New Developments in the Characterization of CMP Pad Conditioners

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Overview

- CMP Consumables: Applications Trends
- New Pad Conditioners: Challenges and Objectives
- CMP Pad and Pad Conditioner Characterization
- Functional Performance Analysis of Conditioners
- Sample Pad Cut-Rate and Surface Roughness Data
- Selected Results from Tribological Studies
- Summary and Conclusions
**CMP Consumables - Applications Trends**

- **Increasing complexity and changing requirements of next-generation CMP processes**
  - More stringent specifications of CMP solutions for 22 nm and smaller technology nodes
  - Introduction of thinner wafers, copper, ultra low-k, high-k, and other newer materials

- **Emerging applications, new consumables, APC, integrated metrology and RTPC**
  - Different applications may have unique CMP, PCMP cleaning, and metrology requirements
  - eSIC, TSVs, T-RAM, SOI, GaAs, 3-D ICs, MEMS, DWB, and photonic bandgap devices

- **CMP consumables/system suppliers and end users more interested in collaboration**
  - Suppliers and users interested in joint development & evaluating of new consumables
  - Reduce CMP CoO, minimize development/optimization time and repetition of efforts

- **Parallel evaluation of CMP new and disruptive technologies by end users and suppliers**
  - Fixed abrasive, Electro-CMP (ECMP), and Chemically Enhanced Planarization (CEP) may offer advantages for productivity/yield, low stress for ULK dielectrics, and Cu loss
Next Generation CMP Pad Conditioning: Challenges and Objectives

- CMP intensity and complexity (15 CMP steps in 180 nm Logic device and 32 steps in a 32 nm Logic device) is increasing and it continues to be the enabling process of choice for the next generation applications.

- CMP pad conditioning is critical for maintaining pad surface, preserving device yield, and reducing defectivity. Pad conditioner’s performance must be optimized to maintain desired pad morphology throughout pad’s lifetime.

- New generation of conditioners must be created with the goals of significant cleanliness (extractables and particulate) improvements, and more stringent control of abrasive features/contacts size and shape distributions.

- Pad conditioning for advanced processes should provide most consistent pad surface: free from ionic contamination and diamond pull out, and with significantly enhanced process stability as well as extended pad lifetime.

- New pad conditioner designs need to be much more gentler and tunable in nature, with usage in many different applications. Such designs should also contribute to increases pad & conditioner lifetime and reduced CoO for CMP.
CMP Pad Conditioners

- A Typical CMP Pad conditioner uses diamond grit, 35 micron – 250 micron size, randomly or structurally arrayed on a substrate, brazed, electroplated or sintered in place.

- Conditioners may have between 20,000 – 300,000 diamonds, with < 20% active

- Diamond Issues
  - Breaking / release
  - Size, shape and height Variability
  - Wide pad cut-rate range
  - Chemical Compatibility
  - Shorter life
Quality and consistency of CMP Pad throughout its lifetime is essential to obtaining required wafer planarization (low and stable within-wafer and wafer-to-wafer non-uniformity) in the next-generation applications.

Well designed, appropriate material CMP pad can provide desired wafer polishing rates, uniform surface finish and a tight flatness tolerance, in addition to higher material stability and low vibration characteristics.

Key considerations for CMP pad design include:

- Stability and consistency of the pad material and geometry, extended lifetime, and low-level and highly-stable coefficient of friction (COF) between the pad and retaining ring, as well as the pad and conditioner
- Low and uniform wear rate for the CMP Pad, negligible release of debris and extractables from pad, conditioners and rings, and optimized slurry flow through the pad grooves and across the wafer for reduced CoO

Innovative pad groove designs can provide more consistent performance of retaining ring and extend pad lifetime. Optimized pad designs should also result in higher yields and reduced defectivity in new applications.
Key Considerations and Parameters for Pad Conditioner Characterization

- Good conditioners provide conditioning with: (i) less aggressiveness (longer pad life), and (ii) more effectiveness (shorter time for the pad break-in and to stabilize COF). There is a trade-off between conditioner effectiveness (desirable to be high) and conditioner abrasiveness (desirable to be low to provide longer pad life).

- Pad wear rate characterizes the abrasiveness (or aggressiveness) of the conditioner, and it is desirable to have a lower value of it. The pad refreshing rate characterizes the effectiveness of the conditioner. Key parameters include: Pad cut-rate, pad surface roughness, COF and its stabilization time, effectiveness, stability, and durability of the pad conditioners.

- Pad cut-rate and its variation over time is quantified employing the same operating conditions and different consumables set. Benchtop 6 - 12 hours marathon tests are typically conducted measuring mean and fluctuating COF, pad cut-rate, pad surface roughness, temperature, and downforce.

- Relative chemical cleanliness of conditioners can be tested by extraction tests of samples in clear chemicals and slurry blends. It is useful to understand the tribological behavior of different conditioners over time with various pad materials, to identify the “pad and conditioner set” for optimum performance in the CMP process.
The relative functional quality of pad conditioners can be evaluated using benchtop tribomemers. The method can be broadly divided into following two tests:

- **Test 1** involves conditioning the pad with DI water for a period of 30 minutes or longer to measure pad wear rate, characterizing the “Conditioner aggressiveness”.

- This test quantifies the “COF stabilization time”, which may be an important factor to compare conditioner “Effectiveness and consistency”.

- Here, it is hypothesized that the lower the COF stabilization time the more effective the conditioner is, since it would take less time to condition the pad and result in extended pad lifetime. This test may also be repeated with slurr.

