Characterization of ILD scratches

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1. **Introduction to micro-scratches**
   - ILD CMP
   - CMP process and defects

2. **Objective**

3. **Results**
   - Scratch shape analysis
   - CMP conditions (polishing pressure and rotation speed)
   - Slurry types and size
   - Effects of polishing pad types

4. **Summary**
Why are micro-scratches important in CMP process?

As the geometry gets smaller, micro-scratches can lead to severe circuit failure.
The migration of CMP technology

- Polishing recipe
- Pressure control & table speed tuning
- CMP Tool
- Chosen the tool equipped the head of retainer ring and membrane
- Pattern design
- Applied optional slurry for each process
- Slurry
- Compounding the consumable parts
- Consumable part
- AMAT MIRRA tool
- CMP simulation & dummy pattern insert
- Removal profile control
- Removal profile & selectivity, dishing control
- The alternative application of consumable parts
Defects during ILD CMP

Ref. From KLA-Tencor
CMP Process and Defects

- Micro-scratches
- Slurry residues
- Organic residues
- Embedded particles

Oxide CMP
- Micro-scratches
- Polysilicon residues
- Pitting and voids
- Particles

Poly-Si CMP
- Micro-scratches
- Metal residues
- Corrosion
- Damage of barrier metal

Cu CMP
- Micro-scratches
- Tungsten residues
- Corrosion
- Pitting and void
Issues of scratch in ILD CMP

Scratch

Problems

- Electrical shorts
- Circuit failure
- Low durability and reliability
- Low yield

Ultimately, it affects device performance and reliability.
Process Step of ILD CMP
→ Reducing GP step height (Silica)
ILD CMP technology

- Etch back
- ILD CMP (Colloidal)
- ILD CMP (Fumed)
- HPC (Ceria)

200nm - 60nm

Continuous scratch issue

Removal thk. profile

Diameter scan

High initial step height
Main sources of scratches come from consumable parts such as slurry, pad and disk.
Possible sources of scratches in ILD CMP

- Agglomerated slurry particles
- Abnormal shaped slurry particles
- The degraded polishing pad
- The debris of conditioner
- Air born particles & Dropped particles
Micro-scratches from point of view of slurry abrasives

- **Fumed silica**
  - Higher purity than colloidal silica
  - Easily agglomerates by shearing

- **Colloidal silica**
  - Lower purity than fumed silica
  - Fewer and smaller scratches

- **Ceria**
  - Higher density and hardness
  - Higher removal rate
  - Low scratch counts

Effect of slurry particles on scratches

- Scratch-free slurry
- The dilute HF has no effect on the scratch count in colloidal silica slurry.

The effect of incoming slurry particle size distribution on defects

- Slurry particle size (um) vs. Particle counts (ea)

- POU depth-type filter
- High spray bar system
- Decreasing number of particles 3~5 times after filtration
- > 2 um particles removed!

Research Objective

- Scratch dimension analysis
- The effect of polishing pad
- The effect of slurry type
- The effect of polishing condition

Scratch formation mechanism

Scratch Free
ILD CMP
## Experimental materials & Equipments

### Experimental materials

| Sample                  | 200 mm bare Si wafer  
|                        | STI and ILD patterned wafer |
| Slurry                 | Fumed silica slurry  
|                        | Ceria slurry           |
| Pad                    | K-grooved IC-1010 (Rohm and Hass) and custom made pads |

### Equipments

| CMP machine            | 200 mm Mirra polisher |
|                        |  |
| Slurry particle size analysis | Accusizer (APS 780, PSS NICOMP) |
| Polishing pad analysis | CD-SEM (Hitachi) |
| Scratch inspection system | Sufscan (PUMA 9100, KLA-Tencor) |
| Friction force measurement | Frictional polisher (POLI-500,GNP Tech.) |
Typical scratch shape in ILD CMP

Schematic illustration of ILD CMP scratch shape
- A : length of scratch
- B : width of scratch
- C : lip width
Width and Lip Width of ILD Scratches

- **Width(µm) vs. Scratch Counts(ea)**
  - Mean scratch width: 0.53 µm
  - Most scratches width: 0.3 µm ~ 0.6 µm

- **Lip width(µm) vs. Scratch Counts(ea)**
  - Mean scratch lip width: 0.06 µm

**The possible sources of scratches**
- *thin flake* with the width of about 0.06 µm
- *particles* with the diameter of about 0.5 µm
Effect of **Polishing Pressure on Scratches**

- Polishing pressure (psi) vs. COF
- Polishing pressure vs. Scratch count

- The higher polishing pressure, the higher COF and higher number of scratches
The effect of polishing pressure on scratches

- SN (Sommerfeld Number)

\[ SN = \frac{V \cdot \mu}{p \cdot \sigma_{eff}} \]

- V: pad-wafer sliding velocity
- P: applied wafer pressure
- \( \mu \): slurry viscosity
- \( \delta_{eff} \): effective fluid film thickness

- Strubeck-Gumbel curve for CMP application

- It gives direct evidence of the extent of wafer-slurry-pad contact.

The effect of polishing conditions

- The increase of head speed $\rightarrow$ the decrease of removal rate
The effect of *slurries on scratches*

- Top view of scratch by CD-SEM

(a) with fumed silica slurry  
(b) with ceria abrasive

- The polishing condition for the observation of scratches

<table>
<thead>
<tr>
<th>Properties</th>
<th>Fumed Silica</th>
<th>Ceria</th>
</tr>
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<tbody>
<tr>
<td>Mean particle size</td>
<td>180 – 200</td>
<td>220 – 240</td>
</tr>
<tr>
<td>Hardness (Mohs)</td>
<td>6.0 – 7.0</td>
<td>-</td>
</tr>
<tr>
<td>Particle structure</td>
<td>Amorphous</td>
<td>Poly-crystalline</td>
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<tr>
<td>PZC (pH)</td>
<td>2.2</td>
<td>7</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>2.2 – 2.6</td>
<td>7.13</td>
</tr>
</tbody>
</table>
The effect of polishing pad

The SEM images of new and used pad

- **New pad**
  - High removal rate & less micro-scratches

- **Used pad**
  - Many pores are filled by residues.
  - Low removal rate & many scratches
• Removal rates: Pad with pores only: 3076 Å/min, Pad with grooves only: 243 Å/min

• Polishing rate is very much dependent on the presence of pores
The effect of polishing pad types on defects

- Pad with pores and grooves has the lowest defect count.
The effect of polishing pad types on scratches

- Pad with grooves only showed the highest scratch level
The effect of polishing pad

The images of each scratch by CD-SEM at different pad types

- **Only grooves pad**
  - Largest defect size & Large and irregular scratch shape

- **Only pores pad**
  - Scratch shape: similar Caterpillar type
  - Scratch size: larger than that with reference pad
  - Severe underlying pattern failure
The main factors of scratch formation

a. The effect of CMP conditions
   - Increase of P → Increase of scratch #
   - Increase of P → Increase of COF
   - Dependency on head rpm on scratches

b. The effect of slurry types and particle size
   - The scratch formation of same shape and size
   - The lower number of abrasive particles >1 um,
     the lower number of scratches on polished surface

c. The effect of polishing pad
   - Pad with only grooves resulted in the highest number of scratches
   - Pad with pores and grooves has the lowest defect count