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POST-CMP CLEANING APPLICATIONS: CHALLENGES AND OPPORTUNITIES

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Summary and Conclusions

CMP process defectivity and yield performance depends on effectiveness of the post-CMP (PCMP) cleaning process which should reduce roughness of the polished wafer and leave it defect-free, consistently removing particles (nanometer size in smaller feature next generation devices), organic residues, and ionic contamination. This paper presents an overview of PCMP wafer cleaning attributes, trends, challenges and opportunities. PCMP cleaning effectiveness depends on the stability of brush PVA (Poly Vinyl Alcohol) properties, magnitude of brush-wafer frictional force, and the adhesion forces between the particle and wafer, and the particle and brush. Evolution of current and next generation PVA roller brushes designs and discussed.

Tribological and PCMP cleaning performance characterization approaches for brushes are presented with some recent test data. Molded-through-the-core (MTTC) brush design with an integral/disposable core provides positive anchoring and adhesion of PVA with the core and excellent dimensional stability, eliminating any possibility of PVA slippage at the core interface unlike slip-on-the-core (SOTC) brushes. 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 PVA brushes over brush lifetime. This paper presents data from tribological studies using a new benchtop tribology tester (specifically developed for PVA brushes) and a 200 mm wafer test tribometer (accelerated 48 hour tribological stress evaluation).

This study also reports results of comparative PCMP cleaning effectiveness fab evaluation of PVA brushes. This test involved MTTC and SOTC brushes, evaluated under brush break-in, scrub only and PCMP cleaning cycles, after Cu/Low-k barrier step CMP process in a 90 nm production fab using 200 mm (blanket and 180 nm feature MIT854 patterned) wafers on Mirra Mesa tool set. 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, and demonstrates the benefits of using MTTC design PVA brushes in the Cu/low-k PCMP cleaning applications.

1. Wafer Cleaning Attributes and Trends

Current PCMP wafer cleaning processes are contact cleaning techniques which use chemical as well as mechanical action to effectively remove the particles from the wafer surface. Brush cleaning is a very effective PCMP cleaning technique and in an optimum mode, a contact between the particle and the brush is essential to the removal of submicron size particles from the wafer surface. In this operation, Rm>>1 for a 0.1 micron particle, for typical brush and wafer speed, based on a recent experimental study at the Northeastern University, where Rm is the ratio of removal moment to adhesive moment, and the particles are removed if Rm>1.

In the above reported test, 100 % particle removal could be achieved, employing intermediate brush pressure, speed and time. Studies show that brush cleaning is effective in removing particles down to 0.08 micron with different PCMP clean chemistries. Non-contact megasonic cleaning is also very effective in PCMP cleaning. It appears that the current and next generation PCMP cleaning process will continue to depend on PVA brush together with megasonic cleaning in the foreseeable future.

Based on recent published literature, the requirements of surface cleaning must be considered while designing future generations of ICs, since 60 % of fab-related (yield) problems are related to cleans and another 12 % to etching steps, and the design dominates how wet processing is done and processing limitations influence the design process. To meet next generation challenges, many of the cleaning chemistries and approaches will have to change. There are plenty of potential solutions being considered for 45 nm and beyond, and the IC manufacturers will need to adopt new etch chemistries and cleaning regimens for the next generation devices.

Suggested non-damaging nanoparticle removal technologies include: Shock tube-enhanced laser-induced plasma (LIP) shockwaves for sub-50 nm nanoparticle removal, plasma-assisted cleaning by electrostatics (PACE), an ionized molecular-activated coherent solution, and parametric nanoscale cleaning by forming nanoscale bubbles to absorb the contaminants. On photoresist issues, several new or enhanced methods may be used for minimizing silicon and oxide loss during removal, including: photoreactive cleaning, a CO_2 cryogenic press and non-oxidizing chemistry, and methodologies for all-wet chemistries.

