Reducing CMP Variation

Measure What Matters

NCAVS CMPUG

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Outline

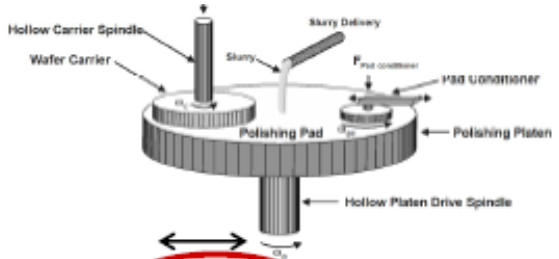
- Confluense Background
- CMP Variability Sources
- Improvement Methodology
- State Variable Measurements
- Summary

Confluense Background

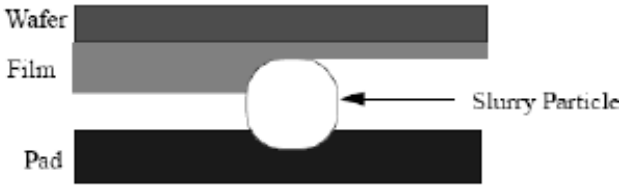
Founded:	**2008**
Location:	**Furlong, PA**
Experience:	**25 years semi CMP materials; 12 US Patents**
Objectives:	**Provide services, technology (IP), and /or systems to CMP users enabling new visibility and control of polishing kinetics.**
	Reduce the variability, cost, and environmental footprint of CMP
Current Focus:	**Early adopter, characterize variability, closed loop control**
	Licensed partners

Universal CMP Challenges

Macroscopic Control



Microscopic Phenomenon

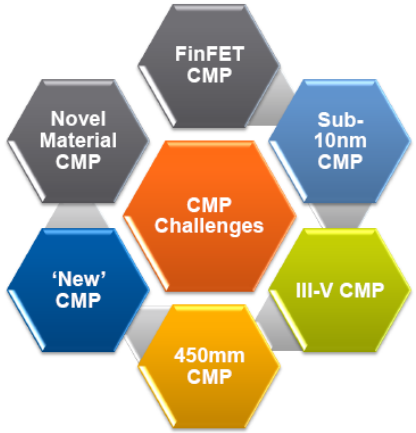


300 mm ~10^7 difference in scale 50 nm

Source: MIT

- High cost of ownership
  - CMP content and cost per wafer is increasing
- Shrinking tolerances
- ***Variability - Non-stable slip stream kinetics***
- Disruptions – Scratching, Foreign Matter

CMP Challenges



- We are facing technical limitation at sub-14nm CMP technology. We must have dramatic improvement in CMP technology.
- Need to pursue technology innovation and non-conventional planarization.
- Strong collaboration among end users, tool makers, consumable suppliers, and academia is the key component to achieve this goal.

7/7/2014 13

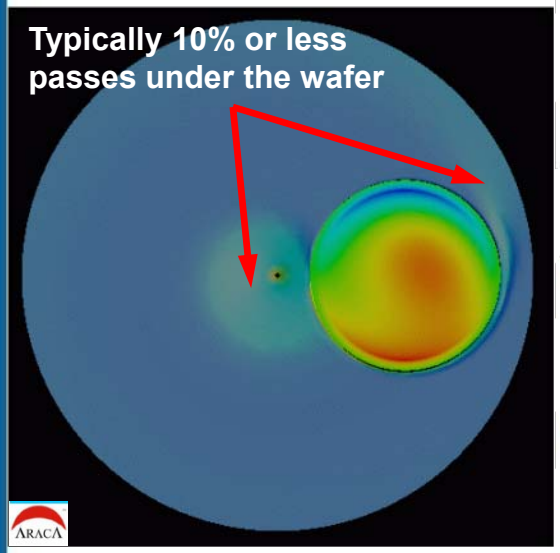
CMP Variability Sources

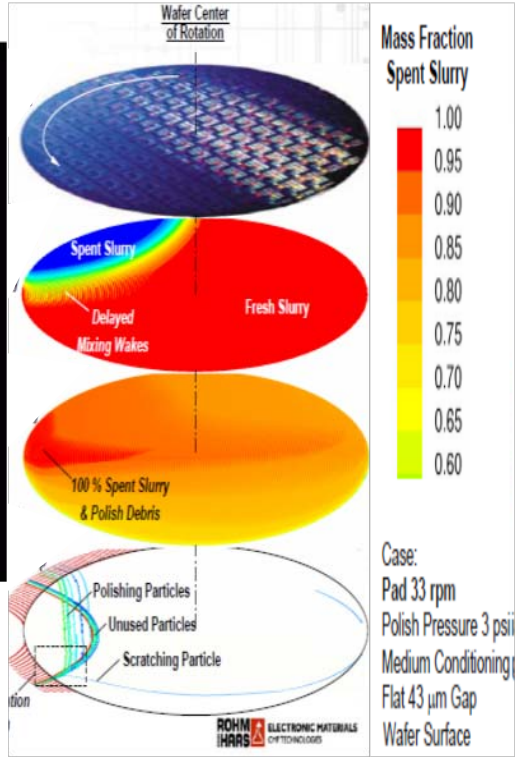
- **Many improvements made in KPIV's**
- **Little visibility into state variation**

