Chemical Mechanical Planarization - Faculty Team

Including ‘slurryless’ planarization - E-CMP

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Mechanical Phenomena

Chemical Phenomena

Interfacial and Colloid Phenomena
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FLCC
CMP Research

Description: The major objective of this work continues to be to establish an effective linkage between capable process models for CMP and its consumables to be applied to process recipe generation and process optimization and linked to device design and other critical processes surrounding CMP. Specific issues include dishing, erosion and overpolishing in metal polishing, which have an impact on circuit performance — all pattern dependent effects at the chip level — wetability effects in polishing, and novel consumable design (pads and abrasives) for optimized performance. We develop integrated feature-level process models which drive process optimization to minimize feature, chip and wafer-level defects.

Goals: The final goals remain reliable, verifiable process control in the face of decreasing feature sizes, more complex patterns and more challenging materials, including heterogeneous structures and process models linked to CAD tools for realizing “CMP compatible chip design.”
Year 2 Highlights

- Developed capability in integrated model for determining and assessing pattern sensitivity.
- The effects of various common additives on zeta potential for alumina slurries used in copper CMP were determined.
- The influence of common slurry additives on the colloidal behavior of alumina suspensions used for copper CMP were characterized.
- Design rules for SMART pad design and fabrication are developed and simulation verification of pad slurry flow characteristics done with initial performance validation tests run.
- Experiments to provide crucial data for prediction of the galvanic damage sometimes seen during CMP were conducted including measurement of relative reactivity of copper and barrier materials in different slurries.
Year 3 Plan

• Mechanisms for coupling of chemical and mechanical phenomena in CMP (M22 YII.7)
  Use kinetic data for weight changes during passivation by peroxide to develop dynamic model for
  response after abrasion of surface layers and creation of new copper surface.
• Wetting and adhesion studies on two phase or multiphase surfaces (M7 [carried forward, with modifications, from year 1] YII.8)
  Study the effects of wetting and adhesional behavior of metals, low-k dielectrics and other phases on
  their polishing behavior, using isolated materials and for standard feature set from the cooperative
  photomask activity. Explore modification of the wetting and adhesional behavior through judicious
  selection of pad material, and optimized use of surfactants and other solvents.
• Further develop basic understanding of agglomeration/dispersion effects (M23 YII.9)
  Relate colloidal chemistry to surface charge and particle size distribution changes.
• Develop SMART prototyping methodology (M24 YII.10)
  Determine best manufacturing processes for prototyping pads for use in validation testing based on
  common photomask design.
• Integrate SMART pad design criteria into comprehensive model (M25 YII.11)
  Develop capability in integrated model for determining process-based or device design-based criteria for
  SMART-pad and other commercial surface and property specifications, specially for assessing
  pattern sensitivity.
• Basic material removal model development (Milestone Added, YII.12)
  Continue development of process model with attention to low down force applications/non-Prestonian
  material removal as well as subsurface damage effects.
An overview of CMP research in FLCC

- **Cu CMP**
  - Bulk Cu CMP
  - Barrier polishing
  - Bulk Cu slurry
  - Barrier slurry
- **W CMP**
  - W slurry
  - Oxide slurry
- **Oxide CMP**
  - Poly-Si slurry
  - Poly-Si CMP

- **Physical models of material removal mechanism in abrasive scale**
  - Chemical reactions
  - Mechanical material removal mechanism in abrasive scale

- **Models of WIDNU**
- **Models of WIWNU**
  - Better planarization efficiency
  - Better control of WIWNU
  - Smaller WIDNU
  - Small dishing & erosion
  - Reducing scratch defects
  - Reducing ‘Fang’
  - Reducing slurry usage
  - Uniform pad performance thru it’s lifetime
  - Longer pad life time
  - Ultra low-k integration
  - E-CMP

- **MIT model**
- **Dornfeld model**
- **Talbot**

- **Pattern**
  - Topography
  - Pad properties in die scale
  - Slurry supply/flow pattern in die scale
  - Wafer scale pressure NU
  - Wafer scale velocity profile
  - Wafer bending with zone pressures
  - Slurry supply/flow pattern in wafer scale
  - Pad groove