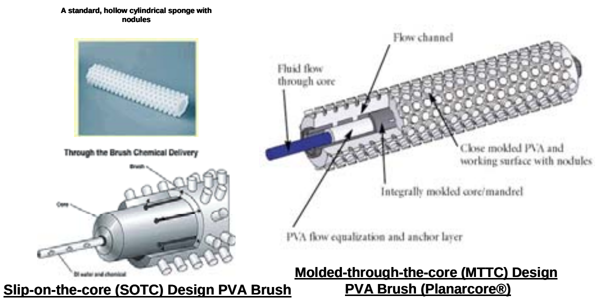
2. Post-CMP Cleaning Process and PVA Brush Design Evolution

Cleaning performance of PVA brush strongly depends on the chemical and mechanical properties and stability of the brush material, magnitude of wafer-brush frictional force, and adhesion forces between the particle and wafer as well as the particle and brush. Zeta potentials of the particle and the wafer in various cleaning solutions and pH of the CMP slurry are very important in the particle adhesion and removal in PCMP cleaning process. Common PCMP technologies include megasonic and double PVA brush based scrubbing (Fig. 1). MTTC design is a disposable PVA brush that reduces tool downtime and provides excellent dimensional stability over its lifetime.

This design eliminates possibility of any slippage at the PVA-core interface (possible in conventional SOTC, especially in the latter part of their lifetime due to possible swelling of PVA). PVA brushes based scrubbing seems to be part of the next generation PCMP cleaning. New processes will require: low particle level PVA brushes for Cu/low-k applications and improved PVA with lower extractable levels for cleaner processes. Also, specific applications may require charged, IPA resistant, or Cu/Low-k specific, and/or next generation CMP slurry compatible PVA brush technology.

More stringent cleaning process requirements over brush lifetime may require innovative products such as MTTC brushes. MTTC design with its positive adhesion/anchoring of PVA with the core provides ease of use and time saving, excellent dimensional stability, improved flow equalization in the core, and very uniform flow distribution (out-of-the-brush) along the brush length. Also, improved and cleaner PVA results in reduced particle counts/adders on the wafer, decreased defectivity, reduced tool downtime, and more consistent PCMP cleaning.

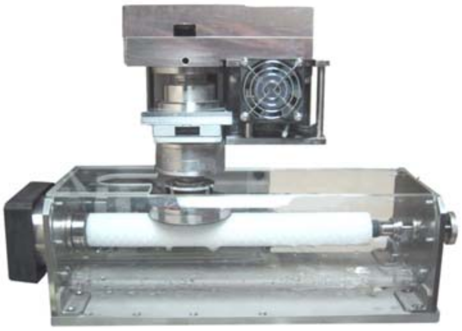
Fig. 1. PVA Roller Brush Designs.



Slip-on-the-core (SOTC) Design PVA Brush

Molded-through-the-core (MTTC) Design PVA Brush (Planarcore®)

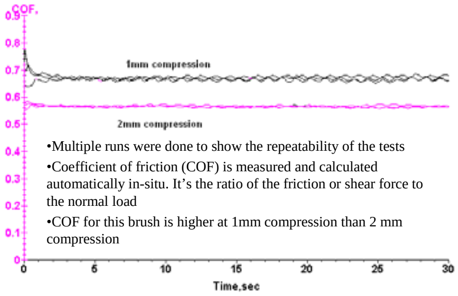
Fig. 2. Tribological Tester for PVA Brushes.



3. Characteristics of a New PVA Brush Tribological Evaluation Tool

A new PVA brush benchtop tribological testing system (CETR modified PMT) was developed at the Center for Tribology (Fig. 2). Parameters measured by this tool include: coefficient of friction (COF), skin friction and normal force, creep and effect of chemistries, adhesion force, compressibility, Stribeck curves, temperature, acoustic properties, and material wear rate and lifetime. The PMT can accommodate full-size brushes or smaller brush-coupons on semiconductor wafers, magnetic disks, flat displays and other to-be-cleaned specimens. Typical data from such measurements for different brushes are included in Figs. 3a – 3h below.

Fig. 3a. Coeff. of Friction (COF) Results of a PVA Brush.



Process Conditions

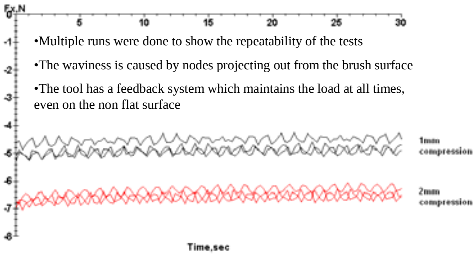
Brush rotating at 400 RPM

Water flow rate 60 mL/min

Wafer rotating at 100 RPM

- Multiple runs were done to show the repeatability of the tests
- Coefficient of friction (COF) is measured and calculated automatically in-situ. It's the ratio of the friction or shear force to the normal load
- COF for this brush is higher at 1mm compression than 2 mm compression

Fig. 3b. Skin Friction Results of a PVA Brush.



