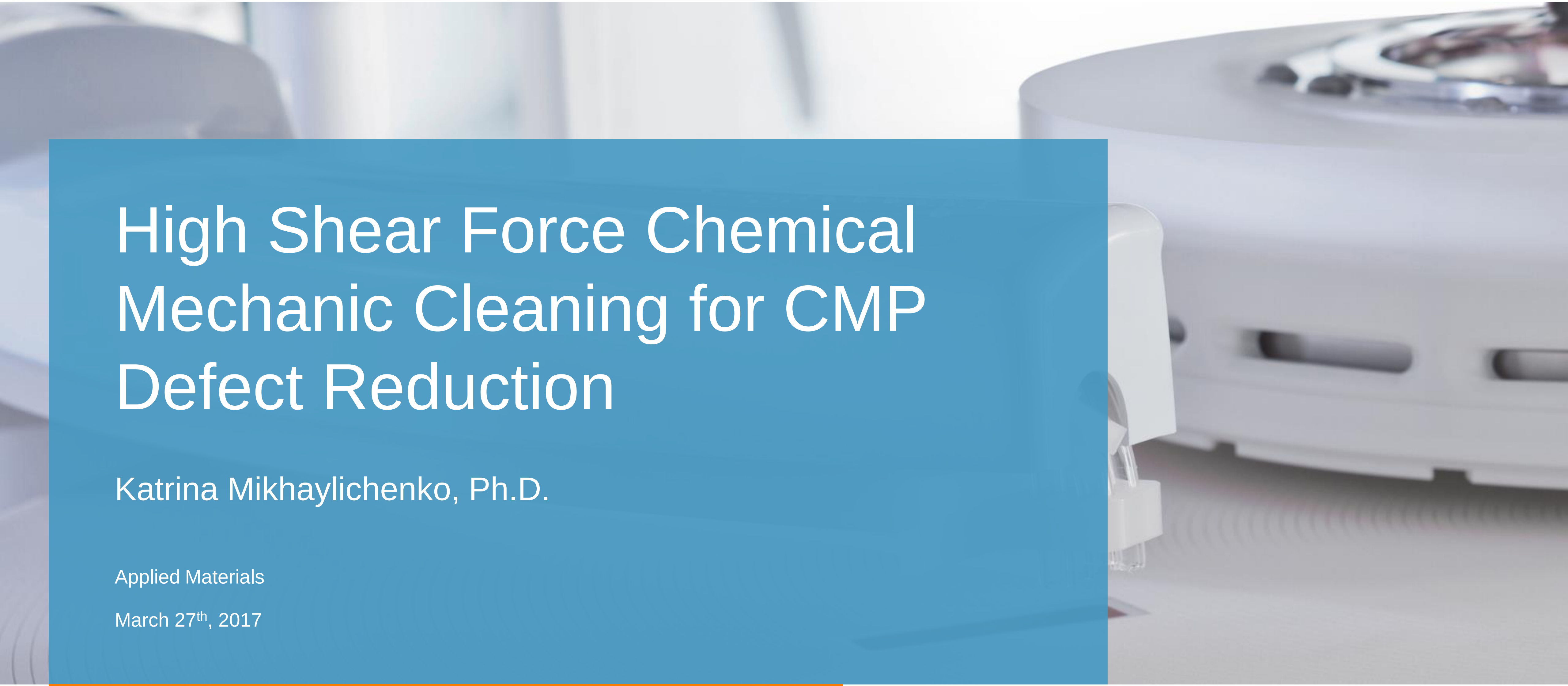

High Shear Force Chemical Mechanic Cleaning for CMP Defect Reduction

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Applied Materials

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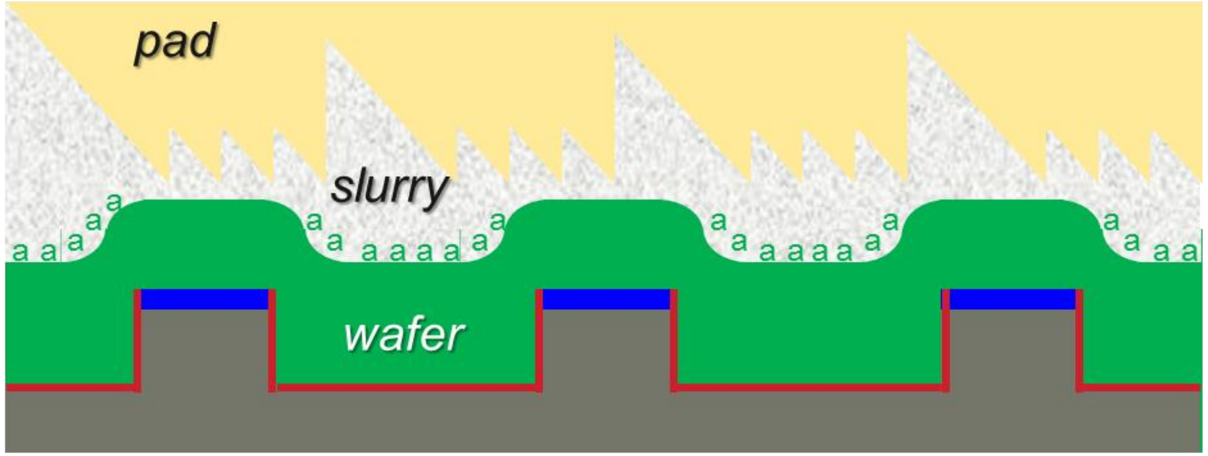
High Shear Force Chemical Mechanic Cleaning for CMP Defect Reduction

- Post-CMP Cleaning Challenges for Advanced Nodes
- Concept of Chemical Mechanical Cleaning
- Cleaning Capability of Applied Pre-Clean Module
  - Pre-Clean Benefit Example: 3D NAND Thick / High Step Height ILD
- Addressing Post CMP Cleaning Challenges in LKP System

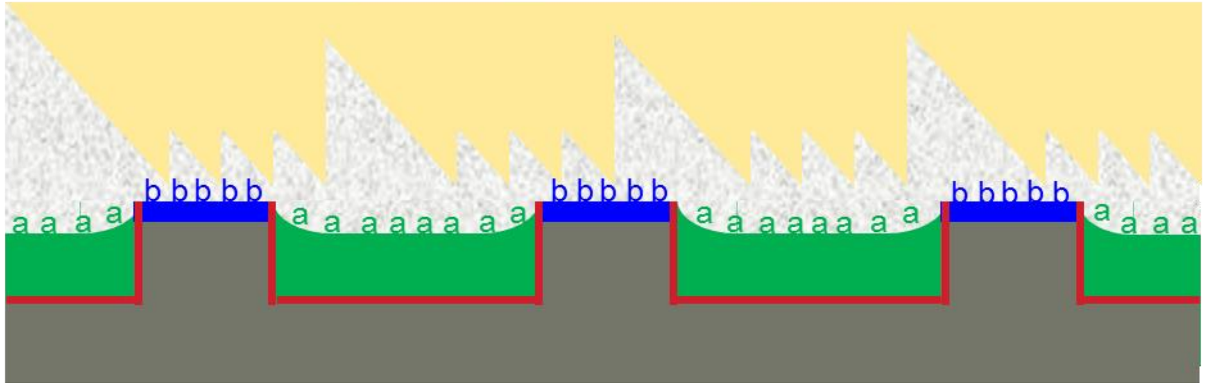
CMP Mechanism and Cleaning Challenges

- Three-body interaction: Wafer, Pad, Slurry
- Slurry: Complex suspensions containing abrasive particles, stabilizing agents and inhibitors
- Pad & abrasive remove inhibitor(a) from high pressure areas
- Remaining inhibitor(a) protects low areas.
- After polish layer cleared from stop layer, inhibitor(b) protects stop area and inhibitor(a) represses dishing of oxide in trenches
- Polishing by-products (chemical reactants, agglomerated slurry and pad/conditioner debris) are present on wafer after polish and needs to be removed during post-CMP cleans

