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Characterization and Performance of PVA Brushes for Post-CMP Cleaning of Cu Low-k Films

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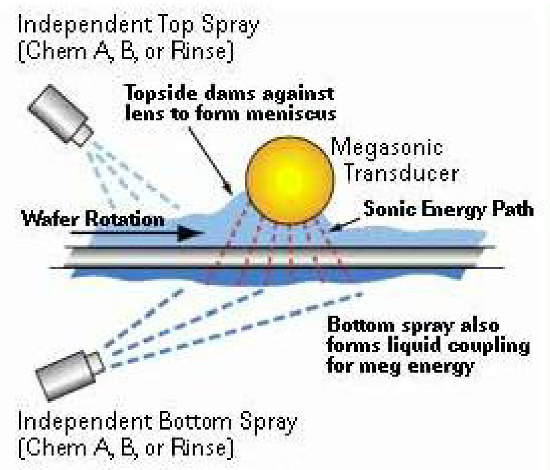
Overview

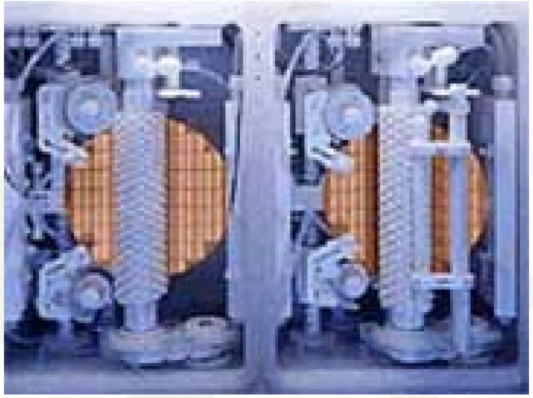
– Post-CMP Cleaning Technologies
– Poly Vinyl Acetal (PVA) Brush Designs
– Post-CMP Cleaning Process Characteristics and Trends
– Mechanism of Particle Removal through Brush Scrubbing
– Case Study 1 - Comparative Tribological Consistency of Brushes
– Case Study 2 - Post-CMP Cleaning Performance of Brushes
– CMP and PVA Brushes Technology Development
– Summary and Conclusions

Common Post-CMP Cleaning Technologies: Megasonic and Double Sided Brush Scrubbing



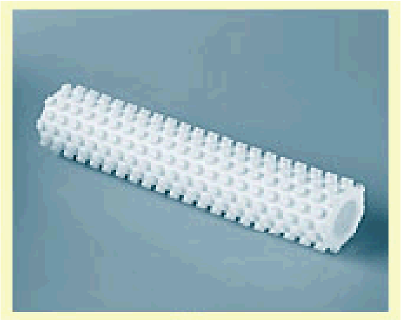
Megasonic Cleaning

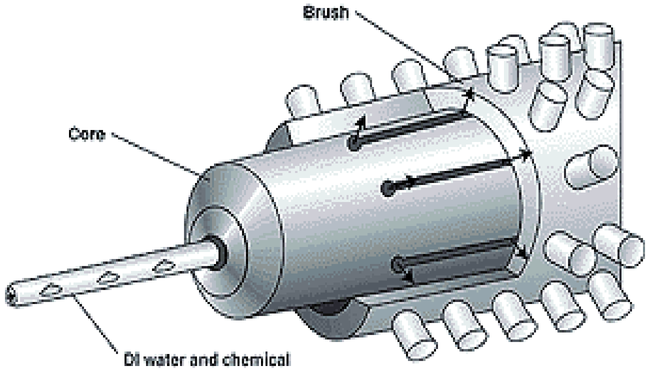
Double Side Brush Scrubbing



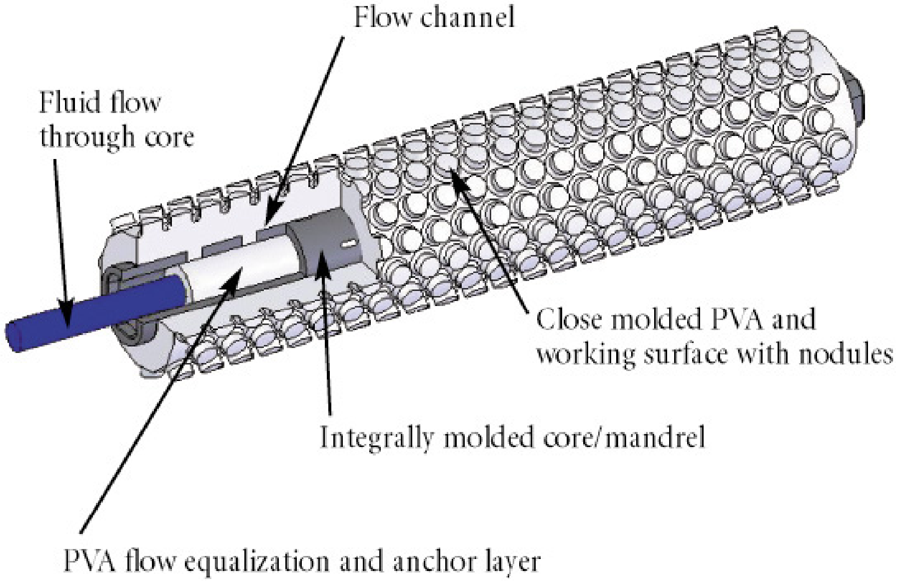
Slip-on-the-core (SOTC) and Molded-through-the-core (MTTC) PVA Brush Designs

A standard, hollow cylindrical sponge with nodules





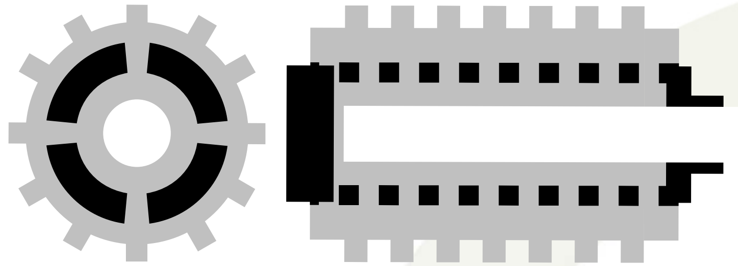
Slip-on-the-core Design PVA Brush



Molded-through-the-core Design PVA Brush (Planarcore™)

Planarcore™ Brush Design for Post-CMP Cleaning

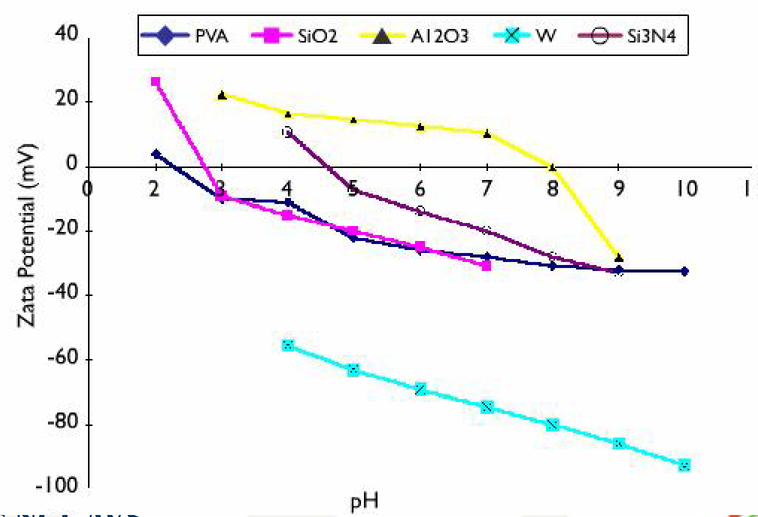
- PVA (poly vinyl acetal) brushes used to be an industrial product before being introduced at IBM and commercialized in the early 1990's
- Entegris molded-through-the-core (MTTC) design is a disposable PVA brush that reduces tool downtime and provides excellent dimensional stability over its lifetime
- MTTC design provides positive anchoring of PVA to the core and eliminates possibility of any slippage at the PVA-core interface (possible in conventional slip-on-the-core design brushes, especially in the latter part of their lifetime due to possible swelling of PVA)
- MTTC design also provides very good core flow equalization, resulting in throughout brush lifetime consistency in the post-CMP (PCMP) cleaning performance



Post-CMP Cleaning Process Characteristics

- **CMP processes use abrasive slurries in the planarization process. 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 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 NH4OH at pH ~10-11, PVA brush, wafer and the slurry abrasive particles, all have similar negative zeta potential.**
- **The above results in:**
  → Repulsion between PVA and particles
  → No particles deposit on PVA
  → No scratches

Zeta Potential vs. pH



Wafer Cleaning at 45 nm & Beyond – Key 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. In such applications PVA brush loading/shedding is important to monitor.
- Brush cleaning is a very effective PCMP cleaning technique. In brush cleaning is the optimum mode, a contact between the particle and the brush is essential to the removal of submicron size particles from the wafer surface.
- In above operation, Rm>>1 for a 0.1 micron particle, for typical brush and wafer speed, based on an experimental study at NEU, where Rm is the ratio of removal moment to adhesive moment, and the particles are removed if Rm>1.
- In above 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 very effective in PCMP cleaning. Current and next generation PCMP cleaning process will continue to depend on brush together with megasonic cleaning in the foreseeable future.

[Ref: Information from a Surface Cleaning Tutorial at NEU]

Wafer Cleaning at 45 nm & Beyond – Key Attributes and Trends (Continued)

- The requirements of surface cleaning must be considered while designing future generations of microchip circuits, 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 the processing limitations in turn influence the design process.
- Many of the cleaning chemistries and approaches will have to change, and there are plenty of potential solutions being considered for 45 nm and beyond. Integrated Chip manufacturers will need to adopt new etch chemistries and cleaning regimens for the next generation devices.
- Suggested non-damaging nanoparticle removal technologies include:
  - (i) Shock tube-enhanced laser-induced plasma (LIP) shockwaves for sub-50 nm nanoparticle removal,
  - (ii) Plasma-assisted cleaning by electrostatics (PACE),
  - (iii) An ionized molecular-activated coherent solution, and
  - (iv) 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 (from UVTech Systems), a CO2 cryogenic press and non-oxidizing chemistry (from DuPont EKC Technology and BOC Eco-Snow Systems), and methodologies for all-wet chemistries (from FSI International and SEZ Group).