Process Conditions

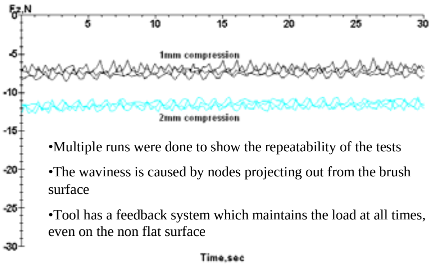
Brush rotating at 400 RPM

Water flow rate 60 mL/min

Wafer rotating at 100 RPM

- Multiple runs were done to show the repeatability of the tests
- The waviness is caused by nodes projecting out from the brush surface
- The tool has a feedback system which maintains the load at all times, even on the non flat surface

Fig. 3c. Normal Load Results of a PVA Brush.



Process Conditions

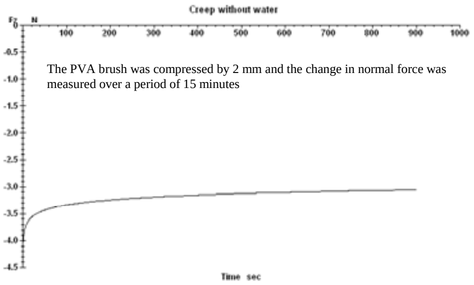
Brush rotating at 400 RPM

Water flow rate 60 mL/min

Wafer rotating at 100 RPM

- Multiple runs were done to show the repeatability of the tests
- The waviness is caused by nodes projecting out from the brush surface
- Tool has a feedback system which maintains the load at all times, even on the non flat surface

Fig. 3d. Creep Measurement Data of a PVA Brush.



Process Conditions

Brush stationary

Water flow rate 0 mL/min

Wafer rotating at 0 RPM

The PVA brush was compressed by 2 mm and the change in normal force was measured over a period of 15 minutes

Fig. 3e. Stribeck Curves for Different PVA Brushes.

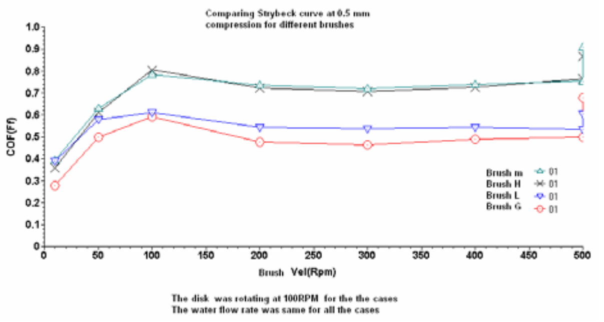


Fig. 3f. Stribeck Curves for Brush with Different Chemistries.

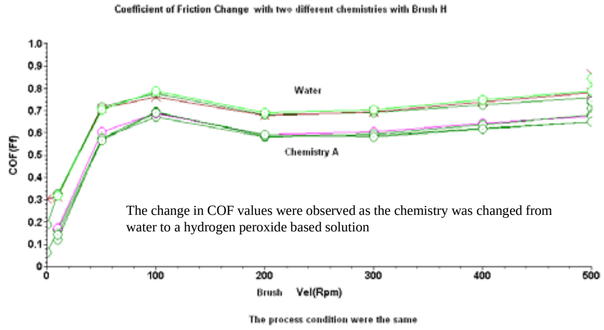


Fig. 3g. Example of Static Friction Data for a Brush.

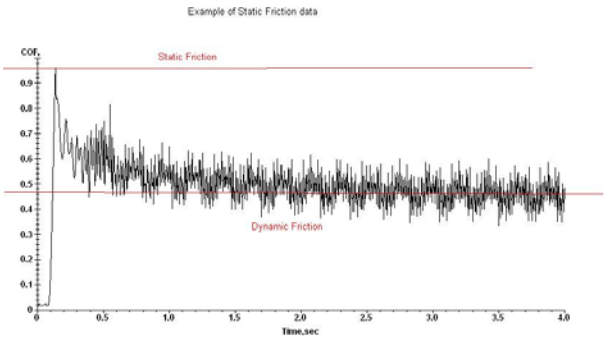
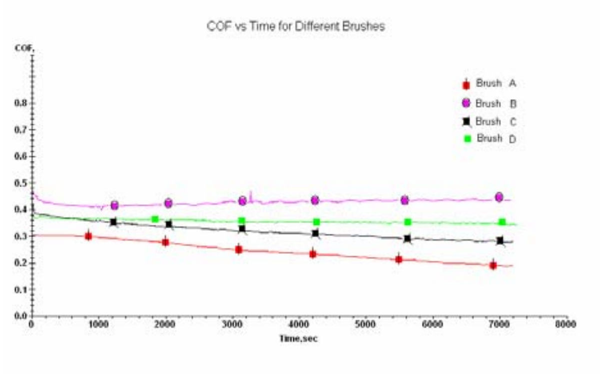


