Silica B
- Organic

Abrasive
Effective [BTA]
Planarization Mechanism: Sequential Events

Initial Step Height → Chemical Conversion → Promoting abrasion

Pad

High MRR → Oxidized film

Low MRR

Passivation against Static dissolution

Step height reduction → Planarization
Removal mechanism: Influential Factors

- Copper oxidization
  - Chemically ( CMP) or electrochemically (ECMP)
  - Thin porous film that is rich in Cu(I) or Cu (II)
- Copper-complexing film
  - Complexing agent is water soluble, will not stay effectively
  - Passivating agent is water insoluble, will stay longer
- Passivating film
  - Passivating agent stack onto each other due to hydrophobicity or other force
  - Can form multilayer
- Chemical attack
  - In competition with passivating film formation: oxidizer, complexing agent, etc
  - In competition with mechanical force: copper ion, protonation, etc
- Mechanical attack
  - Strong enough to remove passivating film
  - Weak enough not to generate defects
Viscosity Issues: Slurry with Higher Viscosity Gives Lower SHRE

<table>
<thead>
<tr>
<th>slurry</th>
<th>Relative viscosity</th>
<th>SHRE (%)</th>
<th>Dishing at 100/100 um lines (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>original</td>
<td>1.00</td>
<td>89</td>
<td>600</td>
</tr>
<tr>
<td>Original plus IPA</td>
<td>1.35</td>
<td>65</td>
<td>1200</td>
</tr>
</tbody>
</table>

Simulated linear velocity difference between the fluid in a recessed area and near the pad. The reduced flow, to certain extent, helps the preservation of the passivating film in the recessed area.
Abrasives Free System
but, not particle free

Self-assembled supramolecular structures
encapsulated with an active ingredient that
could accelerate metal removal

Upon activation: shear or pressure
At high topographic area
Localized Activation During CMP

- High shear or pressure
- Low shear or pressure

Enhance MRR and Step height reduction
Impact on Step Height Reduction Efficiency

Without supramolecular structures

With <1 wt % of supramolecular structures
Encapsulation of metal ions in vesicles to separate catalyst from oxidizer

- Metal ions encapsulated in the core
- No free metal ions outside, lower static etch rate
- Not to scale
- 4 nm bilayer wall
- w/o/w
- Kinetically stable
- Process dependent preparation

∞ = DSPC
Encapsulation of metal ions increase the stability of the slurries

Relative chemical stability of liposome-based slurry (round) and the control slurry contains no liposome (square)

- H$_2$O$_2$ 3%
- Proline 1%
- Alumina 5%
- Cu ion 1.35ppm
- pH ~ 5.8
Systems Containing Supramolecular Structures
Bench top polisher for ECMP
Novel Organic Based Abrasive Particles

- Negative zeta potential and wide formulation window
- Relatively narrow particle size distribution and WIWNU
SEMATECH 854 Patterned Wafer Data
Average Dishing on 100/100 um Lines

Copper thickness

Excellent Copper Surface Quality Indicating Good Balance Mechanical and Chemical Strength
Unique Prestonian Behavior
– Low Sensitivity to Down Force

M102 and M103 are slurries based on organic particles
Commercial slurry with the same oxidizer as control
High Cu/Barrier Selectivity

Control silica slurry

Slurry based on organic abrasive particles
Erosion (total) = Erosion + EOE
Total Cu loss = Erosion (total) + Dishing

(source: SooKap Hahn of SKW Associates. 1/2005)
(1) **Effect of line widths (0.12~15um) at 750x750um arrays of PD 50%**

<table>
<thead>
<tr>
<th>Line Width</th>
<th>Graph 1</th>
<th>Graph 2</th>
<th>Graph 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.12um</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
</tr>
<tr>
<td>0.14um</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
</tr>
<tr>
<td>0.25um</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
</tr>
<tr>
<td>0.5um</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
</tr>
<tr>
<td>1um</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
</tr>
<tr>
<td>2um</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
</tr>
<tr>
<td>5um</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
</tr>
<tr>
<td>10um</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
</tr>
<tr>
<td>15um</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
</tr>
</tbody>
</table>

(source: SooKap Hahn of SKW Associates. 1/2005)
Simulation of slurry flow over a feature in FUENT 6.1 software showing slurry velocity contours.

Inadequate removal of copper ions accumulated at the edge of a large array leads to extra dishing on the narrow copper lines. The weak dielectric pillars are then eroded by harsh particles.
9_1 array on an 854 patterned wafer after polishing with a commercial slurry: EOE developed already.

9_1 array on an 854 patterned wafer after polishing with a new slurry with stronger resistance to copper ion induced corrosion: EOE did not develop.
Cu slurry, step height reduction efficiency is important
- Competitive surface adsorption onto particles can alter the slurry performance such as SHRE
- Effective local BTA concentration can change significantly as it can complex with metal ions, adsorb onto surfaces, and aggregate

Surface defects can be influenced by various factors
- Slurry viscosity
- Particle concentration homogeneity
- BTA concentration homogeneity

Some of the issues described above can have a direct link with slurry delivery and transport