New Developments in Post-CMP Cleaning Technology

R.K. Singh, D. Trio, E. McNamara, C. Patel and C.R. Wargo
Entegris, Inc.

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Overview

- CMP Trends and Post-CMP (PCMP) Cleaning Challenges
- Next-Generation Polyvinyl Alcohol (PVA) Brushes
  - Negative Zeta Potential (NZP) Planarcore PVA Brushes
  - New Brush Designs for Enhanced Wafer Edge Cleaning
- Effect of Cleaning Chemistries on Brush PVA Properties
- Desirable Attributes of Next Generation Brushes
- Brush Operating Parameters for Optimum Performance
- Summary and Conclusions

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CMP Consumables - Industry and Applications Trends

- Increasing complexity and changing requirements of next-generation CMP processes
  - More demanding CMP solutions for 32 nm, 22 nm and smaller technology generations
  - Introduction of larger/thinner wafers, copper, ultra low-k, high-k, and newer materials
  - Improved planarity and metrology specifications in Cu/low-k, STI, and poly-si CMP
- Emerging applications, new consumables, APC, integrated metrology and RTPC
  - Different IC solution might have unique CMP, PCMP cleaning, and metrology requirements
  - eSIC, TSVs, T-RAM, 22 nm SOI, GaAs, 3-D ICs, MEMS, DWB and photonic bandgap devices
  - Changed operating parameters (lower polishing pressure, higher PVA brush speeds, etc.)
  - Innovation/evolution in PCMP clean methods (laser, gaseous aerosols, supercritical CO_2)
- CMP consumables/system suppliers and end users more interested in collaboration
  - Ability to evaluate and fine-tune next generation consumables independently and as a set
  - Reduce CMP CoO and minimize development/optimization time as well as repetition of efforts
  - Improve understanding of CMP process needs and share cost of research & development
- Parallel evaluation of CMP disruptive technologies by the end users and tool suppliers
  - Fixed abrasive, Electro-CMP (ECMP), and Chemically Enhanced Planarization (CEP) may offer advantages for productivity, low stress for ULK dielectrics, and Cu loss in new application
  - Reduced need for CMP processing, PCMP cleaning, and slurry and chemical filtration

PCMP Cleaning Challenges for Advanced Applications

- CMP intensity (i.e., number of wafer starts) as well as complexity (e.g., 15 CMP steps for a typical 180 nm Logic device and 32 CMP steps for a 32 nm Logic device) is increasing with the shrinking feature sizes of the new ICs.
- CMP continues to be the enabling process and PCMP cleaning is critical for preserving device performance/yield. In Cu process, it is essential to remove Cu contamination from some areas of wafer (front-side dielectric, edge, and backside) while avoiding/limiting Cu removal from other areas (the Cu lines).
- In smaller node ICs, particles often cannot be distinguished from the IC structures in terms of the size or adhesion forces. The challenge of removing smaller particles without causing damage to the wafer structures is becoming increasingly difficult.
- The lateral force required to remove particles from wafer surface may have the same order of magnitude as would collapse a line on a typical advanced gate structure. This requires extreme consistency and continuous innovation in the PVA brush-based PCMP cleaning technology.

Next Generation PVA Brush Development

- PVA brushes for next-generation PCMP cleaning need to be more tunable in nature, with usage in many applications, created through PVA cleanliness improvements, and PVA structure, material, and charge modifications. The brushes must provide consistent and more gentler cleaning performance throughout their lifetime.
- Planarcore molded-through-the-core (MTTC) design brushes (with positive PVA anchoring with the core) were developed to meet above requirements and provide most effective and consistent PCMP cleaning performance in advanced nodes.
- New MTTC brushes have been developed with PVA charge modification for more effectively removing the smaller particles from the wafer surface, without potential redeposition on brush PVA or the wafer. These brushes provide the combination of highest wafer cleanliness with longer lifetime in advanced Cu PCMP cleaning.
- Next generation devices with high pressure sensitivity and/or more fragile features require gentler action of the brush in the central region of the wafer surface, and enhanced cleaning in the wafer edge region. Planarcore MTTC modified geometry brushes offer such differentiation in demanding PCMP cleaning applications.

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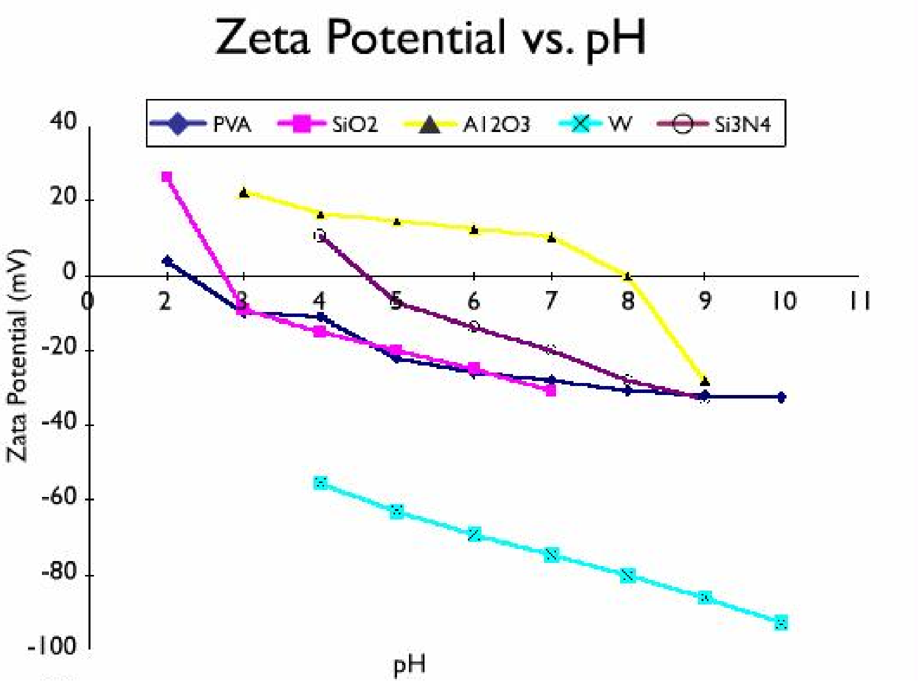
Post-CMP Cleaning Chemistries Evolution

- PCMP cleaning chemistry should effectively remove:
  - Organic residues, provide corrosion protection (static etch rate), galvanic corrosion protection, dendrite protection, and minimize CuO formation post cleaning.
  - Trace metal ions from the wafer surface, provide excellent cleaning on TEOS/OSG/CDO dielectrics and excellent film wetting properties (water mark free cleaning), and not support biological growth.
- Acidic cleans:
  - Typically comprise of organic acids, employ an under etching mechanism, where a layer of CuO (outermost Cu oxide) and Cu_2O (underlying Cu oxide) is dissolved from the wafer surface, thereby liberating the lodged particle.
  - Ideally this would be capable of under etching foreign particles embedded in Cu, and smooth over mild physical CMP induced damage. However, there are potential downfalls (such as organic residue and Cu corrosion) of using an acidic PCMP clean chemistry.
- Alkaline cleans:
  - Typically use a dissolution mechanism with water soluble organic solvents, which penetrates, swells, and dissolves the BTA film while lifting off surface particles by dissolving the CuO film, but only minimally attacking the Cu_2O film.
  - In alkaline pH cleans, the negative zeta potential (NZP) aids in keeping the removed particles in the solution and does not allow them to reattach to the wafer surface or brush PVA.

PCMP Cleaning and PVA Charge Modification

- PCMP cleaning is accomplished employing different cleaning tools (mostly integrated with the CMP polisher) and PCMP cleaning chemistries. The CMP cleaning chemistries are typically sprayed on top of the brush PVA, with the DI water flowing out through the brush core. A combination of chemical action (provided by the cleaning chemistry) and mechanical action of the rotating PVA brush removes the wafer surface deposits.
- For example, with diluted ESC 784 clean at pH ~ 10, PVA brush, wafer and the silica slurry particle all have similar negative zeta potential (NZP).
- This results in:
  → Repulsion between PVA and slurry particle
  → No particles deposit on PVA and no scratcl
- Higher magnitude of Negative ZP of the PVA minimizes the possibility of particle deposition on the brush or wafer and results in enhanced post-CMP cleaning performance.
- This further reduces the potential of any wafer circular-arc scratching issues due to the particle(s) entrapment between the brush nodule top surface and the wafer.