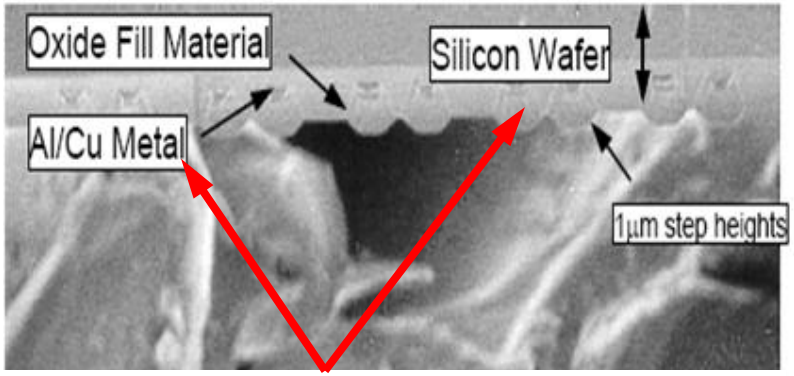
Key Process Input Variables KPIV's		State Variables	Key Process Output Variables KPOV's
Machine	Down Force, Back Pressure, Platen Velocity, Wafer Carrier Velocity, Slurry Flow, Vibration, etc.	Stress Distribution, Velocity Distribution	**Endpoint Control** (Remaining Thickness Control)
Polishing pad	Stiffness (or Hardness), Macrostructure, Microstructure, Porosity, Topography, Pattern, etc.	Condition, Wet Hardness, Degradation, Temperature Distribution	**Material Removal Rate** (Å/min)
Slurry	Oxidizers, pH, pH Stabilizer, Complexing Agents, Dispersants, Selectivity ratio, Temperature	pH drifts, Concentration, Temperature Rise, Slurry Thickness	**Planarity** : Within Wafer Non-uniformity (WIWNU), Wafer to Wafer Non-uniformity, Within Die Non-uniformity (WIDNU)
Abrasive Particles	Size, Shape, Hardness, Chemistry, Density, Oversized Particles	Size Distribution, Aggregation, Agglomeration, Concentration, Debris	**Defects & Contamination** : Dishing, Erosion, Micro-scratch, Pits, etc.
Wafer	Size, Curvature, Properties of Coating (*E, v, H*), Initial Coating Thickness, Coating Thickness Variation, Pattern Geometry	Direct Contact, Semi-Contact, Hydroplaning	**Surface Finish** : Roughness, Waviness, Form Accuracy

REF: Statistical Characterization of the Chemical-Mechanical Polishing Process, Prahalada K Rao, OSUSchool of Industrial Engineering and Management

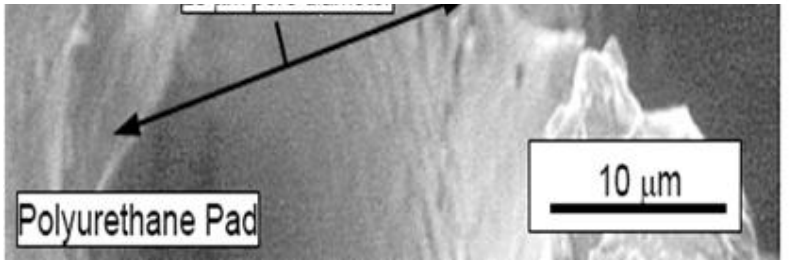
Longer Residence Time = Larger material state variation







Pad: Texture, Glazing, Temp. Distribution, Contact area
Slurry: pH, Concentration, Temp. Rise, Film Thickness
Abrasive: Size Distribution, Agglomeration, Debris



- **90% of fresh slurry carried away by bow wave [1]**
- **Average slipstream residence time 30 seconds [2]**
- **70% of steady state mass fraction is 'spent' slurry [3]**

