Effect of Water Dilution and Method of Slurry Dispense on Silicon Dioxide Removal Rate for STI CMP using a Ceria Slurry

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Outline

- Motivation and ceria-based slurry removal theory
- The Araca slurry injection system (SIS)
- Mixing methods and dilution effects on RR
- Applying the Araca SIS
- Selected Cases Studies

  - Pre-mix dilution
  - Point-of-use dilution (pad-center single-point application)
  - SIS rotation studies
  - Point-of-use dilution (with the SIS at -8°)

- Summary
Experimental Conditions

- **Wafer**: 300-mm blanket Silicon Dioxide
- **Wafer pressure**: 4.0 PSI
- **Platen/Carrier RPM**: 77/75
- **Slurry flow rate**: 100 cc/min
- **Slurry**: HVM Ceria-Based “Reverse”

- **Pad**: DOW IC-1000 K-Groove
- **Conditioner**: 3M A165
- **Conditioning downforce**: 9.91 lbf
- **Conditioning**: In-situ at 95 RPM & 10 per minute sweep frequency
- **Polishing time**: = 20 seconds
Why Reduce Slurry Use?

- Slurry accounts for nearly half of the consumables COO in the CMP module.
- In addition, slurry abrasives and additives present significant EHS issues.
- Slurry utilization efficiency is less than 5% in commercial processes.
- Reducing use or applying “smarter” methods can significantly impact COO and EHS.
The Slurry Injection System (SIS)

• Reduces slurry consumption (usually by 40%).

• Slurry is applied between the injector bottom and the pad (uniform slurry film with minimal MHDL effects due to excess slurry)

• Injector bottom is made of PEEK and it contacts the pad.

• Normally, the injector blocks residual water from entering pad-wafer interface, reducing fresh slurry dilution.

• However, we will use the SIS in this study to increase dilution by modifying the rotational orientation.
SIS Video
SIS Orientation Effects

Pad residual rinse water and used slurry are mostly squeegeed off.

Pad residual rinse water and used slurry are mostly re-directed towards the wafer and are only partially squeegeed off.
A Brief Theory on Ceria-Silica Removal

- $\text{Ce}^{3+}$ is responsible for silica removal

- Stoichiometry states that $\text{CeO}_2$ particles should consist of $\text{Ce}^{4+}$ ions.

- Surface defect model: $\text{CeO}_2$ particles have oxygen vacancies.

- Vacancies lead to localized electrons that reduce $\text{Ce}^{4+}$ to $\text{Ce}^{3+}$

- Particle surface consists of both $\text{Ce}^{4+}$ and $\text{Ce}^{3+}$ (extent of each species modified by additives, stabilizers, ...).

A Brief Theory on Ceria-Silica Removal

• Particular ceria slurries exhibit “reverse” behavior (i.e. we see an increase in RR with increasing dilution).

• Literature claims that Ce$^{3+}$ is responsible for removal, and that addition of water reduces the ionic state of the ceria particle surface.

• Many differing models exist, but all are rooted in same principle (see RHS figure).

• In our case, slurry dilution increases RR.
Ceria RR with “Pre-Mixing” Method

• Slurry and water are pre-mixed in a single tank at each dilution ratio prior to each run.

• Pad is rinsed between each run and then air-dried to remove residual water.

• RR increases with addition of UPW up to a slurry-to-UPW ratio of 1:7.5 owing to increasing presence of Ce$^{3+}$

• Further dilution does not affect RR.

• The ceria binding mechanism is taken over by mechanical limitations past a ratio of 1:7½ (next page)
COF & Temperature with “Pre-Mixing” Method
Average COF & Temperature with “Pre-Mixing” Method
Ceria RR with “Point-of-Use” Method

- Slurry and water are kept in separate tanks and individually pumped to a T-valve at the dispense nozzle.

- Pad is rinsed between each run and then air-dried to remove residual water.

- Similar trend to pre-mix case, but at higher RR for each dilution ratio.

- Likely cause for higher RR: No pre-mixing means FRESH SLURRY; prevents slurry from equilibrating; particles are less agglomerated.
COF & Temperature with “Point-of-Use” Method
Average COF & Temperature with “Point-of-Use” Method
SIS Angle Study – Orientation Schematics

- SIS was rotated to different angles as measured from the center-point of the leading edge.

- Maximum positive rotation angle of 12° (top left).

- Maximum negative rotation angle of -9° (top right).

- The 0° reference point (bottom).
SIS Angle Study – Removal Rates

- Pad is rinsed between each run and IS NOT air-dried to remove residual water.
- RRs increase with increasingly negative angles.
- -8° produces average RR of 2,595 Å/min
- -9° produces average RR of 2,397 Å/min
Pad residual rinse water and used slurry are mostly squeegeed off.

Pad residual rinse water and used slurry are mostly re-directed towards the wafer and are only partially squeegeed off.
SIS Angle Study – Bow Wave Screenshots

- All screenshots taken 7 seconds after ramp-up phase.

- SIS at -8° has a thick retaining ring bow wave that persists longer than other angles.

- Bow wave serves as continual dilution source (i.e. longer persistence means continual dilution).
Ceria RR with Point-of-Use (SIS at -8 degrees)

- Slurry and water are kept in separate tanks and individually pumped to a T-valve at the SIS inlet.
- Pad is rinsed between each run and then air-dried to remove residual water.
- Similar trend to pre-mix case and pad-center POU, but at higher removal rate for each dilution ratio.
COF & Temperature for “Point-of-Use” with SIS at -8 degrees
Average COF & Temperature for “Point-of-Use” with SIS at -8 degrees
Potential Slurry Savings

• Over 1800% increase in RR over manufacture’s specifications

• Using POU with the SIS at -8 degrees consistently yields 1.5X to 3X higher RR compared to “Pre-Mixing”.

• Allows IC producers to lower polishing times or the amount of slurry used (cost savings and reduced EHS concerns).
Average Temperature vs. Average COF for All Dispense Methods

- Data shown for highest dilution ratios (1:5, 1:7½, 1:10 and 1:15).

- SIS runs at a cooler temperature than both pre-mix and POU.

- Despite this, SIS yields the highest RR possibly owing to the increased slurry utilization efficiency.
Summary

- RRs increase with increasing dilution until mechanical removal mechanisms become dominant.

- Method of mixing has appreciable effects on RR.

- SIS angles produce different retaining ring bow waves, yielding different extents of dilution and therefore RRs.

- Combining the benefits of the SIS with POU mixing led to the highest attainable RRs.

- Slurry as well as polishing time savings could be of tremendous benefit to overall COO while also avoiding large environmental, health, and safety issues.