From: Handbook of Semiconductor Manufacturing Technology, 2000



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1. Enhanced NZP PVA Brushes Development

- Depending on PCMP cleaning chemistry and application, the higher negative charge magnitude PVA brushes can provide more effective wafer cleaning performance as compared to the regular PVA brushes. Planarcore NZP brushes have been found to provide much improved PCMP cleaning in advanced production fab.
- Planarcore Standard PVA and NZP brushes were analyzed for ZP variation with pH (for pH range ~ 2–11), employing SurPASS Electrokinetic Analyzer at the Entegris Analytical & Product Evaluation Laboratory and Anton Paar Applications Laboratory.
- Anton Paar system determines ZP at the solid/liquid interface of macroscopic surfaces based on measurement of streaming potential and streaming current. ZP data for the different brushes PVA are presented in next slide in the normalized form.
- NZP brushes show higher magnitudes of the negative charge, as compared to regular PVA brushes, for complete pH range. NZP brushes PVA maintained its negative charge even at lower (<3) pH condition and was found to be stable even at the end of brush useful lifetime, in an advanced fab PCMP cleaning application.

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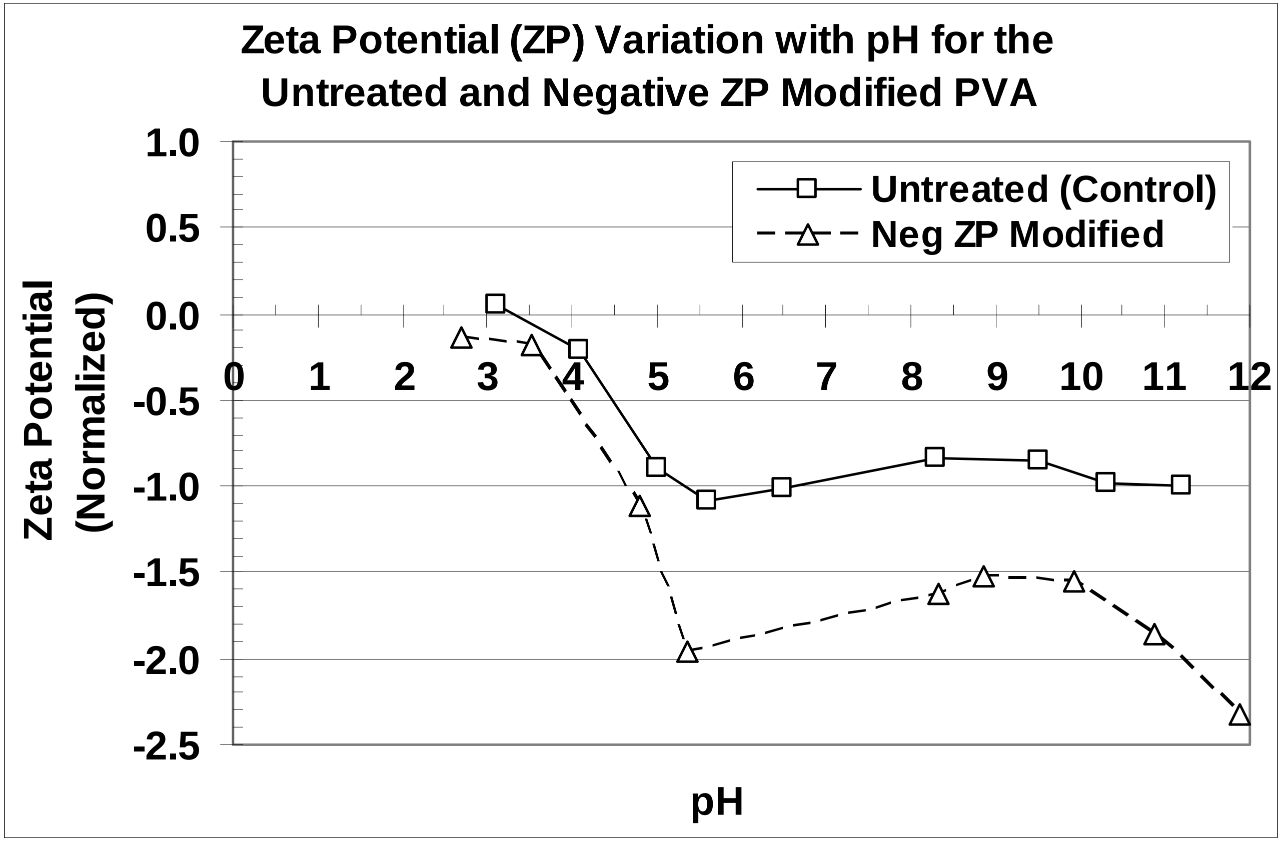
Zeta Potential Variation with pH for PVA Brush



Normalized Zeta Potential Variation with pH for the Standard and NZP Planarcore Brushes. Data Normalized with the ZP Value of Untreated Brush PVA at pH 11.

2. Modified Nodular Design PVA Brushes

- During cylindrical roller brush-wafer interaction, the central region of the wafer experiences more aggressive contact rubbing of PVA and related downforce. This concentration can be modified by: (i) Optimizing wafer and brush speeds, and/or (ii) Reducing the number or nodules touching wafer.
- The above wafer central region enhanced (non-uniform) tribological action can be balanced by employing modified nodule shapes for the brush in the wafer central region and the edge region. Such brush designs may require an unique distribution of different shape nodules along the brush length.
- While regular cylindrical nodule PVA brushes provide stronger cleaning strength in the wafer central region, they may result in less than optimum cleaning action in near wafer edge region. Elongated nodule shapes result in better brush-wafer contact and cleaning efficiency in wafer edge region.

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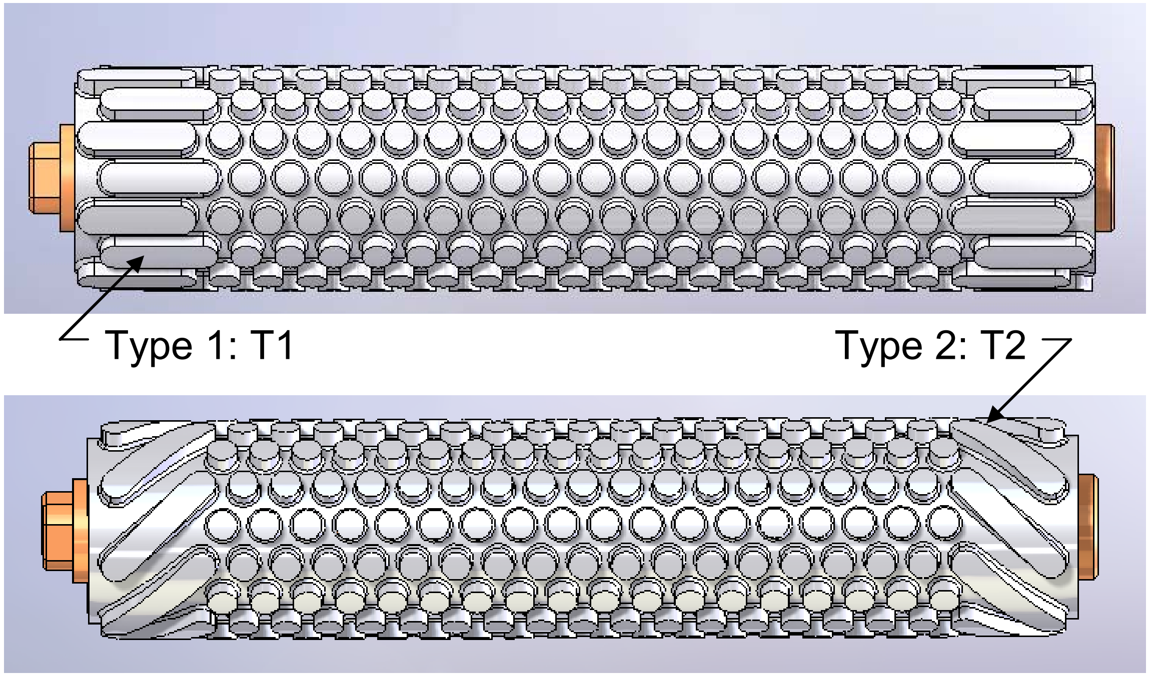
Modified Nodular Design PVA Brushes (Contd…)

- Modified nodules provide increased contact force and contact area in wafer edge region. With reduced initial compression than regular brushes, such brushes can be designed to provide optimum contact force in the wafer central as well as the wafer edge region.