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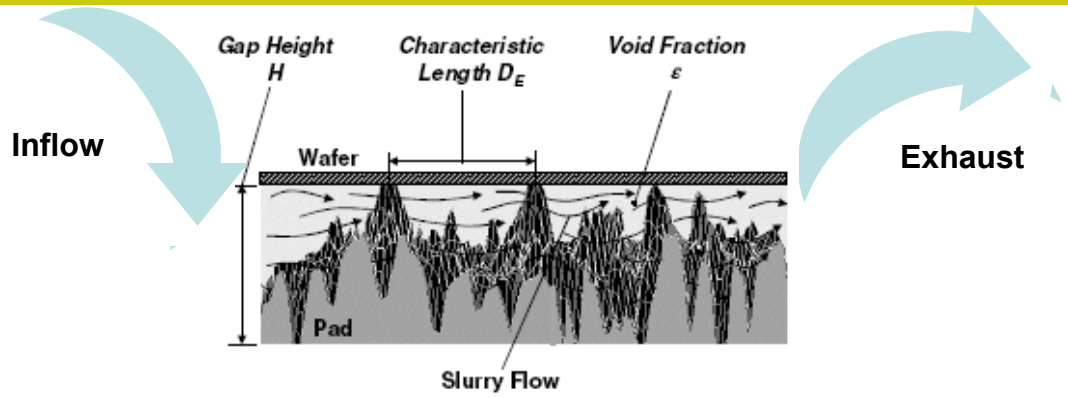
1 Slurry Utilization Efficiency Studies in Chemical Mechanical PlanarizationAra Philipossian and Erin Mitchell
2 Investigating Slurry Transport beneath a Wafer during Chemical Mechanical Polishing Processes; Coppeta,J.,Rogers,C.,Racz,L.,Philipossian,A.,Kaufman,F.B.
3 Muldowney; http://www.avsusergroups.org/cmpug_pdfs/CMP2007_4_Lawing.pdf

Pad Surface Management (PSM) Methodology

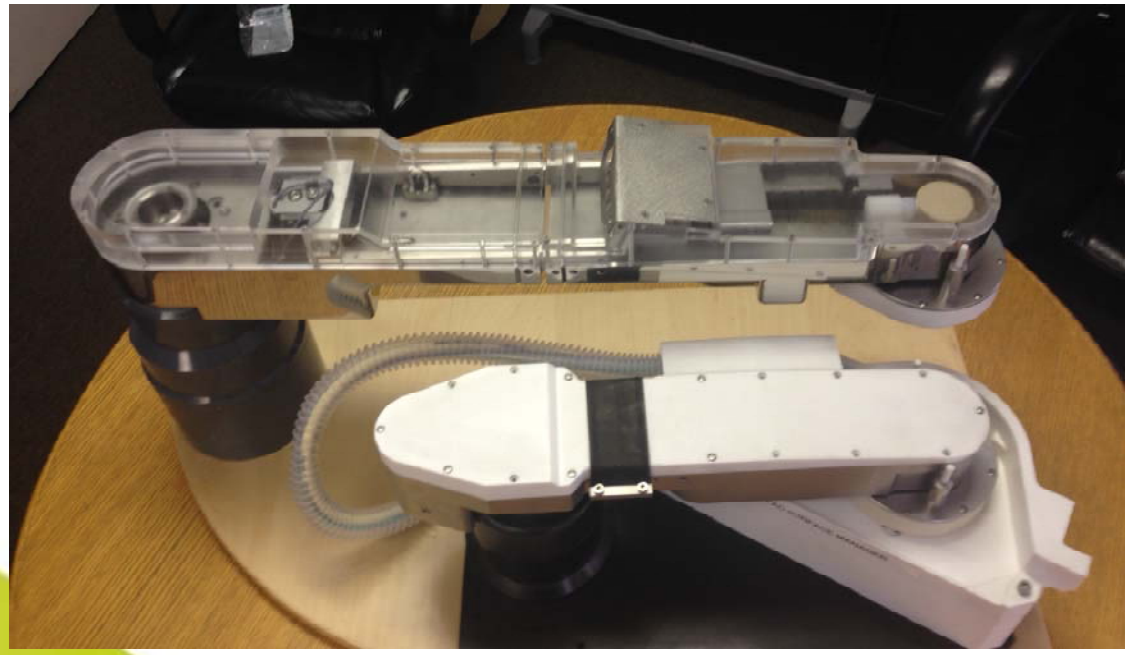
Controlled Interfacial state and residence time