Bulk Polish



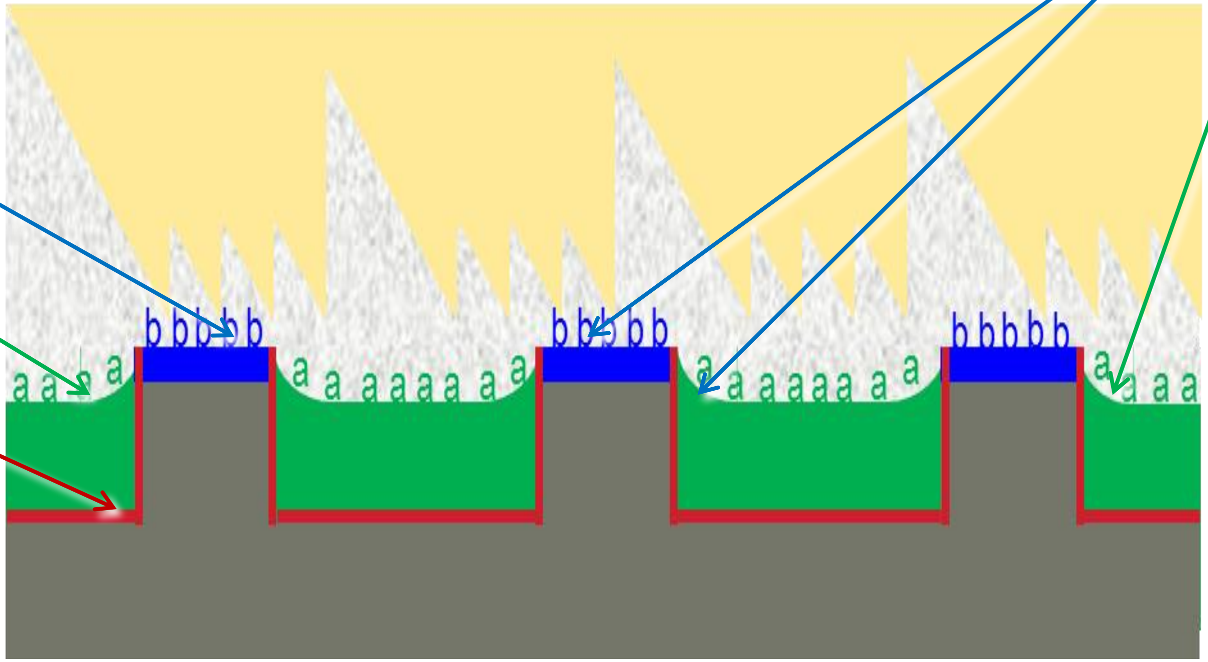
Clearing and Overpolish



APPLIED MATERIALS

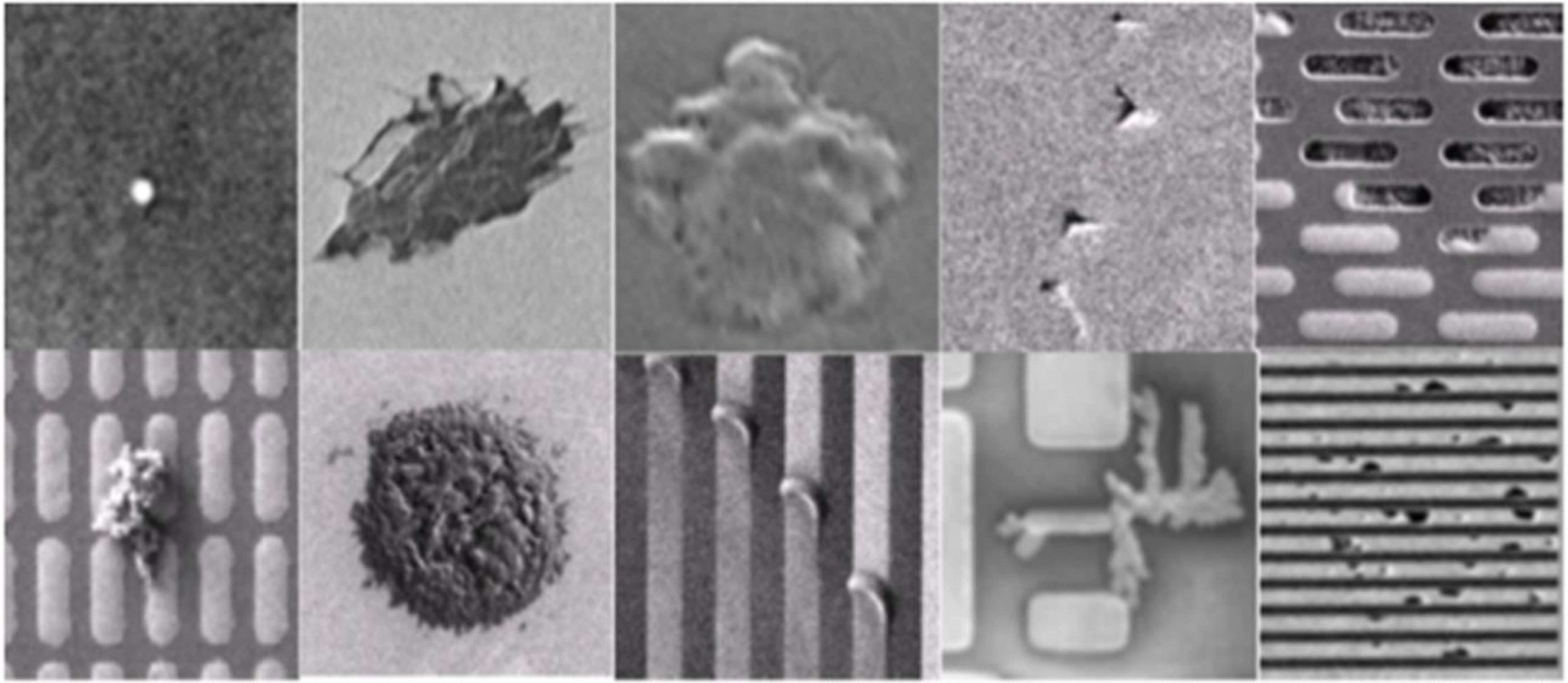
Post CMP Cleaning Challenges

- Difficult to remove contaminants:
  - Slurry particles and polish residues
  - Organic components of the slurry
  - Pad debris
- Corrosion
- Multiple film materials exposed and new metals/liners/barriers (W, TiN, Co, Ru, ULK)
- Particle removal is more difficult with time

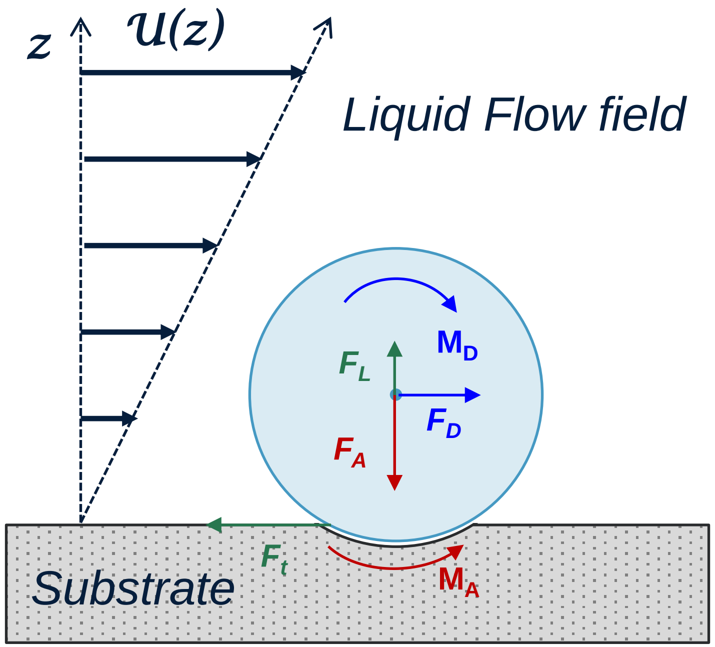


- Hydrophobic films, Philic / phobic surface combination
- Scratches on softer films
- Secondary contamination due to the “Loading” of the cleaning media
- Wafer edge cross-contamination
- Small particles become “visible” to metrology tools only after next film deposition

Examples of Defects Observed in CMP



Particle Removal

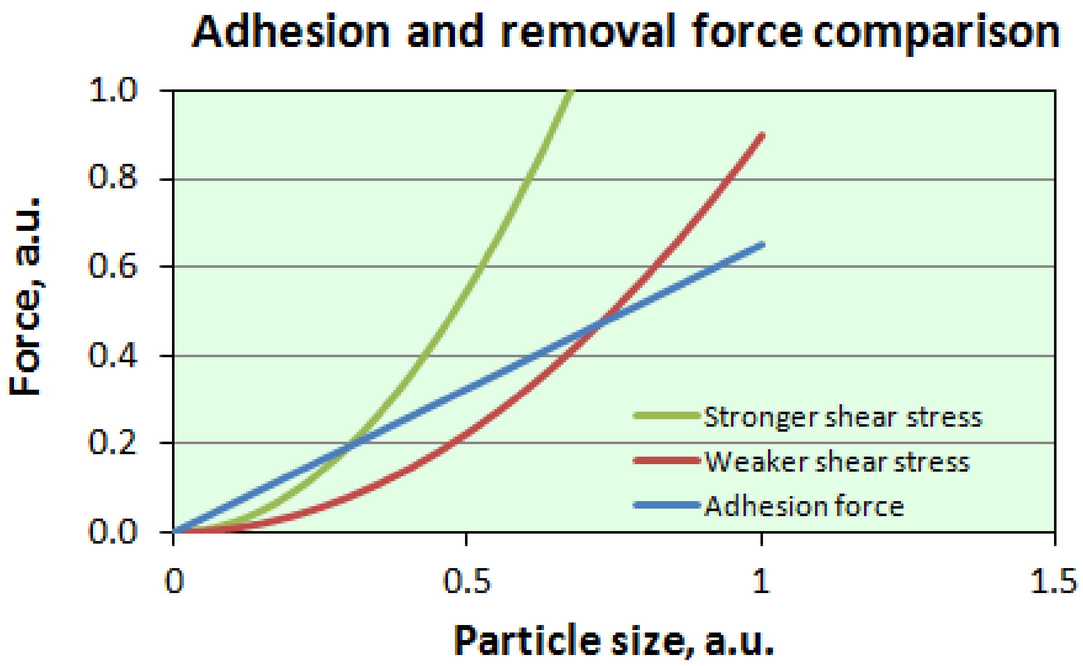


F_D – The Drag force
F_A – the Adhesion force
F_L – the Lift force
F_t – the tangential friction

$$MR = \frac{Removal(Drag)\ Moment}{Adhesion\ Moment}$$

For MR >1, a certain % of particles can be removed

- Adhesion moment
  - Function of adhesion force (van der Waals), particle geometry
  - Proportional to particle radius
- Removal Moment:
  - Function of shear force, double layer interactions, particle geometry
  - Proportional to square of particle radius



