Two Case Studies Involving the Use of a 300-mm PVA Brush Scrubber and Tribometer to Evaluate post-STI and post-W CMP Cleaning Processes

Yasa Sampurno (1), Siannie Theng (1), Fransisca Sudargho (1), Katherine M. Wortman-Otto (2), Carolyn F. Graverson (2), Jason J. Keleher (2) and Ara Philipossian (1)

(1) Araca, Inc. 2550 East River Road, Suite 12204, Tucson AZ 85718 USA
(2) Lewis University, Department of Chemistry, Romeoville IL 60446 USA

PVA Brush Scrubbing and Problem Statement

- **PVA brush scrubbing continues to be the *de facto* method for advanced-node post-CMP cleans.**

- **Based on direct contact between a rotating spongy PVA brush and the wafer surface in the presence of certain chemically-active agents.**

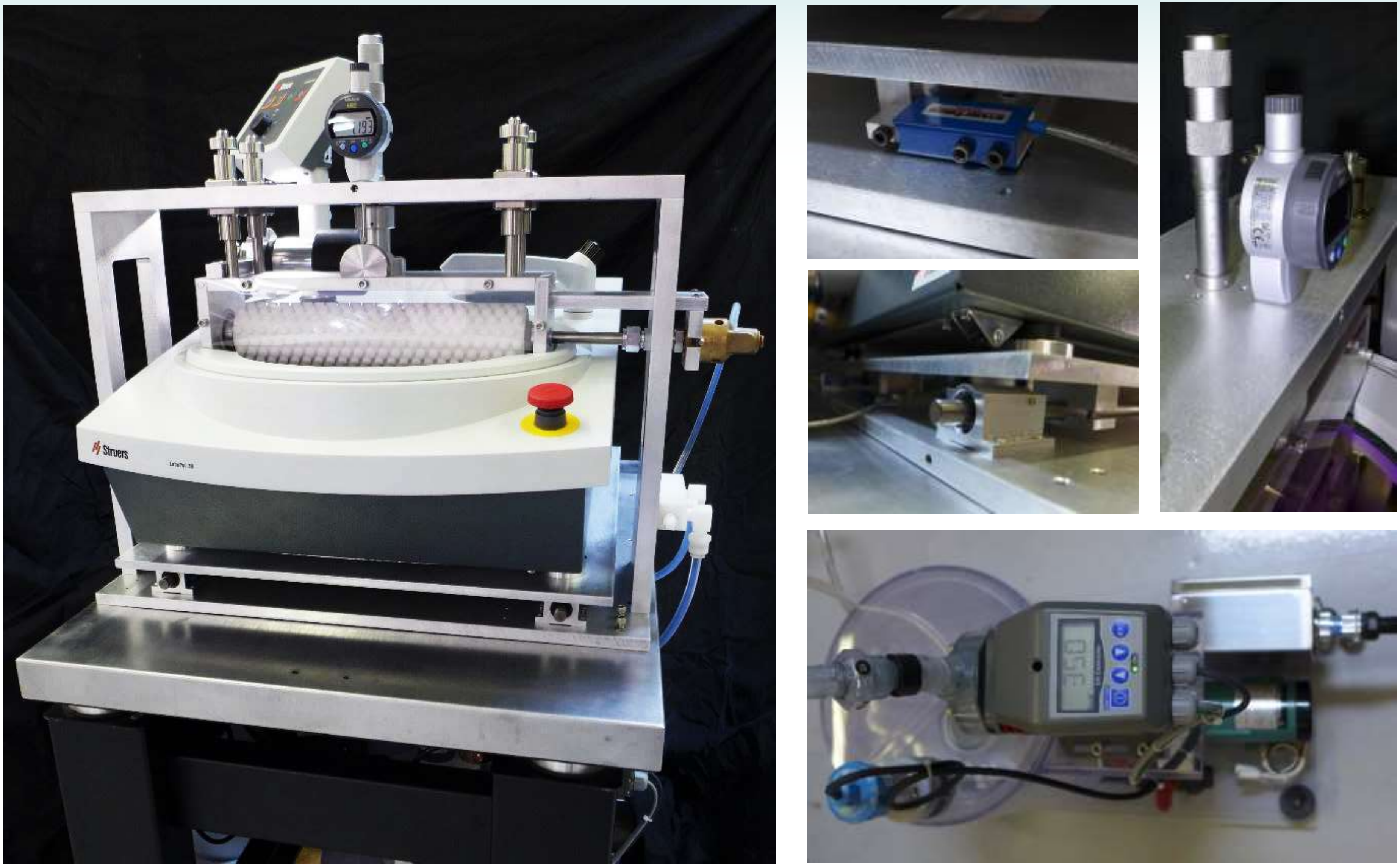
  - ❖ **Particle is first chemically "loosened up" from the wafer surface (via passivation layer formation, charge engineering, charge flipping, shear forces …)**
  - ❖ **Particle is then adsorbed on brush asperities**
  - ❖ **Wafer and brush rotations, and brush pressure, in the presence of a cleaning fluid dislodge and carry the particle away from the wafer surface**

- **Factors such as applied pressure, tool kinematics, physical and chemical properties of the brush and the cleaning fluid, wafer surface condition, cleaning time, and the magnitude of the shear forces at the brush-wafer interface are essential for effective particle removal.**

Outline

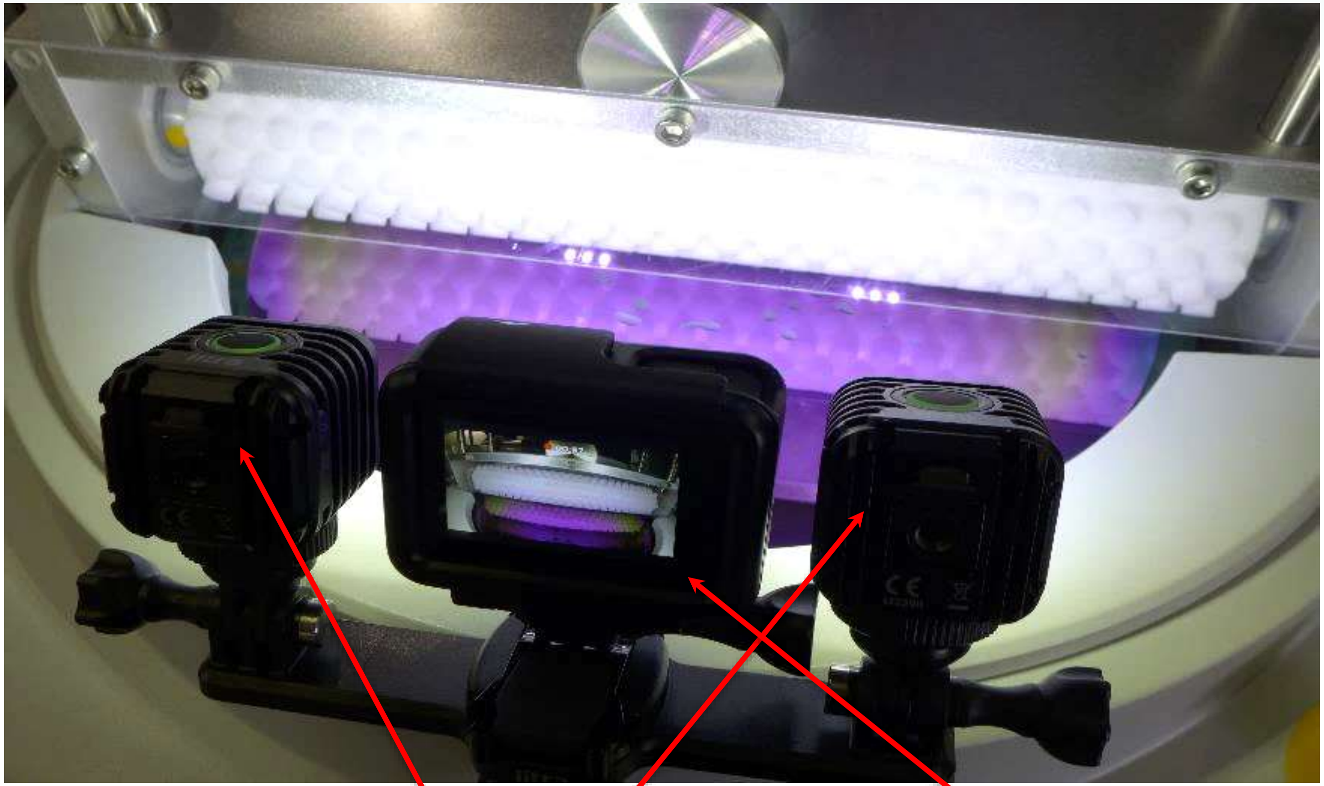
- **Details of the PCC-300® PVA Brush Scrubber and Tribometer**
- **Pressure Studies**
- **Reproducibility Studies**
- **Case Study A – Evaluate the Role of Anionic Supramolecular Assemblies in post-STI-CMP Cleaning**
- **Case Study B – Determine the Effect of Brush Nodule Placement Density on Shear Force in Time and Frequency Domains in post-W-CMP Cleaning**
- **Some Takeaway Messages**