[Ref: Information from a Surface Preparation and Cleaning SEMATECH conference 2007]

Evolution of Post-CMP Cleaning Chemistries

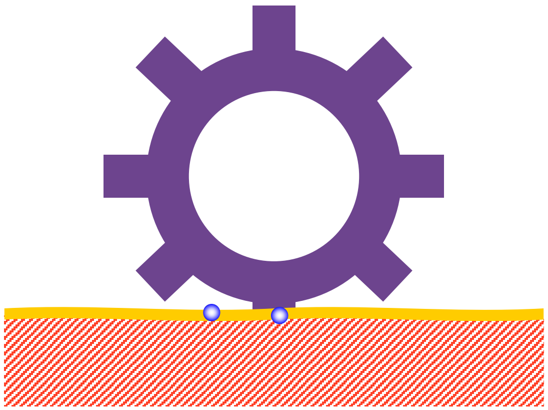
- Post-CMP cleans may range from extremely acidic: pH < 2 (e.g., Kanto MO2, Ashland/Air Products CP-70 / CP-72) to very basic with pH > 11(e.g., TMAH based) and may contain surfactants and chelating agents.
- The 1st generation PCMP cleans use citric/oxalic acid solutions with low pH. These rapidly dissolved both CuO and Cu_2O, undercutting particle or organic defects in the oxide.
- Due to low pH being unfavorable for zeta potential of the substrate and particles in the same sign, the 1st generation chemistries need effective mechanical action such as provided by PVA brushes.
- The removal of passivating oxides using citric acid solutions may yield reactive Cu surface requiring BTA (benzotriazole) passivation. In general, these cleaners provided poor cleaning efficiencies.
- The 2nd generation alkaline PCMP cleans (e.g., ESC784 and ESC794 from ATMI) dissolved CuO, while leaving Cu_2O intact.
- These cleaners high pH provide strongly negative zeta potential for the substrate as well as particles, ensuring repulsion and eliminating particle redeposition.

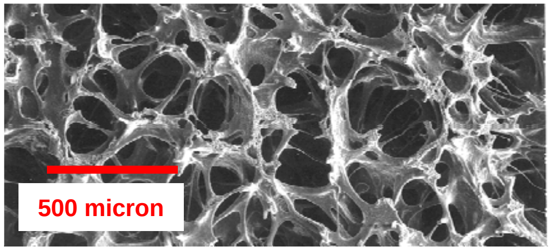
Evolution of Post-CMP Cleaning Chemistries (Continued)

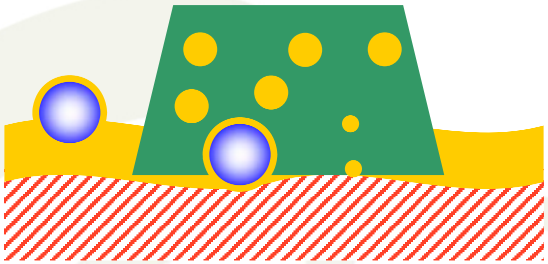
- The 2nd generation cleans require much lesser mechanical action. Also, these chemistries generated less reactive Cu than the 1st generation cleaners.
- Some fabs employ 3rd generation alkaline PCMP clean solutions (e.g., ESC797D, ESC797G, SP50, and SP50A from ATMI) in Cu/Low-k processes. These provide a balance between particle & organic defect removal and surface roughness.
- To reduce surface decoration and problem associated with increased surface roughness, these cleans employ water-soluble organic solvents. These chemistries typically dissolve organic defects and BTA-Cu complexes very efficiently.
- 3rd generation cleans reduce etch rate and surface roughness and at the same time undercut and lift the abrasive particle and organic defects left over from the CMP processing/slurries.
- Due to their alkaline nature these 3rd generation cleaning chemistries have strongly negative zeta potential, which helps in very efficient and effective particle removal.
- The new trend in Cu/Low-k PCMP clean applications is to use alkaline PCMP clean chemistries incorporating water-soluble organic solvents. Typically used in the 2nd brush box, these alkaline chemistries use a dissolution mechanism for the organic residue removal.

Mechanism of Particle Removal through PVA Brush Scrubbing during Post-CMP Cleaning

- 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
  - Cause the exposed surface of the particle to adsorb on the surface of the brush (either mechanically, chemically or by capillary suction)
- Torque created by the rotation of the brush dislodges the particle from the surface
- Fluid present on 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 Comparative Tribological Performance Evaluation in Cu/Low-k Application

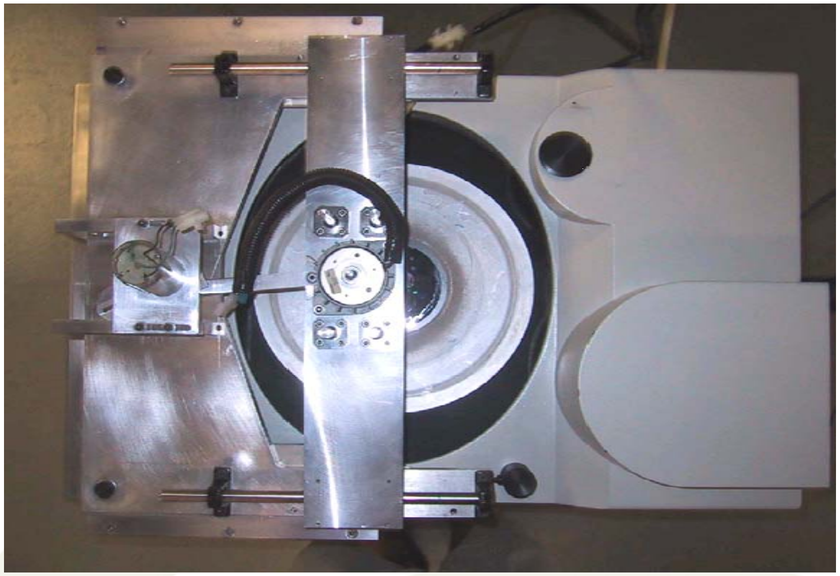
- Factors affecting cleaning efficiency
  - Contact pressure at the brush PVA nodule surface and the wafer
  - Physical and chemical properties of cleaning fluid and its flow rate
  - Overall kinematics of the brush in relation to the tool
  - Cleaning time
  - Mechanical properties of the brush
  - Magnitude of frictional forces between wafer and brush relative to magnitude of adhesion forces between:
    - Particle and wafer
    - Particle and brush
- 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 and lifetime

Brush Tribological Study Experimental Conditions

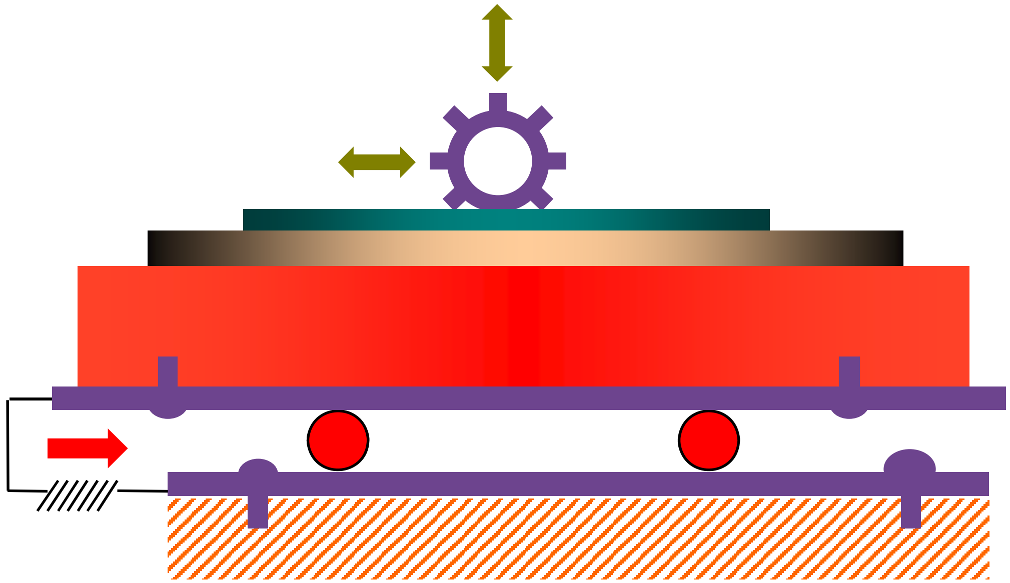
- **Constants**
  - **Applied pressure = 0.5 PSI**
  - **Cleaning solution type and flow rate = Ashland CP – 70 at 120 cc/min**
  - **Brush and wafer rotational velocity = 60 and 40 RPM, respectively**
  - **Frictional force data acquisition frequency = 1,000 Hz (3.6 million samples / hour)**
  - **Wafer type = 200-mm International Sematech 854 Copper wafer**
  - **Scrubbing time = 48 Hours marathon run (continuous)**
  - **All tested PVA 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**
  - **Brush - C**
    - **Molded-through-the-core PVA design from Supplier C (Planarcore™)**

