Research Activities on Defect Improvement of CMP Process in 1x nm Foundry Device

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1 CMP, Advanced Technology Development (ATD) , 2 CMP, Advanced Module Engineering (AME)
Confronting Reality in semiconductor field.

- Scaling Challenges
- Device Structure
- Flow Complexity
- New Material Introduction
- Complex Interdependencies

Critical Insights Needed to Manage Dynamics
CMP is becoming **COMPLEX**!

- CMP steps doubled from 28nm to 10nm node in order to enable new integration schemes such as replacement metal gate or self-aligned contact.
- Higher increased in 10nm CMP steps at MOL due to the complexity of contact module from gate and contact engineering.
### CMP process challenges

<table>
<thead>
<tr>
<th>Selectivity Materials</th>
<th>FEOL: SiN, Ox</th>
<th>MOL: SiN, Ox, W, TiN, Al</th>
<th>BEOL: Cu, Ta, TaN, TiN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dishing/Erosion</td>
<td>Higher PD &lt; 100 (A.U)</td>
<td>Higher PD &lt; 83 (A.U)</td>
<td>Higher PD &lt; 66 (A.U)</td>
</tr>
<tr>
<td>Uniformity (100x100um)</td>
<td>3sigma &lt; 100 (A.U)</td>
<td>3sigma &lt; 66 (A.U)</td>
<td>3sigma &lt; 46 (A.U)</td>
</tr>
</tbody>
</table>

- More new materials are expected in the future nodes in order to meet stringent process requirement in CMP
Increasing challenge in 3 D’s

- **Within-die uniformity**
  - High Density | Low Density
  - High within-die-non-uniformity
  - Low within-die-non-uniformity

- **Within-wafer uniformity**
  - Within-die-non-uniformity due to pattern density
  - Within-wafer-non-uniformity due to non-uniform CMP

- **Within-macro uniformity**
  - Minimum/no recess
  - Cu recess

• Must deliver minimal & stable non-uniformity
Increasing challenge – defect translation

- Increased # layers = increased defect translation
Unforgettable and endless problem in CMP

Micro and Nano Scratches
Improvement activities for Micro Scratches
Nanoparticle-Ceria: CMP Performance

Case I: Poly CMP

Macro to Macro Variation

<table>
<thead>
<tr>
<th></th>
<th>Macro 1</th>
<th>Macro 2</th>
<th>Macro 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Abrasive</td>
<td><img src="image1.png" alt="image" /></td>
<td><img src="image2.png" alt="image" /></td>
<td><img src="image3.png" alt="image" /></td>
</tr>
<tr>
<td>Nanoparticle Abrasive</td>
<td><img src="image4.png" alt="image" /></td>
<td><img src="image5.png" alt="image" /></td>
<td><img src="image6.png" alt="image" /></td>
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Nano-ceria based slurry showed microscratch reduction in multiple process steps with different integration scheme, however most processes are limited to buffing CMP only so far. Planarity and selectivity control is the key challenges (i.e., proper slurry chemistry) with nano-scale abrasive application for CMP slurry (removal rate is tunable with easy and comparable to conventional ceria based slurry).
Soft Pad Effect on Microscratch

Microscratch Trend

Post CMP Pad Thickness: Planarity

- Microscratch reduction can be achieved by soft pad implement, however, planarity and removal rate degraded either (this is reported many times in different conferences, publications, and business reports). For the soft pad application, proper pad conditioning is necessary to maintain polishing performances.
Process Scheme for Microscratch Reduction

CMP: Scratch generating process and *scratch removal process* as well!

Non-selective buffing CMP help to scratch reduction → *selectivity and uniformity control* is challenge for this application
Conditioner Design Change to improve scratches

Advantages of CVD Tip Formation

- **Guaranteed Quality**
  - No Design Limitation: tip to tip distance,Tip height distribution, etc.
  - Can control pad surface roughness and polishing Debris

**3D Patterning**

- Tip Height Control
- Working with SHINHAN Diamond & 3M

Ji Chul Yang, 60th KCMPUGM, Suwon, South Korea, 2015
Strategies for Scratch Mitigation

- Soft Pad w/ Proper Conditioning
- Ultrafine Abrasive Particle
- Recipe Optimize (Low Down Force, Slurry Flow)
- Cleaner Brush Treatment
- CMP Friendly Process

Scratch SOLELY can be minimized?
In-Wafer Uniformity (iAPC)
Challenges of CMP Process

- Incoming height variation: variation in multiple upstream processes add up

- Removal rate drop as pad life (removal rate stability)

- CMP loading effect on removal rate
  - Polishing rate is not constant
  - Sinusoidal removal behavior observed
  - Early stage of polishing (< 10s) is not predictable
iAPC: Integrated Advanced Process Control

Implement of on-board metrology

CMP

In-situ Metrology

http://blog.nus.edu.sg/me4105precisionengineering2012/types-of-metrology-equipments/
iAPC Algorithm and Process Sequence

- Polishing time set by self-learning process: Empirical
Gate Height Control with iAPC

- Incoming process variability → CMP needs to accommodate and compensate it and tight gate height control → in-situ (or real time) process control improve wafer to wafer variation
Contact W CMP with iAPC

- >50% Reduction in raw level delta to target (contact height)
Cu CMP with IAPC

- WTW Rs control demonstrated and in use
- Need further WID/WIW/WTW enhancement
- Endpoint improvements (On-platen / In-situ?)

Example of Rs control by iAPC

In-situ Cu height control with Barrier EPD and Dielectric removal amount control

In-situ monitoring flow

1. Cu CMP

2. Barrier CMP Start

2-1. Barrier Clear

2-2. Dielectric Removal Amount Control

1. Cu CMP -> Cu clear + O.P.

2. Dielectric removal amount control with in-situ optical sensor

Cleaner Defect
Cu CMP Defect – lots of cleaner defect type

- Ring Scratches
- Organic Residue
- Brush Particle
- Cu Flake
Recipe Test

- Recipe is major driven solution for CMP defect
Brush Surface Modification

Working with Rippey
Changing profile by different Process condition

Cu Protrusion
Tool Configuration for effective cleaning

Target 100%

Performance

Two Fluid Jet

Mag Tank & IPA Dryer

Typical Brush

Pencil Brush
In Conclusion,

<table>
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<tr>
<th>Fundamental Studies</th>
<th>Structures &amp; Materials</th>
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<tbody>
<tr>
<td>Defect-Preventive Process Design</td>
<td>“Selectable” Selectivity</td>
</tr>
<tr>
<td>Advanced Diagnostics (FDC, SPC sensor)</td>
<td>Manufacturing-Friendly Equipment Design</td>
</tr>
<tr>
<td>Defect Management</td>
<td>The Next “Silver Bullet”</td>
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