The Araca PCC-300®



The Araca PCC-VIZ®

High-Speed Videography System



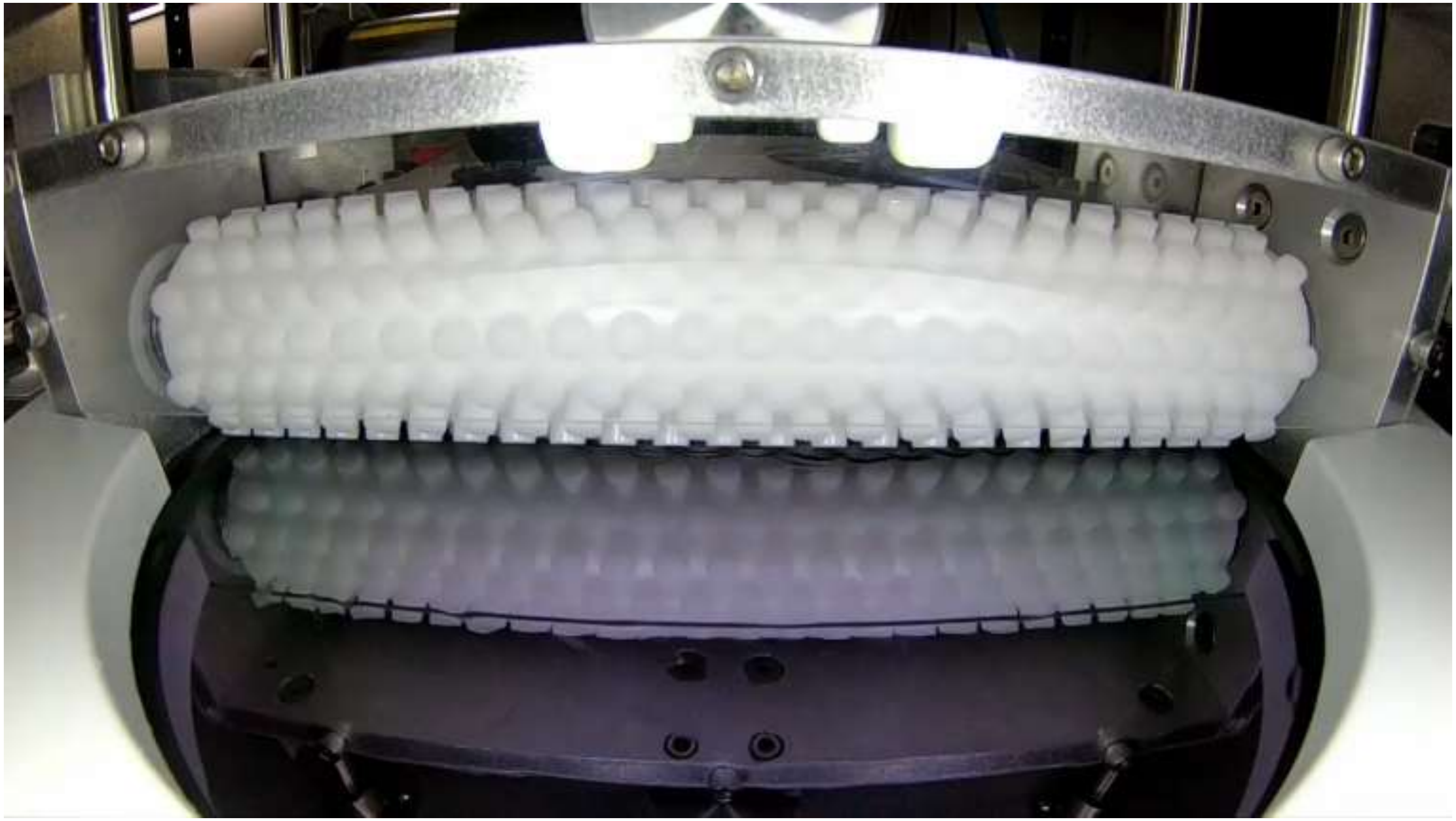
240 Hz Video Camera

Specialized Non-Flickering Dual LED Lights

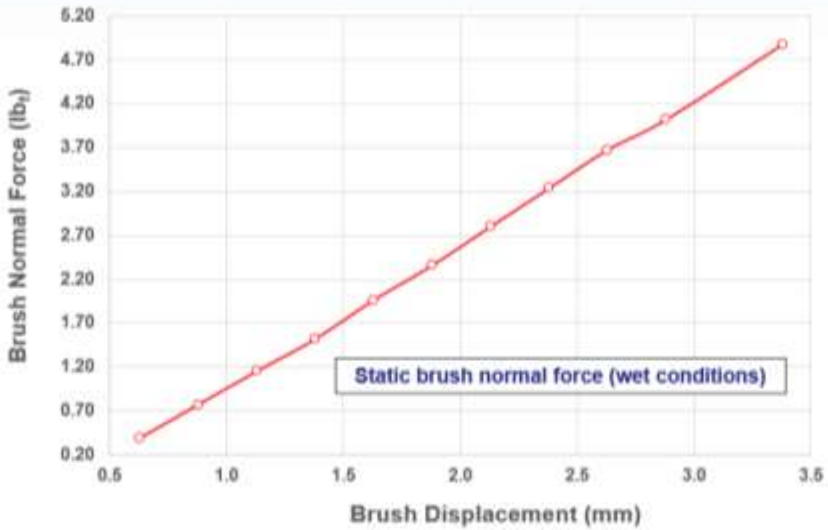
The Araca PCC-VIZ®

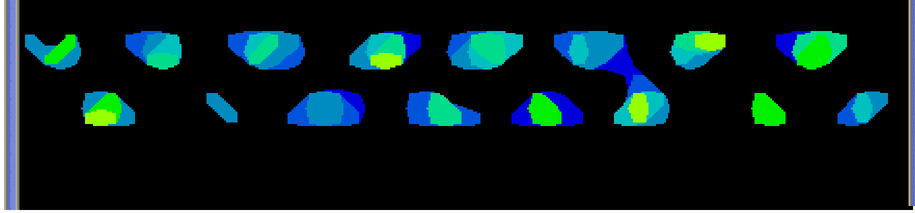
Brush at 50 RPM – Wafer at 100 RPM (2 mm Displacement)

