Post-CMP Clean PVA Brush Advancements and Characterization in Cu/Low-K Application

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The stable behavior of brush-wafer contact-pressure, contact-area and dynamic-friction could be useful indicators of post-CMP (PCMP) cleaning effectiveness and mechanical consistency of polyvinyl alcohol (PVA) brushes over brush lifetime. The newly developed advanced molded-through-the-core (MTTC) PVA brush design with a disposable core and positive anchoring of PVA to the core, eliminates the possibility of PVA slippage at the PVA-core interface and results in consistent performance throughout the brush lifetime. PCMP cleaning methods and brush designs are discussed with the evolution of PCMP cleaning chemistries and the mechanism of the particle removal through brush scrubbing. Accelerated tribological stress evaluation (48-hour marathon run) of PVA brushes employing two slip-on-the-core (SOTC) brushes (A and B) and one MTTC brush (C), demonstrates a very different behavior of wafer-liquid-brush contact-pressure, contact-area and dynamic coefficient of friction (COF). Brushes A and C showed a more consistent behavior of mean COF, whereas design Brush B experienced catastrophic failure somewhere between two and eight hours. The total variation range of COF for the MTTC Brush C was found to be minimal. In another test, the PCMP cleaning performance of Entegris PVA MTTC design brushes was found to be similar or better than the fab POR SOTC design brushes. This study highlights the importance of PCMP clean brush design (chemically, mechanically and dimensionally) and the methods of tribological and PCMP cleaning evaluations to ensure consistent wafer cleaning performance throughout the brush lifetime.

INTRODUCTION

In PVA brush PCMP cleaning, the particle removal is accomplished by a direct contact between the brush and the wafer surface, in which the brush asperities engulf the wafer surface contaminants and the rotational motion of the brush and the cleaning fluid supplied to the wafer surface dislodge and carry the particle away from the wafer. The chemical cleaning action depends on the nature of the chemicals in the PCMP cleaning chemistries, which typically provide a desirable zeta potential environment for efficient removal of particles away from the wafer and brush PVA, and also resist any particle redeposition on surfaces. Newly developed MTTC (Figures 1–2) roller brushes provide positive anchoring and absolute adhesion of PVA with the core. This eliminates any possibility of slippage of PVA at the PVA-core interface, unlike SOTC conventional brushes, especially in the latter part of the brush lifetime. Advantages and limitations of PVA roller brush designs in the double-sided PVA brush scrubbing processes are discussed with the results of an accelerated tribological stress evaluation (48-hour marathon run) of PVA brushes. Results show that those brushes that experienced the least amount of deformation variability during the 48-hour marathon test also exhibited the least amount of variability in their frictional attributes. The PCMP cleaning comparative performance of Entegris PVA MTTC design brushes in a Cu/Low-k process was found to be similar or better than the fab POR SOTC design brushes in a third party characterization of brushes. The present study highlights the importance of PCMP clean brush design and methods of tribological and PCMP cleaning evaluations to ensure consistent frictional characteristics and wafer cleaning performance over brush lifetime.

POST-CMP CLEANING PROCESS CHARACTERISTICS

CMP processes use abrasive slurries for planarization. After CMP, the wafers need to be cleaned to remove the slurry abrasive, organic residues and other particles. This PCMP cleaning is accomplished employing different tools and PCMP clean chemistries. Advanced CMP tools have integrated PCMP modules, enabling the wafer cleaning cycle to be dry in and dry out to prevent contamination. The PCMP cleaning chemistry is typically sprayed on top of the brush, with DI water flowing out through the core. A combination of chemical action (provided by cleaning chemistry) and mechanical action of the rotating PVA brush removes the wafer surface deposits. With NH_4OH at pH ~10 – 11, the PVA brush, wafer and the slurry abrasive particles all have similar negative zeta potential. The above results in repulsion between the PVA and the particles; no particles are deposited on the PVA or the wafer and there are no scratches. An efficient PCMP process removes particles, organic residues and ionic contamination, controls the copper corrosion, prevents water marks on the dielectric and leaves the polished surface free from all defects, providing consistent process throughput and cost of ownership. The cleaning performance of PVA brushes strongly depends on the chemical and mechanical properties, the stability of the brush material, the magnitude of the wafer-brush frictional force, and adhesion forces between the particle and the wafer, as well as between the particle and the brush.