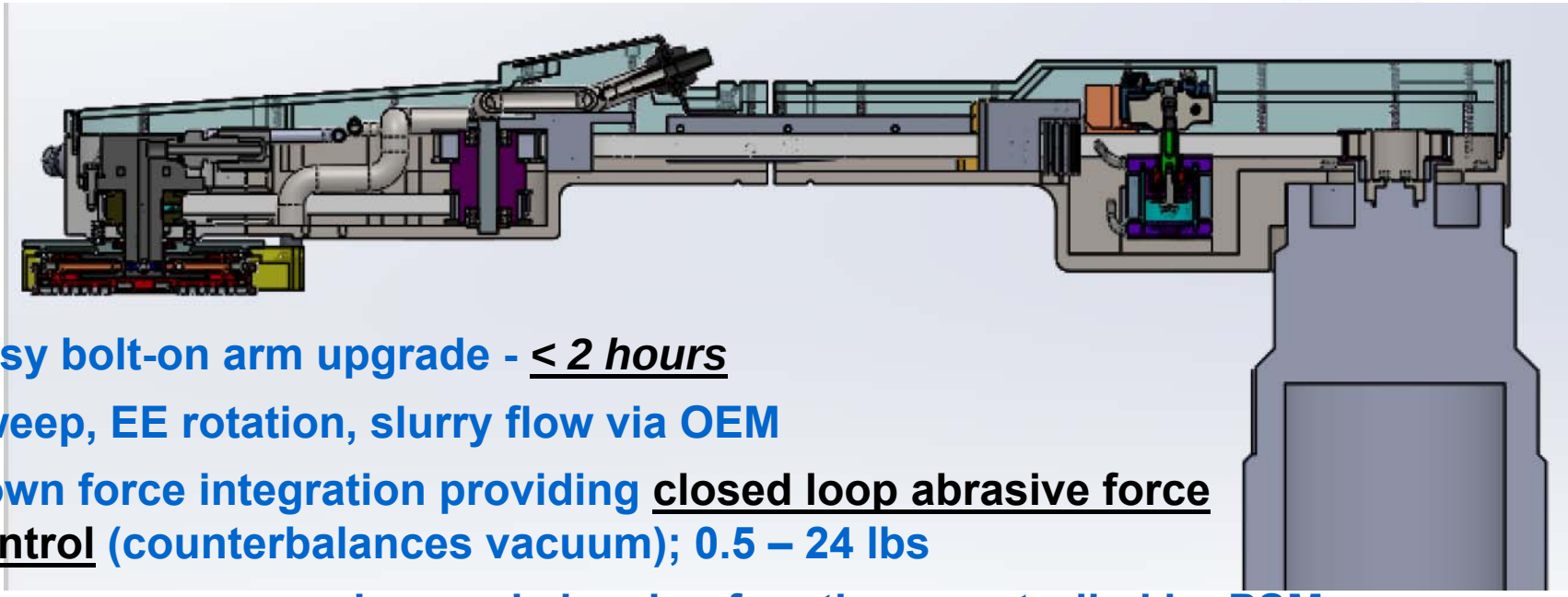
- **Positively Control Interfacial condition; chemistry, colloids, contact**
  - **Improved Slurry 'inflow' focused replenishment vs. global mixing / dilution**
  - **Controlled waste 'exhaust': volume, timing, location.**
  - **Improved DF control (0.5 -24lbf), integrated cut rate and profile metrology**
  - **In-Line Effluent Instrumentation – Concentration, LPC, Conductivity, pH, Species of interest (NIR,Raman), Temp, …**
  - **Localized and contained pad cleaning functions (High pressure microjets)**
  - **Enables advanced process control – eliminate oversize particles, reduce slip stream variation, control furrow density, in-situ surface treatments, POU recycle, waste segregation.**

Animated video available here:
https://www.youtube.com/watch?feature=player_embedded&v=LBrmIDyKqnE

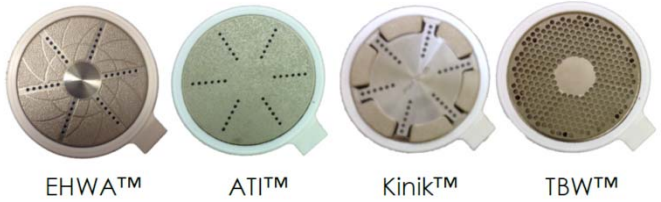
Pad Surface Manager™



Pad Surface Manager (PSM) - How



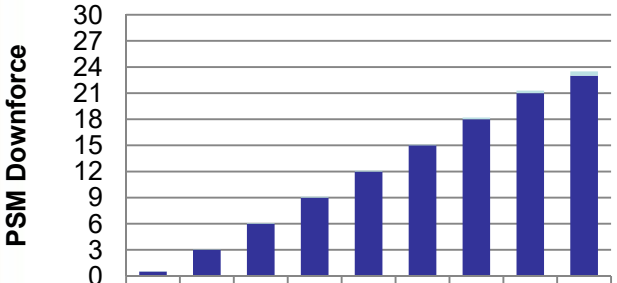
- Easy bolt-on arm upgrade - ***< 2 hours***
- Sweep, EE rotation, slurry flow via OEM
- Down force integration providing **closed loop abrasive force control** (counterbalances vacuum); 0.5 – 24 lbs
- Vacuum, wear sensing, and cleaning functions controlled by PSM controller synchronized with OEM recipe (event and setpoint)
- Optional effluent sensing and in line sample capability
- Can be operated as conventional conditioner w/o PSM functions
- Accommodates many abrasive manufacturers disks



“Unseen” Pad Variable Measurements

KPIV

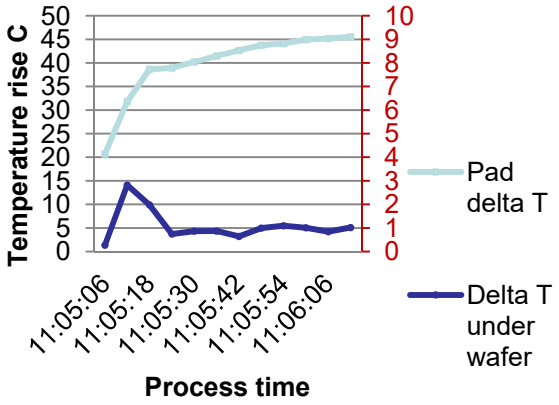
PSM closed loop downforce
Setpoint vs. Actual