Played at 10X slower motion

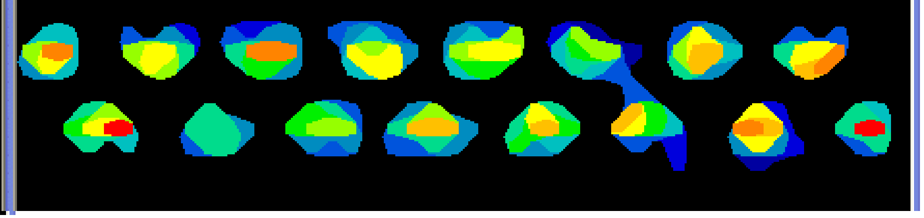


The Tekscan® Pressure Sensor

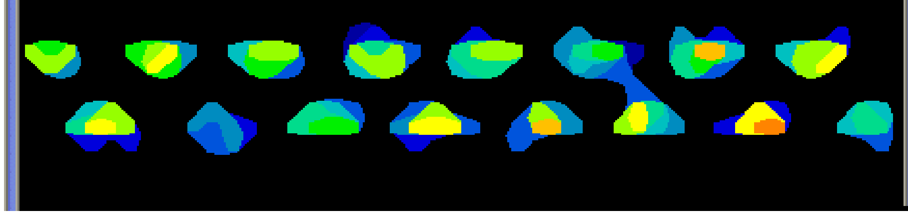




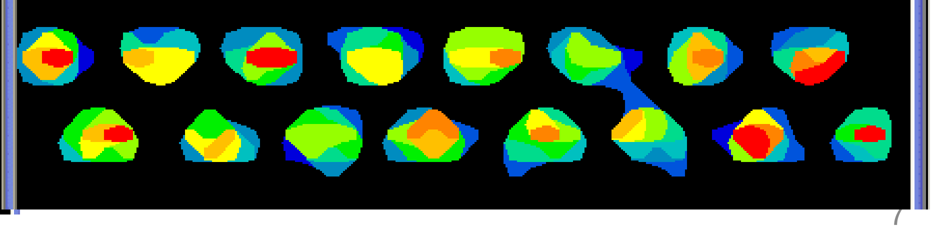
Actual brush displacement of 1.38 mm



Actual brush displacement of 2.38 mm



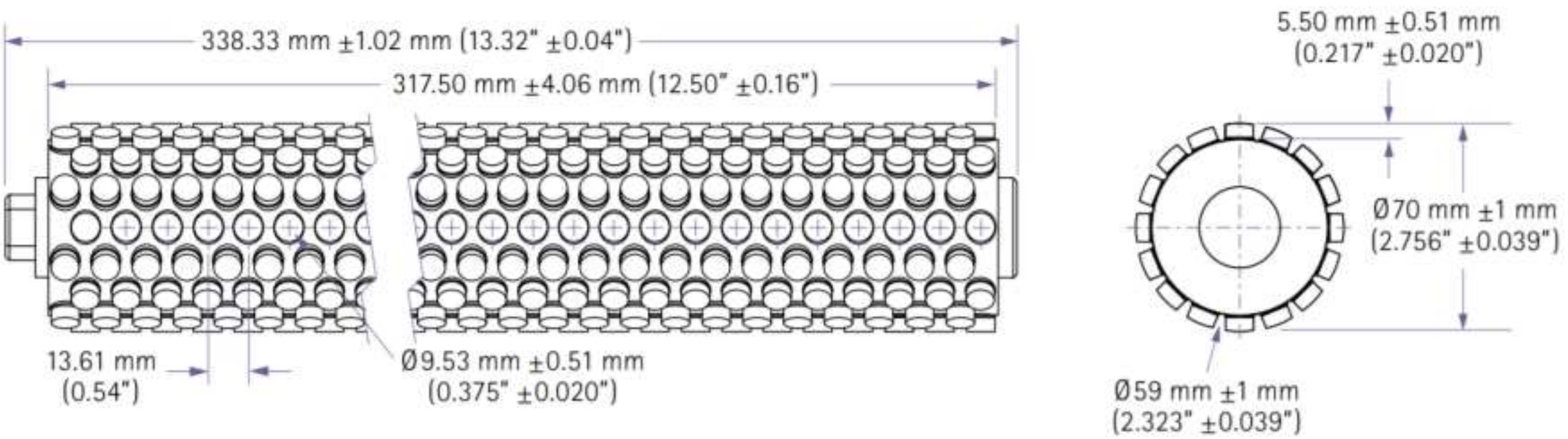
Actual brush displacement of 1.88 mm

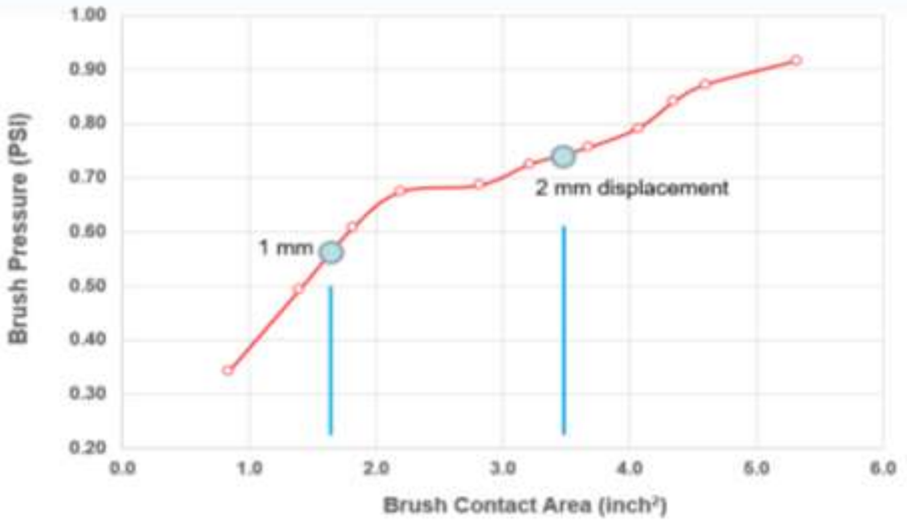


Actual brush displacement of 2.88 mm

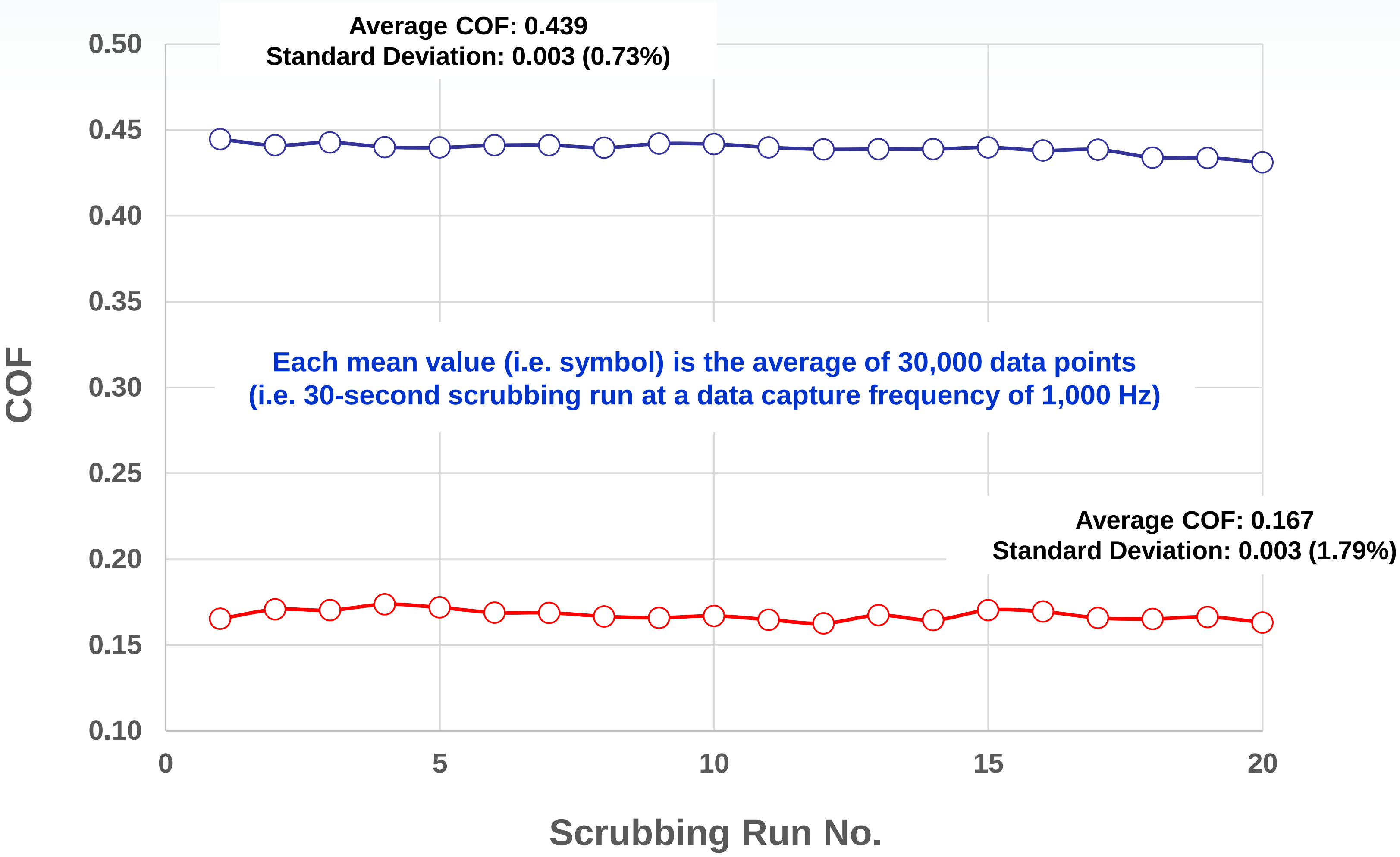
Area – Pressure – Displacement Relationships

PVP1ARXR1 and PVP0ARXR1 Planarcore Brush



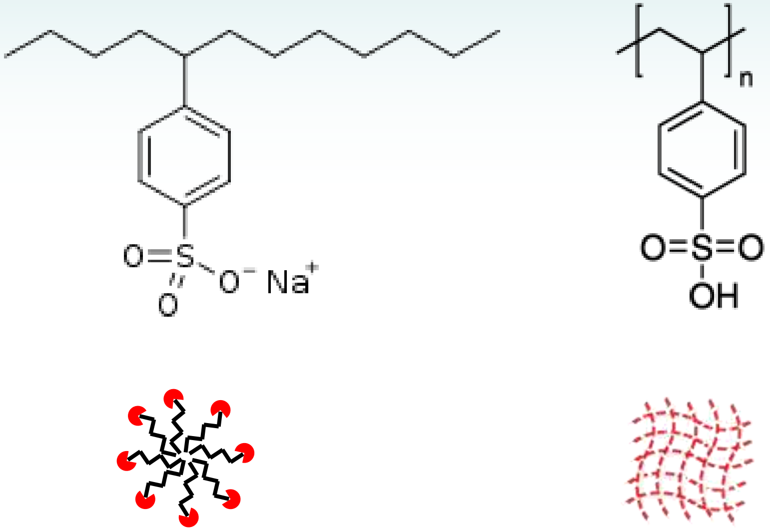


Example: Mean COF Reproducibility Results



Case A – Anionic Supramolecular Assemblies

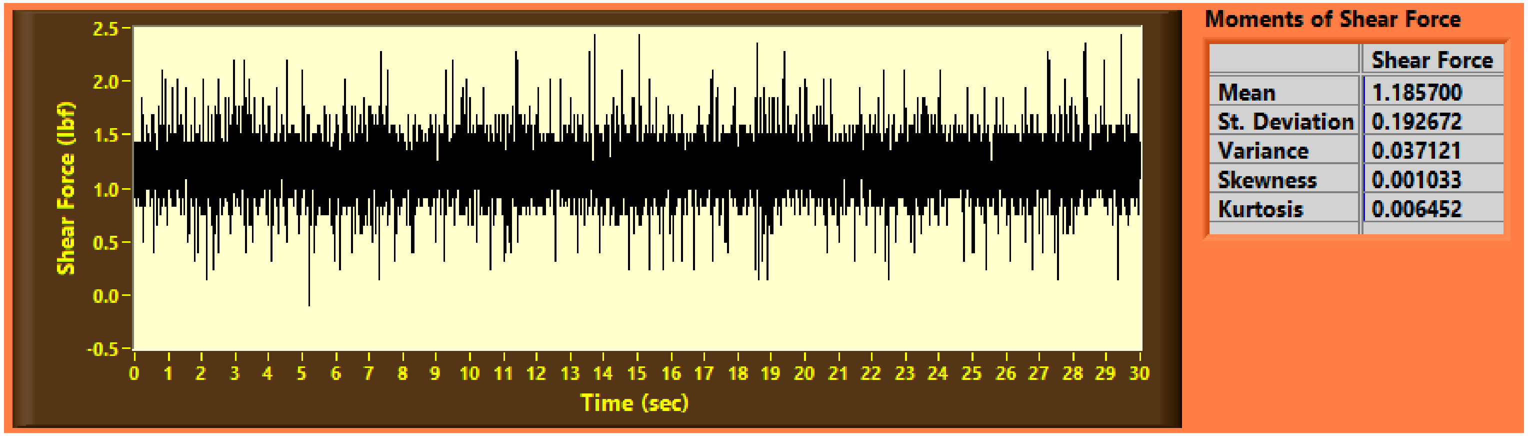
- **Entegris Planarcore® PVO1ARXR1 PVA Brush**
- **300-mm Blanket PETEOS SiO_2 Wafer**
- **Cleaning Solutions**
  - **0.1 % Sodium dodecylbenzenesulfonate (SDBS) at pH = 4**
  - **0.1 % poly-4-styrenesulfonic acid (PSSA) at pH = 4**
- **1-Hr break-in at 300 RPM wafer rotation, 250 RPM brush rotation and 0.68 PSI brush pressure.**



- **Test Conditions**
  - **Time = 30 seconds**
  - **Applied Pressure = 0.60 and 0.75 PSI**
  - **Wafer Rotation = 100 and 500 RPM**
  - **Brush Rotation = 50 and 500 RPM**

Case A – Example Shear Force Time Traces

SDBS at 2 mm Vertical Displacement



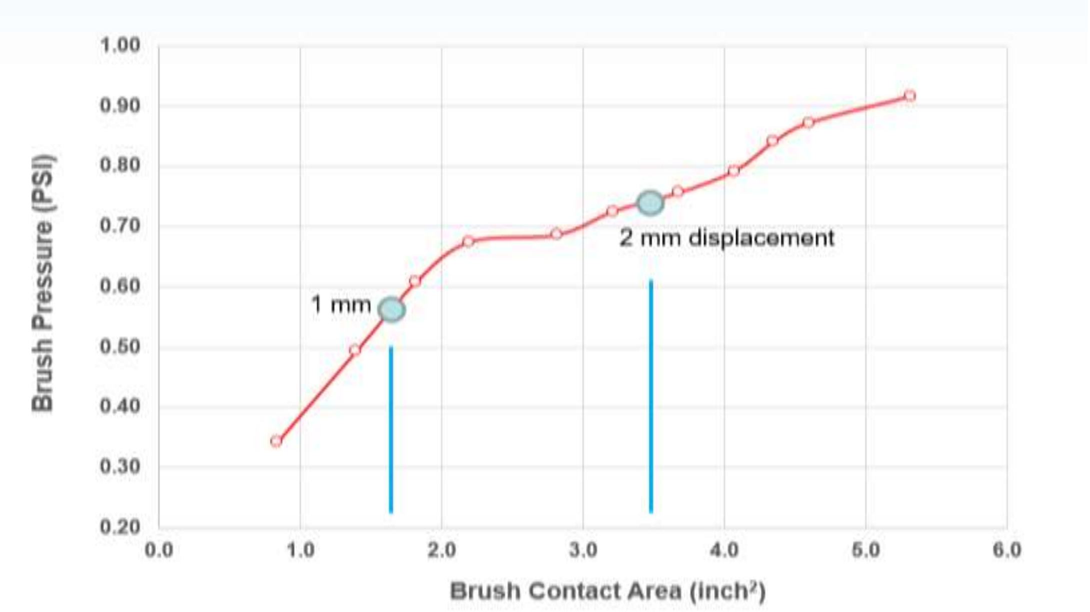
Moments of Shear Force

	Shear Force
Mean	1.185700
St. Deviation	0.192672
Variance	0.037121
Skewness	0.001033
Kurtosis	0.006452