- **Pad design**
- **Fabrication technique**
- **Test**
Today’s Presentation
- see the posters for details -

SMART Pad
- Model-based pad design
- Initial experimental results

Corrosion studies/wettability
- galvanic corrosion of Ta-Cu couple
- Wetting studies on multi-phase surfaces

Comprehensive model
- Linkage with model beyond end-point (dishing/erosion)
- Expansion to copper CMP model
- Pad development for low down force CMP / E-CMP
- Study on non-uniform break thru in a die scale in copper E-cmp
SMART Pad - Pad Characterization (1)

- $R_a = 12.5\mu m$
- $R_z = 96.7\mu m$
- Pore diameter: 30~50 µm
- Peak to Peak: 200~300µm
Pad Characterization (2)

Asperity: Real contact area

1. Reaction Region (10~15 µm)
2. Transition Region
3. Reservoir Region

Reaction region
Transition region
Reservoir region
Defects from Conventional Pads

Stress concentration
- Pad asperity
- Wafer

ILD-CMP defects
- Small asperity
- Over polishing
- Large asperity
- Rounding

Cu-CMP defects
- Fang
- Dishing Erosion
Design Rules for a New Pad

<table>
<thead>
<tr>
<th>Macro scale</th>
<th>Micro scale</th>
<th>Nano scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Stacked layer (Hard/soft)</td>
<td>• Constant contact area (width: 10-50µm)</td>
<td>• Compatible features to abrasive</td>
</tr>
<tr>
<td>• Slurry channel</td>
<td>• The ratio of real contact area (10-15%)</td>
<td>• Constant re-generation of nano scale surface roughness</td>
</tr>
<tr>
<td></td>
<td>• Conditioning-less CMP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• High slurry efficiency</td>
<td></td>
</tr>
</tbody>
</table>

Channel Nano scale features

Hard Layer (i.e. high stiffness) Soft Layer (i.e. low stiffness)

50-200µm

50-70µm

FLCC - CMP
Fabrication Process

1. Master  
2. PDMS Casting  
3. PDMS Mold  
4. Hard Layer Casting  
5. Soft Layer Casting  
6. Demolding

New pad
Simulation of Slurry Flow

**Type A – Without slurry guidance**
- Area: $4.3 \times 10^{-10}$ m$^2$
- Flow rate: $3.93 \times 10^{-11}$ kg/sec

**Type B – With slurry guidance**
- Area: $4.294 \times 10^{-10}$ m$^2$
- Flow rate: $3.24 \times 10^{-10}$ kg/sec

8 times more flow rate on contact area
Results

ILD pattern

Type A (squares) (Not planrized)

Type B (V shape) (overpolishing: 800Å)

IC1000/SUBA400 (overpolishing: 2500Å)
Corrosion - the Problems

Copper tends to corrode in solutions open to air, barrier materials such as Ta have similar corrosion problems.

Polarization curves for corrosion reactions, describing the change in reaction rate as each half cell reaction is polarized away from equilibrium state; both the anodic dissolution of metal and cathodic reduction of an oxidant are polarized to a common potential, the corrosion potential, $E_{corr}$.

Cu corrosion in aerated solution. The nature of copper species depends on the solution chemistry. Continuous corrosion requires electrical and electrolytic conduction paths and the presence of a potential difference.

Copper tends to corrode in solutions open to air, barrier materials such as Ta have similar corrosion problems.
Galvanic effect: accelerates corrosion of the more active metal, N, because of anodic polarization and suppresses corrosion of the more noble metal, M, because of cathodic polarization

Solution chemistry might change the polarization behavior of each material; thereby affecting the preferential galvanic corrosion of the corroding material

Increasing the area of the more noble material accelerates corrosion of N

Galvanic effects lead to more severe corrosion of the more active metal. Damage sensitive to solution chemistry and area ratio effects
The Problems

### The Problems

<table>
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<tr>
<th>Radius, r (cm)</th>
<th>Bulk electrolyte</th>
<th>0.1 um-thick electrolyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
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<tr>
<td>1.0</td>
<td>1.0</td>
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</table>

<table>
<thead>
<tr>
<th>Potential, E (V)</th>
<th>ANODE</th>
<th>CATHODE</th>
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</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
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<tr>
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Galvanic corrosion in bulk solution

Galvanic corrosion in thin-layer of solution

The characteristic pronounced corrosion at the phase boundary in galvanic corrosion is due to the steep potential gradient and high current density at the boundary between two phases.