COMMON POST-CMP CLEANING TECHNOLOGIES

- Megasonic
- Double-sided brush scrubbing
  - Slip-on-the-core (SOTC) brush
  - Molded-through-the-core (MTTC) brush

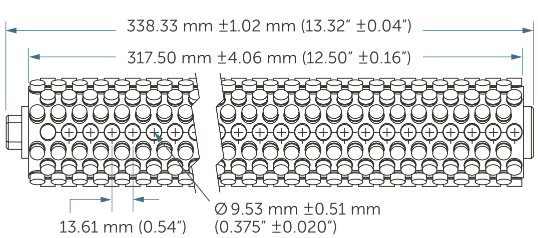


Figure 1. Planarcore PVA brush with polypropylene core.

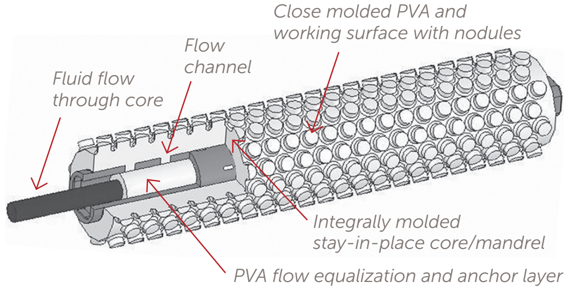


Figure 2. Molded-through-the-core (MTTC) design PVA brush (Planarcore).

PLANARCORE PVA BRUSH DESIGNS FOR POST-CMP CLEANING APPLICATIONS

PVA brushes used to be an industrial product before being introduced at IBM and commercialized in the early 1990s. Entegris' MTTC design is a disposable PVA brush that reduces tool downtime and provides excellent dimensional stability over its lifetime. The MTTC design provides positive anchoring of PVA to the core and eliminates the possibility of any slippage at the PVA-core interface (possible in conventional SOTC design brushes, especially in the latter part of their lifetime due to possible swelling of the PVA). The MTTC design also provides very good core flow equalization, resulting in throughout-brush-lifetime consistency in the PCMP cleaning performance. In the particle removal, through PVA brush scrubbing, during PCMP cleaning the PVA is compressed when it contacts a particle adsorbed on the surface of the wafer. Pores and asperities on the surface of the brush capture the particle and cause the exposed surface of the particle to adsorb on the surface of the brush (mechanically, chemically or by capillary suction). Torque created by the rotation of the brush dislodges the particle from the surface. Fluid present on the wafer surface, and being pumped in and out of brush pores (during compression and elastic recovery of the brush), carries the particle away from the wafer.

CASE STUDY 1

PVA Brushes Tribological Performance in Cu/Low-k Application

Factors affecting cleaning efficiency: Contact pressure at the brush PVA nodule surface and the wafer; physical and chemical properties of cleaning fluid and its flow rate; overall kinematics of the brush in relation to the tool; cleaning time; mechanical properties of the brush; magnitude of frictional forces between wafer and brush relative to magnitude of adhesion forces between particle and wafer and particle and brush

The present study addresses how the extent of brush deformation (as measured by the brush-pressure versus brush-wafer contact-area curves) and the magnitude of frictional forces (as measured by the brush-fluid-wafer coefficient of friction, COF) vary as a function of extended use for various types of brushes. The above information is critical in predicting brush performance consistency. The results of this study are presented in Figures 3 – 11.

Table 1. Case study 1 experimental conditions and setup

CONSTANTS	
Applied pressure	0.5 psi
Cleaning solution type and flow rate	Ashland CP – 70 @ 120 cc/min
Brush rotational velocity	60 RPM
Wafer rotational velocity	40 RPM
Frictional force data acquisition frequency	1,000 Hz (3.6 million samples/hour)
Wafer type	200 mm International Sematech® MIT854® copper wafer
Scrubbing time	48-hour marathon run (continuous)

All tested PVA roller brushes were similar in dimension, commercially available and had cylindrical nodules.