$$W_{vdw} = -\frac{\pi^2 C \rho^2 D}{12H}$$

$$F_{drag} = 8.02\,\eta\,\dot{\gamma}_o (D)^2$$

η_s = shear viscosity

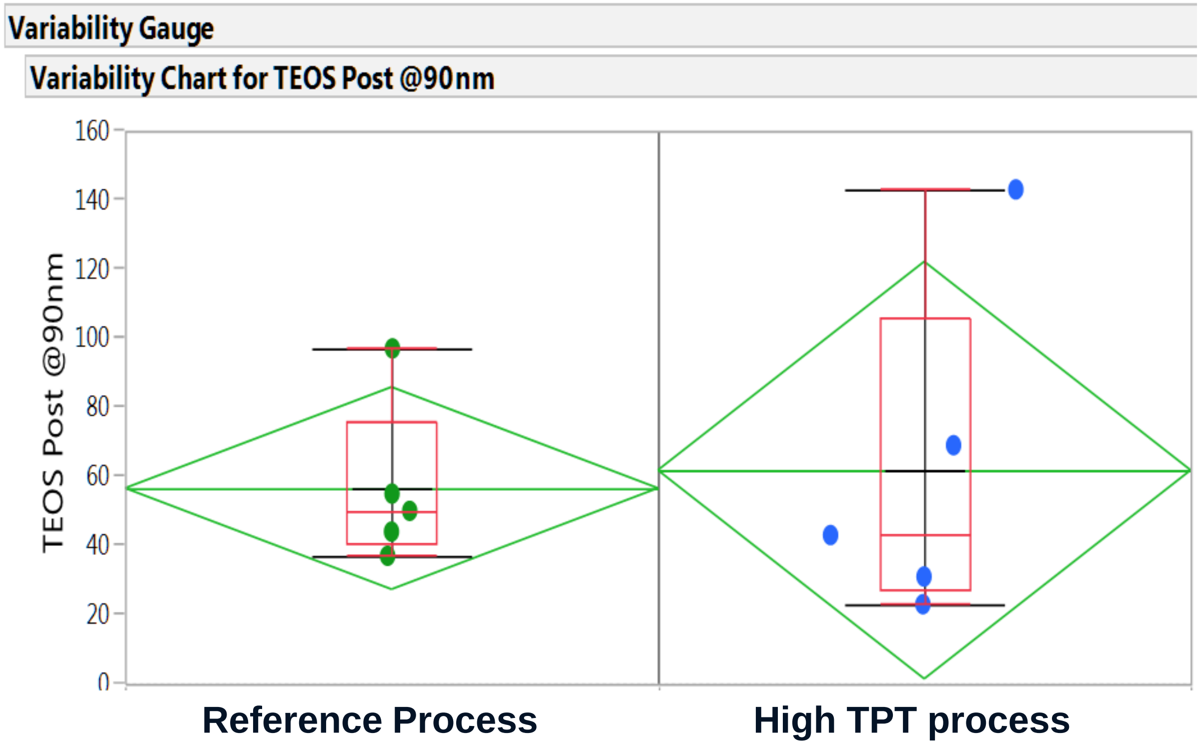
$\dot{\gamma}_0$ = shear stress

Smaller particles are more difficult to remove

Smaller Particles are More Difficult to Remove

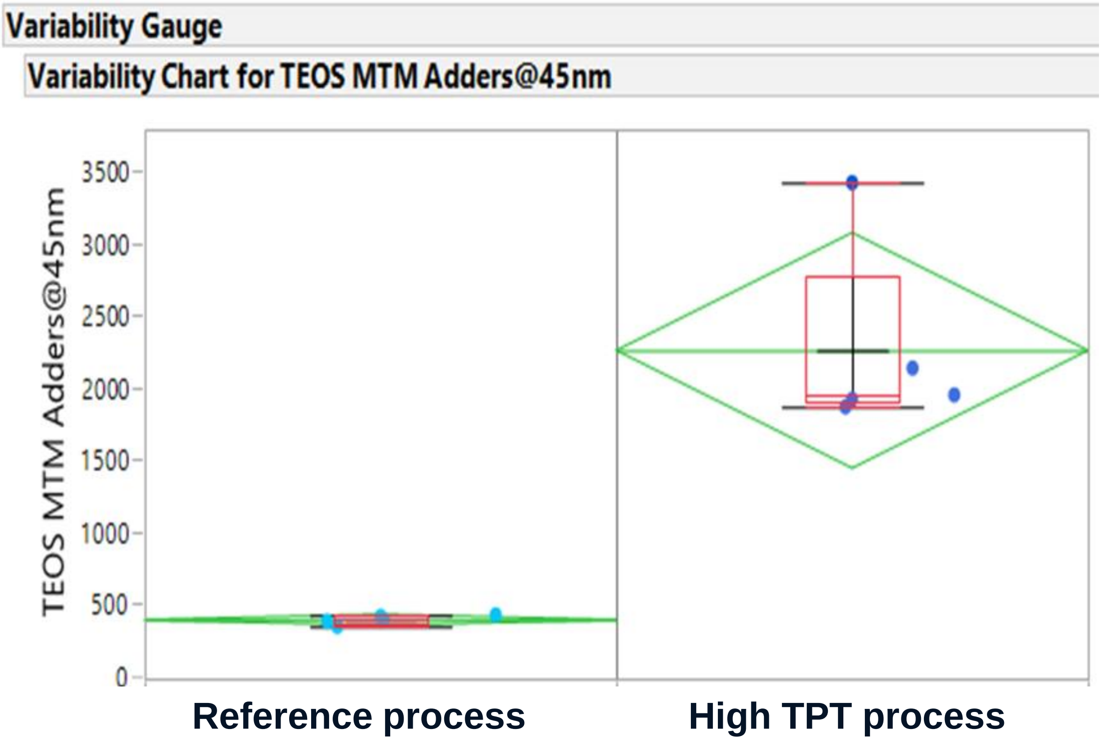
ILD0 (TEOS) Ceria Polish at 90 and 45nm

Defect comparison at >90 nm by SP2



Comparable performance: Reference vs High TPT

Defect comparison at >45 nm by SP5-XP

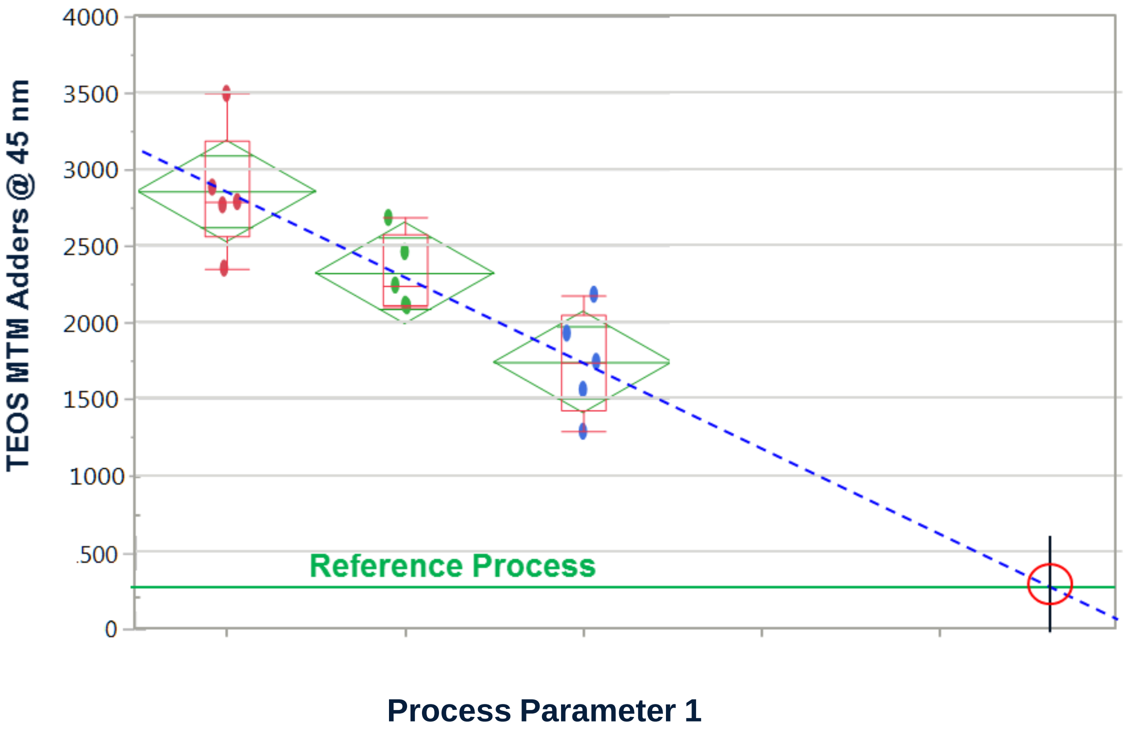


High TPT process 5x worse than Reference

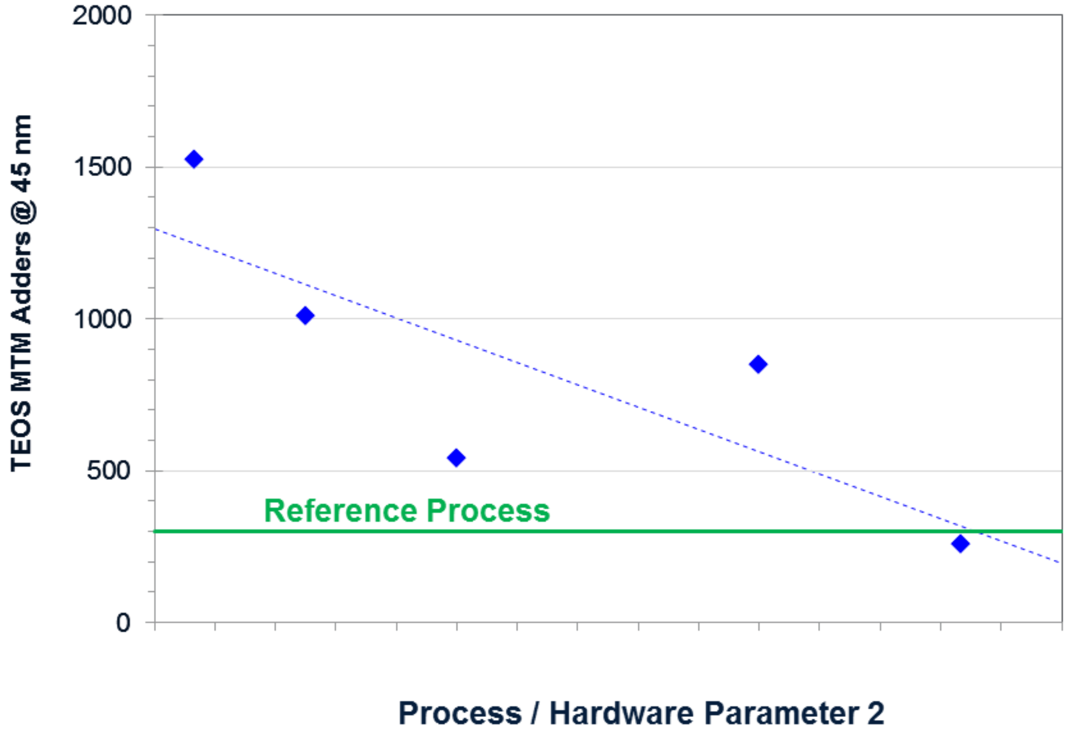
Small particle measurements capability reveals deficiency of the processes optimized with older metrology tools

Smaller Particle Removal Requires Advanced Capabilities

ILD0 (TEOS) Ceria Polish at 45nm



Process Parameter 1 increases particle removal efficiency



Process / Hardware Parameter 2 increases particle removal efficiency

AMAT implements small particle measurements capability to optimize on-wafer performance for advanced nodes

APPLIED MATERIALS®

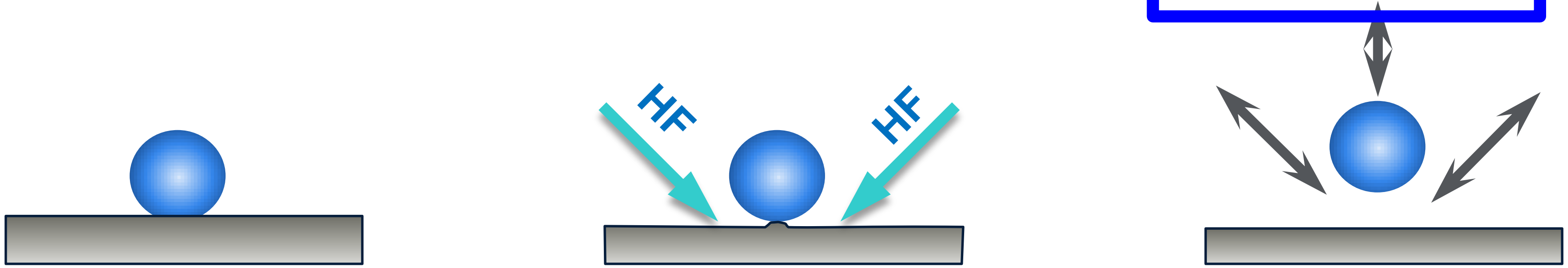
Particle Removal and Re-Deposition

Particle Removal

Particle attached on wafer surface

Breaking van der Walls forces:
- ➢ Undercutting by HF
- ➢ Shear force by brush scrub, Megasonics, Fluid jet…

Lift off by repulsive forces:
- ➢ Shear force by brush scrub, Megasonics, Fluid jet…
- ➢ Electrostatic forces



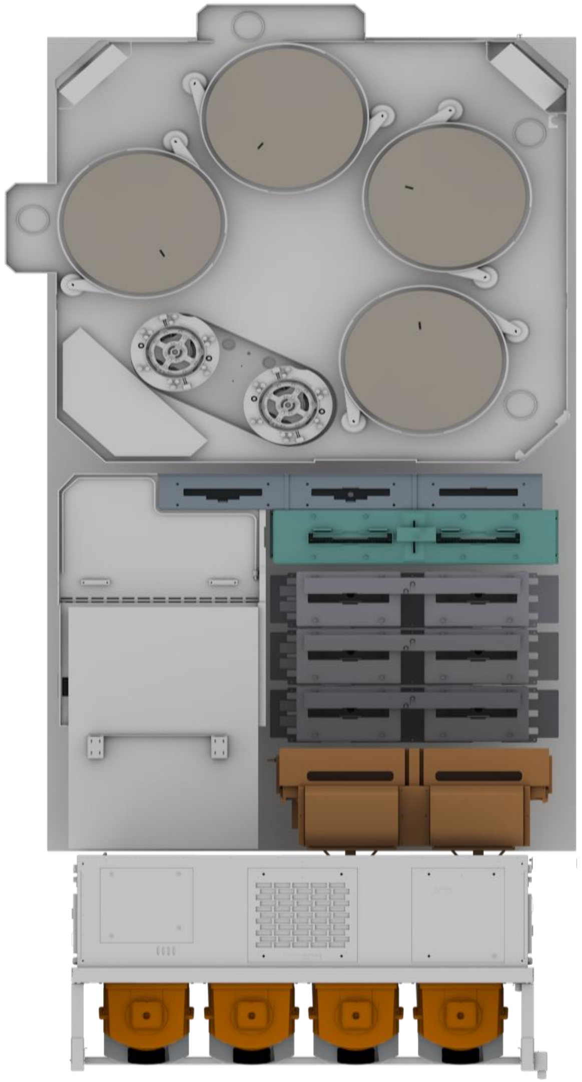
Particle Deposition

Van der Walls interactions: rapid deposition of particles close to the surface

Diffusion of particles to surface due to overall attraction force and electrostatic force

- Particle removal: interaction force between the particle and the substrate has to be eliminated by shear force:
  - Fluid shear flow, Brush scrub, Megasonic cleaning, Fluid jet
- Chemical etching is used to assist with breaking the particle-surface bond
  - Undercut on the substrate and/or wet etch of the particle
- After breaking the bond, the particle has to be removed away from the surface to prevent re-attachment