θ: contact angle for characterizing the wetting of a surface by a specific solution; zero or small contact angles = good wetting

The accessibility and distribution of electrolyte (ions and water) on surfaces may affect galvanic corrosion. The wettability of materials may affect the distribution of the solution on surfaces.
Experimental Study
Experimental setup and samples

Galvanic currents and potentials will be measured with or without polishing, to investigate the effects of surface modification by chemicals and mechanical force on the polarity and galvanic current; area ratio of Cu:Ta is to be varied using different sample assemblies with different relative areas.
Results of electrochemical measurements

Area ratio effect, without polishing

in pH=9 carbonate buffer, 0.01M glycine and 0.3%H₂O₂

**FLCC**
Results of electrochemical measurement

Effects of $[\text{H}_2\text{O}_2]$, pH=9, without polishing

in pH=9 carbonate buffer, 0.01M glycine and varying $[\text{H}_2\text{O}_2]$
Effects of polishing on galvanic currents and potentials


Figure 7. OCP of Cu and Ta in slurry Al. ΔOCP(Cu-Ta) indicates the potential difference between Cu and Ta.

Figure 5. Relation between tensile stress and corrosion current density of Cu plates both in regions of elastic and plastic deformation with slurry Al at 20°C.
Contact angle measurement

Kruss Contact Angle Measuring System (Goniometry approach)
The basic elements of a goniometer include a light source, sample stage, lens and image capture. Based on the image of the liquid drop, contact angle can be assessed directly by measuring the angle formed between the solid and the tangent to the drop surface.

Sessile drop method: Angle between the baseline of the drop and the tangent at the drop boundary is measured.

The contact angles as function of solution chemistry on Ta/TaN, Cu and dielectric material (TEOS or SiO₂) will be explored.
Comprehensive CMP Model

- Statistical representation of CMP pad surface
- Interaction between wafer topography and pad asperities
- Hertzian contact model for elastic pad deformation
- Linkage with conventional chip-scale pattern density model

\[ MRR(x, y) = C \cdot \frac{V_p E^{3/2} \int_{z_{pad}}^{z(x,y)} \varepsilon(x, y, \delta)^{7/4} \times PHD(\delta) d\delta}{\rho(x, y) D_p \kappa^{1/4} H_w^{3/2} R} \]

- process parameters
- wafer topography
- pad surface condition

- chemical reactions
- pad material properties
- abrasive size
- thin film properties
- pattern density effect
Effect of Pad Asperity Height Distribution

**Rough Pad**

- \( \sigma = 3 \mu m, \ \alpha = 3 \mu m \)

**Smooth Pad**

- \( \sigma = 6 \mu m, \ \alpha = 3 \mu m \)

Lower planarization efficiency,
Higher removal rate

Higher planarization efficiency,
Lower removal rate
Effect of Nominal Down Pressure

![Graphs showing the effect of nominal down pressure on oxide thickness with time. The graphs compare low and high pressure conditions.](image)

**Low Pressure**

**High Pressure**

9/15/05

FLCC - CMP
Oxide Test Pattern Wafer for Model Calibration and Verification

4 inch wafer
(11 dies across the diameter)

Line width: 20 µm

CVD nitride

Pattern nitride (mask #1)

CVD Oxide

Etch oxide (mask #2)

FLCC - CMP
Model vs. Experiment (Oxide CMP)

Experiment:
- t=0min
- t=2min
- t=4min
- t=8min

Model:
- highest point in the die (measured)
- lowest point in the die (measured)
- highest point in the die (model)
- lowest point in the die (model)
Comparison of Final Oxide Thickness Variation Over the Test Die

RMS error = 30.8 nm
(100 measurement sites)