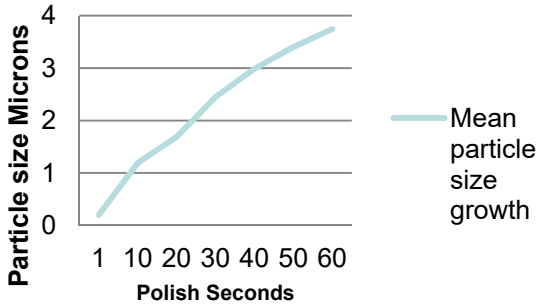
Setpoint	0.5	3	6	9	12	15	18	21	24
Range	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.5
Actual	0.5	3	6	9	12	15	18	21	23

WIW State Variation

Cu CMP Pad Temp Response

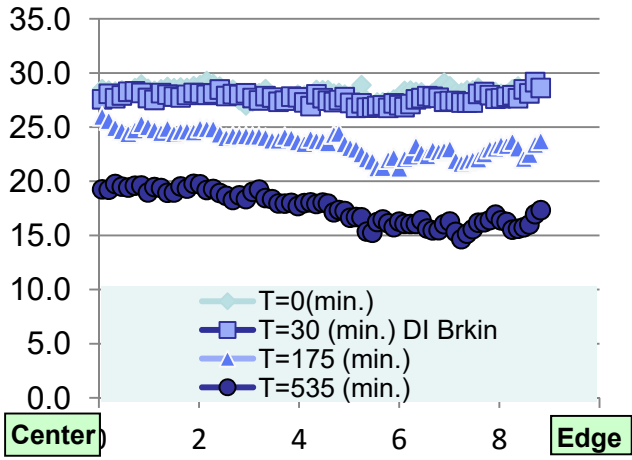


Slipstream particle size growth



WTW State Variation

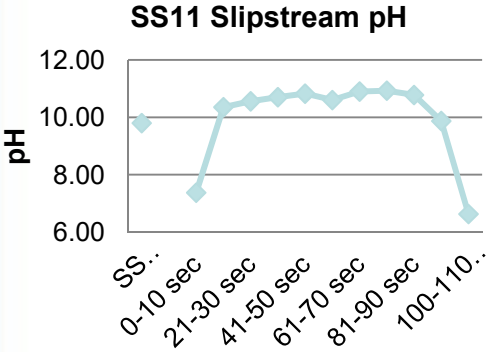
Mirra - PSM
IC1010 Cut Rate / Kleb1501-50

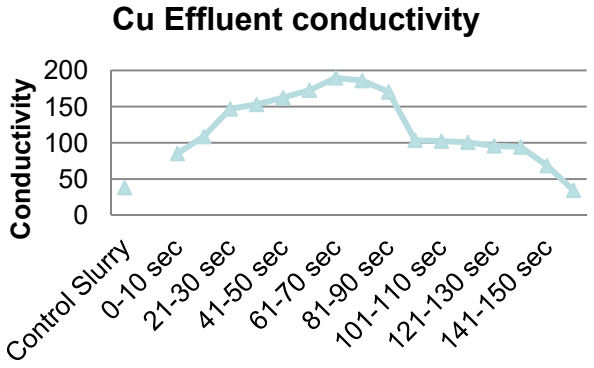


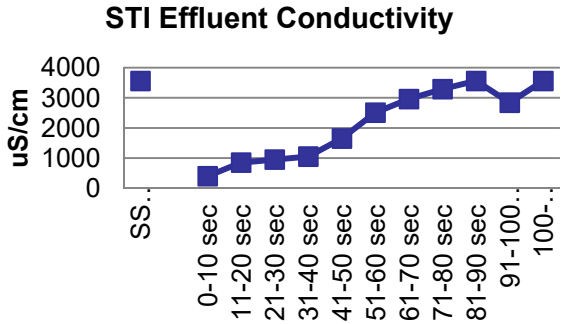
Pad Temperature rise and cycles affect chemical rates, conditioning abrasive penetration / “chip size” /volume, pad and asperity profile