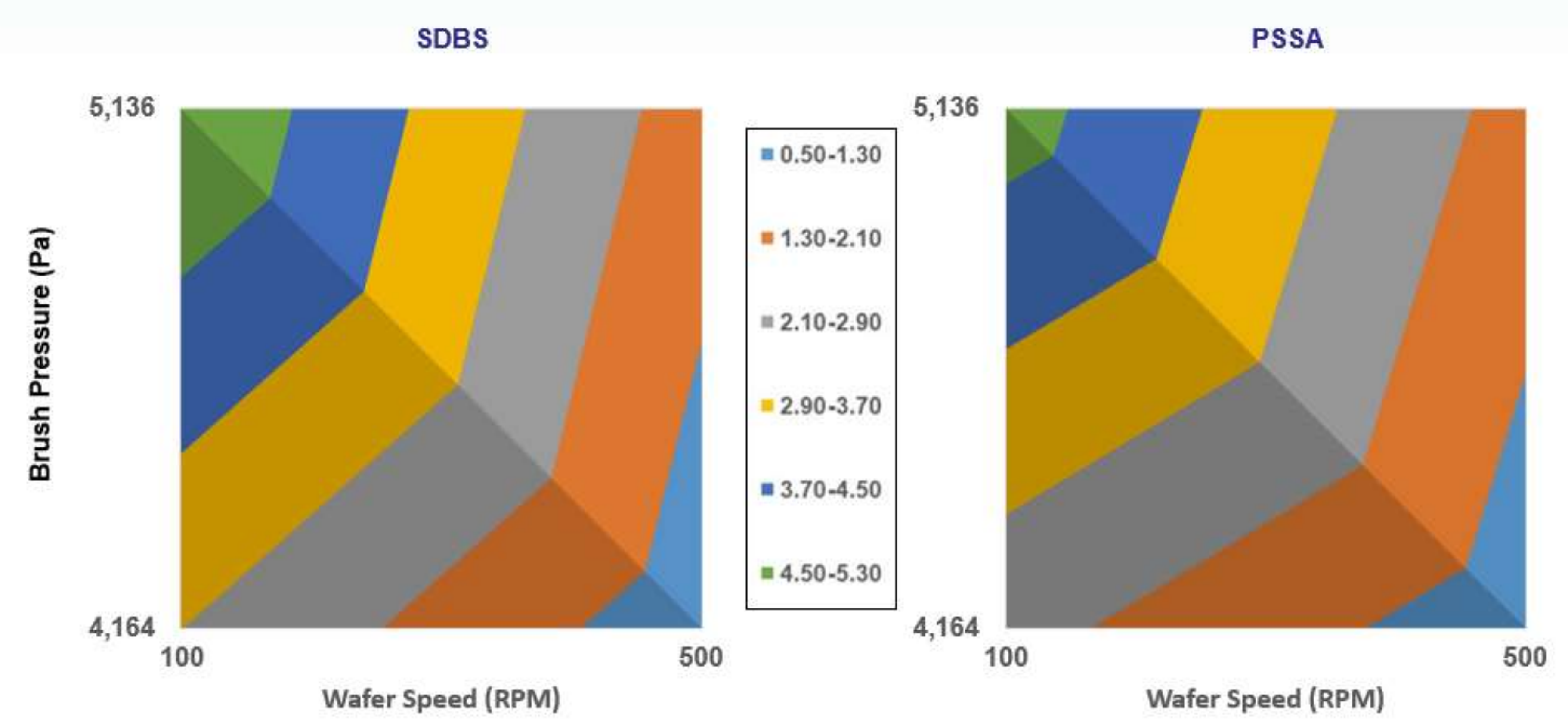
Coefficient of Friction (COF) = Shear Force ÷ Normal Force

Normal Force = Pressure × Contact Area

COF = Shear Force ÷ [Pressure × Contact Area]



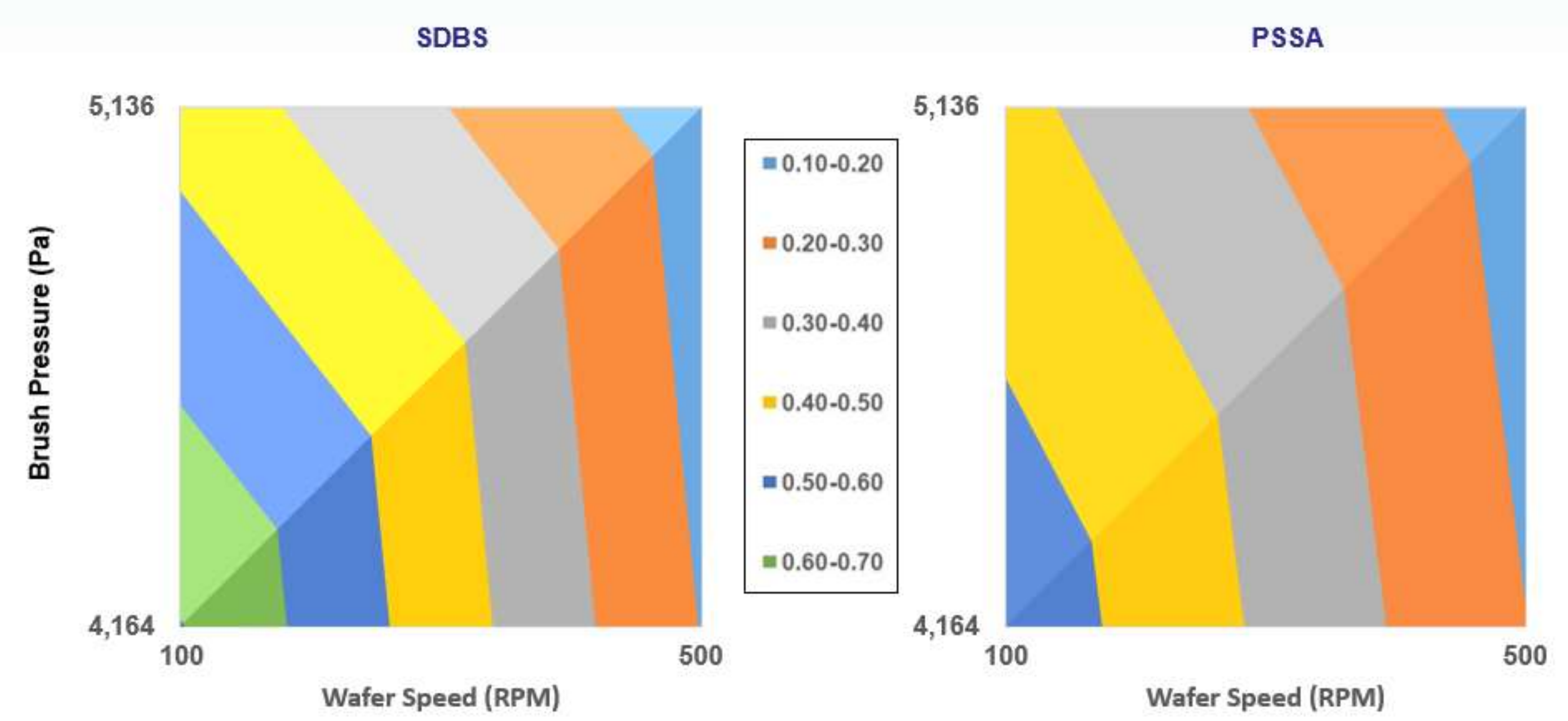
Shear Force (N) Lim-Ashby Plots – Brush at 500 RPM



As pressure increases, shear force increases
As wafer velocity increases, shear force decreases
(tribological mechanism is partial lubrication)

At all conditions, SDBS causes higher shear forces as compared to PSSA which can be correlated to the shape of the supramolecular structure (micelle vs. polyelectrolyte)

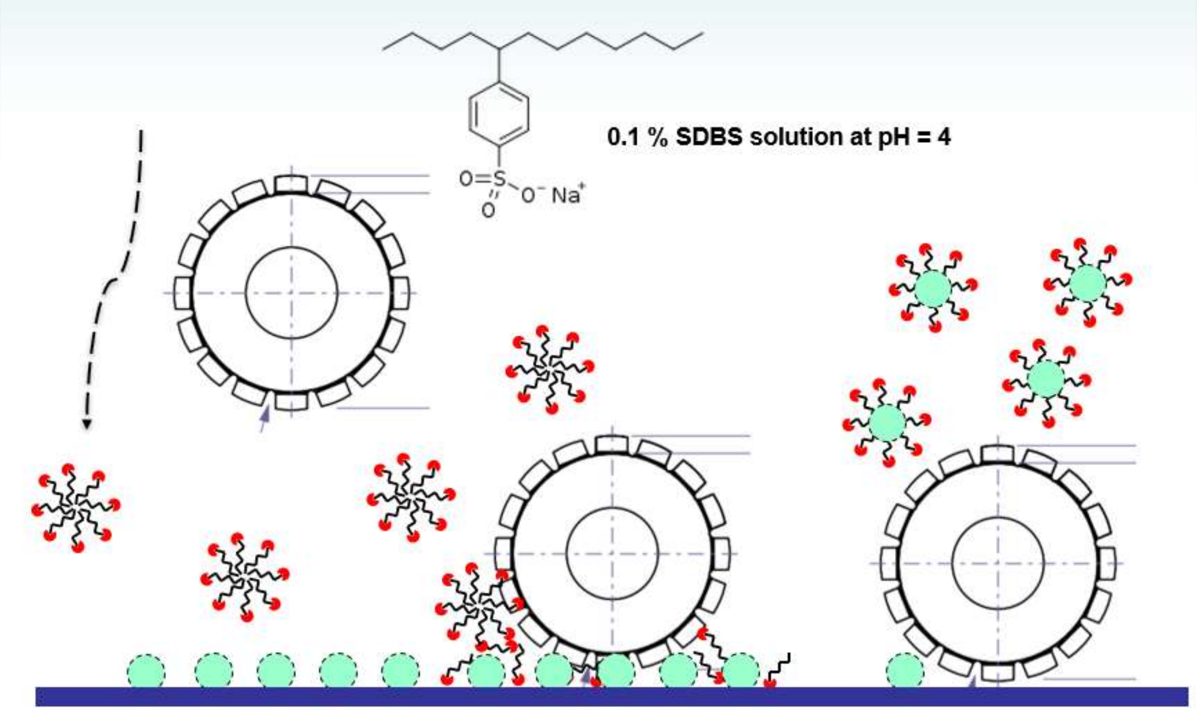
COF Lim-Ashby Plots – Brush at 500 RPM



As pressure increases, COF decreases (contact area increases which lubricates faster)
As wafer velocity increases, shear force decreases (tribological mechanism is partial lubrication)