Fig. 3h. COF Vs. Time Data for Brushes.



4. Results of PVA Brush Characterization Studies

(A) Case Study 1 – PVA Brushes Comparative Tribological Performance

An accelerated tribological stress evaluation (48 hour marathon run) of PVA brushes was conducted employing two slip-on-the-core (SOTC) brushes (A and B) and one MTTC brush (C) at the University of Arizona. These tests demonstrate a very different behavior of wafer-liquid-brush contact–pressure, contact–area, and dynamic coefficient of friction (COF) for different brushes. Brushes - A and - C showed a more consistent behavior of mean COF, whereas design Brush - B experienced catastrophic failure somewhere between 2 and 8 hours (Figs. 4a, 4c and 5). Further, the total variation range of COF for MTTC Brush - C was found to be minimum (Fig. 5). The experimental conditions and equipment details for this study are included on the next page.

These tests also demonstrate 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 (Figs. 4b and 4d). This information is critical for brush performance consistency. Results further 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 frictional attributes.

Fig. 4a. COF Results for Brush – B (SOTC Design).

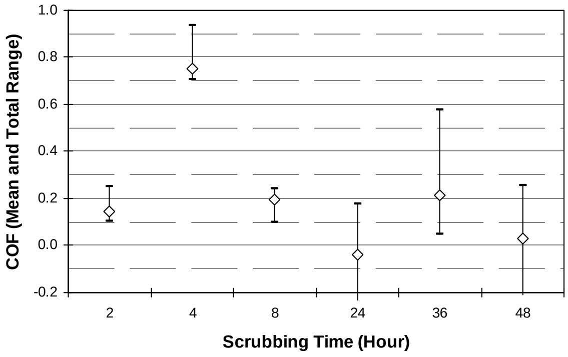


Fig. 4b. Pressure Contact-Area Plot for Brush – B. (The enveloped area bounded by the curves shows the extend of brush deformation)

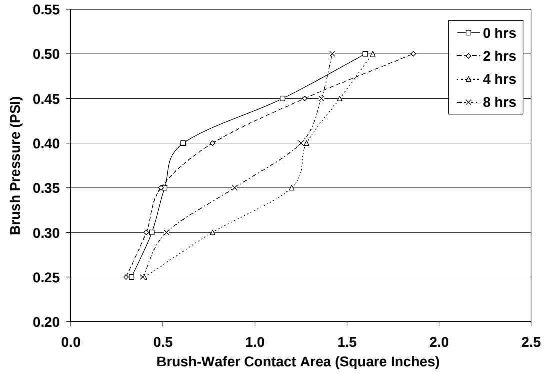


Fig. 4c. COF Results for Brush – C (MTTC Design).

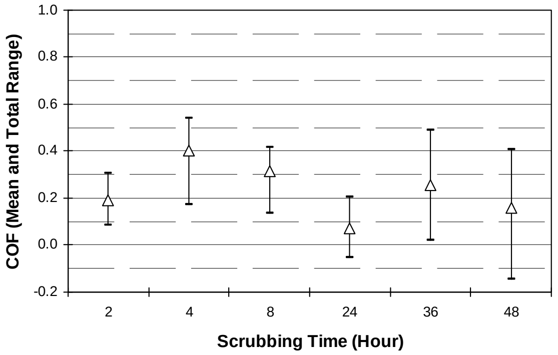


Fig. 5. COF Mean and Total Fluctuation Range during 48-Hour Accelerated Stress Test for Brushes - A, - B, and - C.