Addressing Post CMP Cleaning Challenges in LKP System

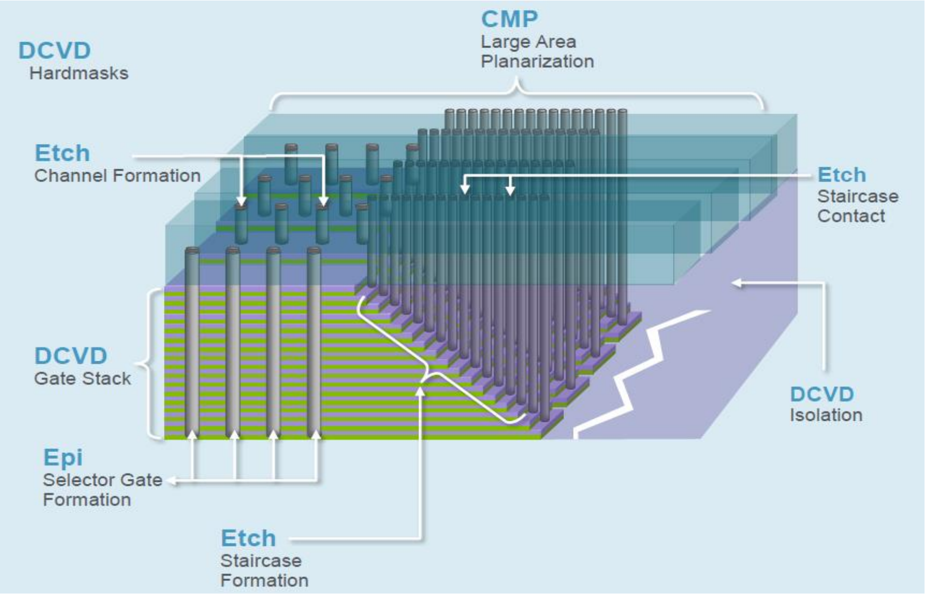


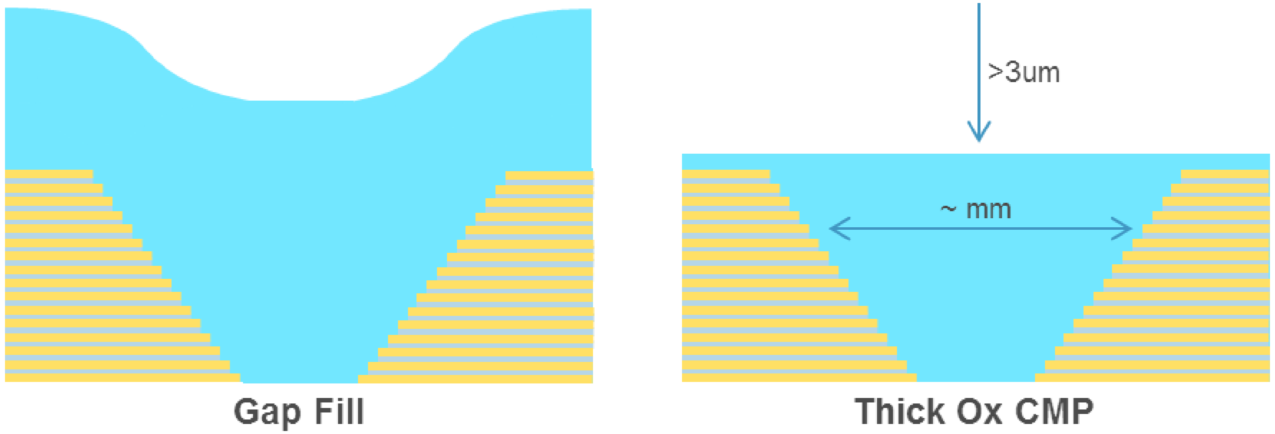
- Cleaner: 5x Side-by-Side Cleaner Stations
  - Megasonics
    - Provides physical force to remove contamination form the features
    - Provides full wafer immersion tank for bevel contamination removal
  - Pre-Clean
    - Provides means to perform chemical buff in a dedicated slurry-free module
    - Vertical buff enables effective contamination removal off the surface
    - Enable cleaning of top surface of the wafer bevel
  - Two consecutive brush boxes provide high particle removal efficiency and precise brush pressure control
  - Vapor Dryer provides defect-free drying of hydrophilic, hydrophobic and mixed surfaces
  - Cleaner Chemical Flexibility enables particle undercut and lift-off
    - HF-compatible brush box enables SiO_2 substrate etching
    - Proprietary chemicals often include particle etch capability

Chemical Mechanical Cleaning

- Applied Materials Pre-Clean Module in Post-CMP Cleaner
- Use Pre-Clean module to remove strongly adhered defects
- Remove particles with controllable/uniform (in micro scale) mechanical force and chemical action at wafer/pad interface

Pre-Clean Benefit Example: 3D NAND Thick / High Step Height ILD





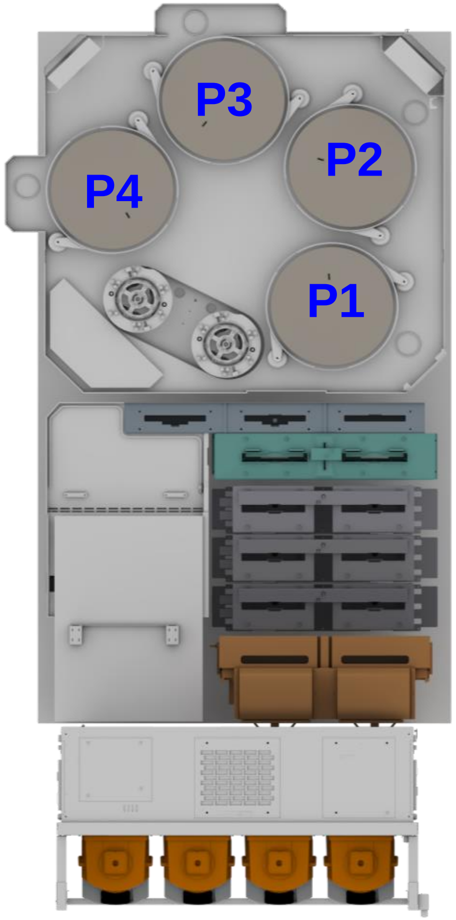
CMP Challenge

- Planarization for high incoming step height (um) at wide space (mm)
- Process drift during thick material removal (Long polish)
- Wafer bow (compressive) from thick film (stack, gap-fill) deposition

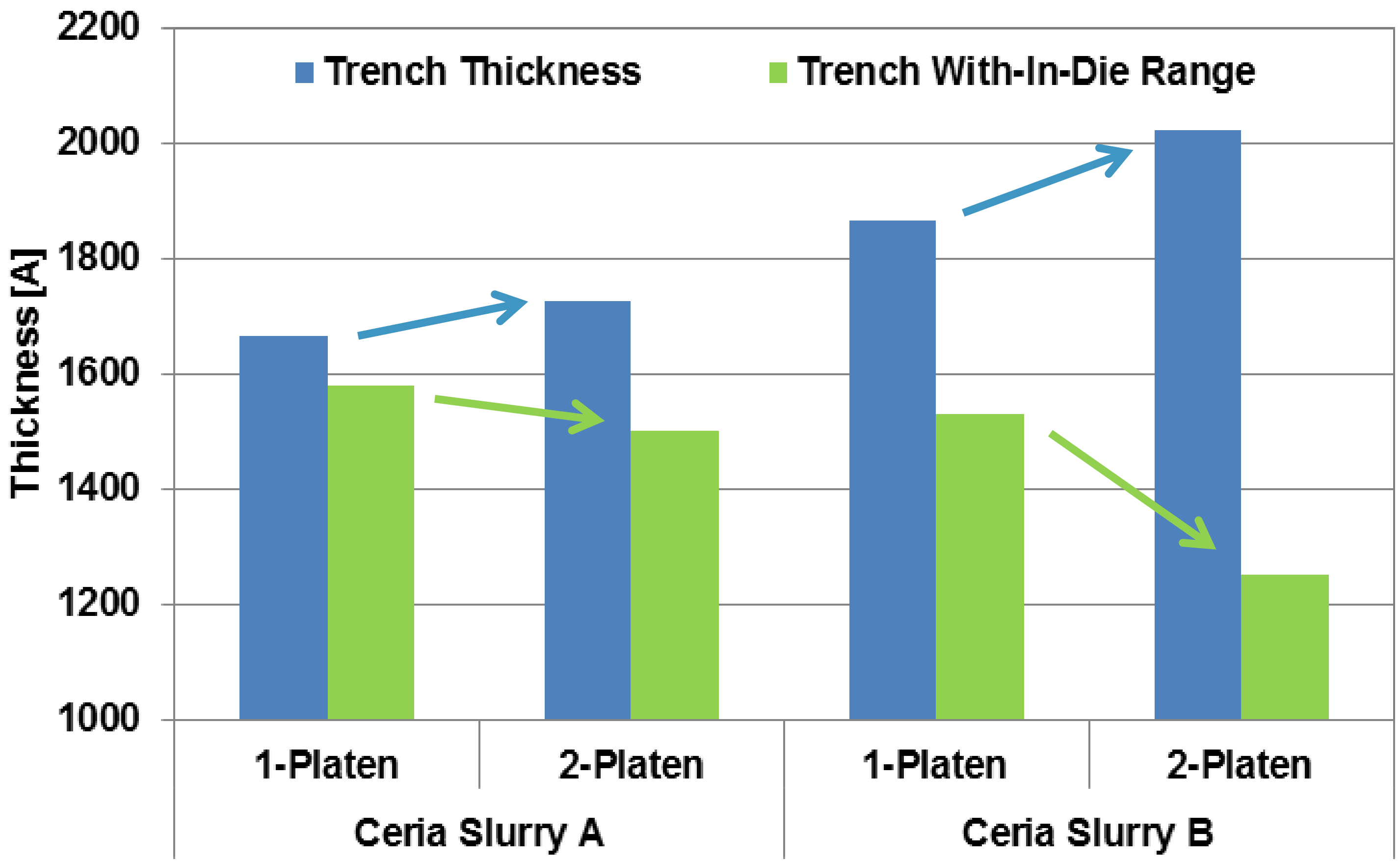
Approach

- Minimize polish time for process stability and low topography (Multi-Platen)
- In-situ remaining profile control for high rate non-Prestonian slurry (ISPC)
- Edge polish capability with Titan Head family

Multi-Platen Polish: Topography



- Conventional:
  - P1 Polish + P3 Buff
  - P2 Polish + P4 Buff
- Multi-Platen:
  - P1 Polish + P3 Polish
  - P2 Polish + P4 Polish
  - No room for buff

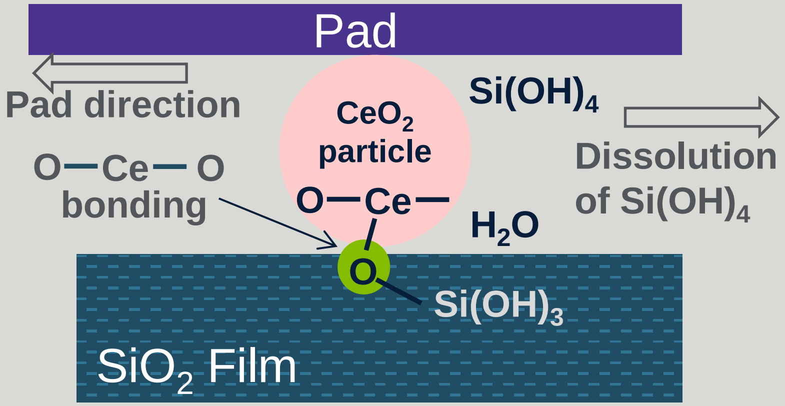


Lower Topography and WID Range by Controlling Pad Temp and By-product

Defectivity challenge: No platen available to perform Buff

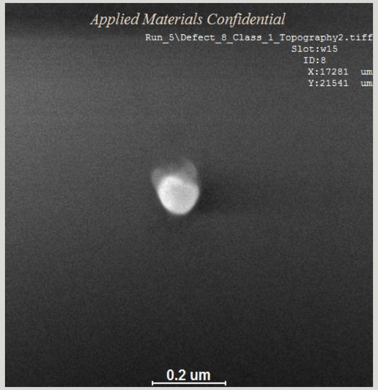
AMAT STI Mask, Slurry A: Hitachi, Slurry B: Asahi RB, IC1010, 100% In-Situ PC