At all conditions, SDBS causes higher COF as compared to PSSA which can be correlated to the shape of the supramolecular structure (micelle vs. polyelectrolyte)

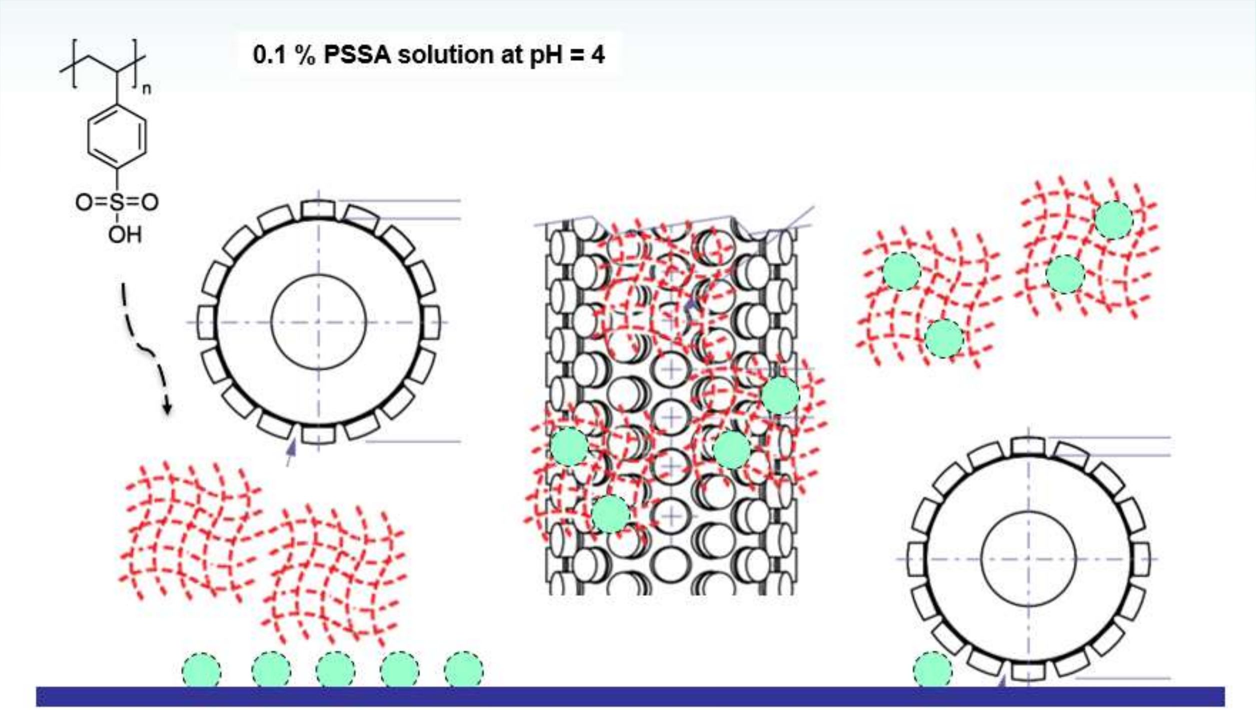
Proposed Mechanism – SDBS



SDBS is an anionic micellar surfactant. We postulate that there is breaking of micelles at the brush-wafer interface due to shearing as well as the micelle being well below CMC. The micelle then recombines and removes ceria in the process.
Ceria removal is facilitated by the bulk and is not necessarily a direct encapsulation.

This causes higher shear forces and should
increase wafer-level defects

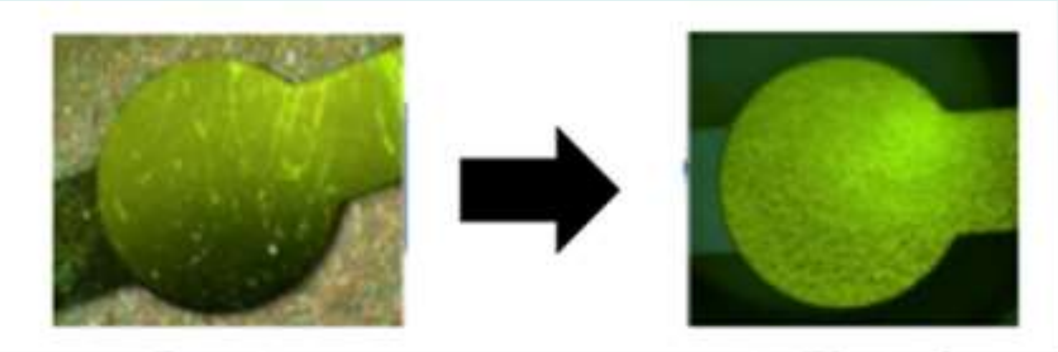
Proposed Mechanism – PSSA



PSSA is an anionic polyelectrolyte.
We postulate that PSSA is involved in a surface adsorbing and charge-flipping encapsulation process. Because there is no structural destruction – reconstruction involved (as in the case of SDBS) and we simply have "sliding", shear forces are much lower.

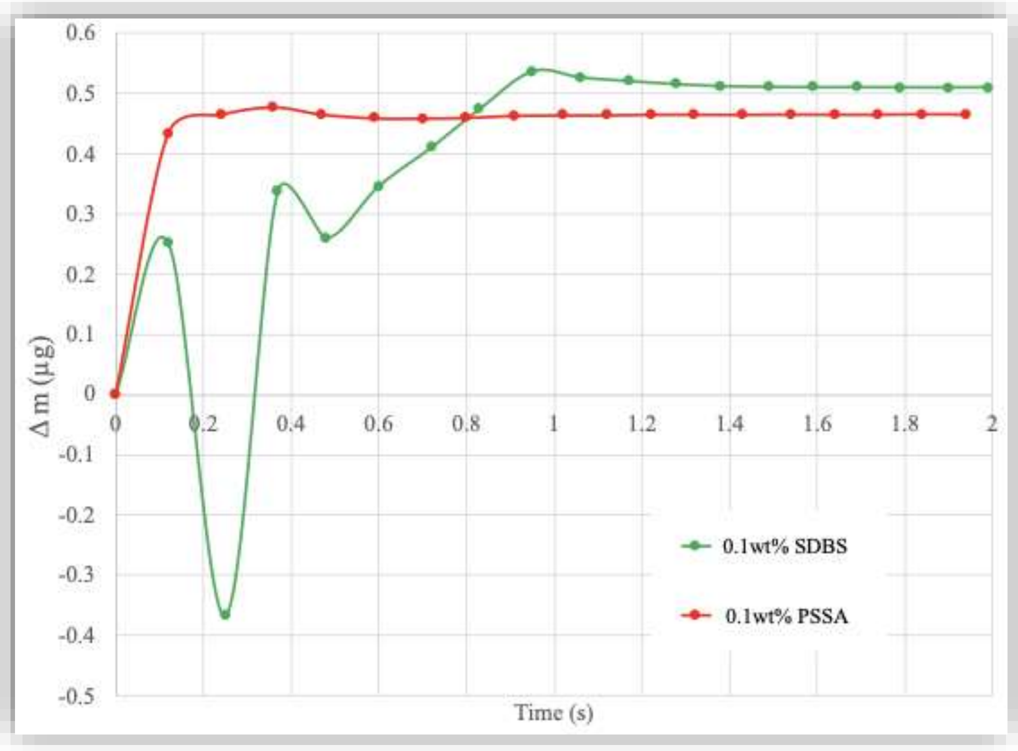
This should cause lower wafer-level defects. Besides, PSSA may be providing a more uniform lubrication barrier.

Microbalance Studies re: Ceria NP Mass Changes



Bare Au Electrode

Au Electrode with CeO_2 film



SDBS undergoes repeated destruction – reconstruction equilibria.
This instability is observed via a super-sensitive microbalance.

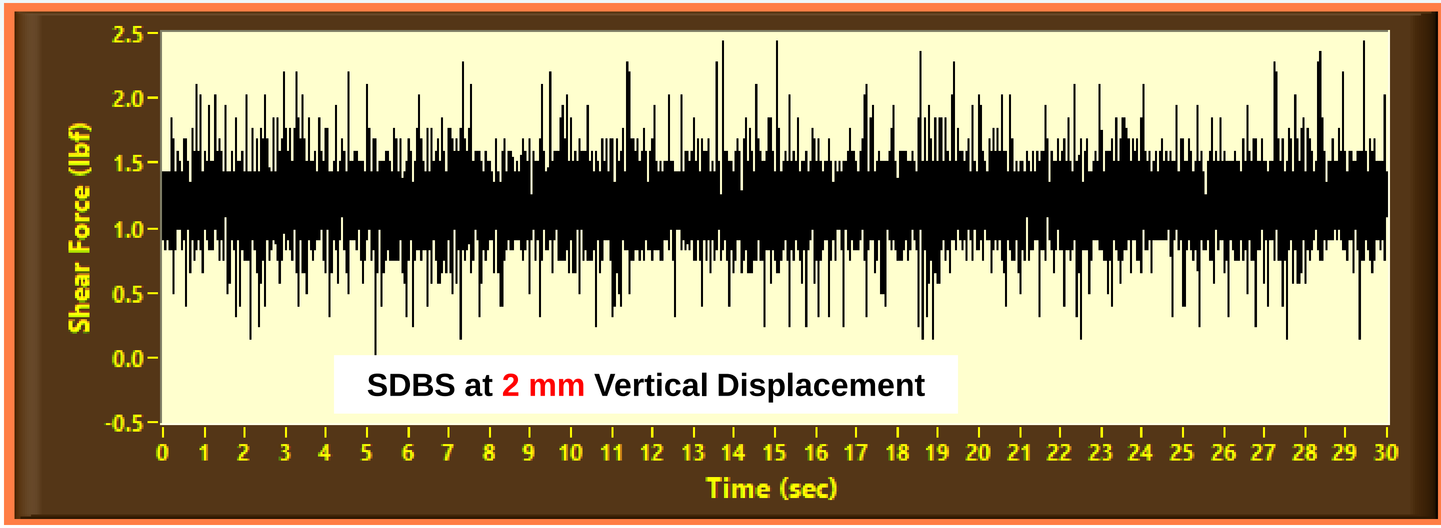
PSSA adsorbs on the surface and causes charge-flipping and encapsulation at a rapid rate.
The stability of this process is evident in the microbalance data.

