Advances in CMP Fundamental Understanding and Applications to Consumable and Process Design

Gregory P. Muldowney, Carolina L. Elmufdi & A. Scott Lawing*

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Introduction

- Contact Area Measurement and Modeling
  - Fundamental understanding
    - Ex: Sub-pad effect
  - Rational consumable design
    - Ex: Low Stress Polishing

- Process Fundamentals: Backmixing
  - Backmixing criteria
  - Backmixing process response
    - Uniformity
    - Defectivity
  - Pattern transfer

- Pad & Conditioning Process Design: VisionPad™ 5000 Polishing Pad for STI
Contact Area Measurement and Modeling

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Point Contact Area and Pressure

- Elimination of defects is more effectively achieved by elimination of high contact pressures

\[
\bar{P}_C = \frac{P_{\text{Applied}}}{A_C}
\]

\[A_C << A_{\text{Wafer}} \quad \therefore P_C >> P_{\text{Applied}}\]

- Breakthrough increases in pad-wafer contact area will reduce defects even with no change in applied downforce or coefficient of friction

Very large \(P_C\) damages surface
- Difference between contact area and cross-section is observed at all scales.
- Difference between contact area and cross-section is strikingly larger when a sub-pad absorbs most of the displacement.
Low-Stress CMP for Emerging Devices

- New materials to planarize
- Unforgiving error budgets
- Fragile device structures
- Low defect tolerance

- Novel slurry chemistries
- Wafer-scale pad flatness
- Low-stress planarization

Bulk Si Alternatives

Transistor Extensions

Interconnect Materials

New Memory Materials & Architectures
Contact State Determines Defectivity

- Defects approach zero as contact pressure drops to same order of magnitude as applied pressure
- There is no general trend of lower defects at lower COF across pad types

Scratch Defect Counts in Cu Barrier CMP at 1.5 psi
AMAT Mirra® Polisher, 93/87 rpm, LK393C4 slurry
- Point contact pressure has emerged as a key driver of scratch defects
- High-contact pads are an ongoing R&D focus to provide low-stress polish
Process Fundamentals: Backmixing

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(Additional data by Lawing)
Backmixing Effect in CMP Tracer Experiments

- Backmixed region resists fresh slurry influx for many wafer rotations
- Non-backmixed condition conveys slurry across full wafer track
Slurry Backmixing Criteria

- Backmixing affects wafer over width \( w^* \) at edge:
  \[
  w^* = R_W - \frac{R}{1 + \frac{\Omega_W}{\Omega_P}}
  \]

- For wafer to be unaffected by backmixing (\( w^* = 0 \)):
  \[
  \Omega_W \leq \Omega_P \left( \frac{R - R_W}{R_W} \right)
  \]

- For \( R_W/R \) of 0.7-0.8, need \( \Omega_P/\Omega_W > 2.5 \) to avoid backmixing

- Larger wafers (higher \( R_W/R \)) make backmixing more likely and affected width \( w^* \) greater
Effect of Backmixing on Steady-State Concentration Field

- **Mass Fraction Spent Slurry**
  - 1.00
  - 0.95
  - 0.90
  - 0.85
  - 0.80
  - 0.75
  - 0.70
  - 0.65
  - 0.60

**Un-Backmixed**

- 0 rpm
- 4 rpm
- 12 rpm

**Backmixed**

- 25 rpm
- 33 rpm
- 61 rpm

Case:
- **Pad 33 rpm**
- Polish Pressure 3 psi
- Medium Conditioning
- Flat 43 μm Gap
- Wafer Surface

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Effect of Backmixing on Steady-State Temperature Field

Un-Backmixed

Backmixed

Backmixing concentrates heat near wafer edge

Case:
Pad 33 rpm
Polish Pressure 3 psi
Medium Conditioning
Flat 43 μm Gap
Wafer Surface

Slurry Temperature (°C)
37
36
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20

Area of Detail
Effect of Backmixing on Wafer Edge Profiles

- No-backmixing improved edge profiles regardless of polish pressure
- Reflects more consistent transport in absence of reverse slurry flow
Desirability functions indicate one way to optimize the process based on the results of the DOE.

In this case targets for rate and profile (Center Fast Factor) were input and uniformity ($\% \sigma$) was minimized.