PVA brush type

A – Slip-on-the-core PVA sleeve design from Supplier A
B – Slip-on-the-core PVA sleeve design from Supplier B
C – Molded-through-the-core PVA design from Supplier C (Entegris Planarcore brushes)

BRUSH A TEST DATA

Brush A (SOTC Design) COF Results

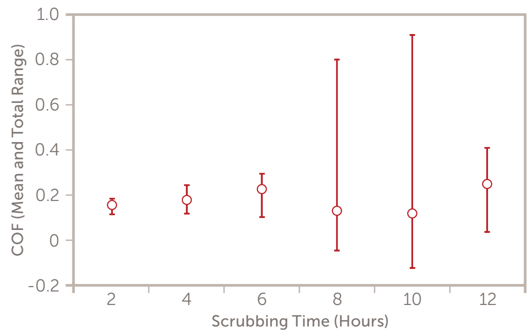
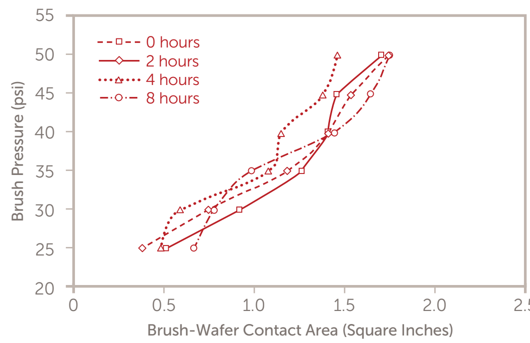


Figure 3. Brush A (SOTC design) COF results.

Brush A Pressure Contact-Area Plot*



Enveloped area bounded by curves shows extent of brush deformation

Figure 4. Brush A pressure contact-area plot.

Brush A Pressure Contour Maps for Various Applied Brush Pressures

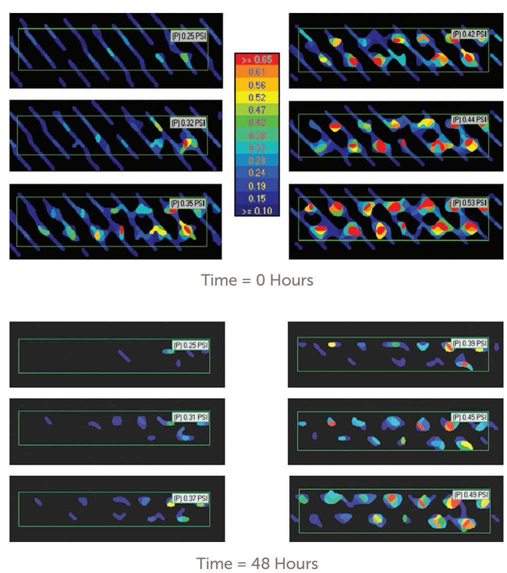


Figure 5. Brush A pressure contour maps for various applied brush pressures

BRUSH B TEST DATA

Brush B (SOTC Design) COF Results

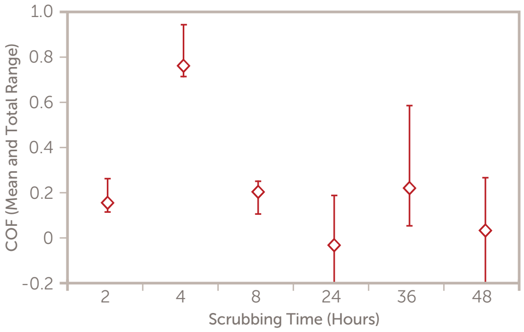
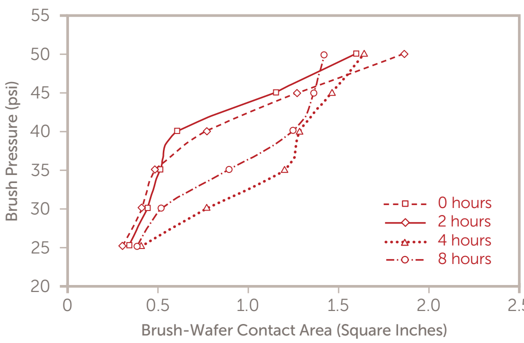


Figure 6. Brush B (SOTC design) COF results.