Brushes Tribological Test Apparatus

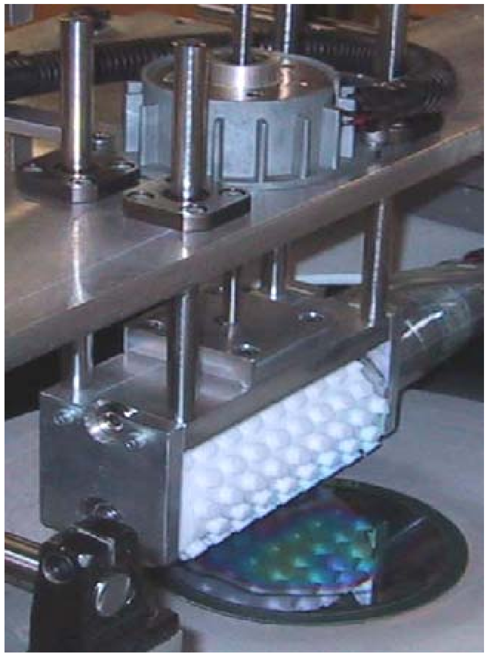


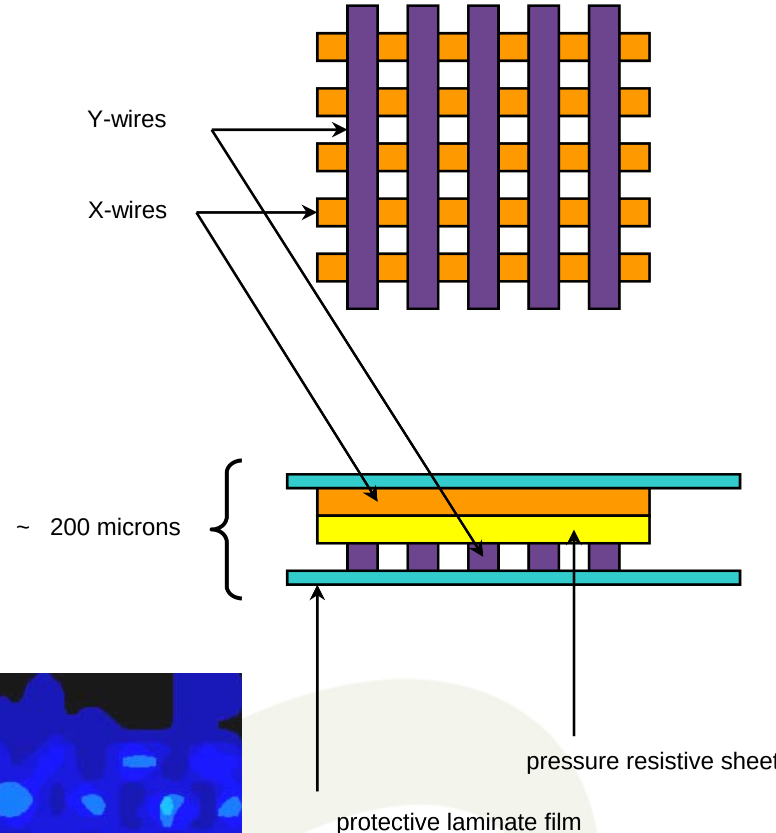
Coefficient of Friction (COF) Measurement

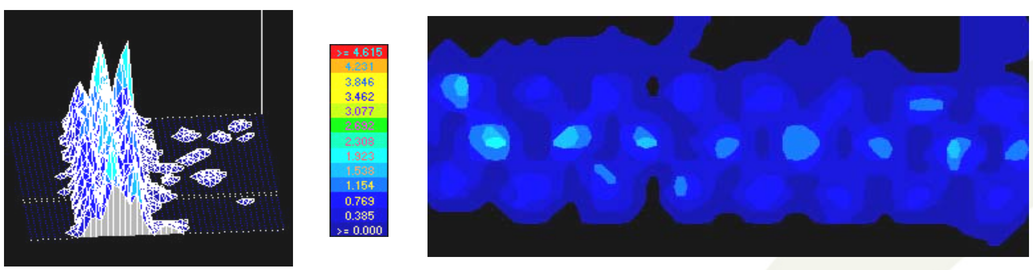


$$COF_{avg} = \frac{\overline{F}_{Shear}}{F_{Normal}}$$

Pressure Mapping Apparatus



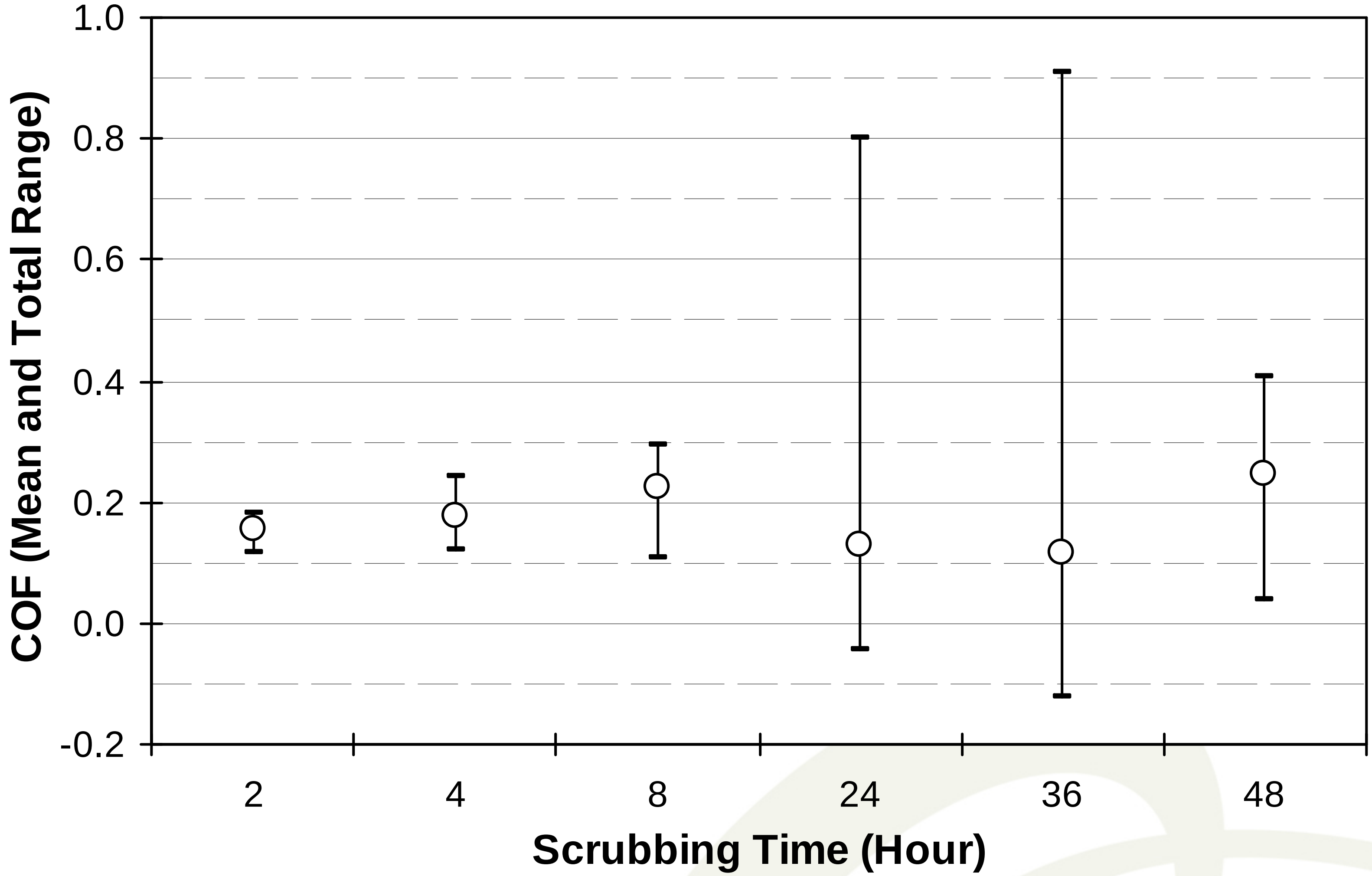




PVA Brushes Tribological Study Data

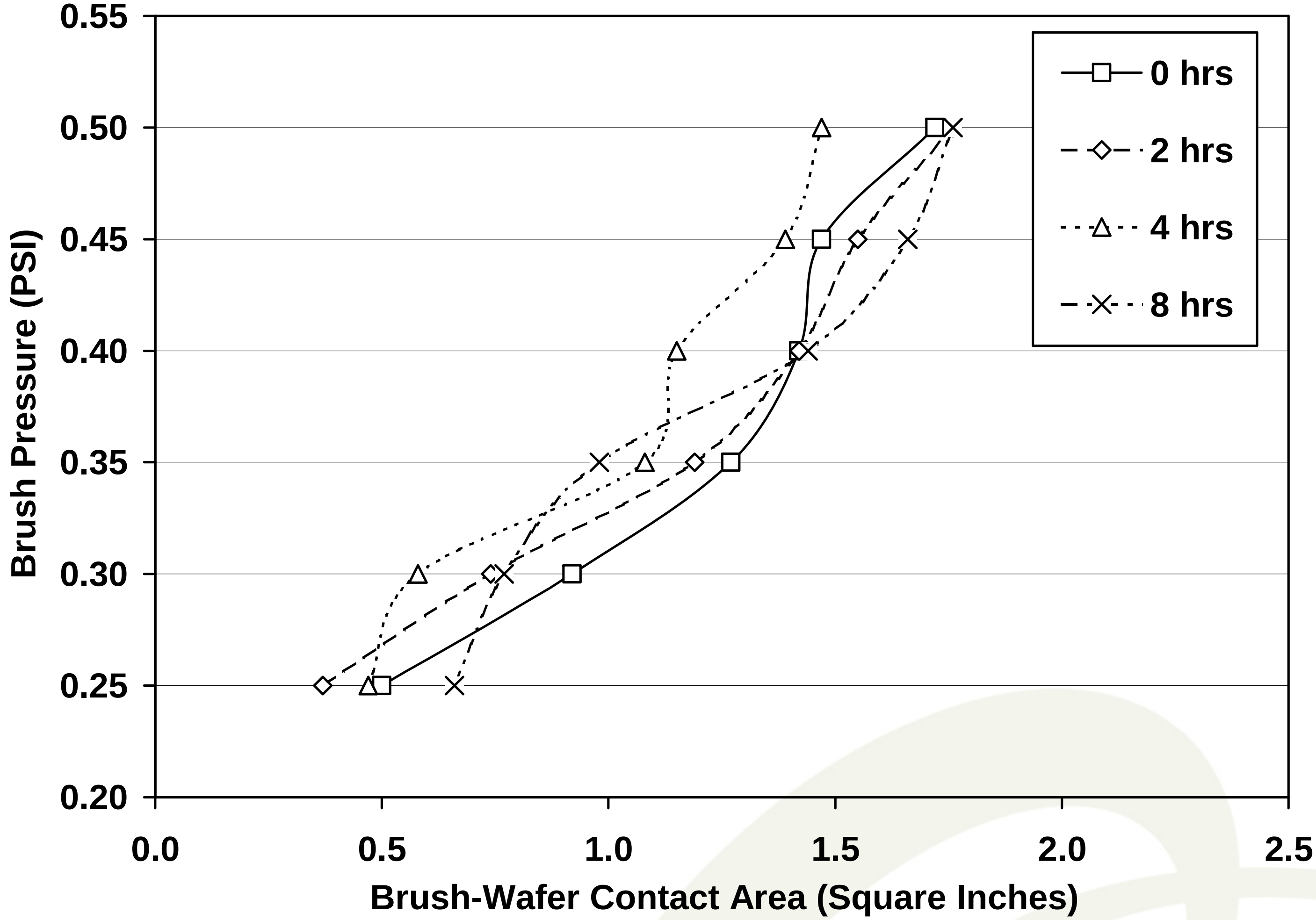
Coefficient of Friction (COF), Brush-Pressure, Contact-Area and Pressure Contour Maps