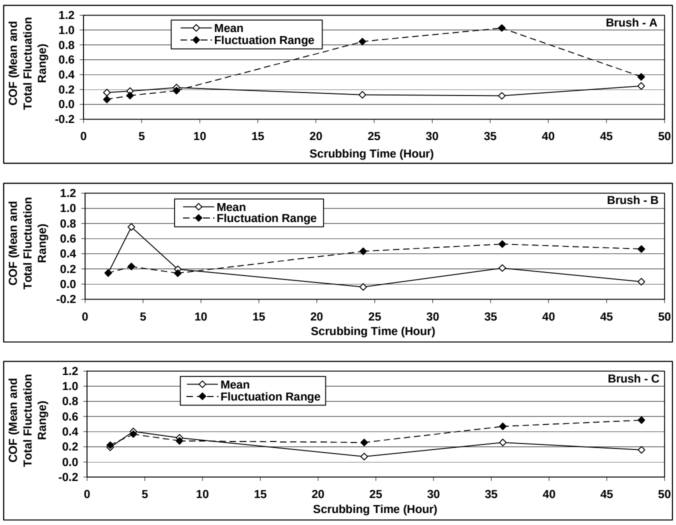
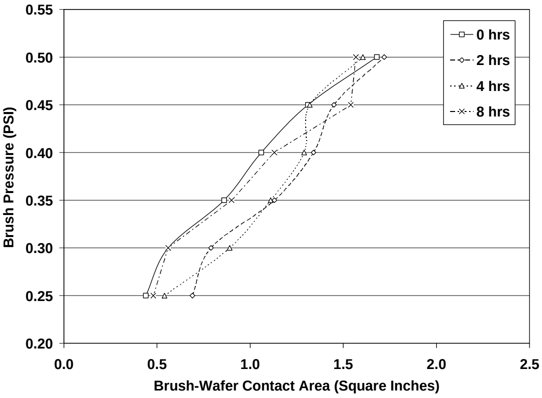


Fig. 4d. Pressure Contact-Area Plot for Brush – C.



Experimental Conditions and Equipment

Constants: Applied pressure = 0.5 PSI, Cleaning solution type and flow rate = Ashland CP – 70 at 120 cc/min, Brush and wafer rotational velocity = 60 and 40 RPM, respectively, Frictional force data acquisition frequency = 1,000 Hz (3.6 million samples / hour), Wafer type = 200-mm International Sematech 854 Copper wafer, Scrubbing time = 48 Hours marathon run (continuous). All tested PVA roller brushes were similar in dimension, commercially-available and had cylindrical nodules. *Variables:* PVA Brush Type; Brush – A: Slip-on-the-core PVA sleeve design from Supplier A, Brush – B: Slip-on-the-core PVA sleeve design from Supplier B, and Brush – C: Molded-through-the-core PVA design from Supplier C (Entegris Planarcore®).

(B) 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 Planarcore® MTTC brushes and 3rd party fab POR SOTC 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.

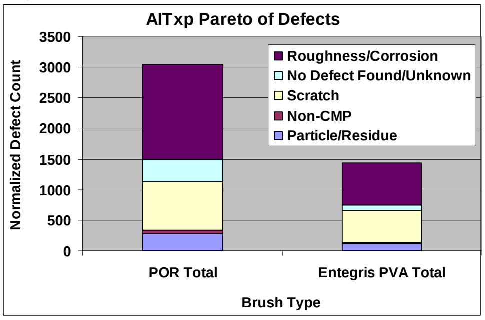
Tested Brushes and Equipment Set

MTTC technology brushes: Entegris PP core (enhanced cleanliness), thicker PVA (more tunable wider range downforce), and advance PVA foam cleaning process (resulting in a shorter brush break-in cycle). *POR brushes:* PVA SOTC design brushes used as POR at the 3rd party site.

CMP Tool and Cleaner: AMAT Mirra Mesa. Wafer metrology: KLA-Tencor Surfscan 6420 and KLA-Tencor SP1 (blanket wafer inspection), and KLA-Tencor 2139 Wafer Inspection System and KLA-Tencor AIT XP Wafer Inspection System (for patterned wafers).

The process conditions were optimized for current POR brush and were not specifically modified to ensure good comparative data for each brush type. Defectivity data classification for the above brushes is presented in Fig. 6. The PCMP cleaning defectivity performance of Entegris MTTC design Planarcore® brushes was found to be similar or better than the fab POR SOTC design brushes.

Fig. 6. Pareto of Defects for Two PVA Brushes.



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