- These designs result in enhanced cleaning action in the wafer outer region. Based on the near end nodule alignments with the brush axis, brush may provide less continuous contact in the wafer edge region, but optimum contact force for effective cleaning.

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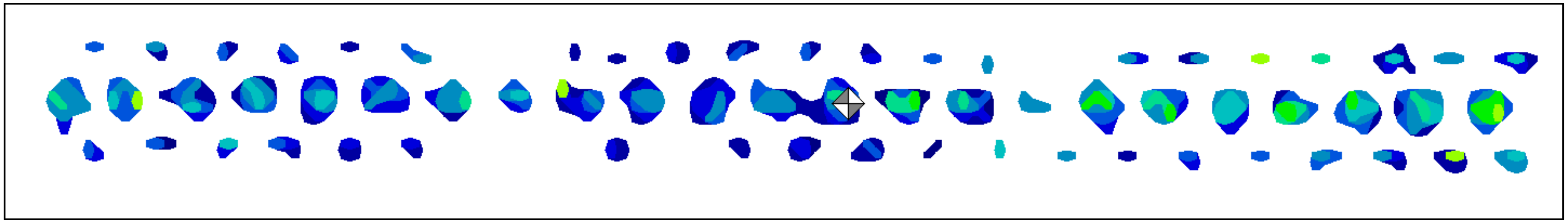
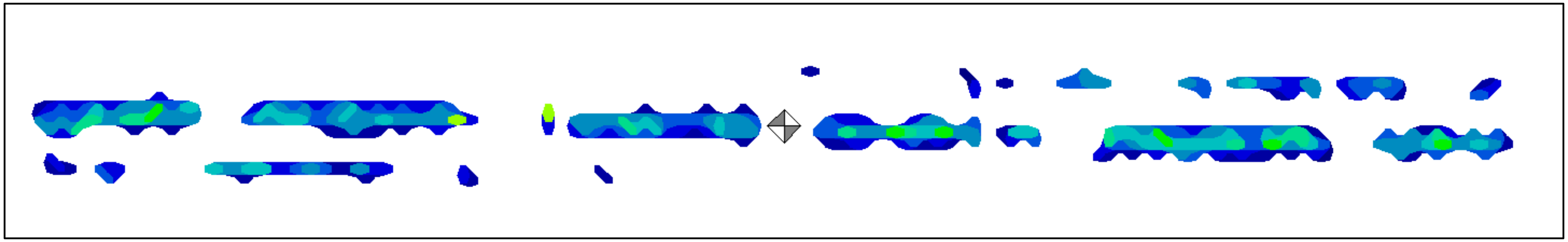
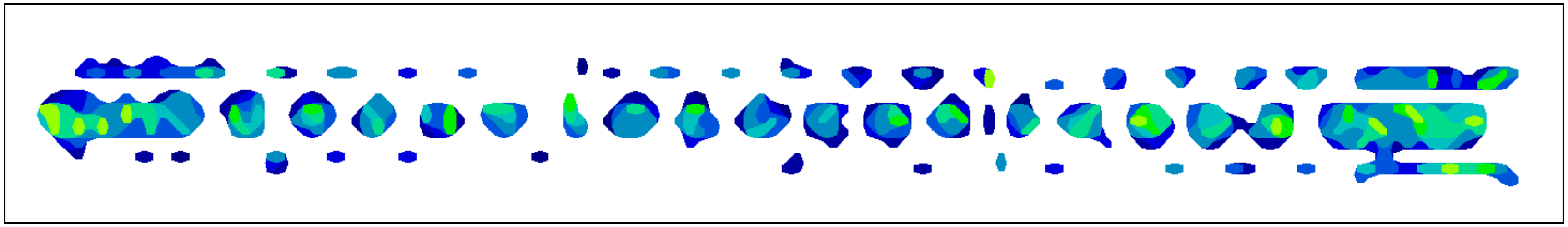
Contact Pressure Profiles for Different Nodule Design Brushes



(a) Regular Cylindrical Nodule Brush



(b) Elongated Nodule Brush



(c) T1 Design Brush with Elongated Nodules Near Brush Ends

3. Effect of PCMP Cleaning Chemistries on PVA

- The PCMP cleaning performance of brushes depends on the chemical and mechanical properties and stability of the brush PVA, magnitude/consistency of the brush-wafer frictional force, and adhesion forces between the particles and the wafer, and the particles and the brush. It is important to understand the PCMP cleaning chemistries effects on PVA properties over time to achieve consistent PCMP cleaning performance.
- In this study, a series of soak tests were conducted with new MTTC brushes to determine the effect of dilute (1:60 ratio of PCMP cleans:DI water) PCMP cleans (4 acidic cleans, pH range ~ 2.5 to 3.1, and 1 alkaline clean, pH ~10.5; all typically used for the copper/low-k PCMP cleaning applications) on the brush PVA, in terms of the coefficient of friction, porosity, water absorption capacity, and 30 % compressive stress.
- Short term (6 weeks) and extended (over ~ 1-1/2 year) soak tests of the new PVA brushes from one lot were performed in the above PCMP cleans. There was not much change in the visual appearance of brushes after 6 weeks soaking in dilute chemistries, except for some discoloration. This is as expected in typical real-life applications of PVA brushes. The brush sample (A1) PVA from the soak test in an advanced high pH (~11) ALK1 alkaline clean looked very much like a new brush PVA even at the end of the above extended test.
- The four acidic cleans dilute solutions caused significant discoloration to the soaked PVA brushes and changes in the soak solution cleanliness, whereas the alkaline clean caused minimal changes, over the extremely extended duration of the above test (beyond any practical applications). It is important to note that the main objective of such extended period test was to quantify any changes in the PVA physical properties over time, which may be a factor in the brush cleanliness effectiveness variation with usage.

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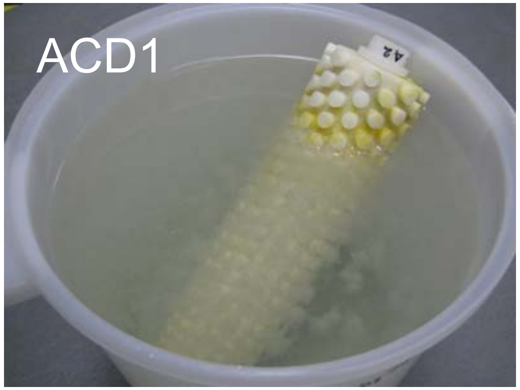
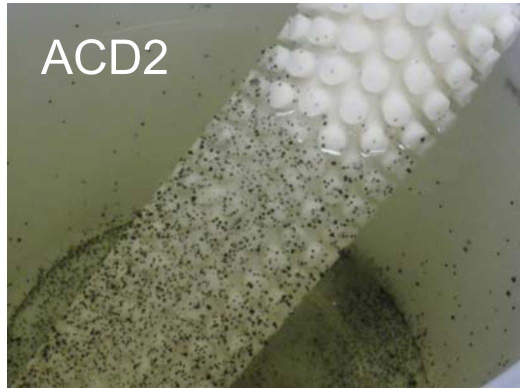
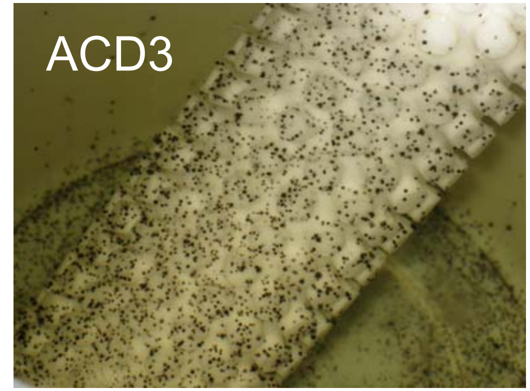
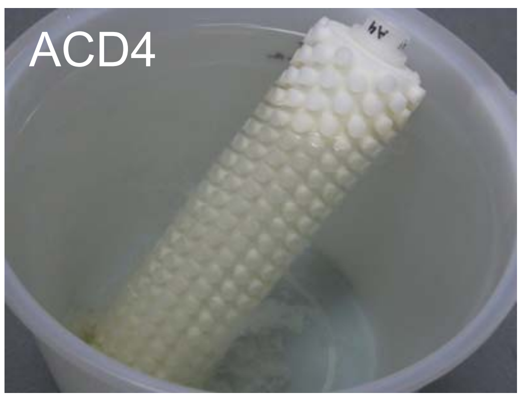
PVA Brushes Soak Test in Different PCMP Cleans









Effect of 1-1/2 year soaking in 5 dilute PCMP cleans. ACD1 – ACD4 are acidic cleans and ALK1 is an alkaline clean. All commonly used and commercially available.