Case A – Wafer-Level Defects and Micro-Scratches

Cleaning Solution at pH = 4	Average No. of Post-Clean Micro-Scratches	Average Post-Clean Micro-Scratch Length (nm)	Average Post-Clean Micro-Scratch width (nm)
0.1 % SDBS	19	9 ± 6	68 ± 39
0.1 % PSSA	9	15 ± 5	33 ± 16

Cleaning Solution at pH = 4	Average No. of Post-Clean Wafer-Level Defects Larger than 50 nm
0.1 % SDBS	72 ± 91
0.1 % PSSA	66 ± 47

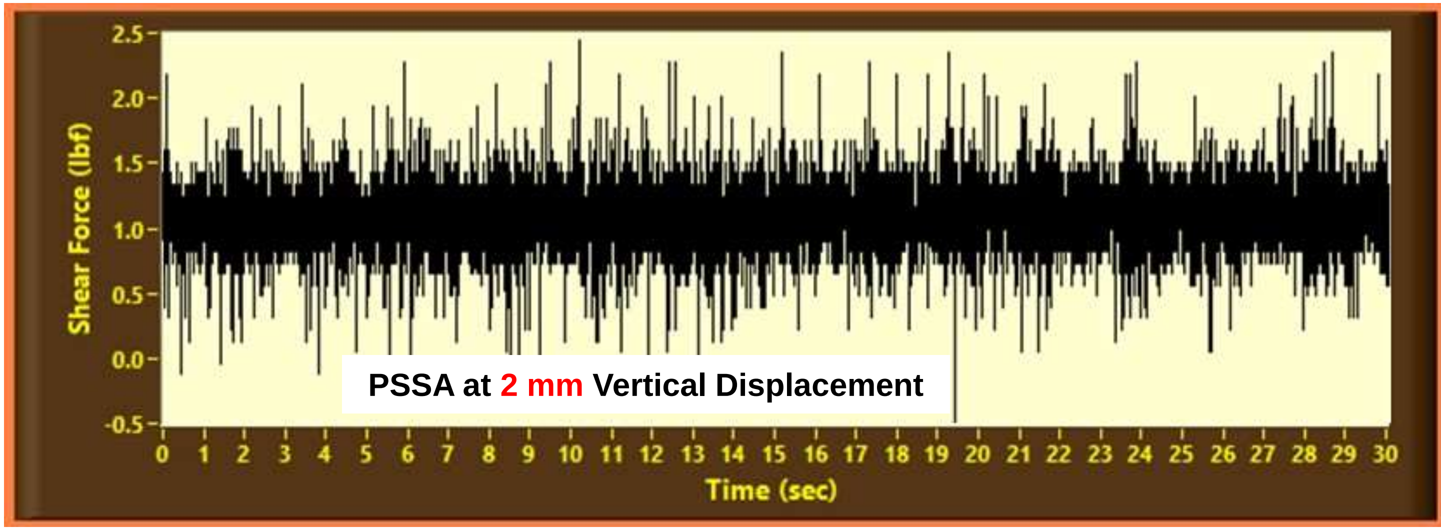
Case A – Example Shear Force Time Traces



SDBS at 2 mm Vertical Displacement

Moments of Shear Force

	Shear Force
Mean	1.185700
St. Deviation	0.192672
Variance	0.037121
Skewness	0.001033
Kurtosis	0.006452



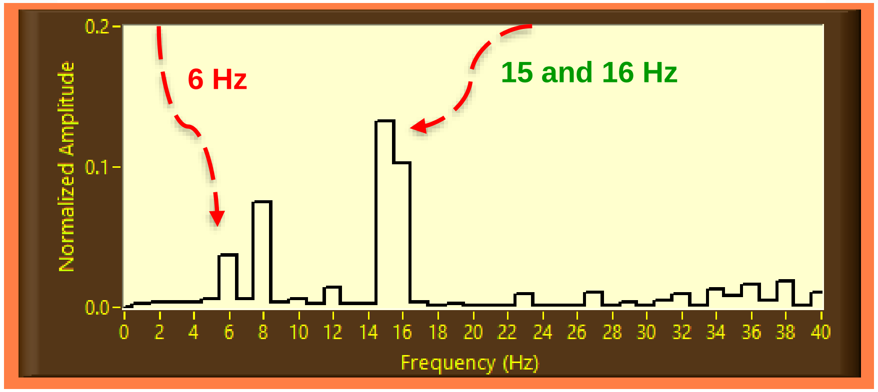
PSSA at 2 mm Vertical Displacement

Moments of Shear Force

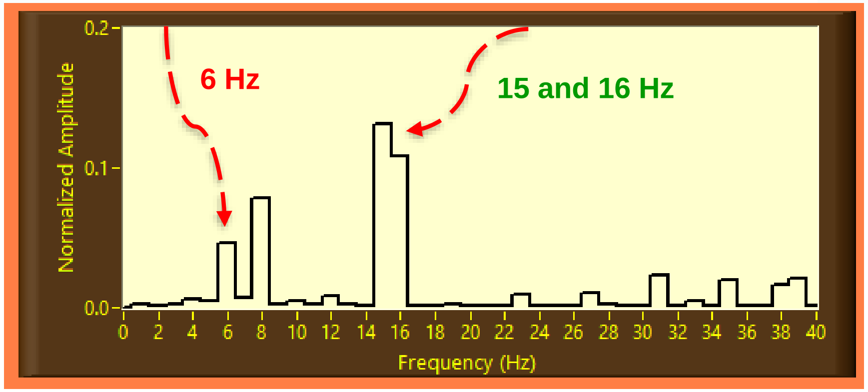
	Shear Force
Mean	1.094512
St. Deviation	0.217694
Variance	0.047389
Skewness	0.000183
Kurtosis	0.010432