Note that increasing PS/CS drives CFF down (i.e. more center slow!)
More control is obtained over center-to-edge profile at high platen speed/carrier speed ratio.
Slurry renewal is slow near pad center due to reverse motion of wafer, allowing debris to collect and recycle.

Agglomerated debris and particles ejected from groove may inflict scratch defects.

Spiral grooves renew slurry more effectively at pad center to arrest this defect mechanism.
**Effect of Backmixing on Cu Defectivity**

<table>
<thead>
<tr>
<th>Process Condition</th>
<th>Total Defects - Scratch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backmixing</td>
<td>130</td>
</tr>
<tr>
<td>No Backmixing</td>
<td>140</td>
</tr>
</tbody>
</table>

Data from Orbot™ WF-720

- No-backmixing improved defect counts by 25% at 3 psi pressure
- Pad rotation conveys away spent particles and polish debris faster than wafer rotation can recapture them
Groove Pattern Transfer

- Rotation/oscillation exposes point on wafer to many points on pad
- Off-center position exposes wafer to all angles with respect to pad surface and grooves
- Despite motions, wafer is imprinted with rings matching groove pitch
Porous IC1000™ Pad

With Carrier Oscillation

Without Carrier Oscillation

0.030” Pitch

0.060” Pitch

0.120” Pitch
Effect of Backmixing on Pattern Transfer

200-mm Wafer

PS/CS = 4

PS/CS = 2

PS/CS = 1

PS/CS = 0.85

PS/CS = 0.67

View
Pad Conditioning & Process Design: VisionPad™ 5000 for STI

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Advanced Pad Roadmap

Node Logic

>65

Standard Mfg. Process

IC1000™

VisionPad™

3000

Advanced Casting (ACT)

- Improved consistency

ACT & Technology Improvements

- Flatter, smoother pads
- Process Control

VisionPads: VP3200, VP3500, VP5000, EV4000

New Platforms

Cu, STI, ILD

IC1000™AT

New VP Formulations for ILD, Cu

Heinchu Mfg. 2007

Advanced Pads

New Mfg. Processes

Pad Formulation Platforms

VisionPads for STI and Cu

IC1000™ pads

VisionPad™

3100

Softers Formulation to Reduce Defects

'04

'05

'06

'07

'08,'09

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Conditioner Design, Natural Porosity & Pad Texture Evolution

- **Pad Surface Height Distribution**
- **Pad Surface Profile**
- **Natural porosity of pad +**
- **Cutting behavior of conditioner =**
- **Final pad surface statistics**
  - Final pad surface is the product of the inherent pad texture (porosity) and the conditioner cutting characteristic (near surface roughness)
    - Each pad-conditioner combination will have a **unique (intrinsic) surface structure**
    - Cut rate, cutting characteristics and the resulting near surface roughness can be driven over a large range through conditioner design
- **Conditioning Held Constant**
  - High Level of Porosity
  - Lower Level of Porosity
  - Zero Level of Porosity
- **Porosity Held Constant**
  - High Cut Roughness
  - Low Cut Roughness
- **Manipulating the size, shape and density of diamonds can change cutting characteristics and cut rate > 10x**

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Conditioning for Textural Compatibility

Compatible
VisionPad 5000 + SPD01
(Cutting depth ≤ porosity depth)

Too Deep
VisionPad 5000 + 181060
(Cutting depth > porosity depth)

- Materials with different pore structures require conditioning tailored to their specific porosity
- Incompatible conditioning results in a disruption of the natural porosity of the material
The natural porosity of IC1000 is compatible with both 181060 and SPD01
  - Note that the negative tail of the distribution is unaffected by conditioning indicating that the natural porosity is intact in both cases

The natural porosity of VisionPad 5000 is incompatible with 181060 and compatible with SPD01
  - Note that the combination of VisionPad 5000 & 181060 results in a widening of the negative tail of the distribution indicating that the natural porosity of the material has been disrupted
Data from STI Polishing with Celexis™ CX97S slurry

Dishing and polish rate are significantly improved with the VisionPad 5000/SPD01 combination
Conclusions

- Rohm and Haas Electronic Materials has a comprehensive CMP fundamental research program in place.
- This research program is designed to provide rational guidance for product and process design.
- Some highlights reviewed here include:
  - Fundamental aspects of pad-wafer contact mechanics
  - Process interactions
  - Next generation pad design