Brush B Pressure Contact-Area Plot*



*Enveloped area bounded by curves shows extent of brush deformation

Figure 7. Brush B pressure contact-area plot.

Brush B Pressure Contour Maps for Various Applied Brush Pressures

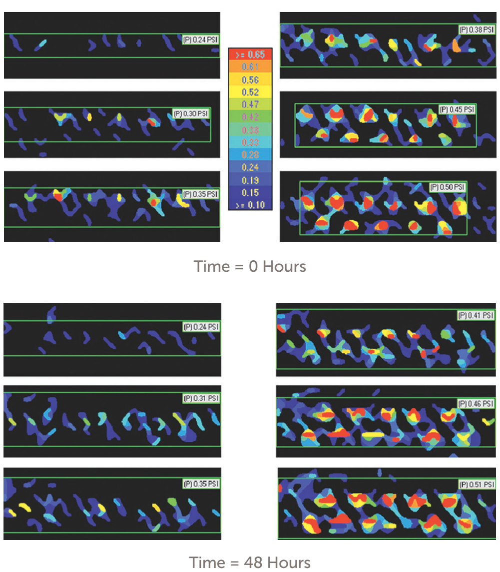


Figure 8. Brush B pressure contour maps for various applied brush pressures.

BRUSH C TEST DATA

Brush C (MTTC Design) COF Results

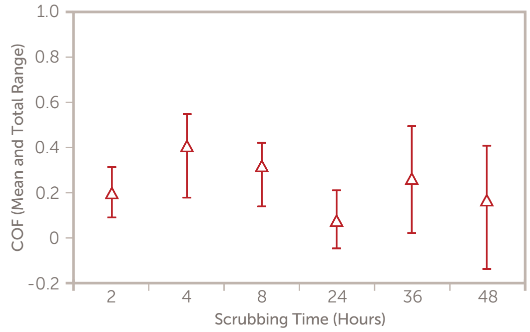
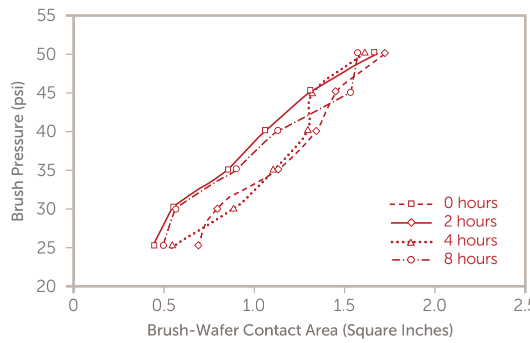


Figure 9. Brush C (MTTC design) COF results.

Brush C Pressure Contact-Area Plot*



*Enveloped area bounded by curves shows extent of brush deformation

Figure 10. Brush C pressure contact-area plot.

Brush C Pressure Contour Maps for Various Applied Brush Pressures

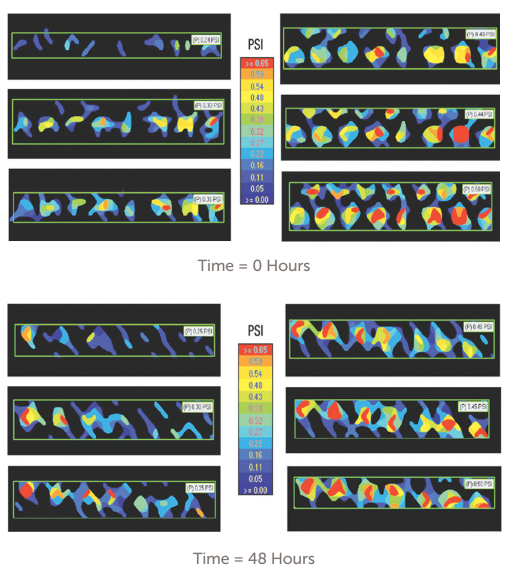


Figure 11. Brush C pressure contour maps for various applied brush pressures.