Case A – Shear Force in Frequency Domain

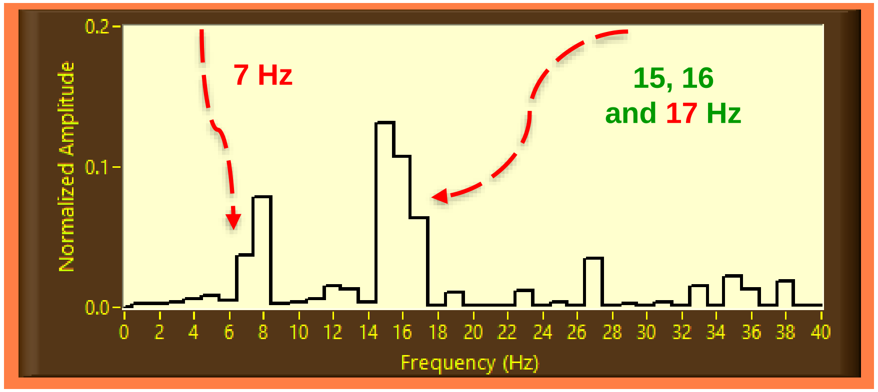
SDBS at 1 mm Vertical Displacement



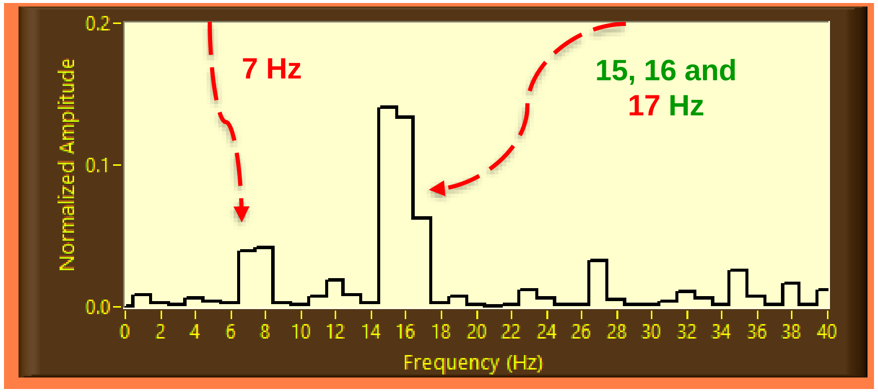
SDBS at 2 mm Vertical Displacement



PSSA at 1 mm Vertical Displacement

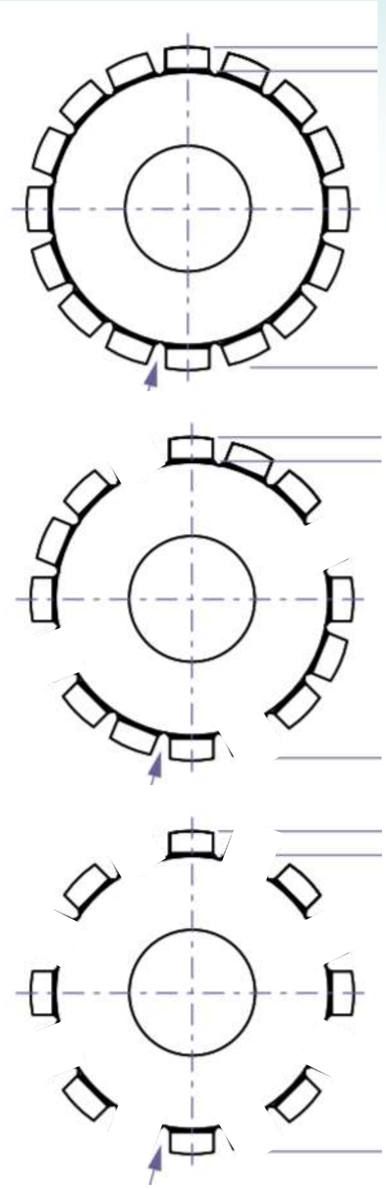


PSSA at 2 mm Vertical Displacement



Case B – PVA Brush Nodule Placement Debsity

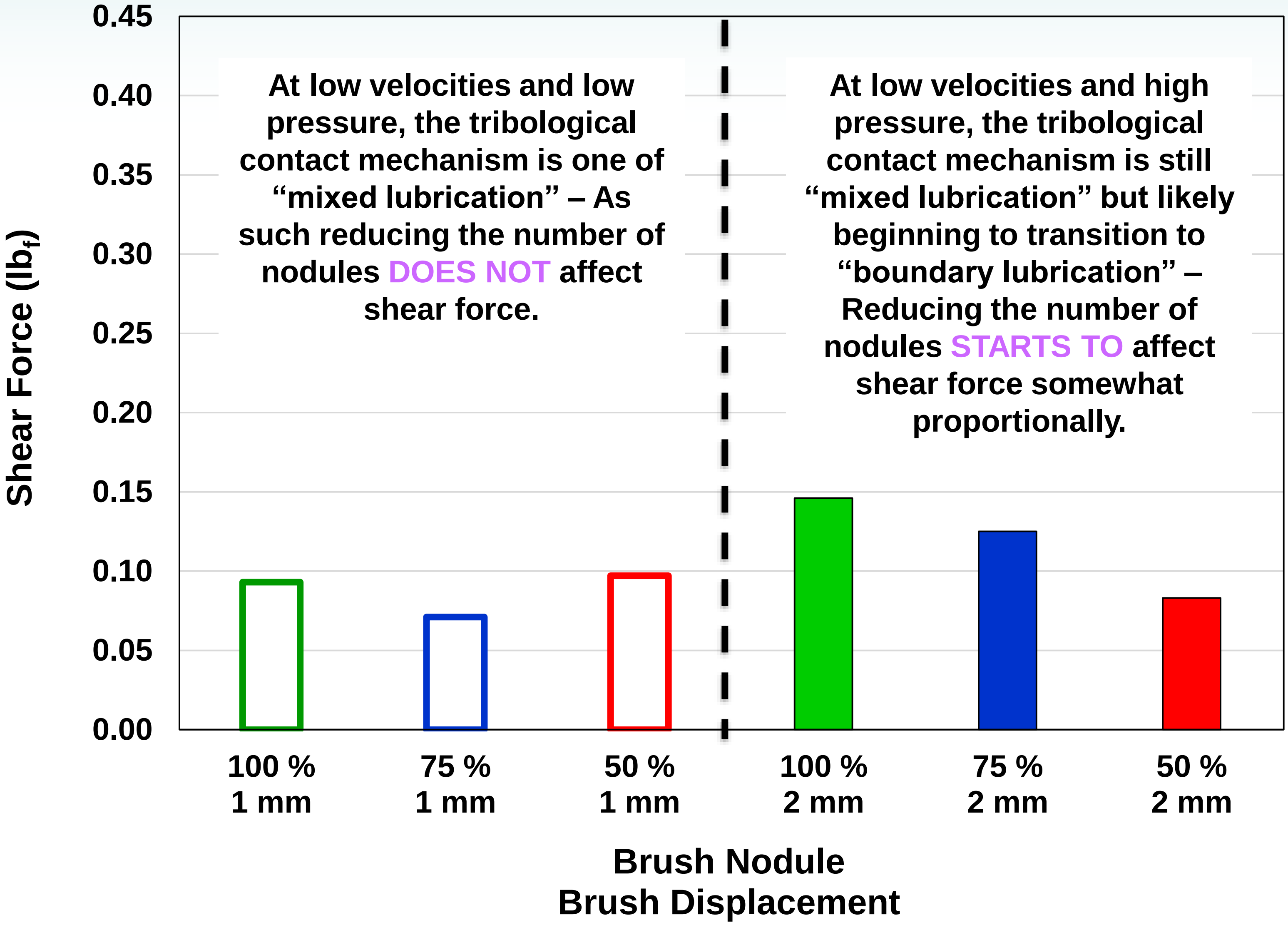
- **Brushes**
  - Entegris Planarcore® PVP1ARXR1
  - Same as above but with 25 % fewer nodules
  - Same as above but with 50 % fewer nodules
- **300-mm Blanket SiO_2**
- **Cleaning Solution = Proprietary post-W-CMP solution**



- **1 Hour Break-in for each Brush**
  - Applied Pressure = 0.68 PSI
  - Wafer Rotation = 300 RPM
  - Brush Rotation = 250 RPM
- **Test Conditions**
  - Time = 30 seconds
  - Applied Pressure = 0.60 and 0.75 PSI
  - Wafer Rotation = 100 and 500 RPM
  - Brush Rotation = 50 and 500 RPM

Mean Shear Force Results

Brush at 50 RPM – Wafer at 100 RPM

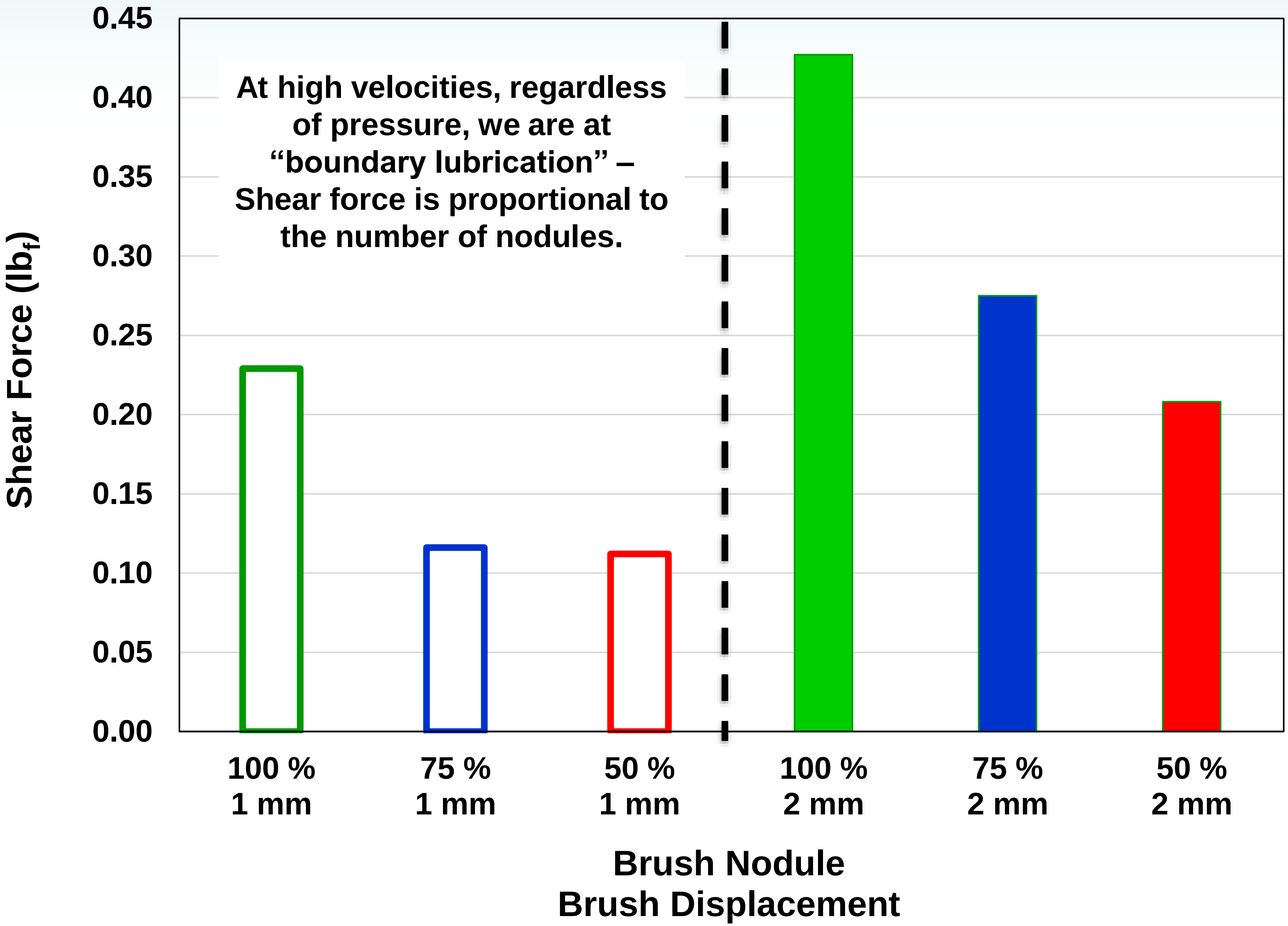


At low velocities and low pressure, the tribological contact mechanism is one of “mixed lubrication” – As such reducing the number of nodules DOES NOT affect shear force.

At low velocities and high pressure, the tribological contact mechanism is still “mixed lubrication” but likely beginning to transition to “boundary lubrication” – Reducing the number of nodules STARTS TO affect shear force somewhat proportionally.