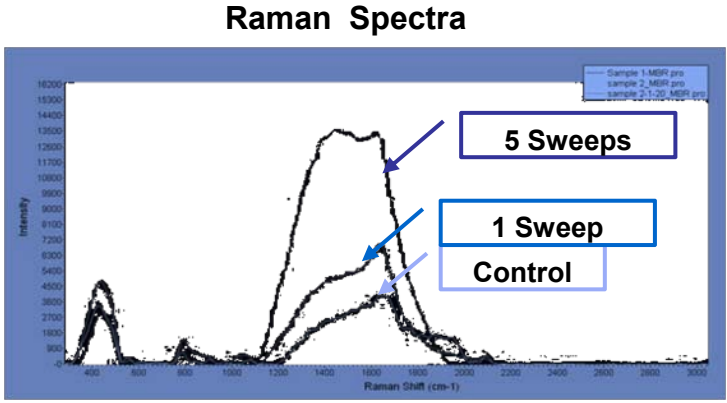
“Unseen” Slurry Variable Measurements

WIW State Variation







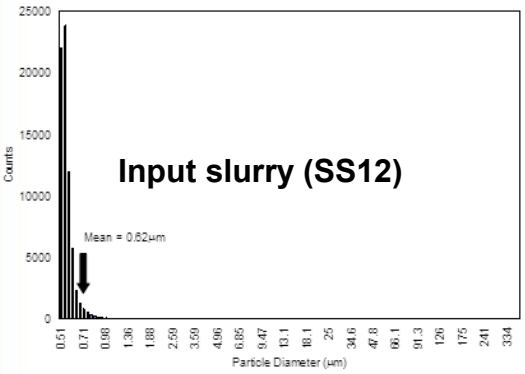


30 Sec Sample	Refractive Index nD	Temp °C	pH	Conductivity mS/cm	Zeta Potential mV
Slip Stream	1.343689 @ 21.6 C	24.1	10.73	3.804	-69.8
Control 1501	1.353395 @ 21.6 C	23.6	11.01	5.174	-68.6

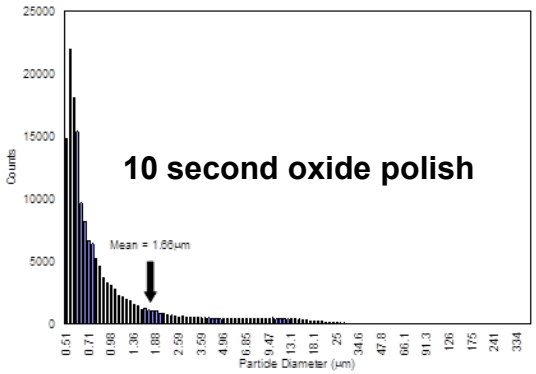
Slurry slipstream pH, reactant and product concentrations, vary significantly throughout the step

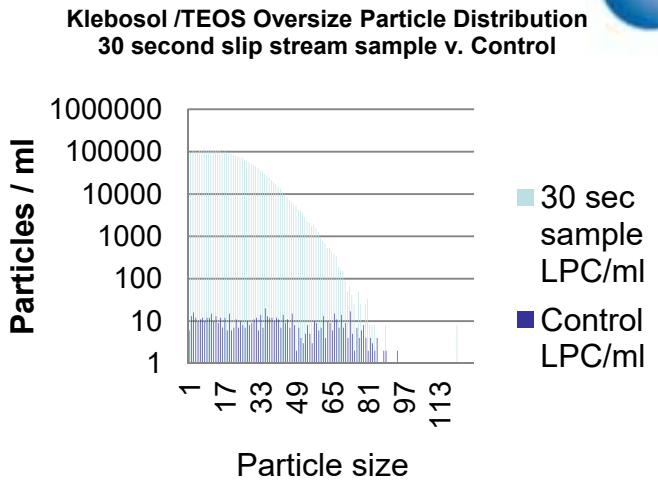
“Unseen” Abrasive Variable Measurements

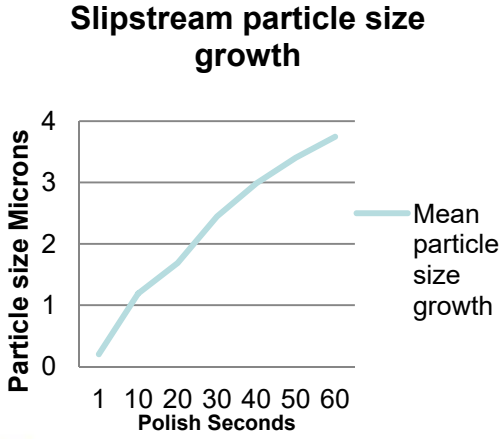
KPIV

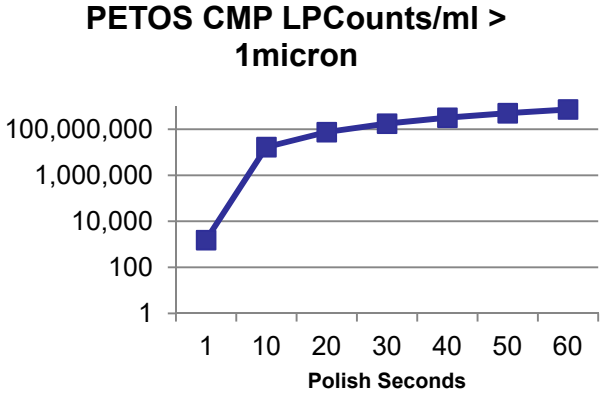


WIW State Variation









“Abrasive” particles (‘rolling asperities’) grow in size and number throughout the step.