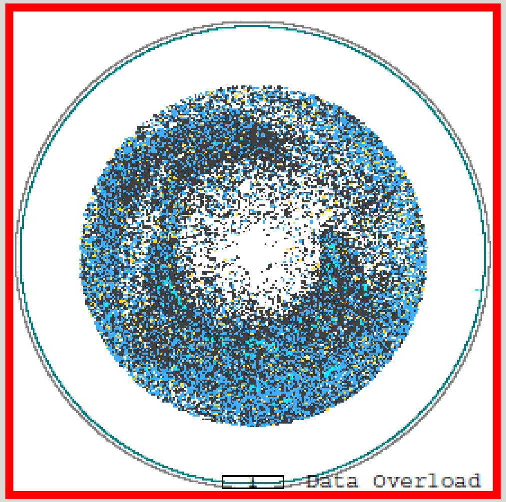
Ce Slurry Cleaning Challenge for High Oxide Removal CMP



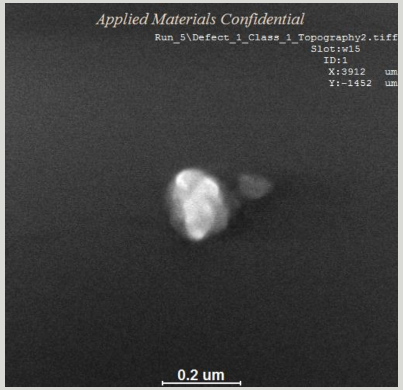
- Ceria abrasive have significant surface chemical action during SiO_2 film polish
- Oxide removal rates are tunable by controlling ceria particle characteristics and the surface activation components
- High oxide removal characteristics of the slurry represent significant challenge for post CMP clean

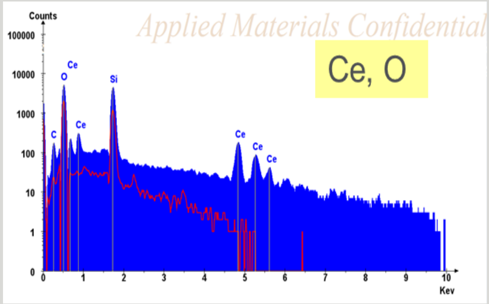
Problem Statement:
High Ceria surface Contamination after CMP





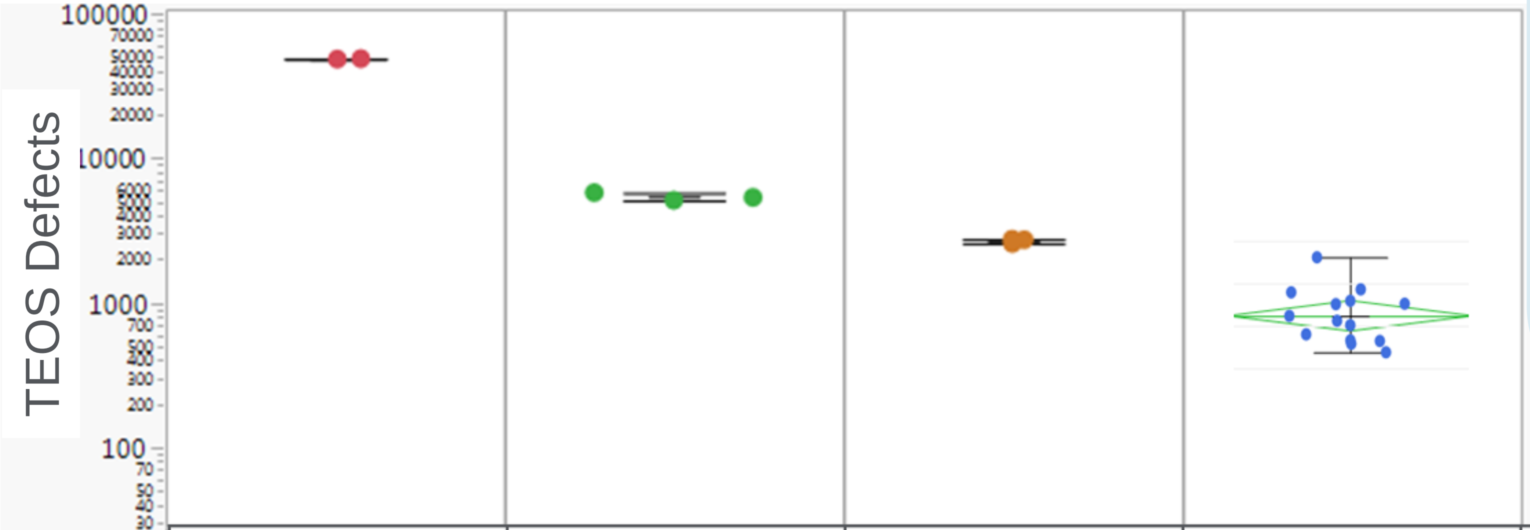
Polish + B1/B2
Saturated



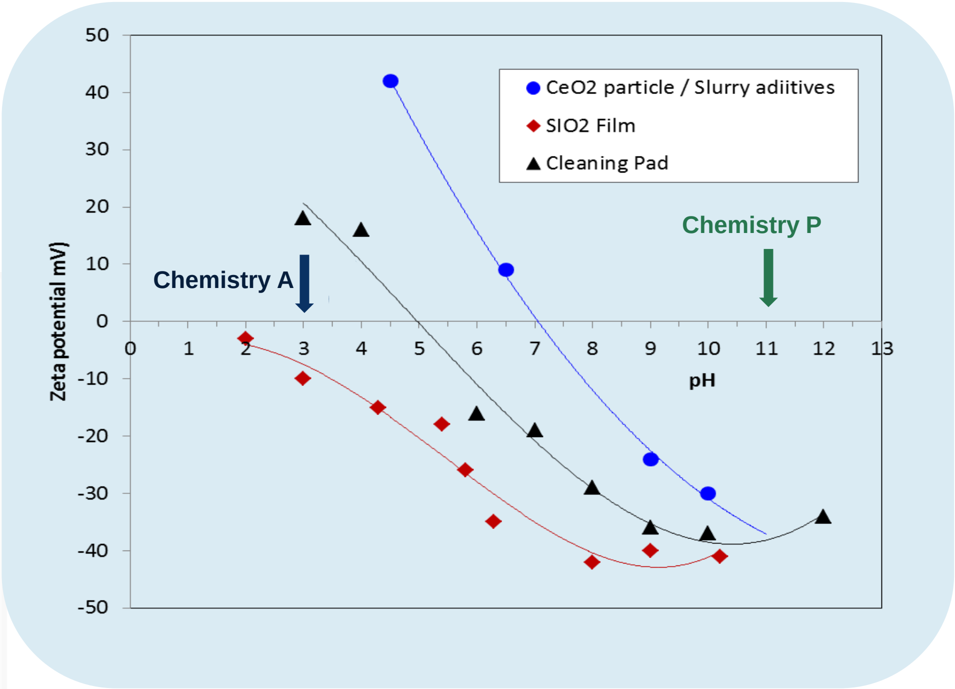


Without Chemical Buff, ceria surface contamination remains high after conventional Brush Scrub

Ce Slurry Clean: Pre-Clean Parameter Optimization
Pre-Clean Chemistry



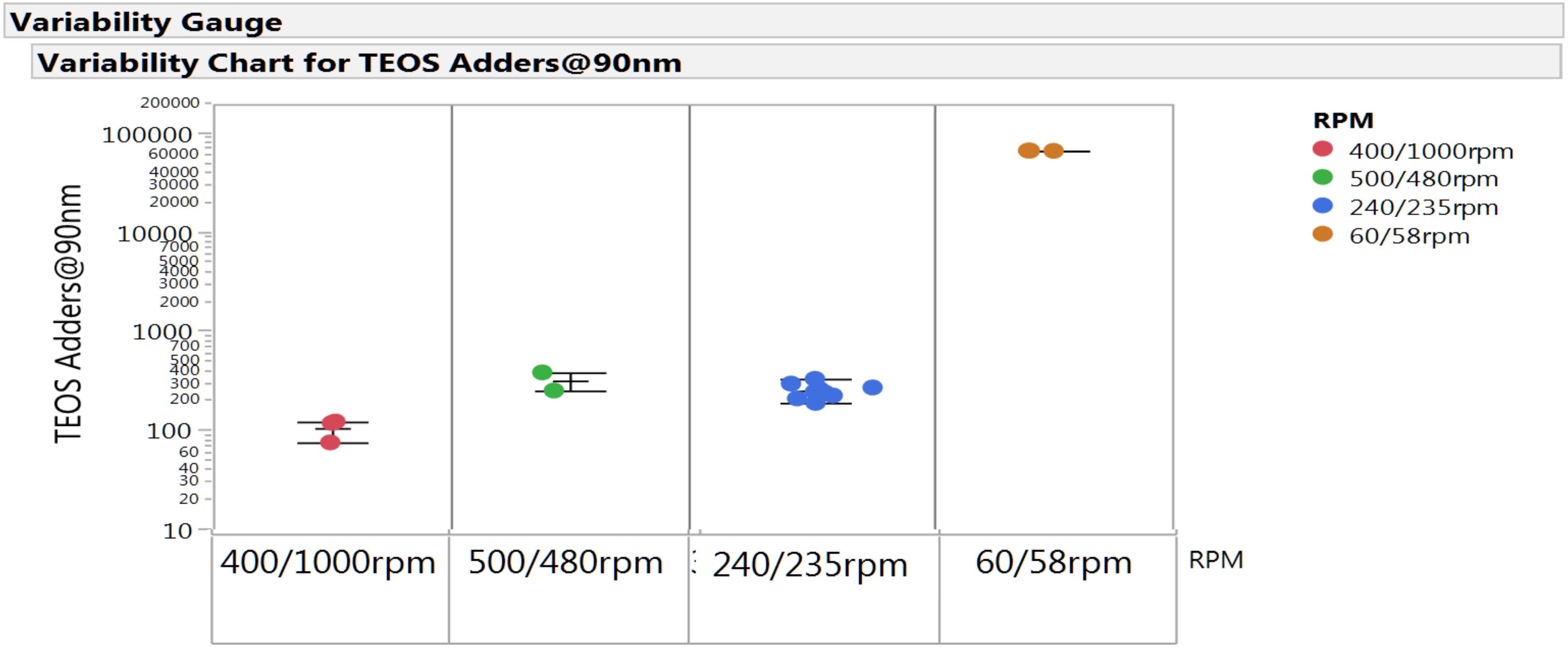
Brush Clean Only	Plated Buff* + Brush Clean	PreClean Buff + Brush Clean	PreClean Buff + Brush Clean	Process
NA	Chem A (Acidic)	Chem A (Acidic)	Chem P (Alkaline)	Buff Chemistry
Chem P (Alkaline)	Chem P (Alkaline)	Chem P (Alkaline)	Chem P (Alkaline)	Brush Chemistry



Pre-Clean buff with alkaline chemistry shows best defect performance, as expected based on Zeta-potential Diagram