COF Results for Brush – A (SOTC Design)

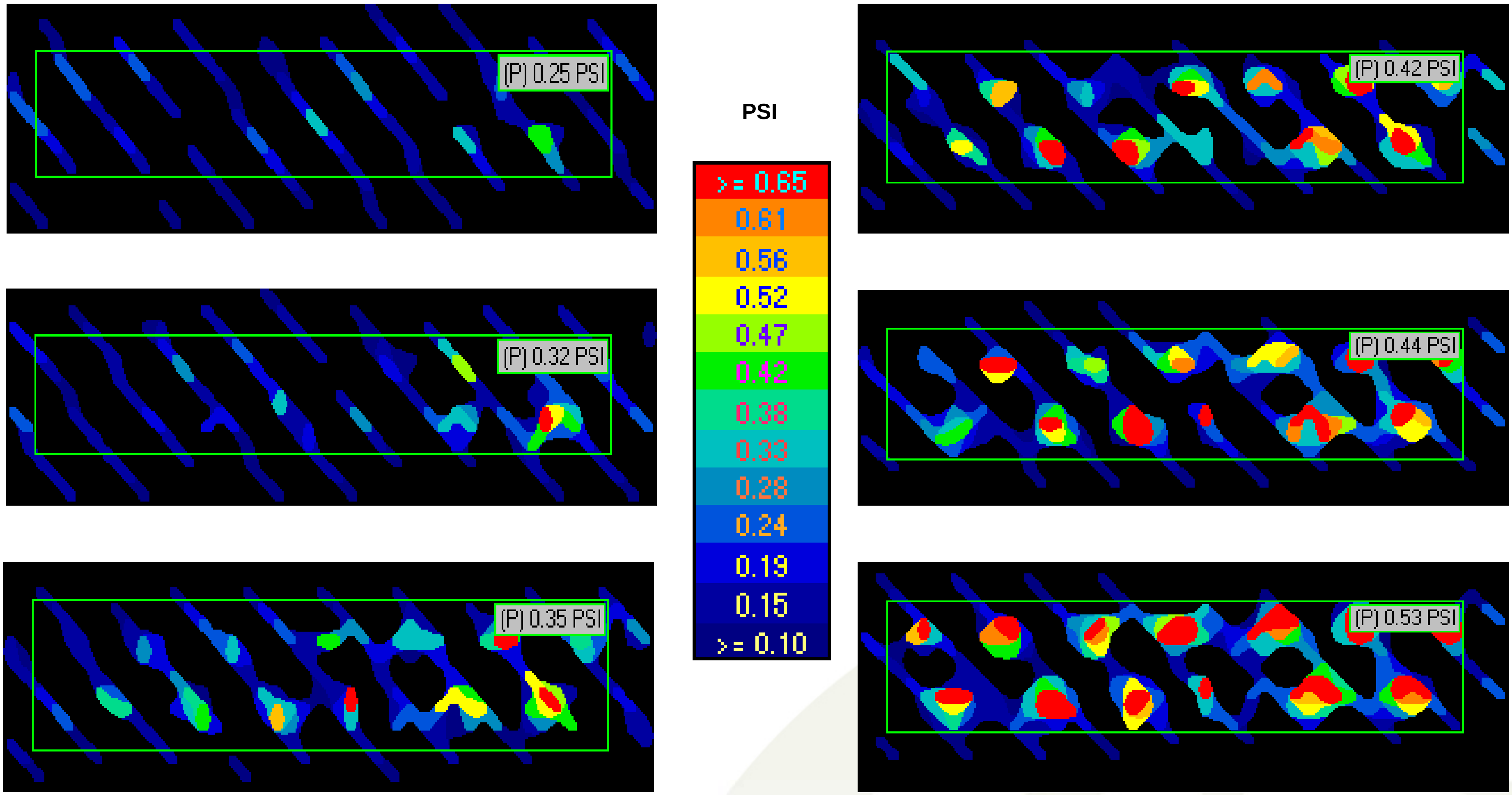


Pressure Contact-Area Relationship for Brush – A

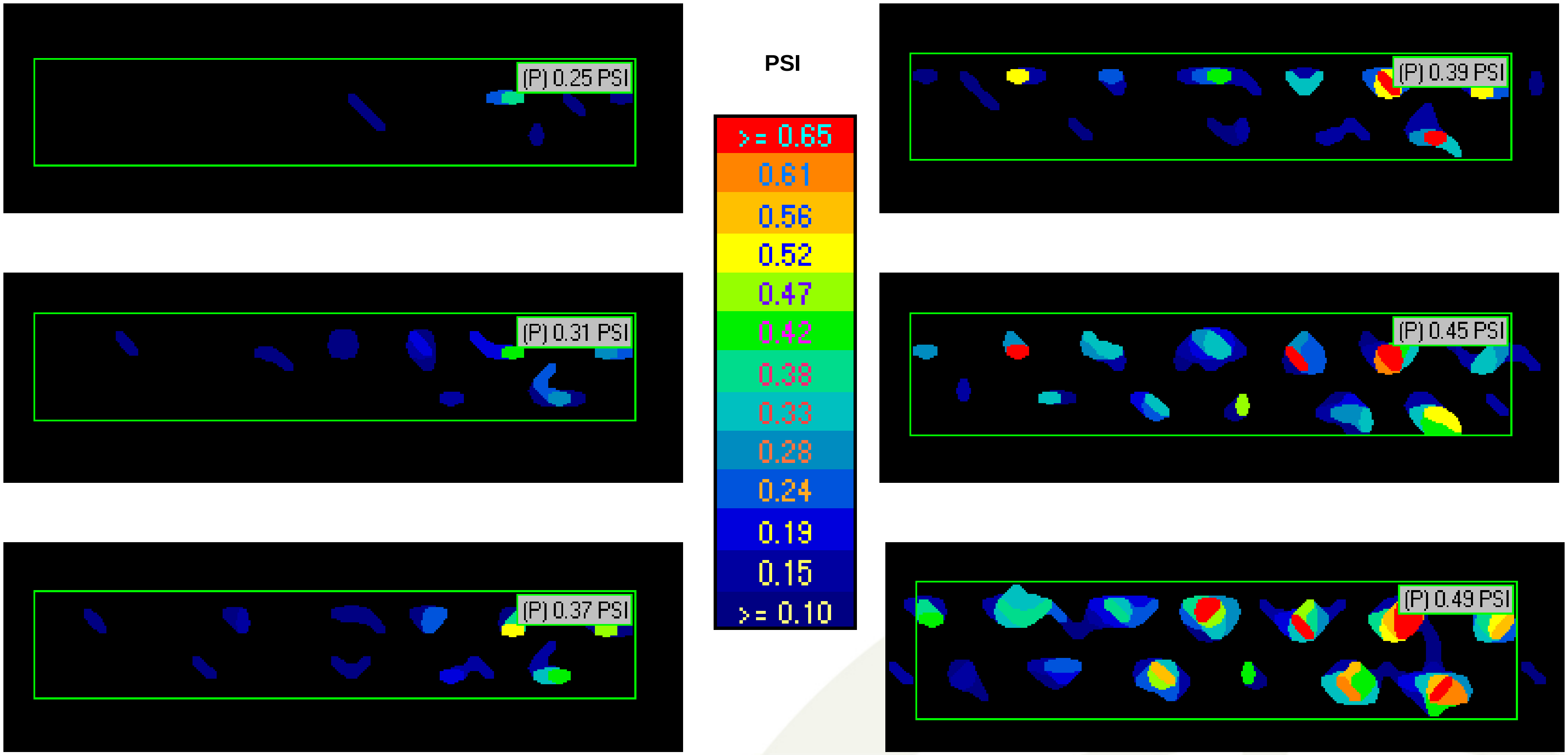
(The enveloped area bounded by the curves shows the extend of brush deformation)



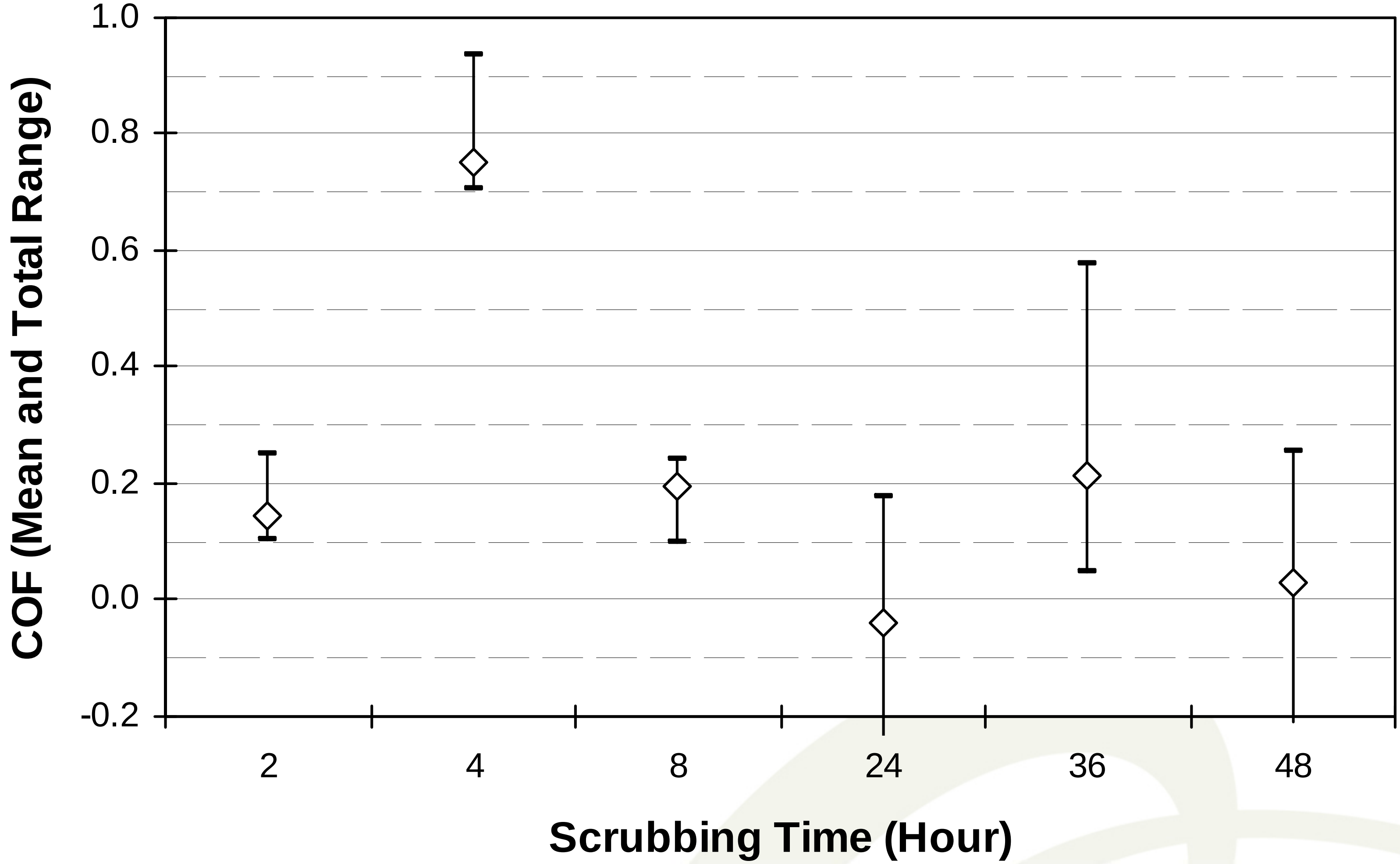
Pressure Contour Maps for Various applied Brush Pressures for Brush - A (Time = 0 hours)