Example: POR vs. *6 second residence*

- Wafers / Film Type: Novellus 40KA PeTeos
- Slurry / Pad Type: DOW Klebosol 1501-50, Colloidal Silica IC-1010
- Pad Conditioner: TBW Grid Abrade for PSM
- CMP Process Tool: 200mm Mirra running Titan II Heads

- 544 wafers were run with a test wafer placed after every 20 PeTeos dummies. All test wafers were run on the same head. Process was a customer Oxide POR polishing for 60 seconds on Platen 2 with PSM™ Conditioner followed by 60 sec buff on platen 3 with water. Platen 1 was not used. For baseline, PSM™ was used without Vacuum for first 100 wafers. The first data point is wafer #11 after 11 min of polish and 41 min of conditioning (30 min Cond Break in). A Control Set of test wafers were repeated at the end without the PSM™.

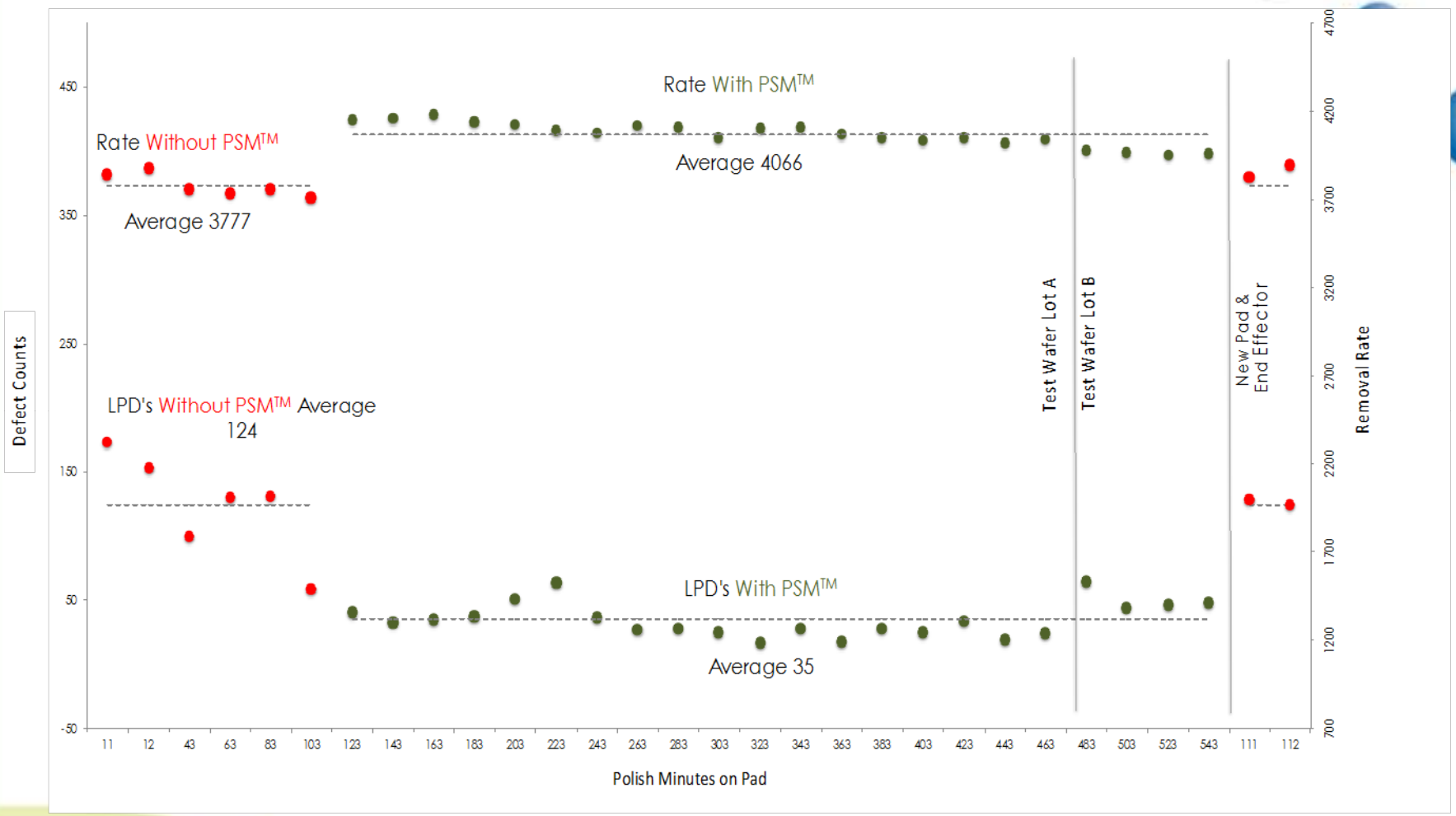
- Average Rate w/o PSM™ : 3777 Å/Min
- Average Rate with PSM™ : 4066 Å/Min