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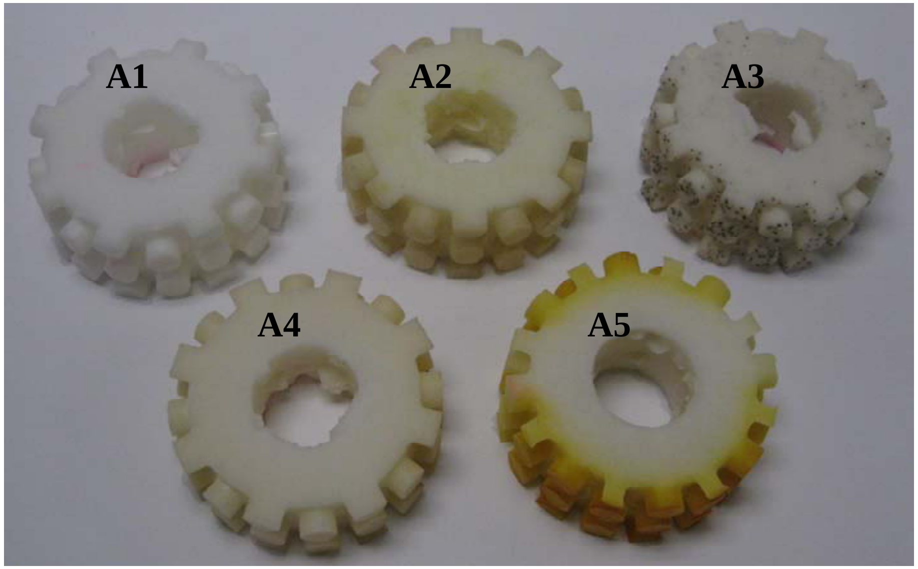
PVA Samples of Brushes Soaked in Various PCMP Cleans

- PVA physical properties, PVA discoloration and dilute clean solutions discoloration were monitored during soak tests. A few of the acidic cleans showed significant color change of PVA under extended exposure (see samples A2 – A5, from soaked brushes at the end of ~ 1-1/2 years, in figure below).
- The important point to note: not much changes in the physical properties of PVA seen even with such significant color changes.



Physical Properties of PVA Brushes after Dilute PCMP Clean Solutions Soak Tests

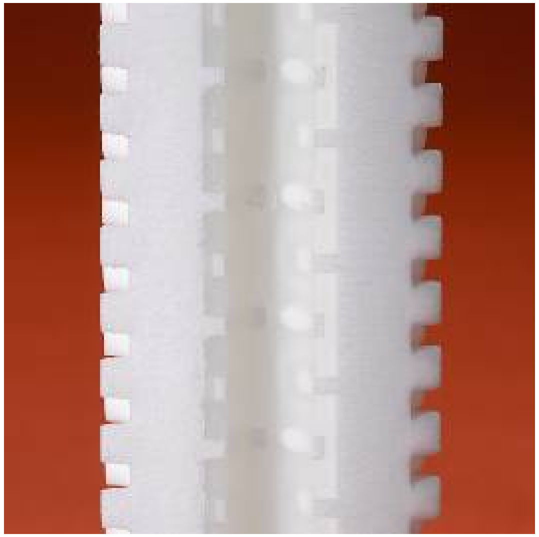
- Common physical properties of brushes PVA: porosity (%), water absorption capacity (weight %), and 30 % compressive stress (g/cm^2), are presented in Table 1 below in the normalized form. The data were normalized with respective parameters values for the brush soaked in DI water over the same period.
- It can be seen that there is not much change in the PVA physical properties and compressive stress values, especially considering the extremely long period of the test and the measurement uncertainty of these parameters.

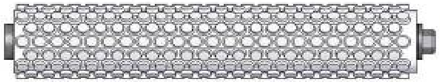
TABLE 1. Normalized physical properties of brushes PVA after PCMP cleans soak tests.

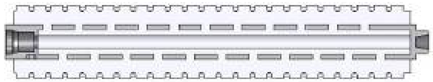
Diluted PCMP Clean and its pH	Porosity (Normalized)	Water Absorption Capacity (Normalized)	30 % Compressive Stress (Normalized)
A1, pH ~10.5	1.005	1.049	1.053
A2, pH ~2.7	1.004	1.037	1.000
A3, pH ~1.9	0.999	0.994	1.044
A4, pH ~2.5	1.003	1.025	1.116
A5, pH ~3.1	1.004	1.036	1.034
A6, DI water	1.000	1.000	1.000

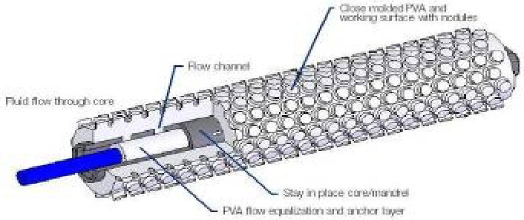
4. Desirable Attributes of Next Generation PVA Brushes

- 1. Installation Benefits (ease of use)
  - Eliminates core-mounting errors and mounting time
  - Most consistent (lot-to-lot) and fastest gapping by best-in-class dimensional consistency and concentricity
- 2. Brush Break-in Cycle
  - Lower particle shedding and reduced break-in with proprietary cleaning / break-in process
- 3. PVA Stability and Cleaning/Process Consistency
  - Aligned, concentric brush with industry-leading OD tolerance
  - Low extractables with custom manufacturing and cleaning process and the PP core
  - Absolute adhesion of PVA to core for no slip
- 4. Defect Reduction and Extended Lifetime
  - Non-slip and well-aligned brush wears more slowly
  - Customers have qualified longer lifetime









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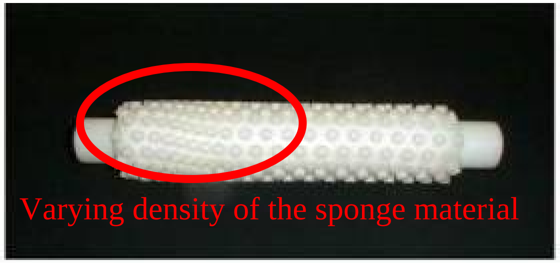
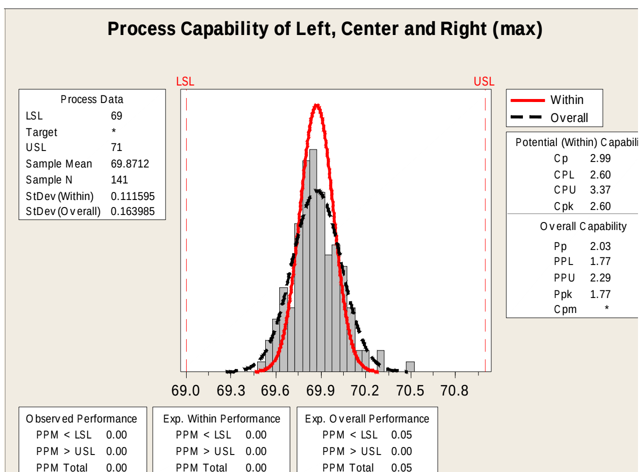
Ease of Installation - MTTC Design simplifies/improves brush mounting/gapping