Pressure Contour Maps for Various applied Brush Pressures for Brush - A (Time = 48 hours)

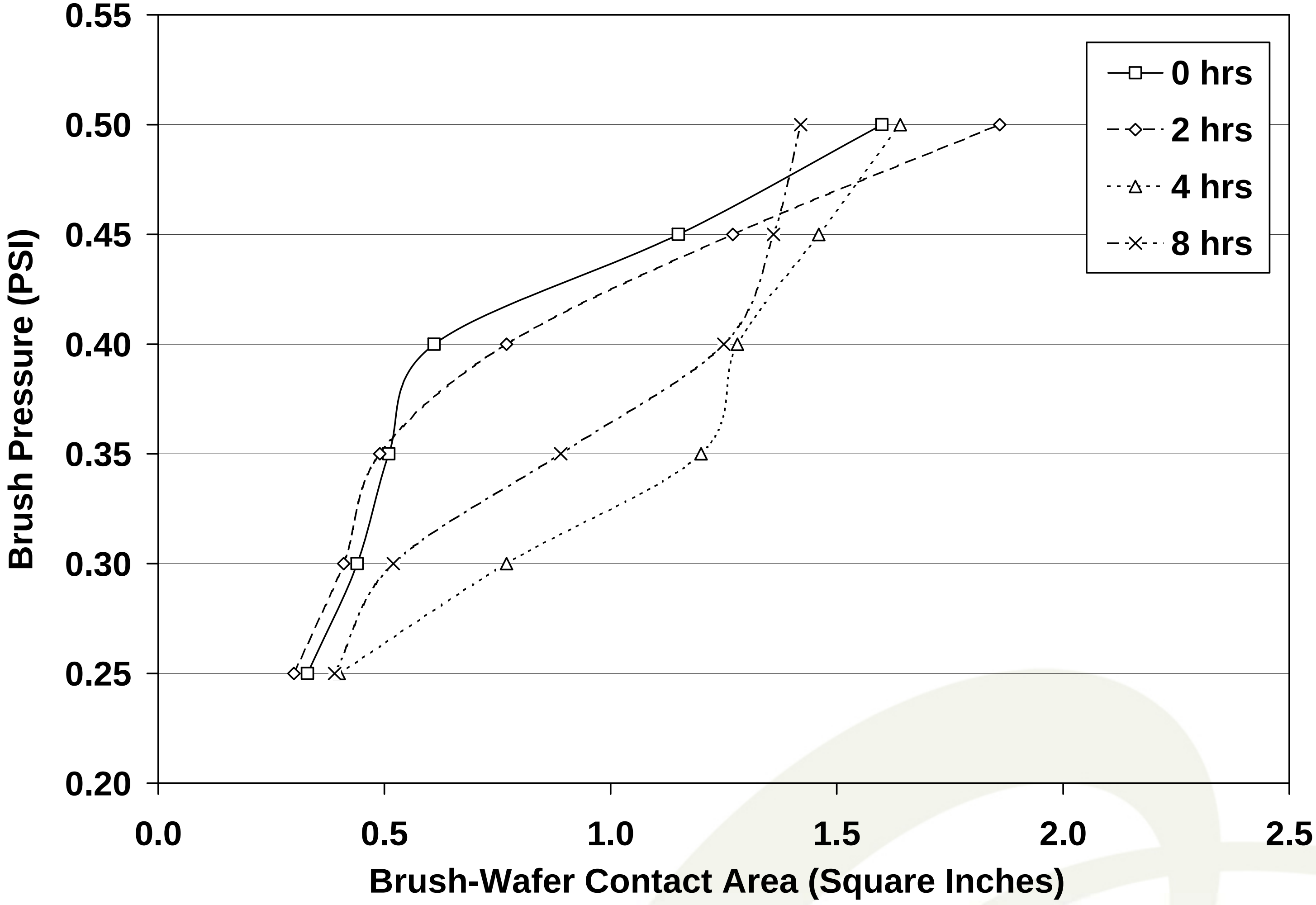


COF Results for Brush – B (SOTC Design)