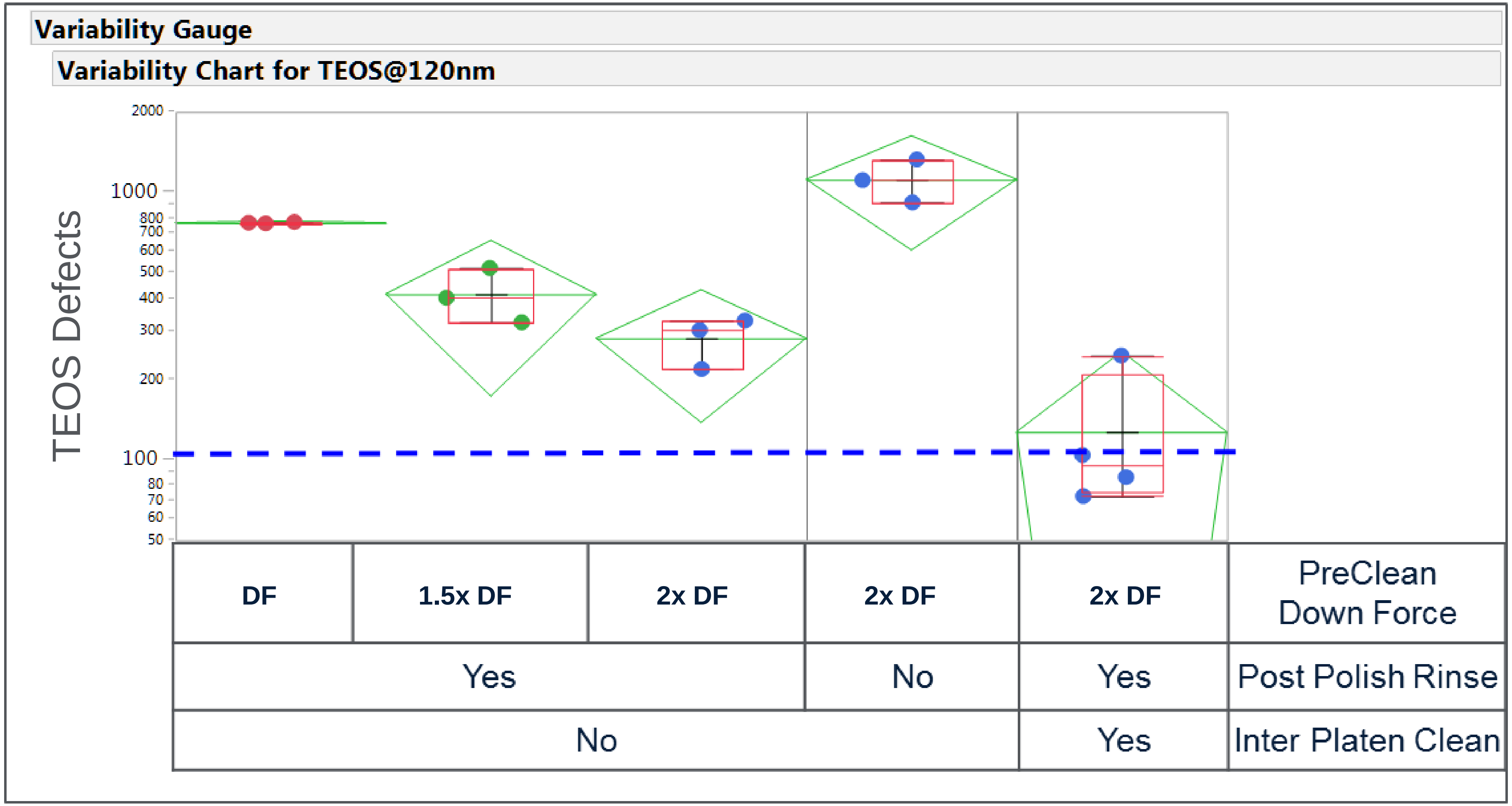
APPLIED MATERIALS

Ce Slurry Clean: Pre-Clean Parameter Optimization
Effect of Wafer / Pad Rotation Speed



High rotation speed with mismatched wafer / pad speeds shows improved performance

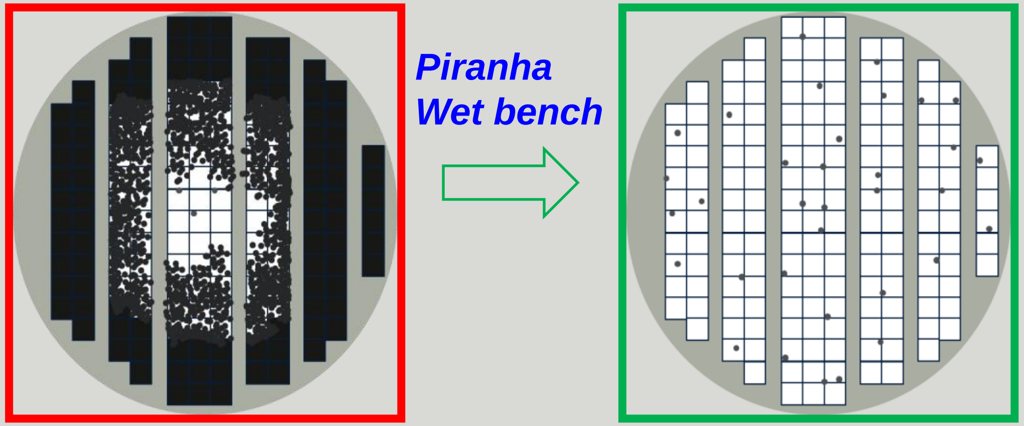
Ce Slurry Clean: Polish and Clean Concurrent Optimization

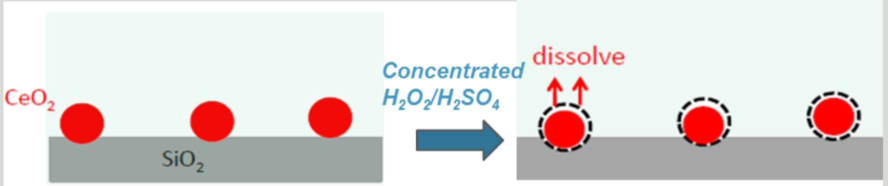


Both Polish and Clean processes must be optimized to achieve best defect performance:
Post Polish Wafer Rinse and IPC significantly improved defect results
High shear rate Pre-Clean process ensures high particle removal efficiency

Ce Slurry Cleaning Solution for High Oxide Removal CMP

Customer previous approach: Additional clean needed post CMP





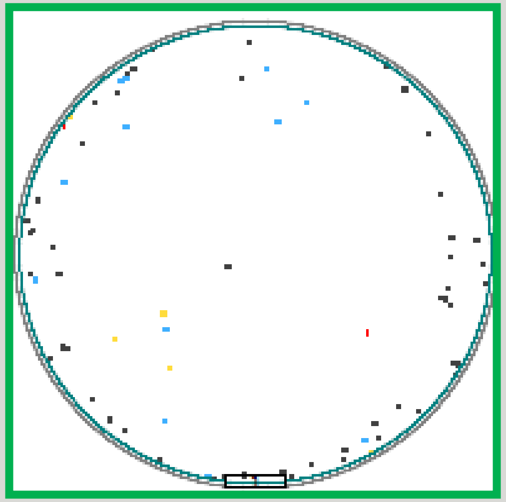
$$2\overbrace{Ce}^{+4}O_2 + H_2\overbrace{O_2}^{-1} + 3H_2SO_4 \rightarrow \overbrace{Ce_2}^{+3}(SO_4)_3 + \overbrace{O_2}^{0} + 4H_2O$$

$+1e^-$ $\quad$ $-1e^- X2$

Peroxide acts as a reducer in an acidic media and as an oxidizer in a basic media. In SPM, ceria is reduced by peroxide

Customer HVP :
Increased Cost and Cycle time to avoid yield loss

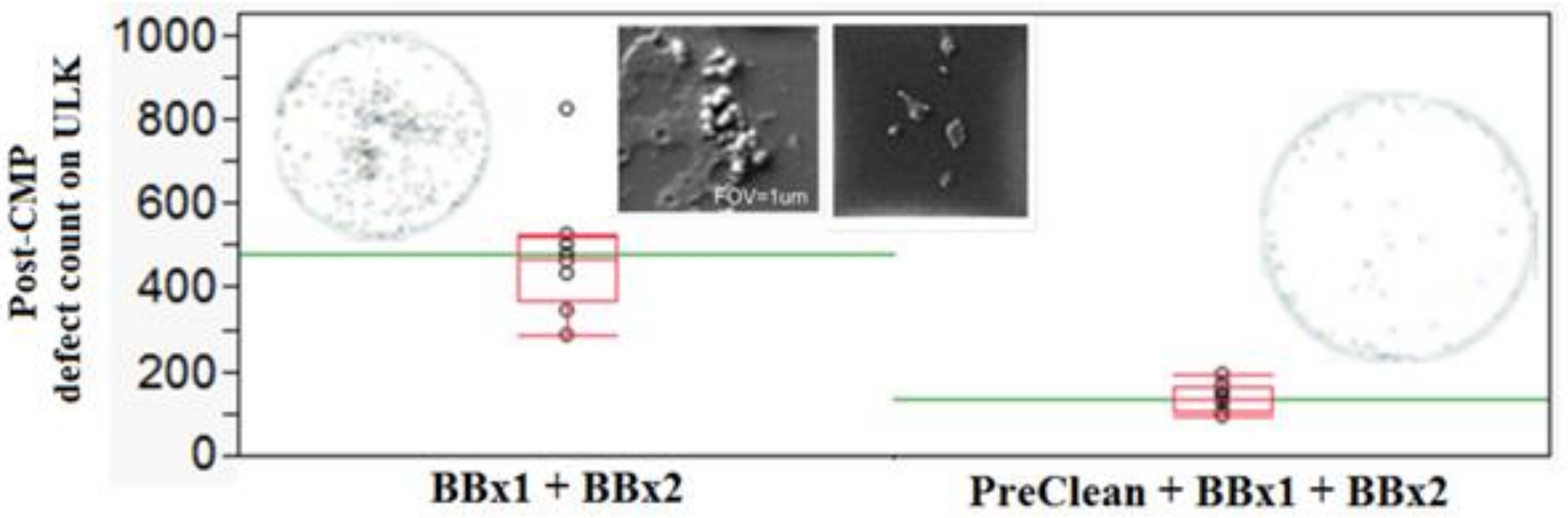
Customer HVP Solution: Chemical buff in Pre-Clean Module



Polish + Pre-Clean + B1/B2
< 100 @ 120 nm

High shear force Pre-Clean in CMP cleaner eliminates need for stand-alone post CMP clean

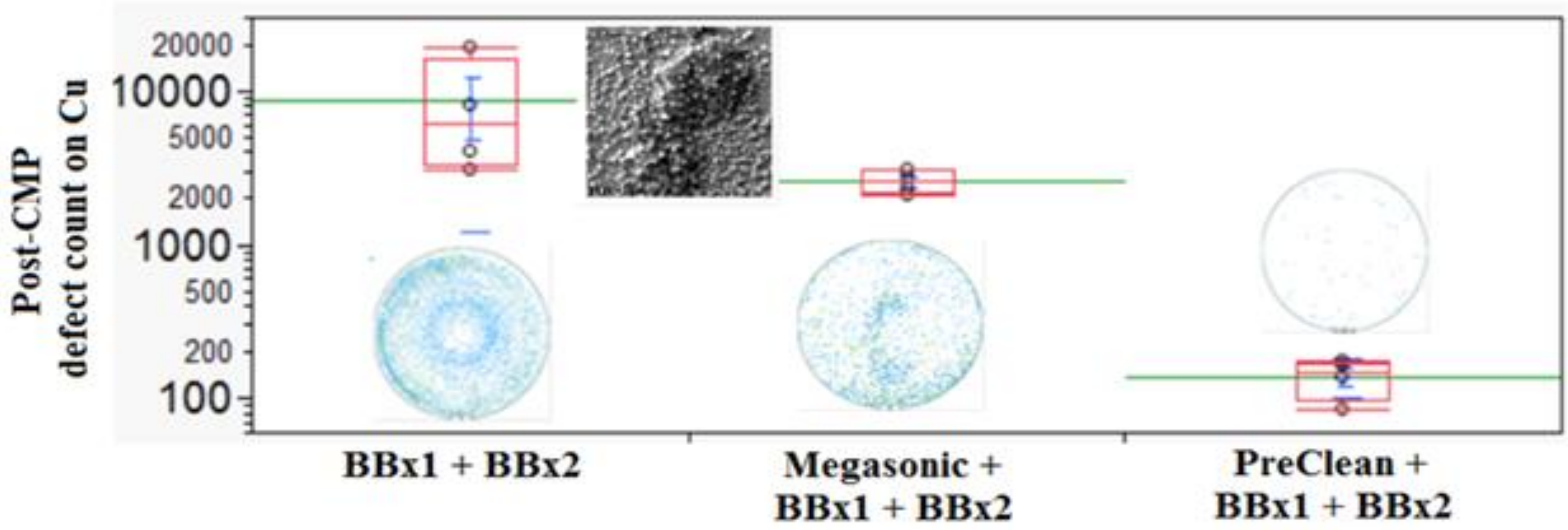
BEOL Slurry Clean:
Pre-Clean for Improving Particle Removal Efficiency