Mean Shear Force Results

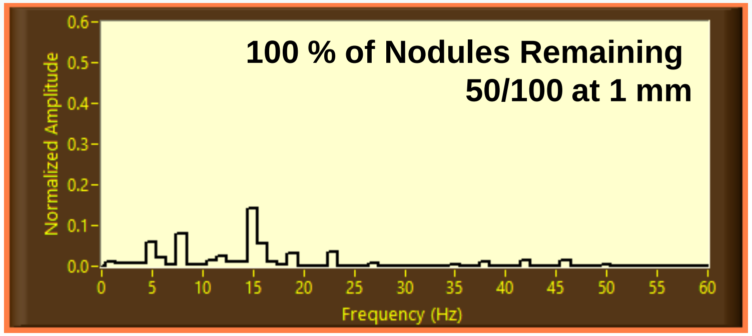
Brush at 500 RPM – Wafer at 500 RPM

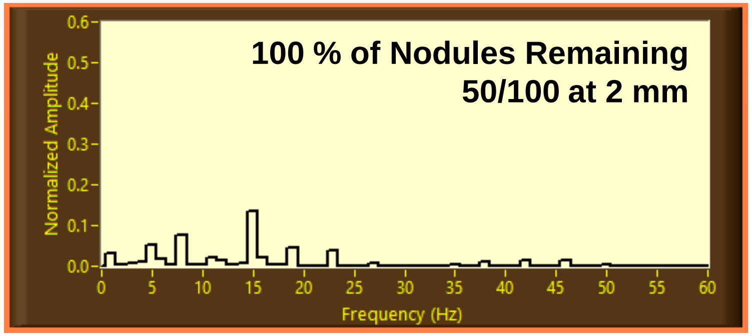


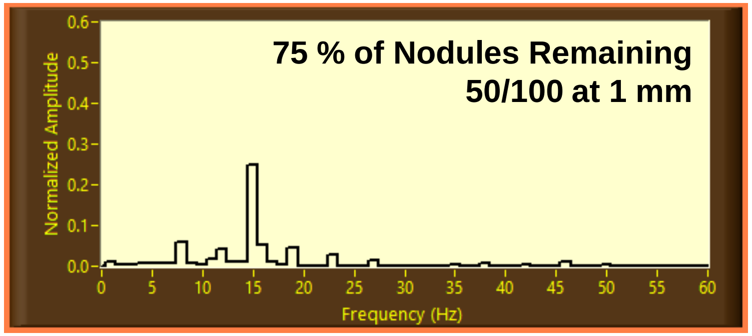
At high velocities, regardless of pressure, we are at “boundary lubrication” – Shear force is proportional to the number of nodules.

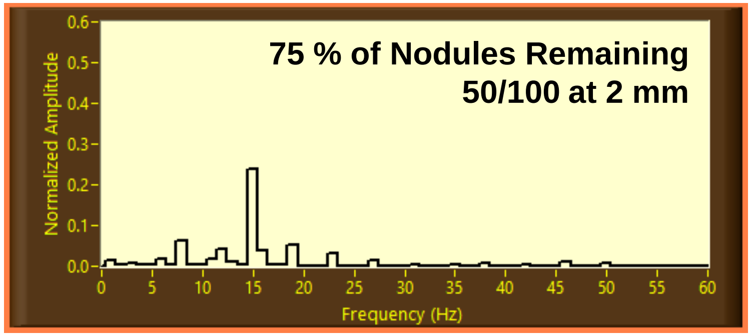
Shear Force Frequency

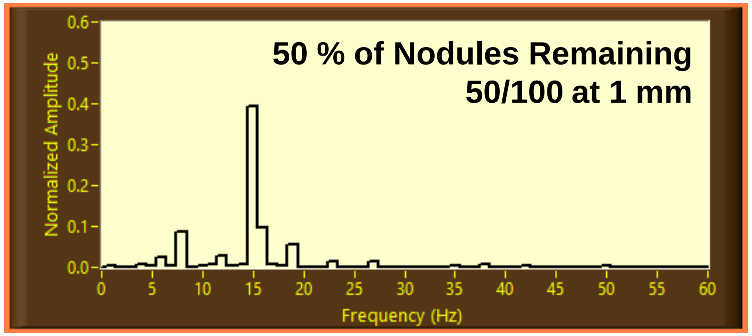
Brush at 50 RPM – Wafer at 100 RPM

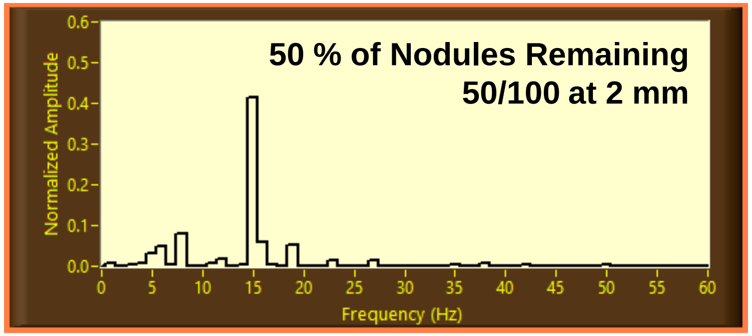






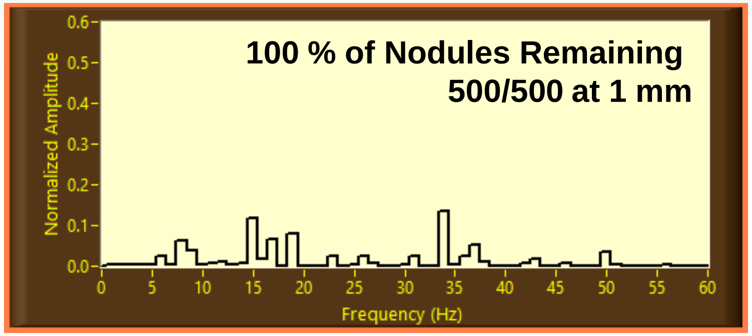


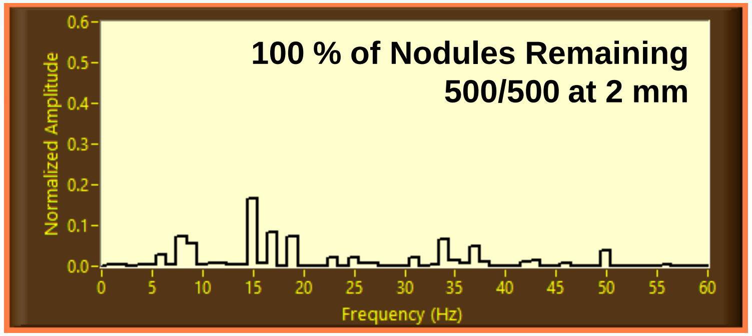


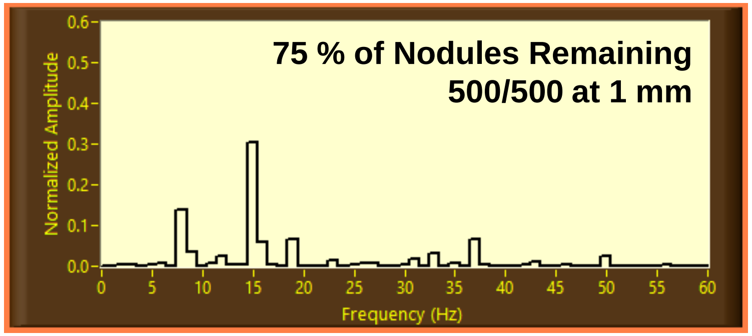


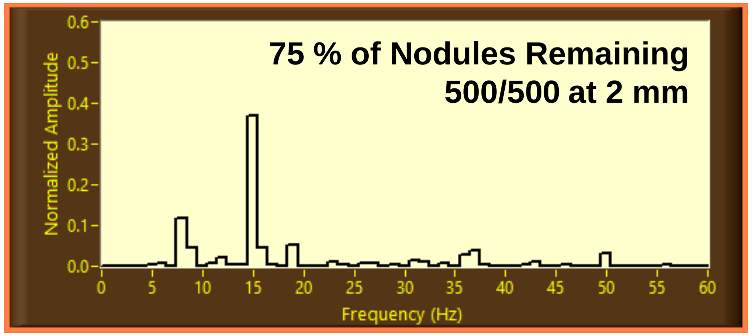
Shear Force Frequency

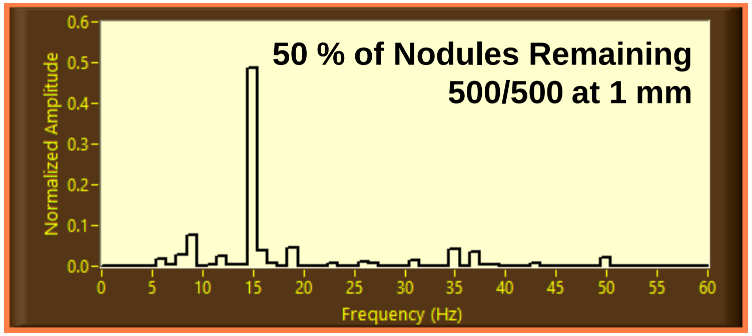
Brush at <u>500 RPM</u> – Wafer at <u>500 RPM</u>

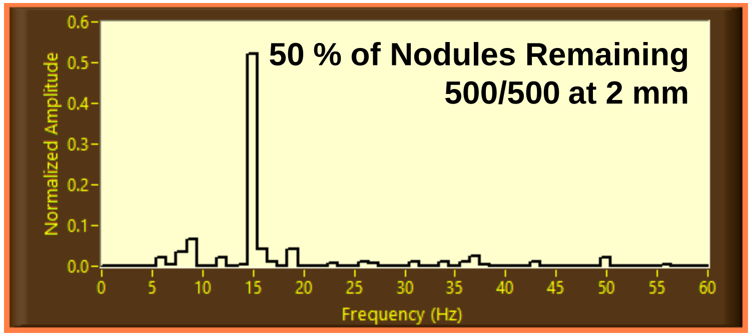

100 % of Nodules Remaining
500/500 at 1 mm


100 % of Nodules Remaining
500/500 at 2 mm


75 % of Nodules Remaining
500/500 at 1 mm


75 % of Nodules Remaining
500/500 at 2 mm


50 % of Nodules Remaining
500/500 at 1 mm


50 % of Nodules Remaining
500/500 at 2 mm

Key Takeaway Messages

- The interplay between “Force Engineering” and “Structure Activity Engineering” has now become critical in PVA brush scrubbing.
- The ability to accurately and precisely measure shear force and COF in the brush-solution-wafer interface is paramount to the success of next generation PVA brush scrubbing technologies.
- Our two case studies have attempted to tackle some of these effects:
  - ❖ In Case – A we see how SDBS and PSSA alter the mechanical forces of the process because of differences in their chemical functionality and supramolecular structure, which in turn, affect wafer-level defects.
  - ❖ It is interesting to see that the PCC-300® can pick up minute changes in the distribution of force frequencies between the two supramolecules. Micro-balance data seems consistent with our observations and hypotheses.
  - ❖ In Case – B analysis of shear force data in both time and frequency domains helps elucidate the role of nodule placement density in the number and frequency of collision events in the wafer-brush interface at various applied loads.
  - ❖ Results shed light on the importance of the nature of wear mechanisms involved in such studies.