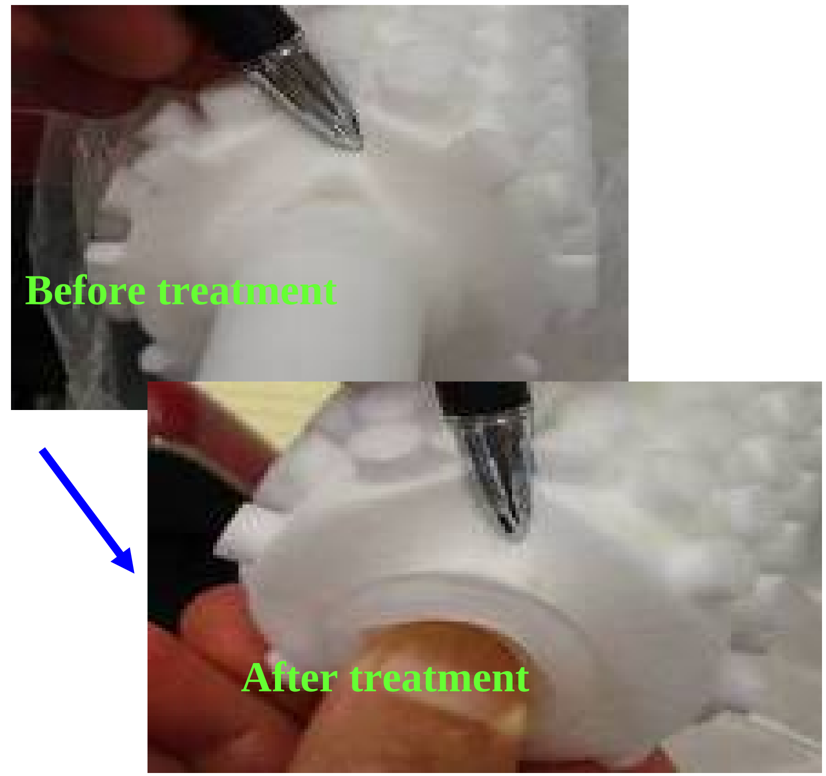


- No need to "pre-mount" brush
  - Reduces risk of handling/contamination
  - Eliminates misalignment of brush
- Best OD Tolerance
  - Only one manufacturing tolerance (rather than three - brush ID, OD, and core OD)
  - Zero "mounting tolerance"



Process Consistency - MTTC Design improves brush cleaning process and provides longer lifetime

- Zero risk of brush slippage on the core
  - Proprietary treatment of PP-core creates absolute adhesion of PVA to PP-core matrix
  - Eliminates misalignment of brush



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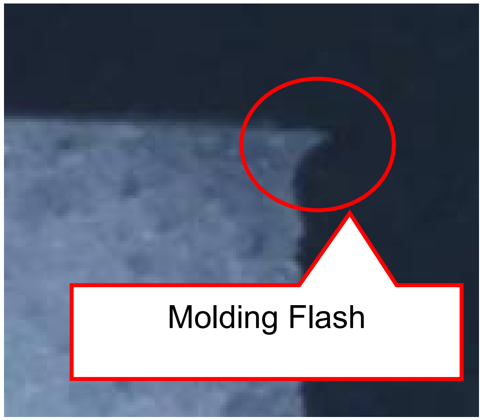
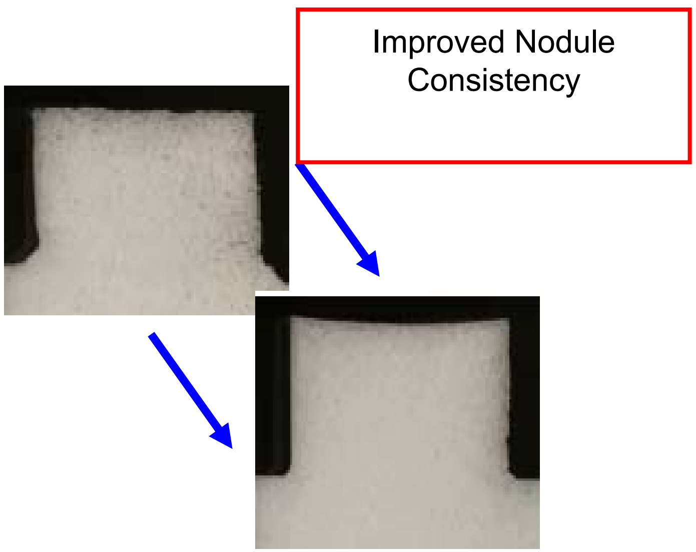
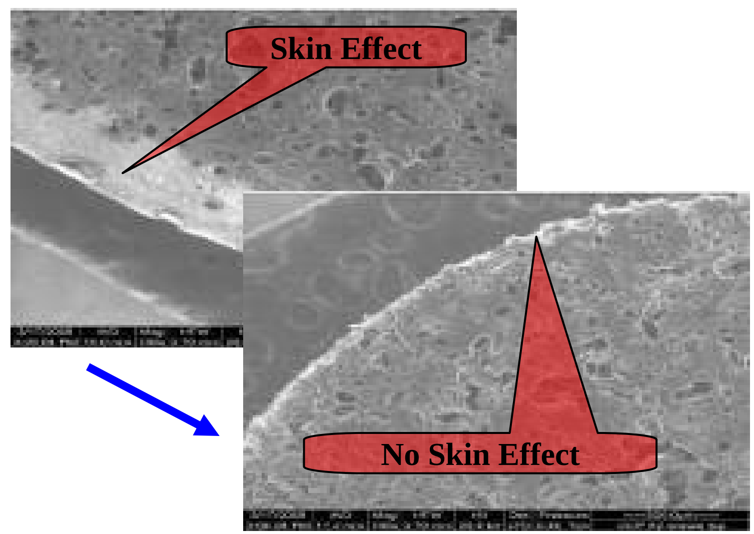
Defect Reduction – Consistent Nodule Shape and Skin-Less PVA Brushes Provide More Effective PCMP Cleaning



- **New, proprietary molding process for best-in-class nodule quality**
  - New molding technology encompasses all faces of the nodule with one continuous surface
  - Eliminates the "shrink-wrap" process – zero "flash" at the top edges of the nodules
    - Improved nodule quality - limits defects induced by this "flash"





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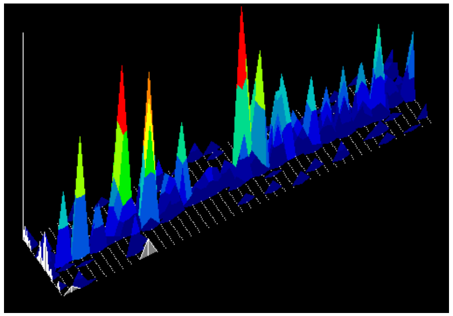
Defect Reduction - Thicker PVA Brush is More Tunable for Next–Generation More Fragile Structures/Surfaces



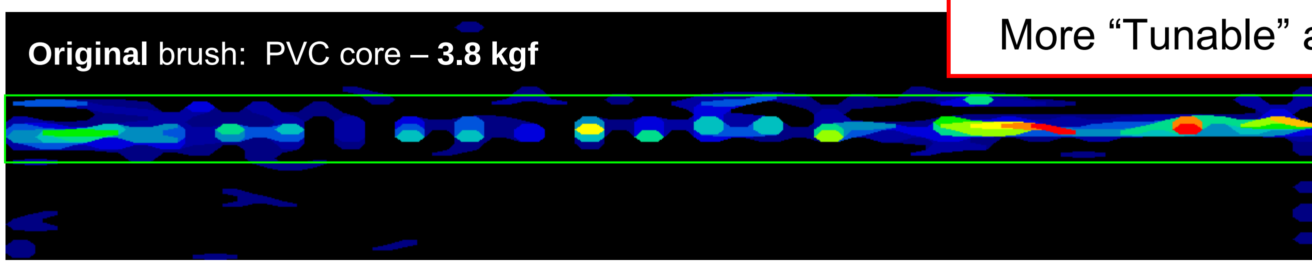
(i) Applications Trend – Copper and Low-k processes have more fragile surfaces requiring lower downforce on the wafer

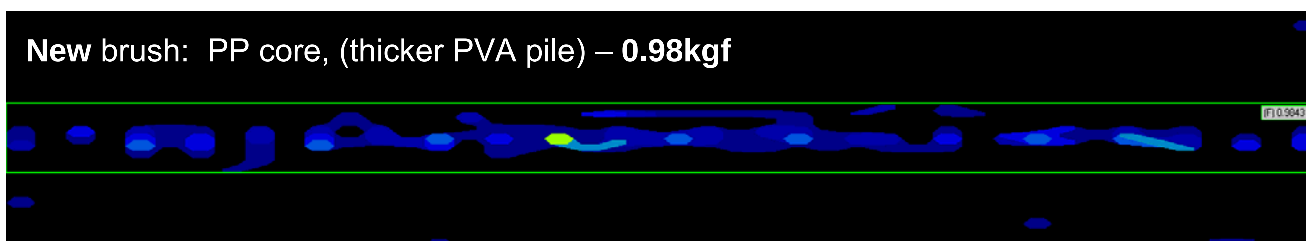
(ii) By using a thicker pile of PVA, Planarcore achieves constant wafer contact at lower downforce on the wafer

Methodology: A paper thin sensor that is divided into 1000s of individual cells is applied to a flat hard surface. The Reflexion brush is held by it's end-connections to be parallel to this flat surface. Pressure profile map is measured, when the brush is brought in contact parallel with the sensor; brush PVA is compressed by 2 mm