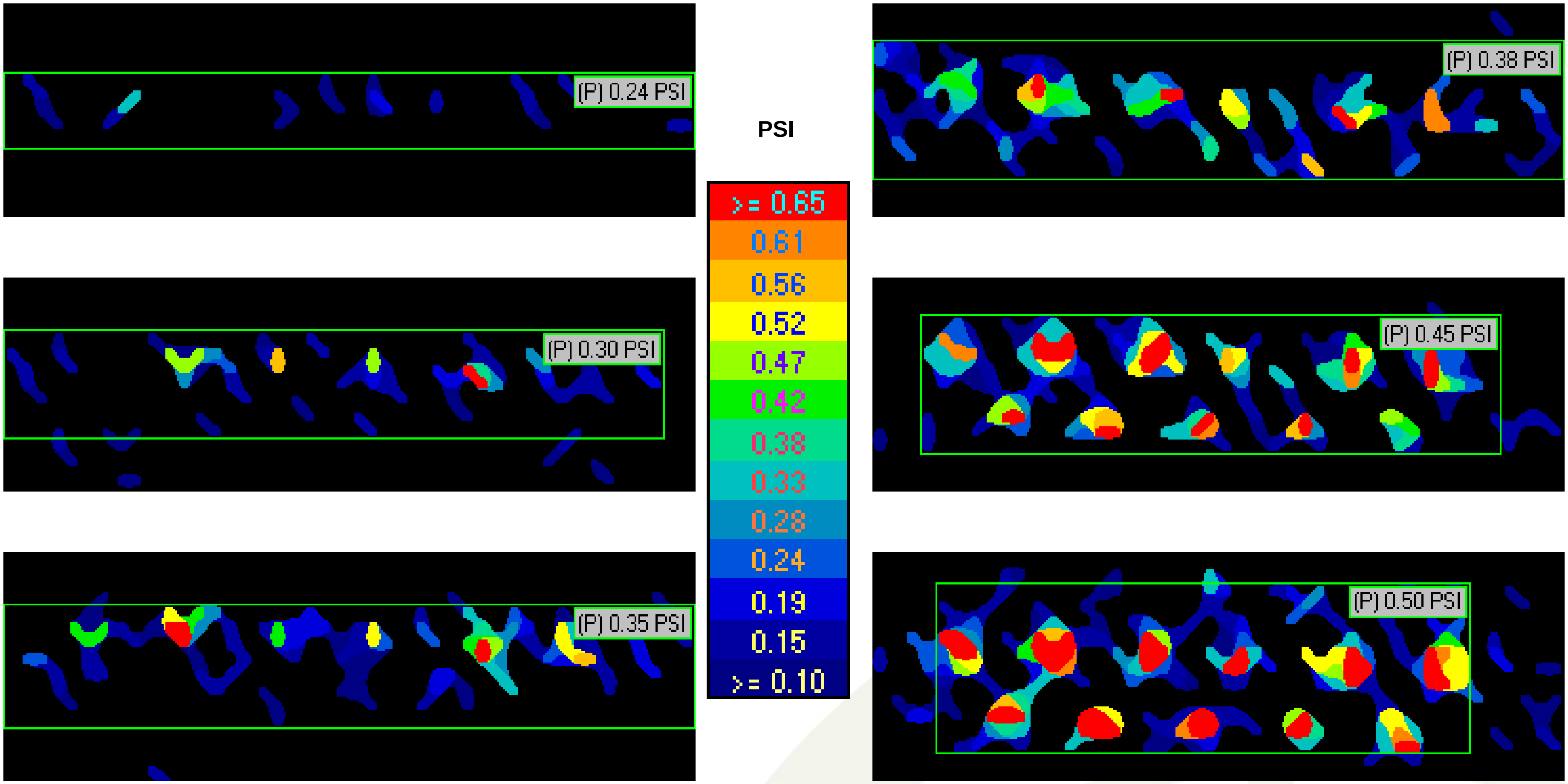


Pressure Contact-Area Relationship for Brush – B

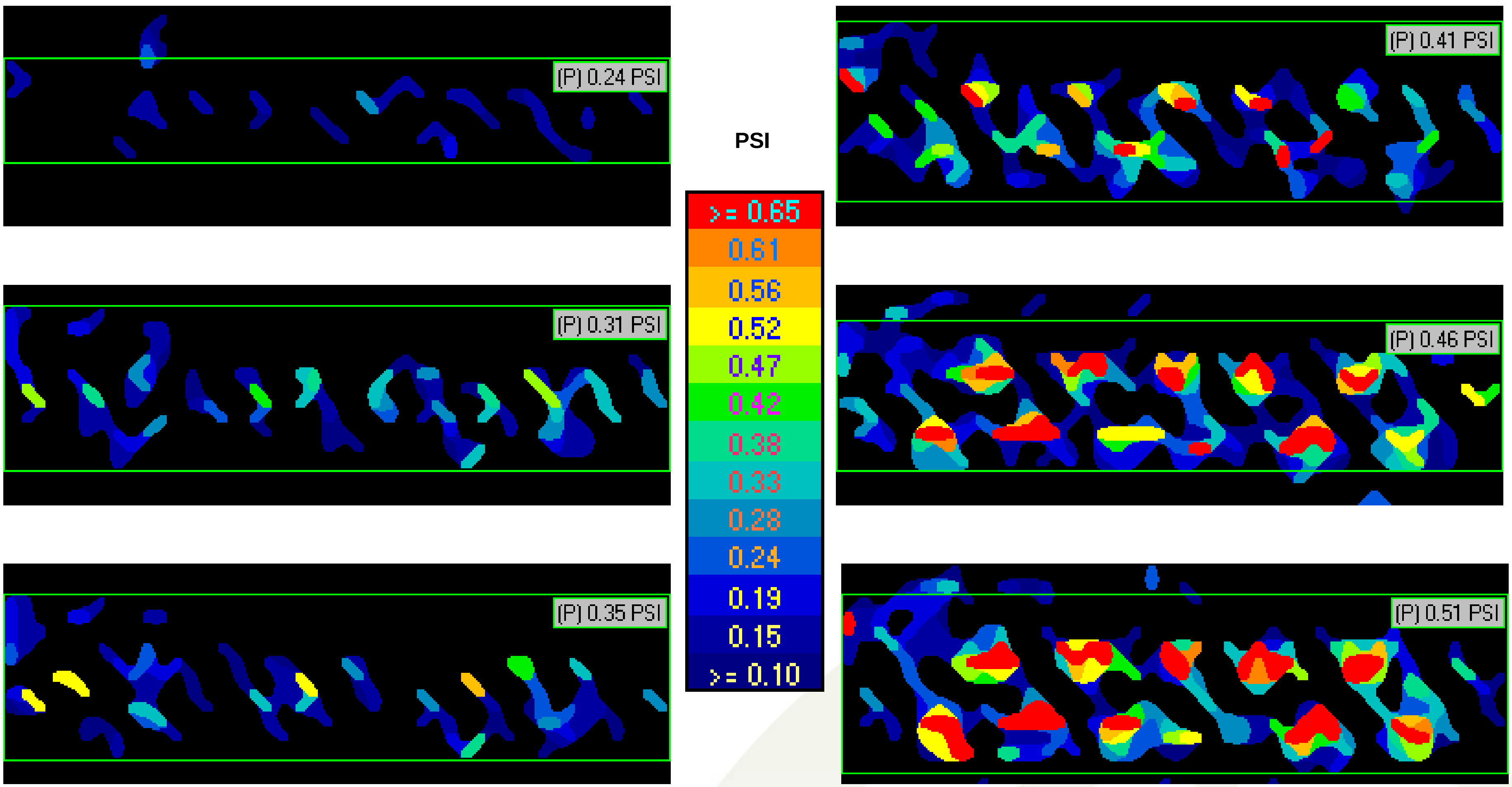
(The enveloped area bounded by the curves shows the extend of brush deformation)



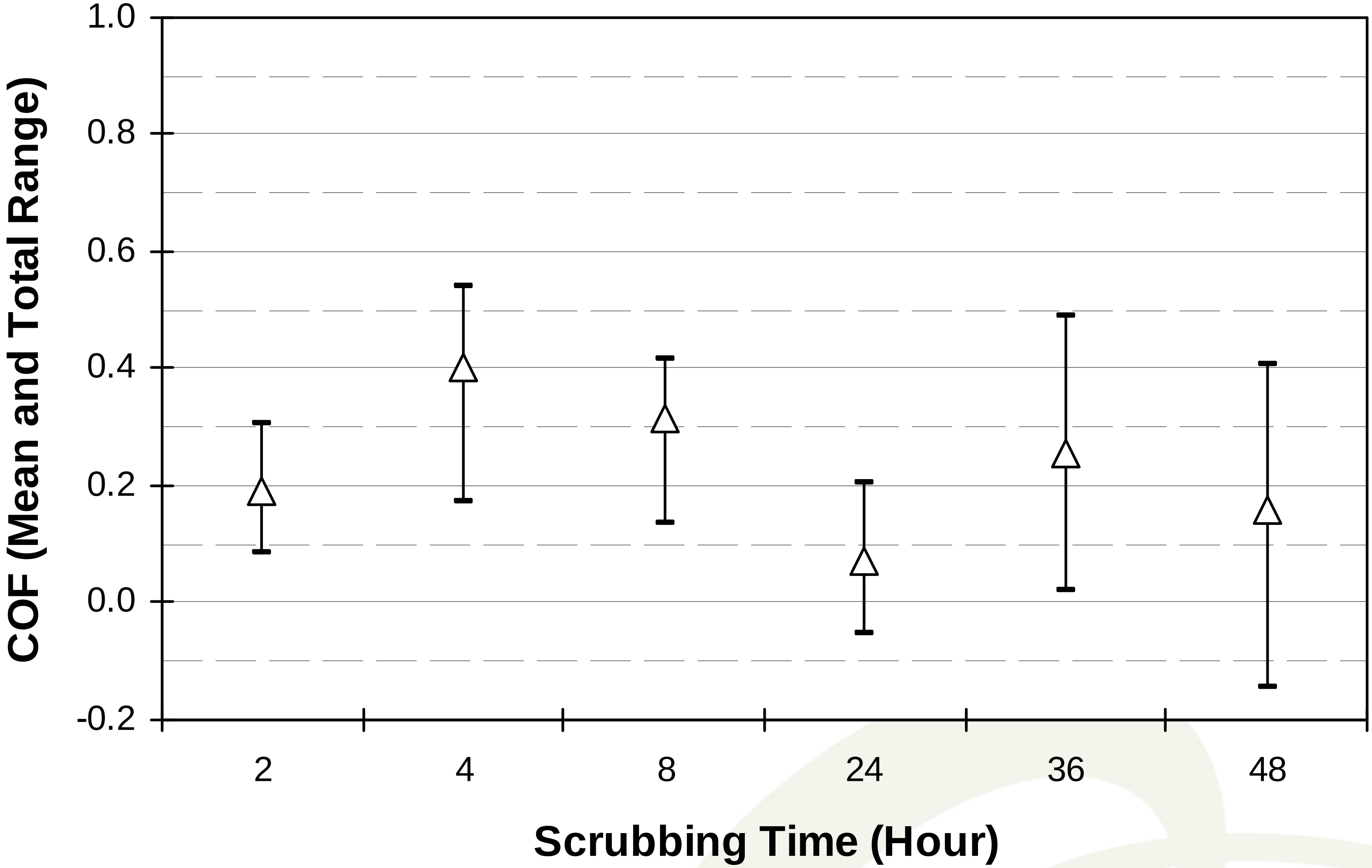
Pressure Contour Maps for Various applied Brush Pressures for Brush - B (Time = 0 hours)



Pressure Contour Maps for Various applied Brush Pressures for Brush - B (Time = 48 hours)

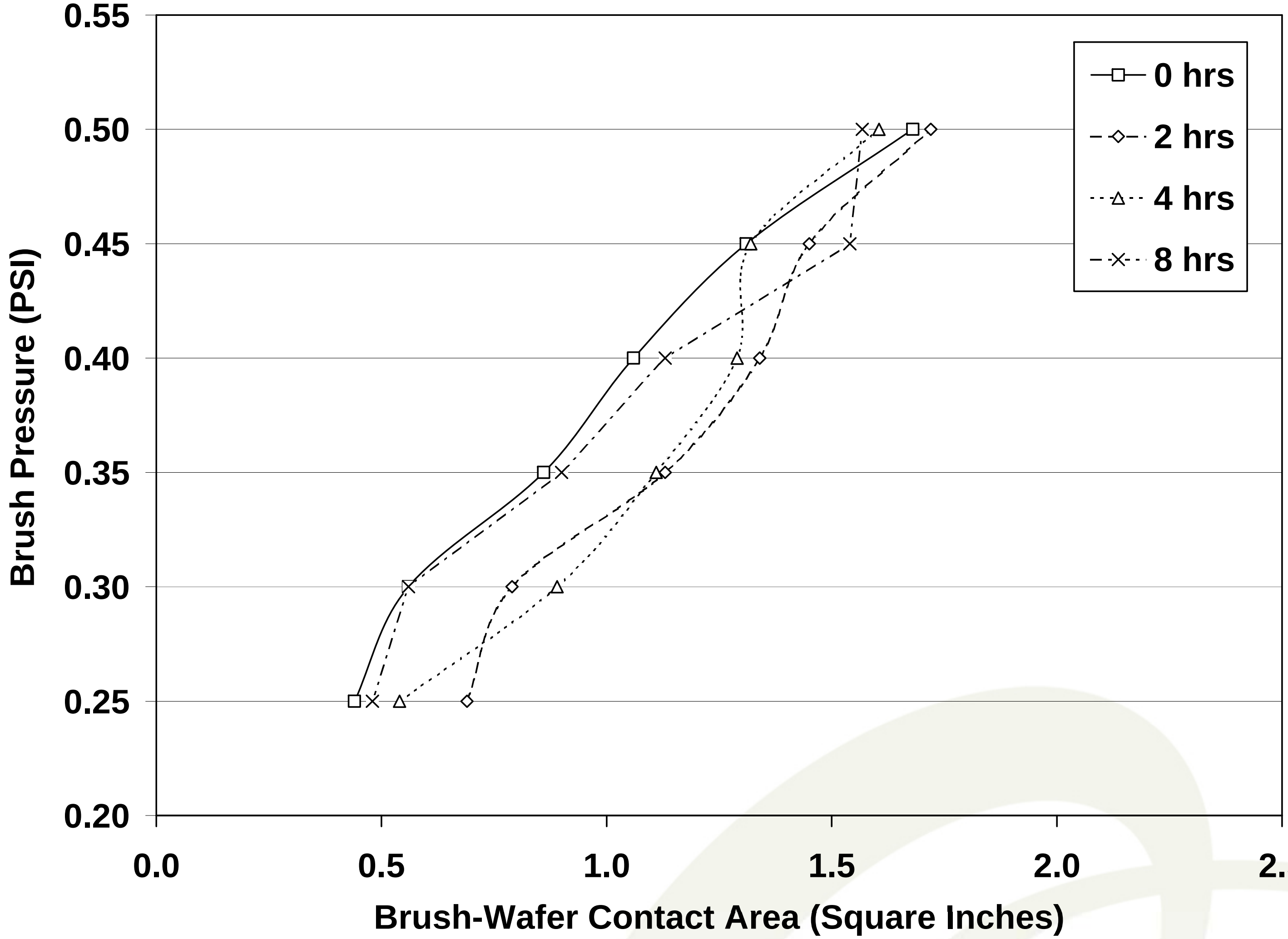


COF Results for Brush – C (MTTC Design)