Pre-Clean effectively removes residues from hydrophobic ULK surface

APPLIED MATERIALS®

BEOL Clean:
Pre-Clean for Improving Particle Removal Efficiency



Pre-Clean removes particles and organic residue from Cu polished with a challenging slurry

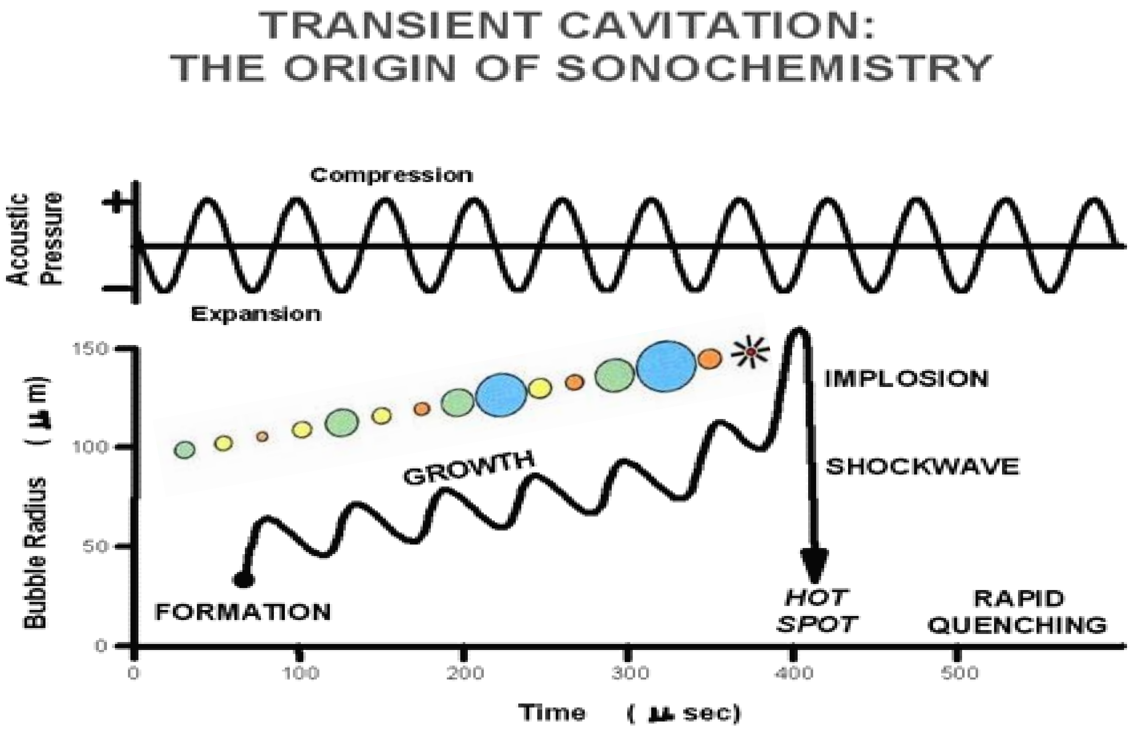
Pre-Clean with Chemical Buff Benefits

1. For customers that use chemical buff on final platen - **FEOL**
   - Move platen chemical buff to Pre-Clean module in the cleaner
   - Enables multi-platen polish for Improved topography and WID range
   - If multi-platen polish is not required, enables significant throughput increase
   - Eliminate the need for additional stand-alone (e.g. wet bench) post-CMP cleaning step with high particle removal efficiency Pre-Clean module

2. For customers with organic residue or nano-defects – **FEOL/ BEOL**
   - Insert chemical buff with Pre-Clean module in the cleaner
   - Aggressive – Can remove many defects that roller brushes cannot
   - Flexible – Allows for chemistries not compatible with platen slurry

3. For customers with circular scratch issues – **BEOL**
   - Use Pre-Clean before roller brushes to reduce the amount of polish residue loading brushes, extending brush life and reducing excursions

Megasonic Cleaning

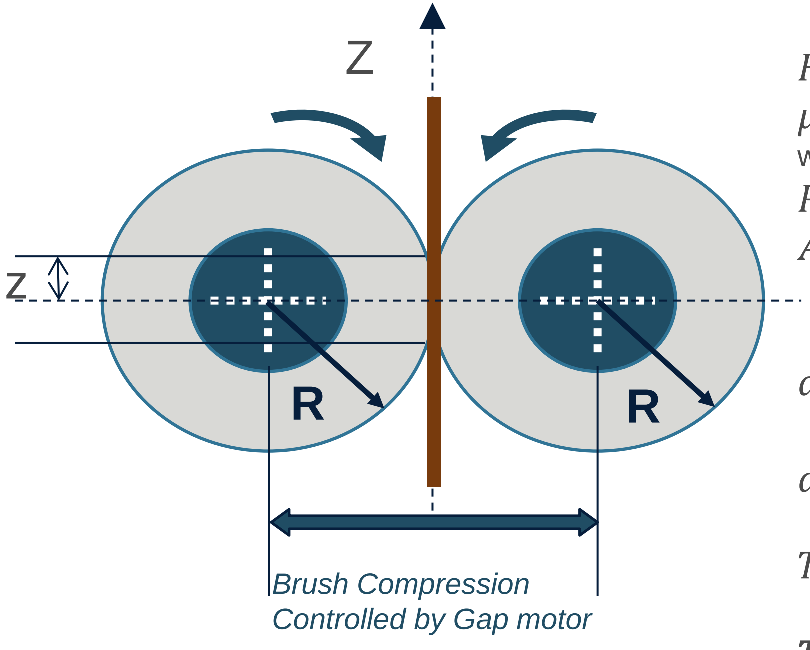


- Physical cleaning method utilizing sonic waves: the liquid undergoes alternating compression (high pressure) and rarefraction (low pressure) in a sinusoidal pattern relative to location and time
  - Nucleation occurs from small gas pockets
  - Cavities grow by rectified diffusion
  - Collapse releases significant amount of energy locally

Cavitation collapse near surface provides shear force for particle removal but can also cause damage

Brush Scrub: High Efficiency Particle Removal Clean

- Clean technology of choice for Post CMP cleans and general Clean applications
- Brush Material: PolyVinylAlcohol (PVA)
- Particle removal efficiency is a strong function of the shear force impacted by the brushes on the wafer
- As brush compression increases, brush pressure increases and shear force increases



$$F_{shear} = \mu F_{normal} = \mu P A$$

μ is the friction coefficient, function of RPM, chemistry, wafer surface, etc.

P is brush pressure

A is the area of contact = $2zL$

$$dF_{shear}(z) = 2\mu\, P(z) L dz$$

$$dT(z) = dF_{shear}(z) R = 2\mu\, P(z) L R dz$$

$$Torque = \int dT(z) dz = 2\mu \int P(z) L R dz$$

$$\boldsymbol{Torque = \mu P\, R\, 2zL}$$

Two consecutive brush boxes provide high particle removal efficiency and precise brush pressure control

Advanced Brush Pressure Cont

Problem Statement

- Brush motor torque is related to the pressure that bushes applies to the wafer surface, and thus, the brush shear force and particle removal efficiency.
- At constant brush spacing set point, brush motor torque changes over the lifetime of the brush.
- In order to keep shear force constant, need to keep the average brush motor torque constant

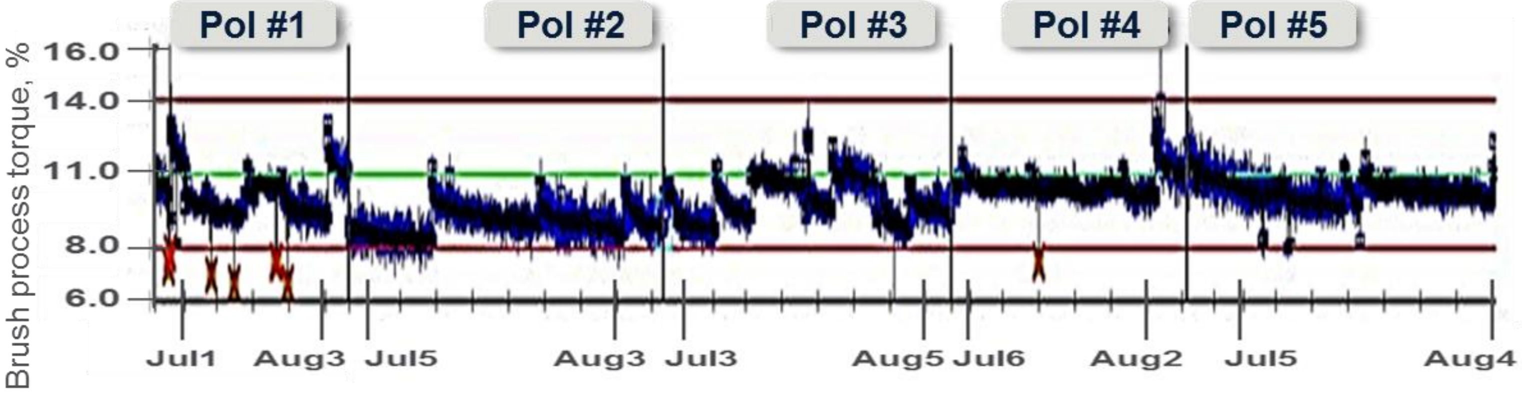
Success criteria:

- <5% error torque drift over brush life

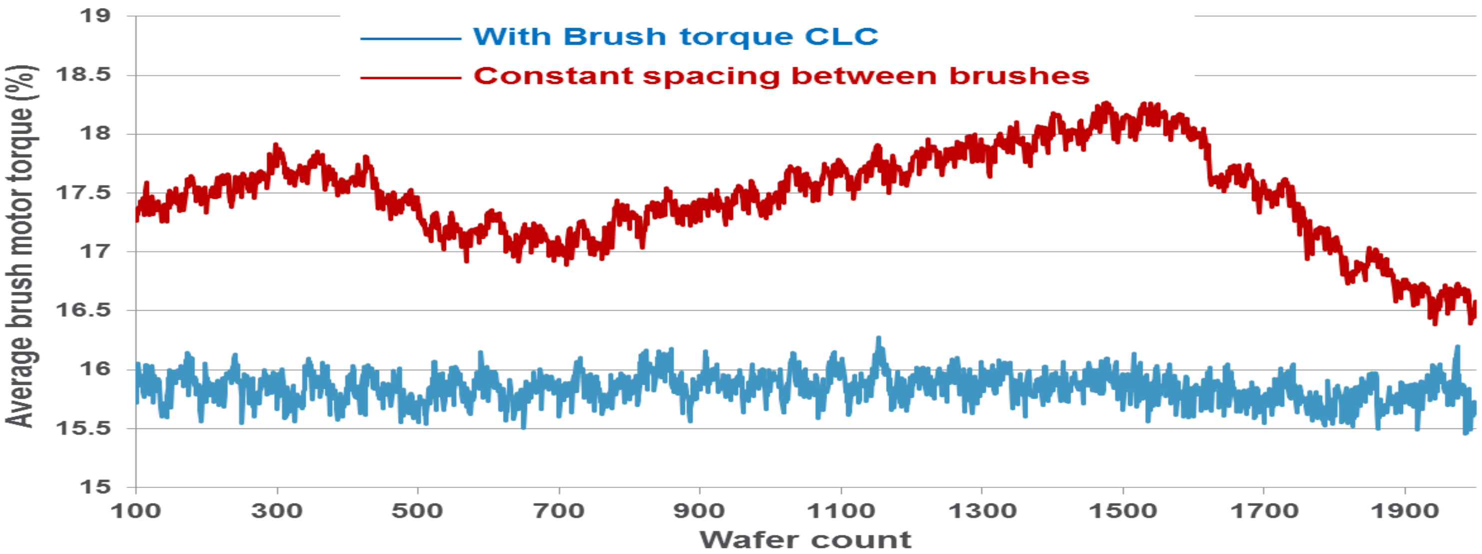
Approach

- Brush Torque CLC algorithm maintains constant average brush shear force on wafer surface by dynamically changing brush spacing to keep brush motor torque constant