- New Planarcore -
  - Thicker PVA depth = Less Downforce (↓74%)

More "Tunable" at lower downforces

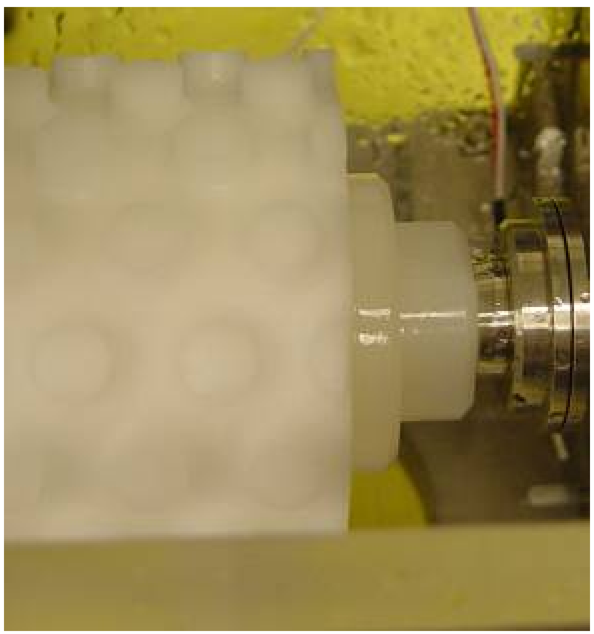




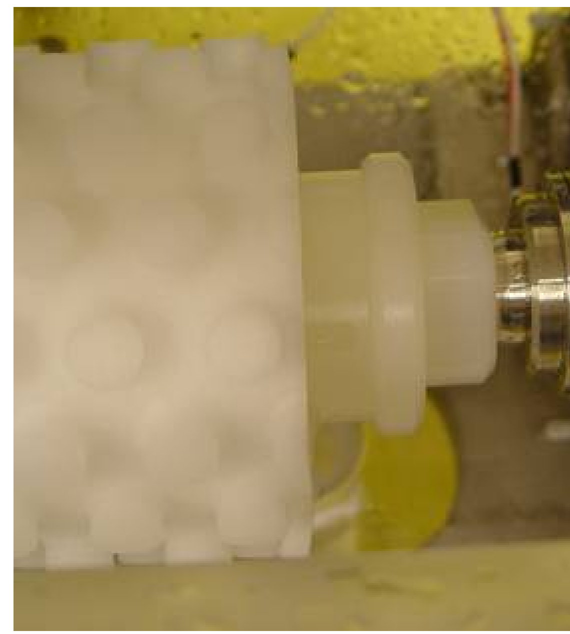
PVA Stability on the Core: Brush PVA Edge Movement Seen in Soft PVA SOTC Design Brushes at High Rotational Speeds

- During brush rotation at higher speeds (e.g., 800 RPM) the brushes made of softer PVA, slip-on-the-core (SOTC) design expand slightly in the diameter (in the center part of the brush) and shrink in the axial direction (near the closed core end of the brush) – As expected, no such observations were made for the MTTC design brushes.

SoftBrush_800RPM.wmv



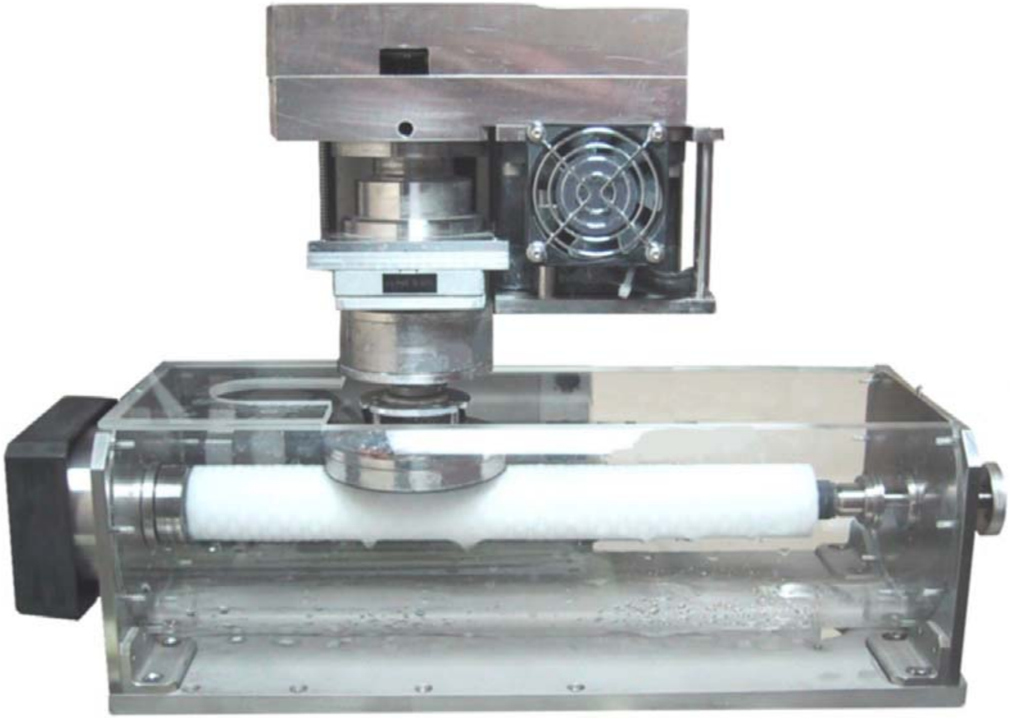
After high speed spinning, the brush PVA edge moves on the core



Brushes Skin Friction (COF) Stability: Test Parameters and Operating Conditions

- Dynamic coefficient of friction (COF) data for the slip-on-the-core (SOTC) and molded-through-the-core (MTTC) brushes were measured at different brush rotational speeds and DI water flow rates, for brushed soaked in DI water as well as various PCMP cleaning chemistries (6 weeks soak in diluted cleans solutions).
- An initial compression of 2 mm was used for most of the study. Planarcore® (PLAN) are Entegris MTTC design brushes, SOFT are softer PVA SOTC brushes, HARD are harder PVA SOTC brushes, and ELON are elongated nodule brushes (all commercially available).
- Brush rotational velocity was varied from 50 to 800 RPM for the 70 mm OD PVA brushes (suitable for AMAT Reflexion Cleaner), while the wafer velocity was held constant at 100 RPM for the 3" oxide wafer.
- Total force data acquisition frequency was 20 kHz, for frictional force (Fx), normal load (Fy), and temperature (Tm) measurements.
- Most PVA brushes were similar in dimension (suitable for 300 mm cleaner) and had cylindrical nodules, except for the ELON – elongated nodule brush.

PVA Brush Tribological Measurement System



A new 300 mm brush – capable benchtop tribology testing tool was co-developed with the *Center for Triobology Research* (CETR)