PSM Improvement of 7%

- Average LPD's w/o PSM™ : 124 LPD
- Average LPD's With PSM™ : 35 LPD

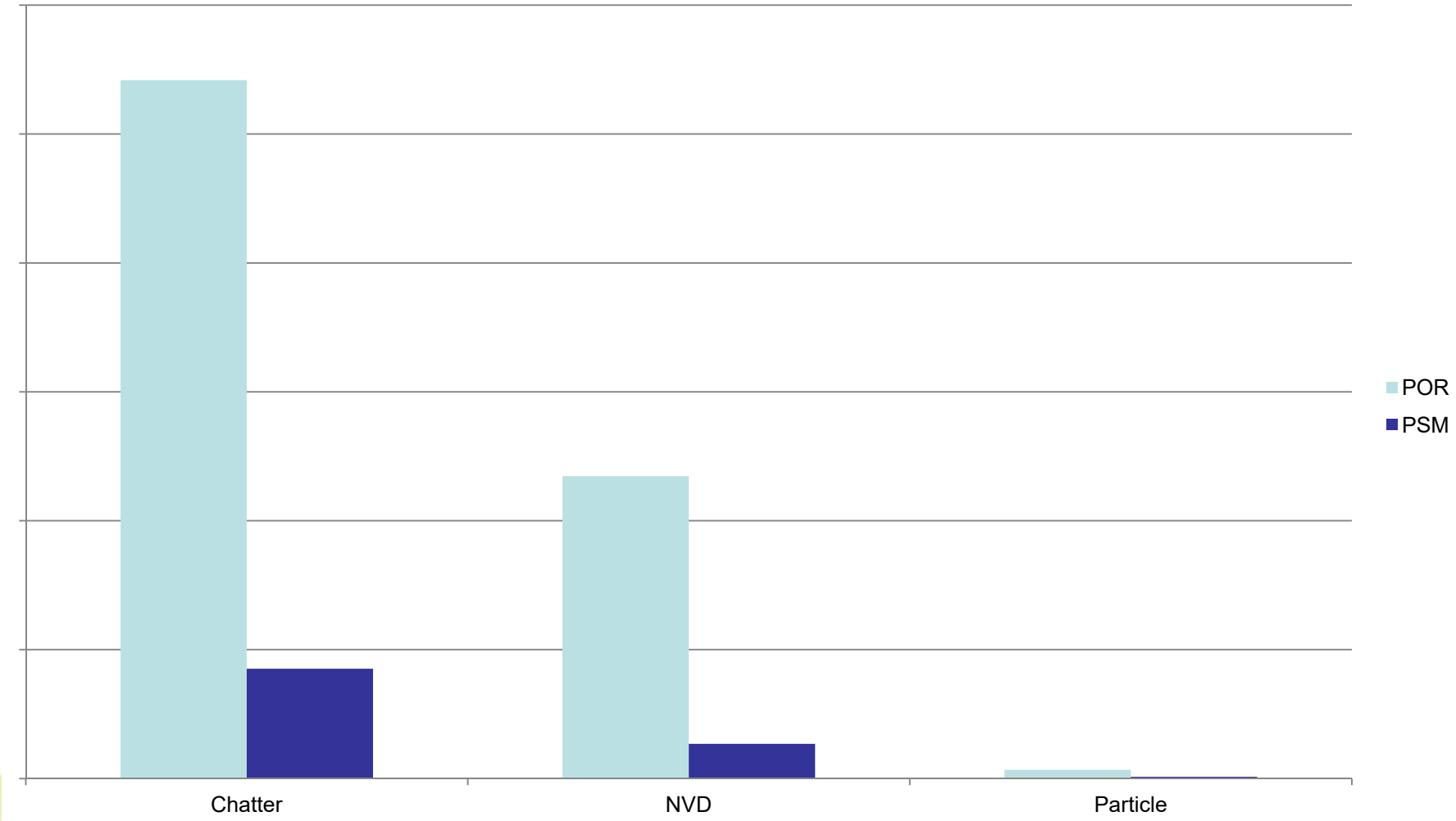
PSM Improvement of 72%

PSM SP1 Defect Results



Non-uniformity (not shown) was stable and unchanged across the run which averaged 3.65 @ 3mm

PSM HF Decorated SEM review



Observed PSM Benefits

- Increased removal rate, slurry utilization efficiency
- Greatly reduced particle counts and defects
- Reduced slip stream (chemical/tribological) variation
- Extended consumable life via reduced dressing duty cycle
- Capable of In-line Effluent Monitoring for more precise slip stream control, real time rate determination, end point
- Contain concentrated waste streams for Recycle and/or EHS improvements, >98% capture rate
- Integrate cleaning or inhibitor steps at landing to reduce cleaning burden and defects

Let us help you see what your missing

- No obligation service offering
- *SEE for yourself* - direct bolt on replacement for OEM arm
  - Installs in <2 hours
  - PSM functions can be turned off and system operates as conventional conditioner
- Capture Slip Stream & characterize variation
- Identify conventional improvement opportunities
- *Demonstrate Controlled Residence Time* process
  - Reduce detritus volume fraction
    - >>50% defect reduction
  - 30%-50% consumable savings
  - Advanced control opportunities

Thank you

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