CASE STUDY 2

PVA Brushes PCMP Cleaning Performance in Cu/Low-k Application

OBJECTIVE

To generate comparative PVA brush PCMP cleaning data (defect maps/classification) for Entegris PVA (molded-through-the-core design) and third-party fab POR (slip-on-the-core design) brushes in a 90 nm production fab, using 200 mm blanket and 180 nm feature MIT854® Cu/Low-k patterned wafers on a Mirra Mesa® CMP toolset PCMP cleaner.

TESTED BRUSHES AND EQUIPMENT SET

- Entegris MTTC technology brushes: PP core (enhanced cleanliness), thicker PVA (more tunable wider range downforce) and advanced PVA foam cleaning process (resulting in less particle shedding and shorter brush break-in cycle).
- POR brushes: competitor SOTC design PVA brushes used as POR at the third-party site.
- CMP tool and cleaner: AMAT™ Mirra Mesa
- Wafer metrology:
  - KLA-Tencor® Surfscan® 6420
  - KLA-Tencor SP1 (for blanket wafers)
  - KLA-Tencor 2139 Wafer Inspection System
  - KLA-Tencor AIT XP Wafer Inspection System (for patterned wafers)

Process conditions were optimized for the current POR brush and were not specifically modified to ensure good comparative data for each brush. Selected results are included in the next section. Defectivity classification data from this study are presented in Figure 12.

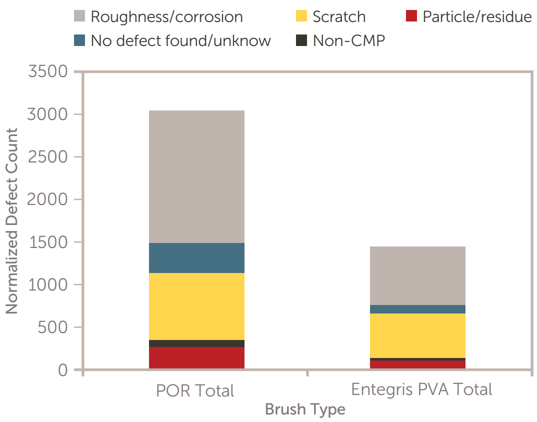


Figure 12. Average AIT XP pareto of defects for two PVA brush types.

SUMMARY AND CONCLUSIONS

- Accelerated tribological stress evaluations (48-hour continuous marathon tests) of three post-CMP clean PVA brushes, including two slip-on-the-core design brushes (types A and B) and one molded-through-the-core design Entegris Planarcore PVA brush (type C), demonstrate a very different behavior of wafer-liquid-brush contact-pressure, contact-area and dynamic coefficient of friction (COF).
- Brush A and Brush C showed a more consistent behavior of mean COF, whereas design Brush B experienced catastrophic failure somewhere between two and eight hours, from start of test. The total variation range of COF for Brush C (molded-through-the-core design) seems to be minimum.
- Results demonstrate that those brushes that experienced the least amount of deformation variability during the 48-hour marathon test also exhibited the least amount of variability in their tribological or frictional attributes.
- The stable behavior of brush-wafer contact-pressure, contact-area and dynamic-friction could be useful indicators of post-CMP cleaning and mechanical consistency of PVA brushes over lifetime.
- The post-CMP cleaning comparative evaluation of Entegris molded-through-the-core design PVA brushes (Planarcore) in a Cu/Low-k process was found to be similar or better than the fab POR slip-on-the-core design brushes in a third-party characterization of brushes.
- This study demonstrates the importance of post-CMP clean brush design (chemically, mechanically and dimensionally) and methods of tribological and post-CMP cleaning performance characterization of the PVA brushes for ensuring consistent frictional characteristics and cleaning behavior throughout the brush lifetime.

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