Problem: Brush Pressure Fluctuations

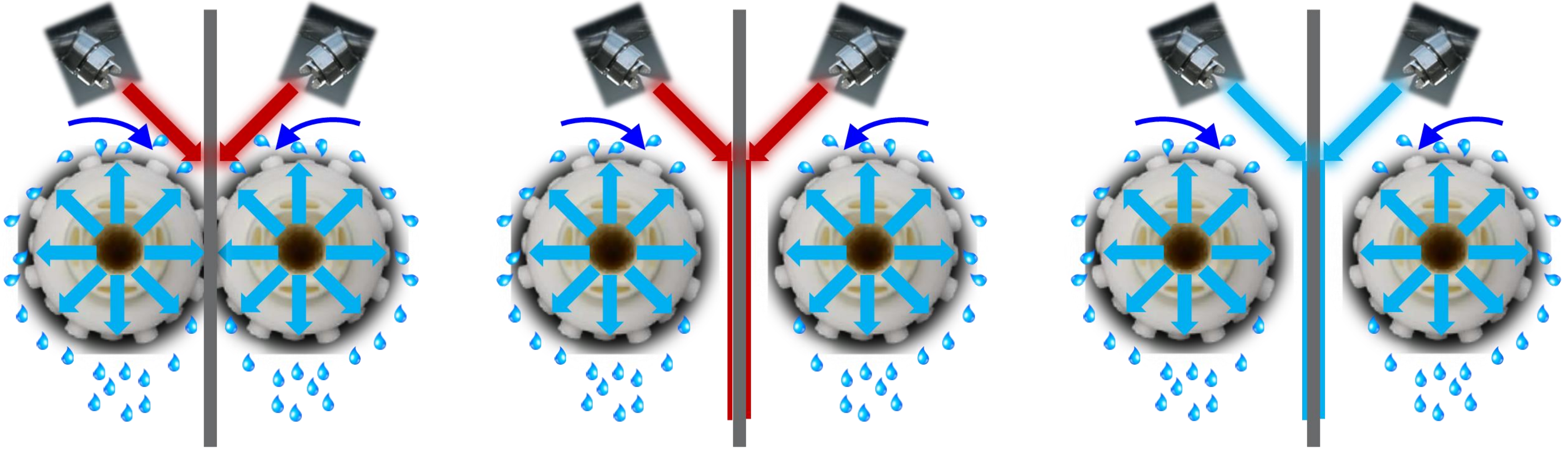


Solution: Brush Torque CLC



Demonstrated capability to maintain constant brush pressure over brush life by dynamically changing brush spacing

Brush Box Recipe Flexibility Required for Cleaning at Advanced Nodes

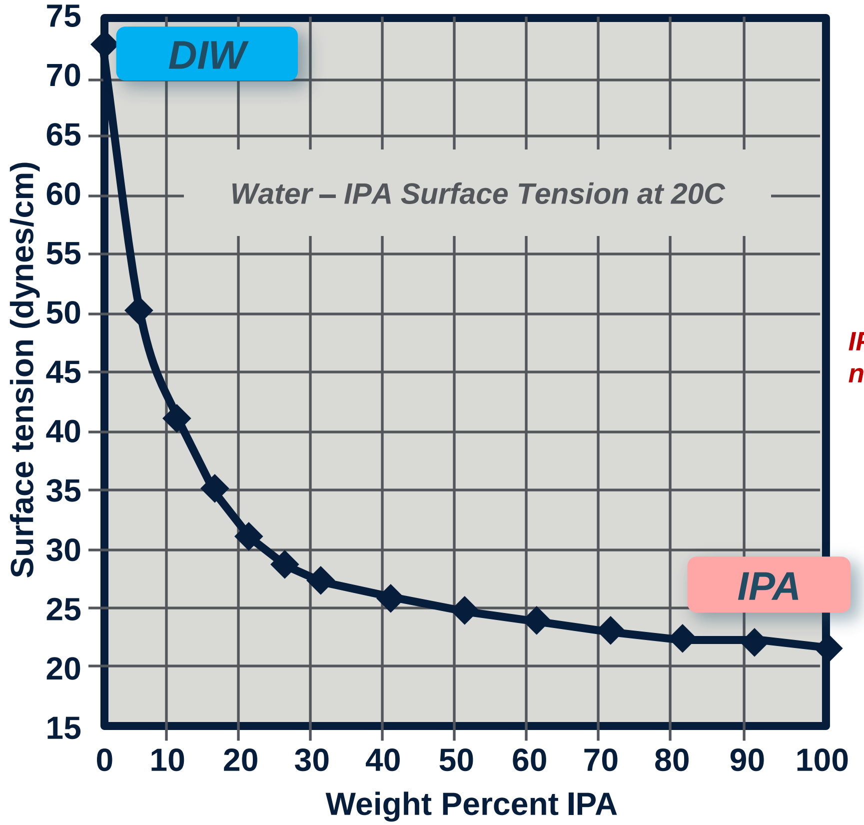


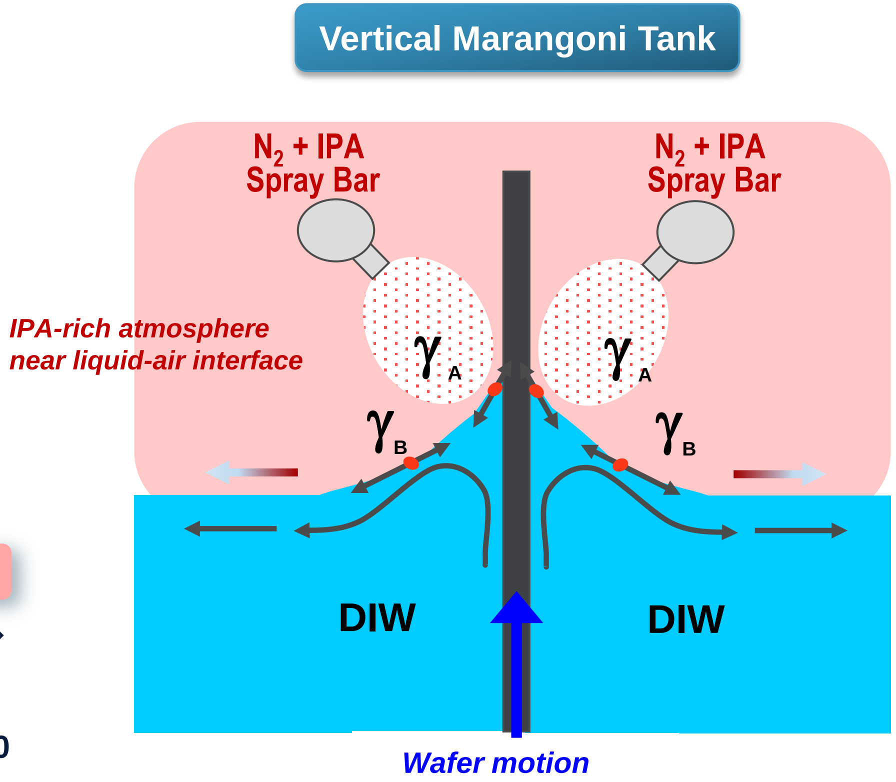
- DIW through brush core cleans out the brush
- Chemistry delivered to Wafer / Brush interface
- Flexible recipe allows for wafer rinse with chemistry without brush contact
- DIW splash back from the brush during rinse is mitigated with low brush RPM

No Dirty Liquid Dripping from the Brush onto the Wafer in Vertical Brush Box

Basic Principle of Surface Tension Gradient Drying

- Surface tension difference caused by surface IPA concentration gradient in DIW helps pull DIW from wafer surface
- Marangoni drying requirement: refreshing of IPA and DIW to keep the gradient





$[IPA]_A > [IPA]_B$

$\gamma_{A(IPA+DIW)} < \gamma_{B(IPA+DIW)} < \gamma_{(DIW)}$

- Gravity removes bulk of the liquid from the wafer
- Tank volume exchanged with fresh DIW (Overflow)
- IPA vapor is continuously fed to the DIW-air interface
- Interface is kept saturated with IPA to produce surface tension gradient drying effect

Vertical Marangoni Dryer provides defect-free drying of hydrophilic, hydrophobic and mixed surfaces

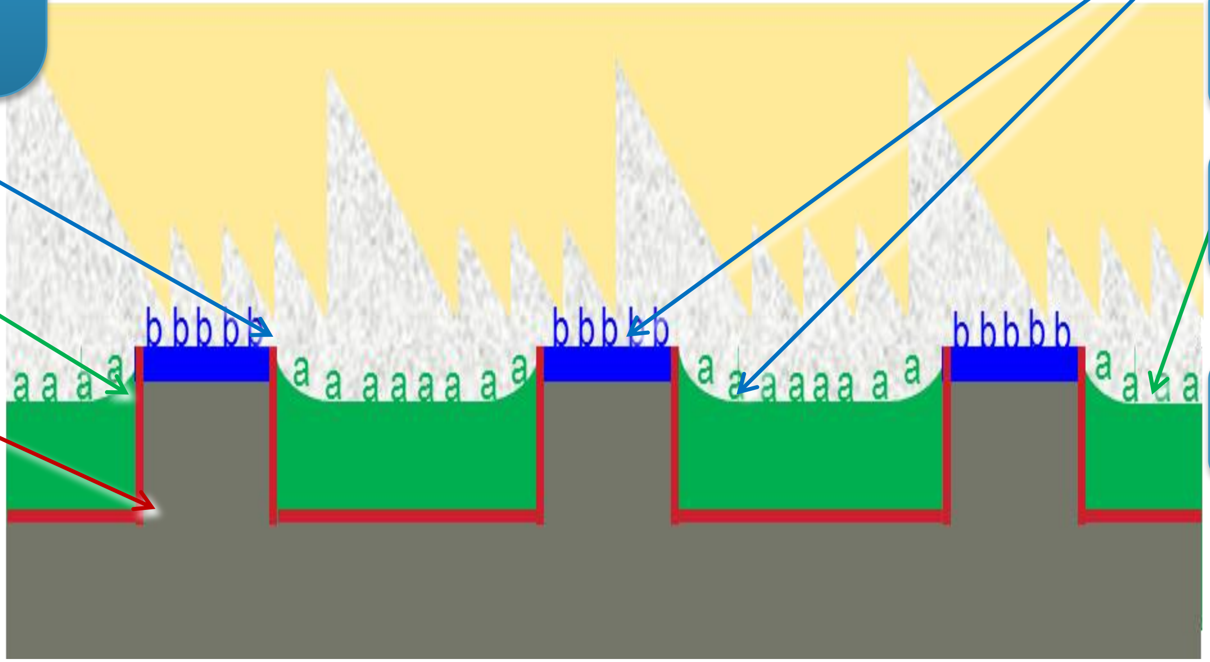
Addressing Post CMP Cleaning Challenges in LKP System

- 5 consecutive cleaning stations
- High shear force Pre-Clean
- Megasonic option
- Two Brush Boxes
- Dryer

Flexible chemistries

Flexible chemistries
Brush box recipe flexibility

Inter-Platen Clean
Chemistry in HCLU Option



Vertical Marangoni Dryer
VD1.5 Dryer enhancement

Contamination removal in Pre-Clean
Advanced brush pressure control

Buff pad conditioning in Pre-Clean
BB2.0 brush conditioning in brush box

Wafer top-bevel Clean in Pre-Clean
Bevel clean in immersion Meg tank

Summary

- Geometry shrinking and new material implementation in advanced nodes demand the achievement of high particle removal efficiency.

- Chemical Mechanical Cleaning combines controlled mechanical force with chemical action to remove strongly adhered particles and residues, without sacrificing film stack integrity

- To address cleaning challenges in various nodes, Applied CMP implements
  - High shear force Pre-Clean module for high defect removal efficiency
  - Single wafer Megasonic module for improving defect removal efficiency
  - Dual brush box module with advanced process control
  - Single wafer IPA dryer for achieving water-mark free drying

APPLIED MATERIALS®

make possible