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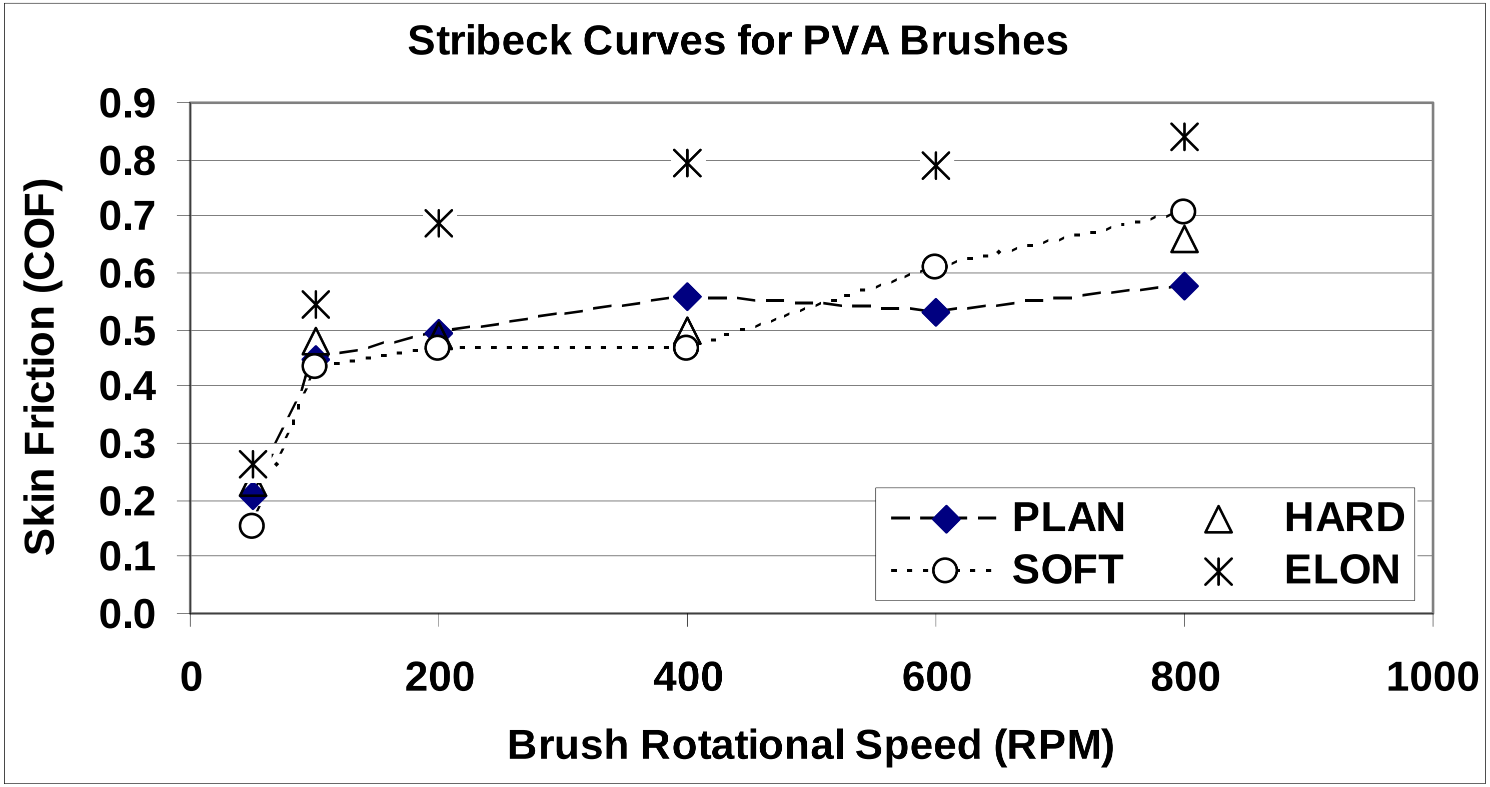
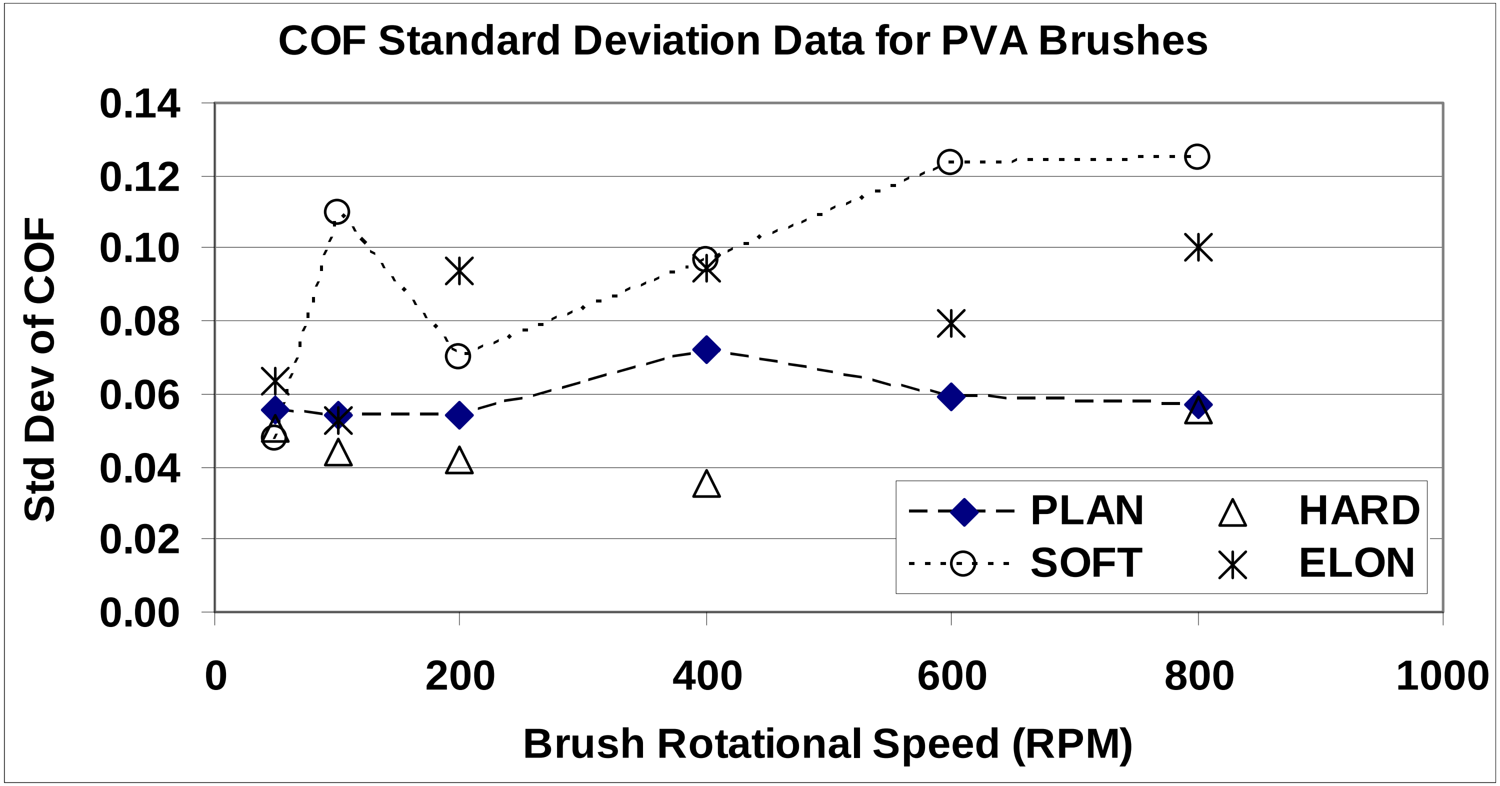
PVA Brushes Mean Skin Friction Data



Test conditions: 2 mm initial compression, 0.5 Lpm flow, and 100 RPM wafer speed
Variation in COF likely due to expansion of PVA at higher speed for the SOFT PVA brush
ELON is Elongated nodule brush. All other brushes have cylindrical nodules and ~70 mm OD.
PLAN is a MTTC Planarcore brush. COF of PVA brushes can be varied by nodule geometry change.

PVA Brushes Fluctuating Skin Friction Data



In general, SOFT PVA brush has high fluctuation in COF data, especially at higher speeds.
Test conditions: 2 mm initial compression, 0.5 Lpm flow, and 100 RPM wafer speed
ELON is Elongated nodule brush. All other brushes are cylindrical nodule brushes.