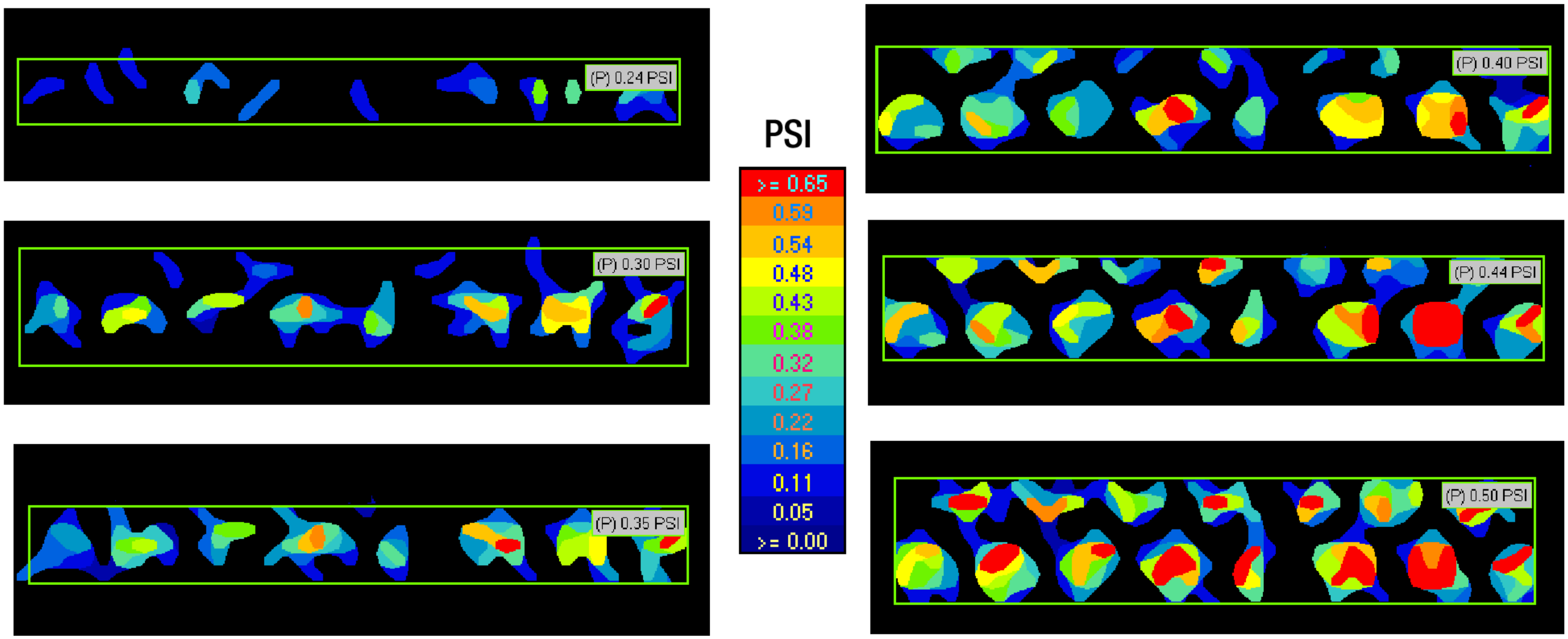


Pressure Contact-Area Relationship for Brush – C

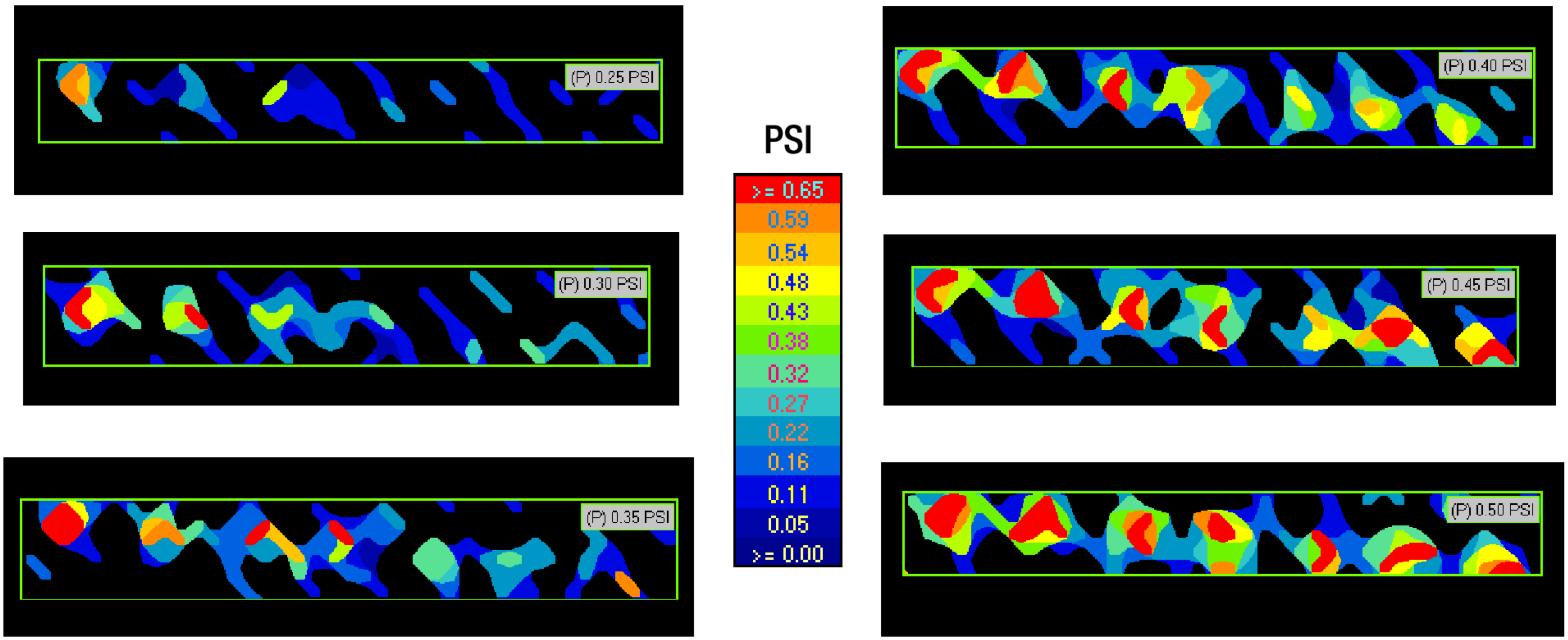
(The enveloped area bounded by the curves shows the extend of brush deformation)



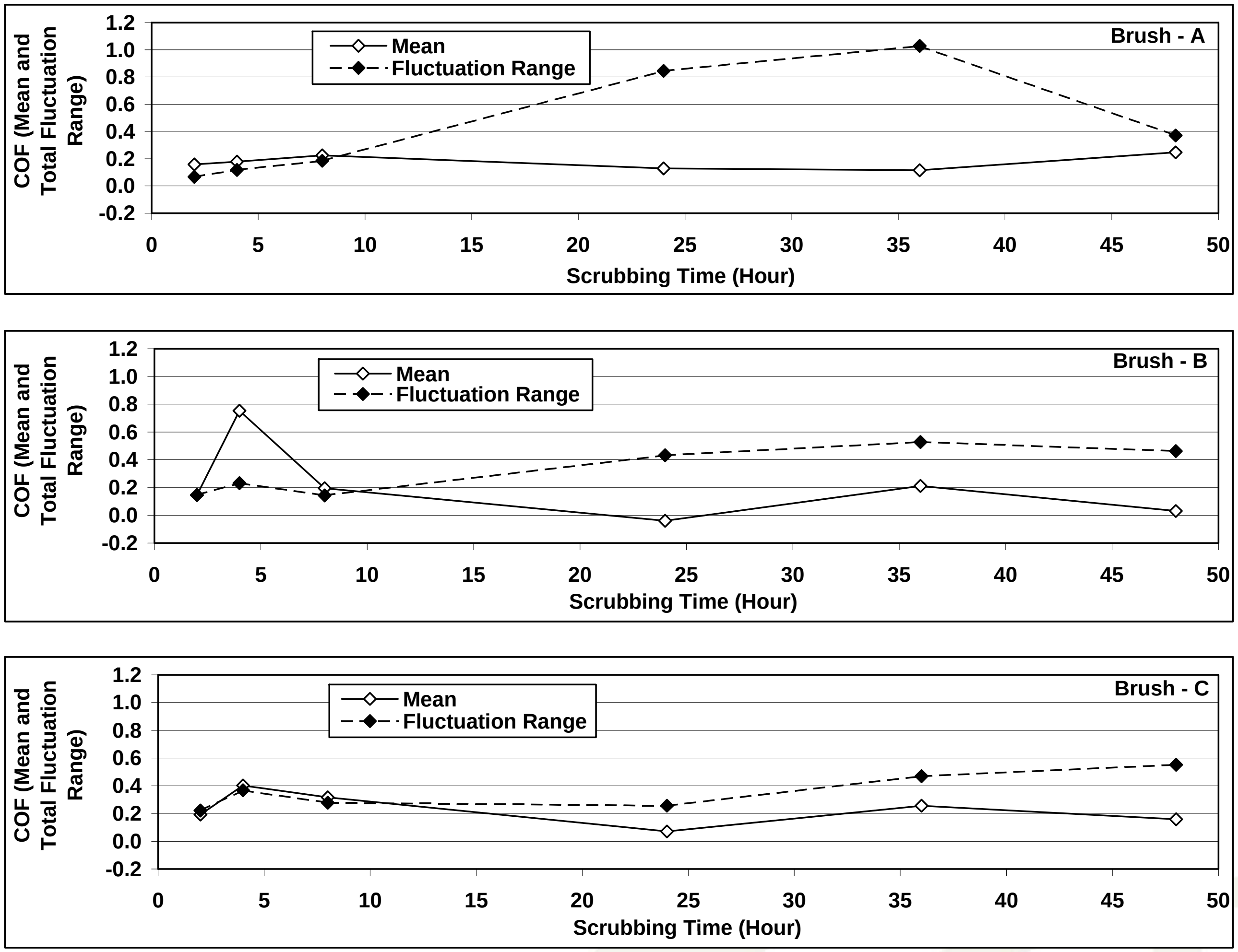
Pressure Contour Maps for Various applied Brush Pressures for Brush - C (Time = 0 hours)



Pressure Contour Maps for Various applied Brush Pressures for Brush - C (Time = 48 hours)



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



Case Study 2: PVA Brushes Post-CMP Cleaning Performance Evaluation in Cu/Low-k Application

Third Party PVA Brush Characterization

Objective

To generate PVA brush post-CMP cleaning data (defect maps/classification) for ENT4, ENT5 (molded-through-the-core design brushes) and a 3rd party fab POR (slip-on-the-core design) brush 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 tool and PCMP cleaner.