- **Test 2** involves a more thorough method to measure “Conditioner effectiveness”. This employs glazing the pad with a 3” wafer in an oxide CMP slurry until the COF is stabilized at the glazed-pad level.

- The above is followed by continuous pad conditioning in the same slurry until the COF is stabilized at the conditioned-pad level. The measured stabilization time for different conditioners is a good measure of “Relative conditioner effectiveness”. The lower the COF stabilizing time the more effective the conditioner is.
**CMP Applications Lab Capabilities for Pad Conditioner and other CMP Consumables Characterization**

- **Custom CETR Tribometer**
  - Planarcore process characterization (shear and normal force, COF, Stribeck curves, etc.)
  - Conditioner characterization; Pad cut-rate and surface roughness, diamond wear, COF, temp.

- **Downforce and shearforce characterization**
  - Static and Dynamic

- **Particle characterization**

- **Analytical & Product Evaluations Laboratory**
  - ESEM, optical microscopy
  - Tensile strength, compressibility

**Laser Confocal Microscope**
Olympus LEXT OLS4000
Particulate Characterization

**ICPMS**
- Model: HP-7500, Agilent
- Principle: Trace metals are ionized in a high temperature plasma. Ions produced are separated and detected by mass spectrometer. Quantitative concentrations are gotten by comparing the intensity of the sample signal with the calibration curve. It is a very powerful and high sensitive multi-elements analysis technique.

  - Application:
    - Routine 13 metals analysis, including Na, Mg, Al, K, Ca, Cr, Mn, Fe, Ni, Cu, Ti, Zn, and Pb.
    - Water samples 16 metals analysis.
    - Water samples boron analysis.
    - Water samples silicon analysis.
    - Contamination root cause analysis.
    - Products and raw material cleanliness analysis.

**Accusizer 780**
**Liquilaz S05 & S02**
**Horiba LA-930**

**ESEM**

**APD-800 300 mm Polisher and Tribometer**

**Custom CETR Tribometer**
with CMP and 300 mm PVA Brush Test Module
Pad Conditioners Extended Period Testing on Buehler Polisher and CETR Tribometer

- This pad conditioning characterization study was conducted to generate extended period (Test A: 30 hour runs on Buehler benchtop polisher; Test B: 9 hour runs on CETR Tribometer) baseline pad cut-rate and surface roughness data using IC1000 pad with 4 different pad conditioners.

- The 12” pad rotational speed for all Buehler tests was held constant at 50 RPM, with conditioner downforce of 7 lbs, and the conditioner rotational speed of 35 RPM. DI water flow was constantly fed on the pad surface @ rate of 80 mL/min during conditioning tests using a Levitronix BPS-1 pump.

- The 6” pad rotational speed for all CETR Tribometer tests was held constant at 100 RPM, with conditioner downforce of 7 lbs, and conditioner rotational speed of 90 RPM. DI water flow was fed on the pad surface @ rate of 30 mL/min during conditioning tests using a Levitronix BPS-1 pump.
Pad Cut-Rate and Surface Roughness Data
30 Hours Marathon Test: Buehler Test

IC1000 Pad Cut-Rate Data for Conditioner A

- Cond A: Cut-Rate
- Cond A: Surface Finish
- Linear (Cond A: Surface Finish)
- Linear (Cond A: Cut-Rate)

Pad Cut-Rate Per Hour (Microns)

Surface Roughness, Ra (Microns)

Conditioning Time (Hours)

New Pad
Pad Cut-Rate and Surface Roughness for Different Pad Conditioners: CETR Tribometer

IC1000 Pad Cut-Rate and Surface Roughness for Different Pad Conditioners

- Pad Ra, Conditioner 4
- Pad Ra, Conditioner 3
- Pad Ra, Conditioner 2
- Pad Ra, Conditioner 1
- Pad Cut-Rate, Conditioner 4
- Pad Cut-Rate, Conditioner 3
- Pad Cut-Rate, Conditioner 2
Copper Wafer Polishing Results for Different Pad Conditioners: Araca APD-800 Data

Copper CMP Results

Araca APD-800 CMP Polisher
FujiFilm Planar Solutions
CSL9041C Cu CMP Slurry

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<th>Conditioner 3</th>
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<tr>
<td>Wafer RR (A/min)</td>
<td>8373</td>
<td>6483</td>
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<tr>
<td>Surface Roughness, Ra (microns)</td>
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The pad surface roughness after 30 Hrs of conditioning (Sa of 5.698 µm) is nearly identical to the new conditioner.
Pad Surface Roughness Measurement: Confocal Microscope Data

**Analysis parameter**

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**Datsheet**

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<th>Result</th>
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**Line roughness**

- Ac: 80.0 μm
- 250 μm
- 800 μm
- None
- As: 2.5 μm
- None
- M: 125 μm
- None
New developments in CMP pad conditioner characterization methods are discussed, with test protocols for lab scale evaluations. Results of case studies are presented with representative data.

A number of 4” disk pad conditioners were analyzed using benchtop polisher and tribometer to determine pad cut-rate and surface roughness behavior.

An Araca APD-800 300mm wafer polisher was used for polishing Cu wafers. The results demonstrate significantly different behavior the pad cut-rate and surface roughness for different conditioners.

Further evaluations are continuing to determine the effects of pad and conditioner parameters, including abrasive/feature type/size and distribution, on wafer RR, and pad properties.
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