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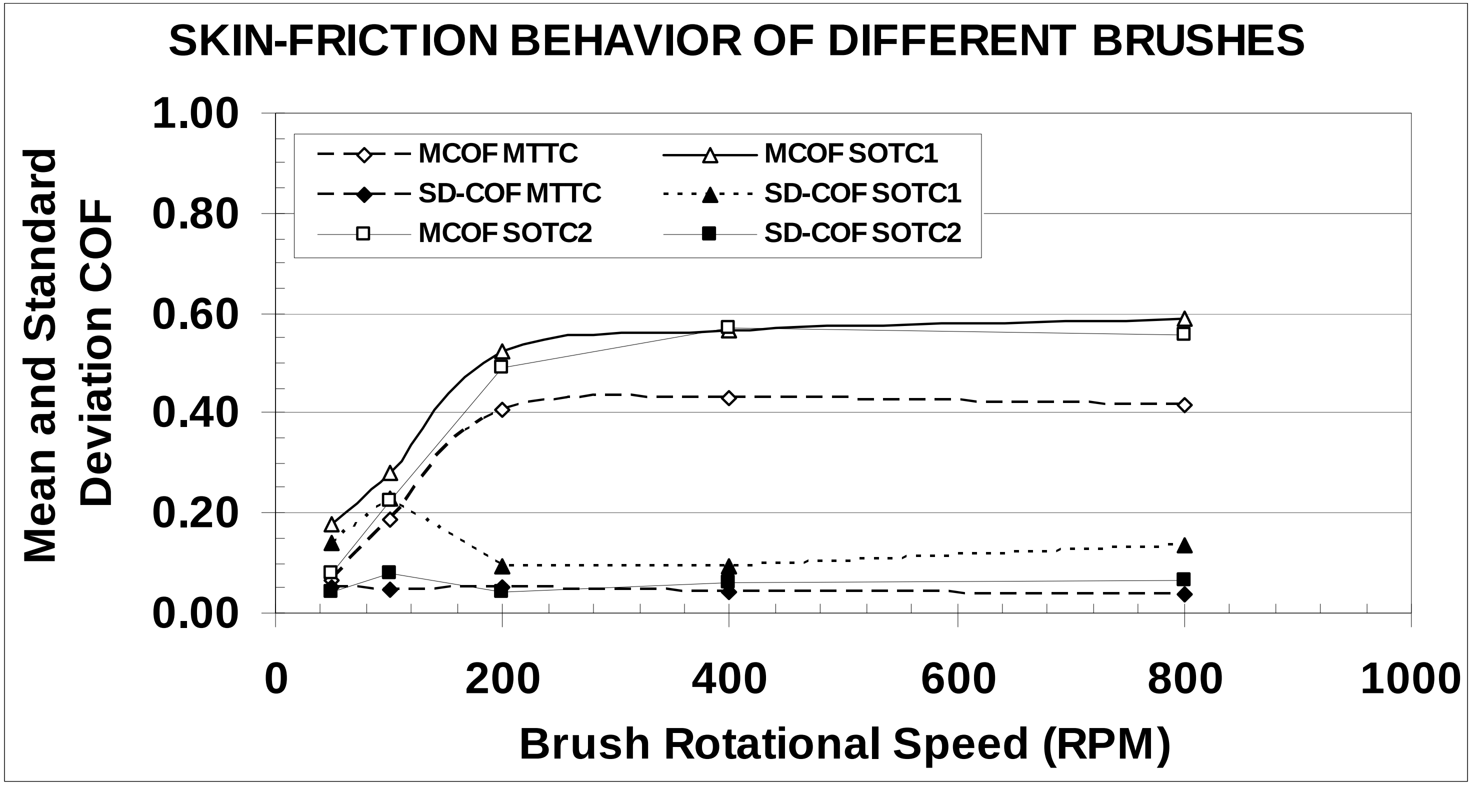
Mean and Std Deviation COF for MMTC and SOTC Brushes



All 3 brushes (~38 mm OD) had cylindrical nodules. MTTC brush is Entegris Planarcore brush, whereas SOTC1 and SOTC2 are other manufacturer slip-on-the-core design brushes. The mean and standard deviation of the COF for the MTTC brush were smaller than corresponding values for the 2 other SOTC brushes. Tests conducted in DI water.

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5. New Brushes Operating Parameters Fine-Tuning for Optimum Performance: Considering Down-Force, DI Water Flow-Rate and Skin-Friction Distributions

- PLAN, HARD, SOFT, and ELON are Planarcore, hard PVA, soft PVA, and elongated nodule PVA brushes, respectively, from different brush suppliers. As seen in Figures 1-3, various brushes result in slightly different down-force, flow-rate and skin friction (COF) data.
- For example, in a HARD PVA POR brush fine-tuned Fab recipe, an initial compression of 2.0 mm in HARD brush would produce nearly same down-force as a SOFT brush would produce with an initial compression of ~3.5 mm. Similar adjustments may be essential also for the DI water flow-rate to get optimum PCMP cleaning performance.

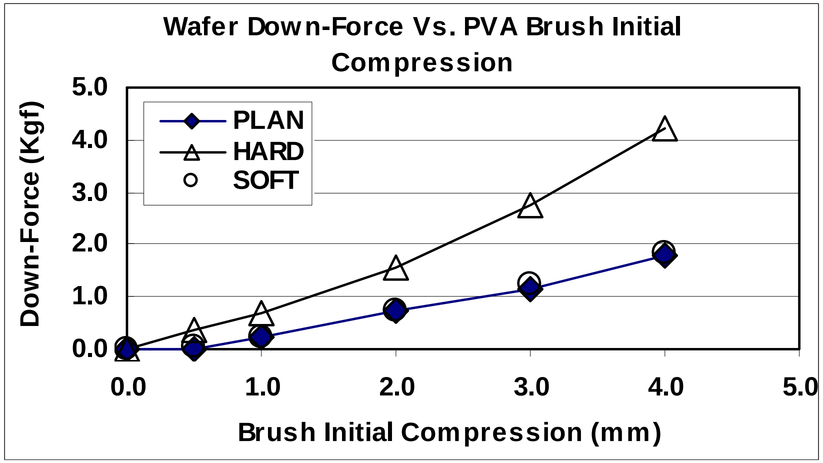

Figure 1

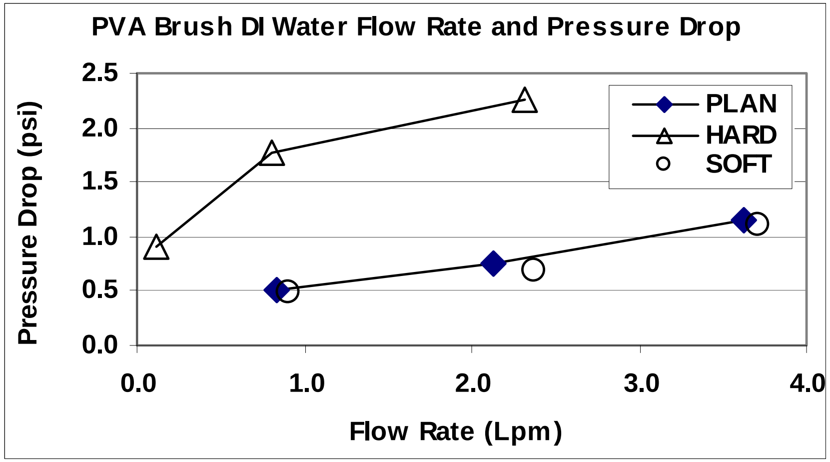

Figure 2

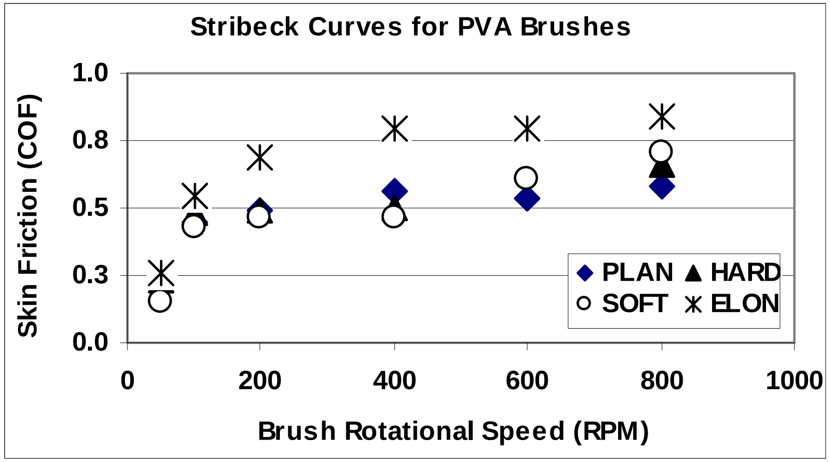

Figure 3

Summary and Conclusions

- New developments in the design and characterization of PCMP cleaning PVA brushes are presented. Special nodular design and negative zeta potential (NZP) brushes were developed to achieve more effective near-wafer-edge cleaning and improved overall PCMP cleaning performance in advanced applications.
- Special nodule design brushes provide more favorable contact area as well as contact force at the brush-wafer interface in the wafer edge region and the central part of the wafer, whereas NZP brushes result in improved PCMP cleaning in the next-generation copper/low-k processes.
- The effect of extended exposure of 1 alkaline and 4 acidic PCMP cleans on brush PVA was studied. All acidic cleans showed significant discoloration, whereas the alkaline clean caused minimal changes in the color of PVA and the soaking solution. This study did not show much change in PVA physical properties as a result of above chemical soaking.
- Considering down-force, flow rate, and skin-friction distribution of different PVA brushes, no new brush designs should be considered a drop in replacement. It may be essential to make minor adjustments to the brush initial compression and/or DI water flow rate to obtain optimum PCMP cleaning performance with any new brush type.

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