Tested Brushes

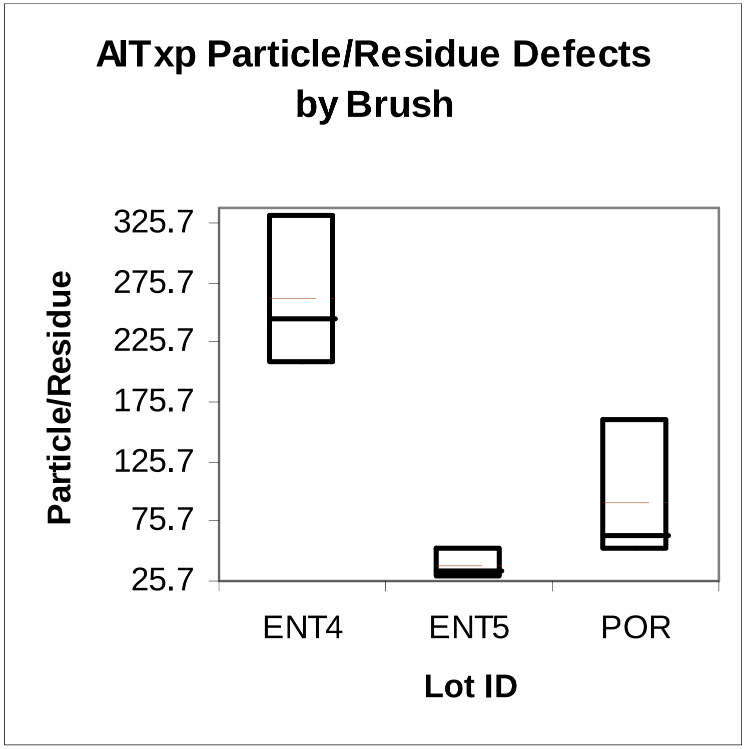
ENT4: Standard formulation PVA with molded PP core
ENT5: Improved PVA with molded PP core
POR: Competitor brush used as POR at 3rd party site

Equipment Set

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

Process conditions were optimized for current POR brush and were not specifically modified to ensure good comparative data for each brush

AIT XP MIT854 Wafer Particle/Residue Analysis

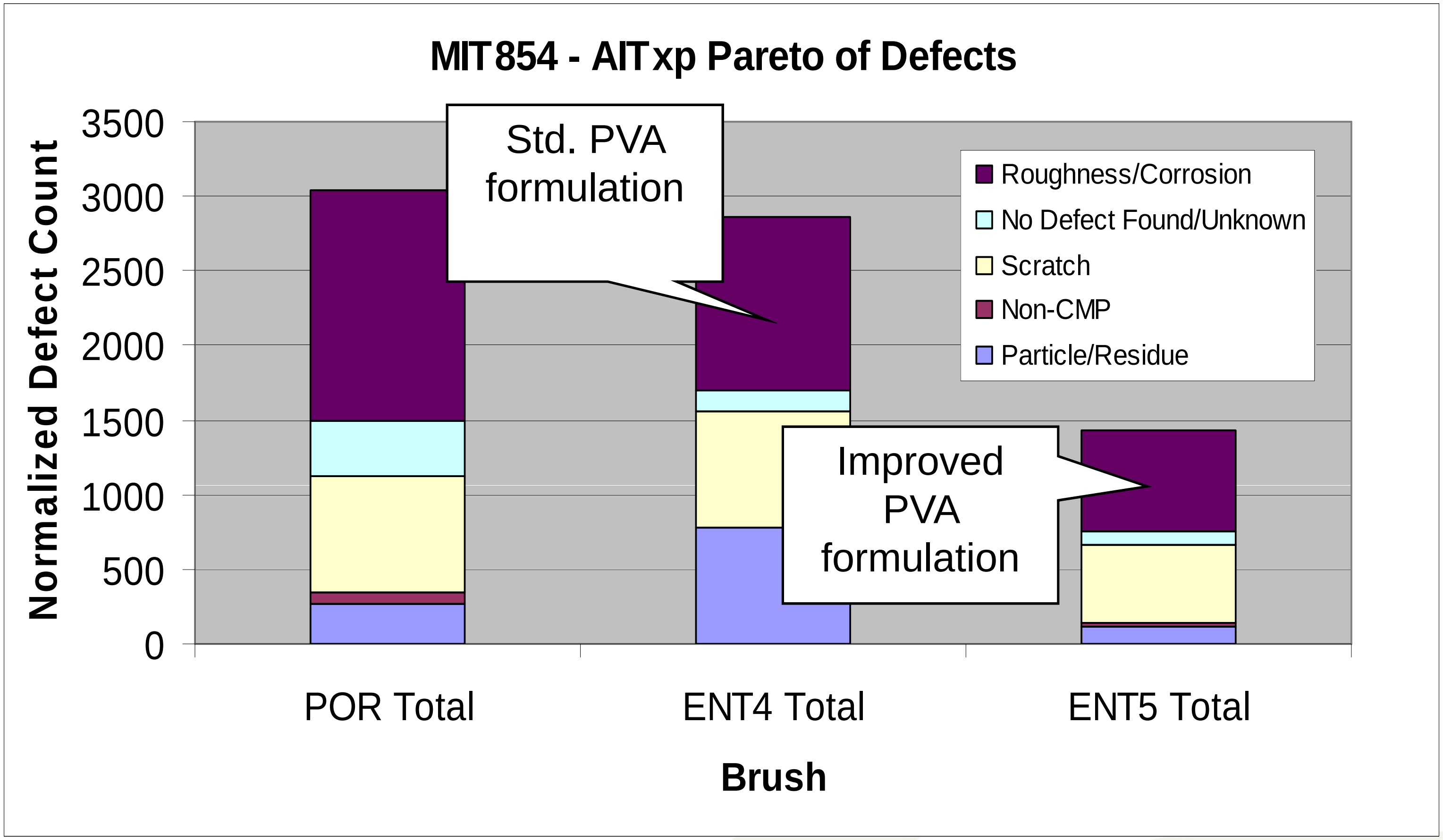


AIT XP Particle/Residue Defects

	ENT4	ENT5	POR
Mean	261.33	38.333	91
Stdev	64.081	13.317	60.108

Analysis shows improved PVA ENT5 has best performance, but may be in the same defect population as POR

Average AIT XP Pareto of Defects for 3 PVA Brushes



Summary and Conclusions

- Efficient Post-CMP cleaning process involves chemical as well as mechanical action. The new trend in Cu/Low-k PCMP clean applications is to use alkaline PCMP clean chemistries incorporating water-soluble organic solvents. These alkaline chemistries use a dissolution mechanism for the organic residue removal.
- An accelerated tribological evaluation of three post-CMP clean PVA brushes, including two slip-on-the-core design (Brushes A and B) and one molded-through-the-core design (Brush - 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 2 and 8 hours. The total variation range of COF for Brush - C (molded-through-the-core design) seems to be minimum.
- 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 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 performance evaluation of the improved PVA molded-through-the-core design brushes 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 3rd party characterization of PVA brushes.
- This study demonstrates the importance of post-CMP clean brush design (chemically, mechanically, and dimensionally) and methods of tribological and cleaning performance evaluation of the PVA roller for ensuring consistent frictional characteristics and cleaning behavior throughout the brush lifetime.

CMP - Industry and Applications Trends

- **Changing requirements of Chemical Mechanical Planarization**
  - More complex and demanding CMP solutions for 45 nm, 32 nm and smaller nodes
  - Introduction of larger wafers, copper, ultra low-k (ULK), high-k, and noble metals
  - Improved planarity and metrology specifications in Cu/low-k, STI, and poly-si CMP
- **Emerging applications, new consumables and refined processes in CMP**
  - Each IC solution might have unique optimized CMP and PCMP clean requirements
  - MEMS, power devices, hard disk, SOI, GaAs, 3-Dim, photonic bandgap devices
  - Changed operating parameters (much lower polishing pressures in Cu/low-k CMP)
  - Innovative PCMP clean methods (laser, gaseous aerosols, supercritical CO_2)
- **Slurry vendors, system suppliers and end users more interested in collaboration**
  - Ability to evaluate and fine-tune complicated CMP slurry new formulations quickly
  - Reduce CoO and minimize development/optimization time and repetition of efforts
  - Improve understanding of CMP process needs and share cost of development
- **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
  - Reduced need for CMP processing, PCMP cleaning, and slurry and chemical filtration

Next Generation PVA Brushes Development

- Application of PVA brushes in future post-CMP cleaning processes
  - 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
  - New applications may employ charged or interminated PVA brushes for enhanced PCMP cleaning
  - There may be a need for IPA resistant, Cu/Low-k specific, and next generation slurry compatible PVA brush technology (surface treated PVA, contact-pressure fine-tuning, etc.)
  - More stringent specifications may required development of Innovative products such as molded-through-the-core (MTTC) brushes for better process stability
    - *MTTC brush design (with positive adhesion/anchoring of the PVA with the core) provides ease of use, excellent dimensional stability, and improved flow equalization in the core, providing uniform flow distribution (out-of-the-brush) along the brush length*
    - *Improved PVA quality results in reduced particle counts on the wafer, decreased defectivity, reduced tool downtime, and consistent PCMP cleaning performance over brush lifetime*

What PVA brush designs/characteristics would be needed for the next generation post-CMP cleaning processes ? Your feedback!

Acknowledgments

– NCCAVS CMPUG committee for the opportunity to present at this meeting
– Dr. Ara Philipossian for information from Univ of Arizona Tribological Studies
– Dr. Ashwani Rawat, Dr. Robert Donis and Dr. Peter Burke for helpful insights
– Liquid Microcontaminations Control Team at Entegris, Inc., for their support

Entegris Corporate Profile

•Company founded as Flouroware in 1966 • Merged with Mykrolis in August 2005 • Corporate headquarters in Chaska (Minneapolis), Minnesota • 2,700 employees worldwide • Key manufacturing, sales and service facilities in the U.S., France, Germany, Malaysia, Singapore, Taiwan, China, South Korea and Japan • Delivers microcontamination control product and service solutions to the semiconductor industry (three-quarters of the companies sales) and other industries including data storage