

Flucto-CMP® Technology



ARACA INCORPORATED

The Polishing and Planarization Experts

November 8, 2022 – PROTECTED BY MULTIPLE PATENTS AND PENDING PATENTS

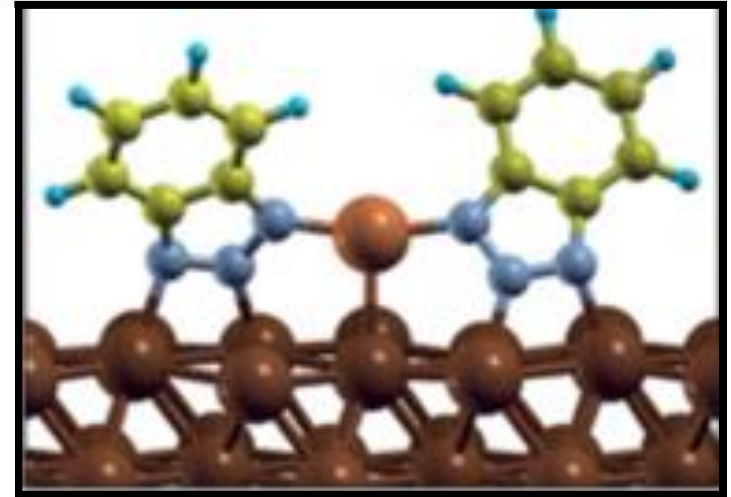
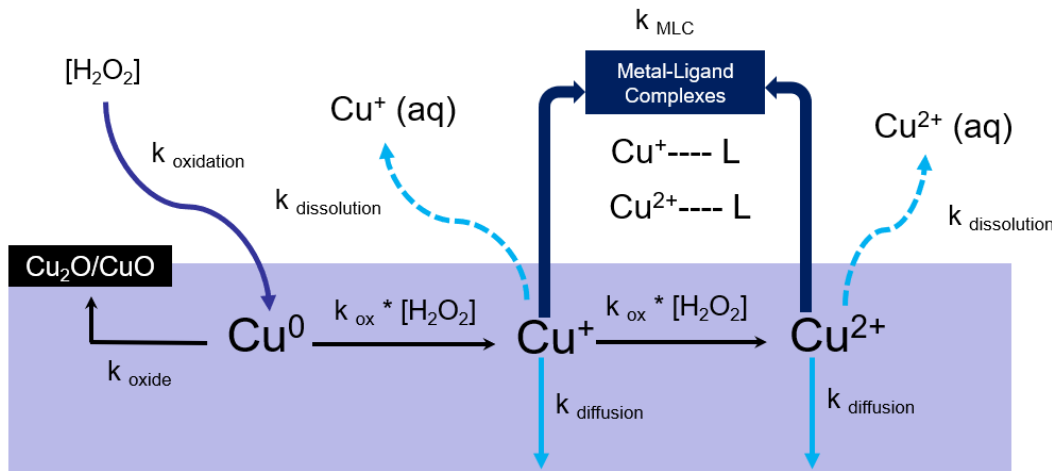
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Our Vision

- Today, the same HVM CMP tool must be able to planarize substrates by removing 2 to 2E7 nm of a single layer without compromising performance – **7 orders of magnitude difference!**
- In addition to platen temperature modulation, there are very few mechanical knobs (e.g., controls, hydraulics, pneumatics, kinematics and the like) that can be perfected in a polisher – **Yet the chemical options are nearly infinite!**
- For 2 years, Araca has been working to partially merge the polisher and slurry roadmaps via our **patent-pending** Flucto-CMP® technology. Here, the combined slurry-polisher strengths complement each other to overcome their individual inherent weaknesses such as defects, gross vibrations, COO, slurry waste, RR, selectivity and WIWRRNU.
- IC makers wish to migrate to a slurry whereby its main properties (such as copper-to-barrier RR selectivity) can be toggled instantaneously and on-demand.
- Flucto means **WAVE** in **Latin** – We now provide on-demand off-the-shelf slurry activation using megasonic waves through:
 - ❖ Add-on polisher equipment (**subject of today's discussion**) – Can also be combined with,
 - ❖ The addition of Sono-Activated® chemicals (**some nuggets presented today**).

BTA Modes of Inhibition in Conventional Copper CMP



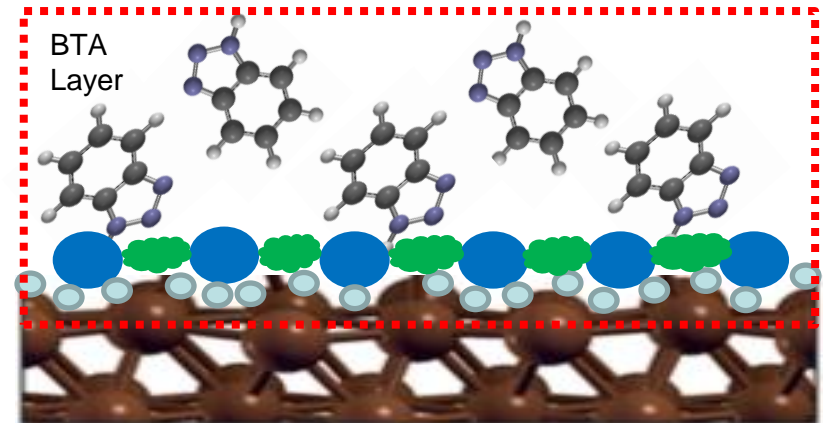
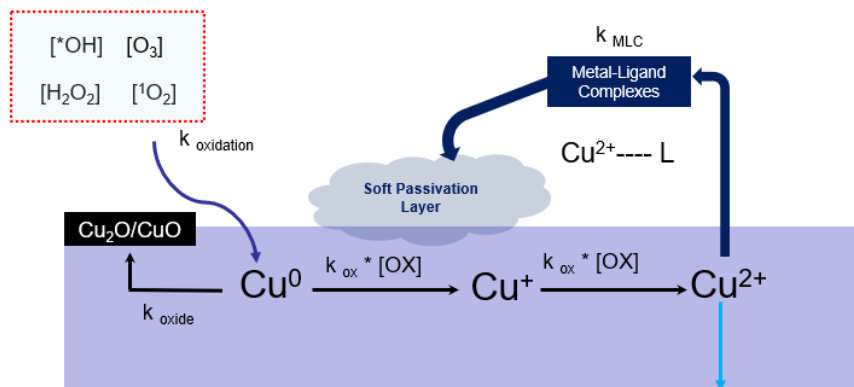
Numerous studies of the interaction of BTA with copper reveal that the BTA molecule forms a coordination polymer above the surface featuring a Cu(I) center bridging between two BTA molecules.

This polymerization leads to the formation of a **DENSE** and **RUGGED** passivation layer that causes large levels of vibration and requires significant mechanical action to remove at appreciable polish rates.

Non-Covalent Passivation Dynamics of Flucto-CMP®

- In Flucto-CMP®, when it comes to material removal, it's all about one's ability to control the interface.
- Enhanced CMP performance evolves from a balance of kinetic and thermodynamic processes. Modulation of these processes get activated by external stimuli such as sonication.
- The subsequent **softer and less dense** film formation dynamics results in effective material removal at less mechanically-aggressive conditions. This reduces vibration as well as wafer-level defects.

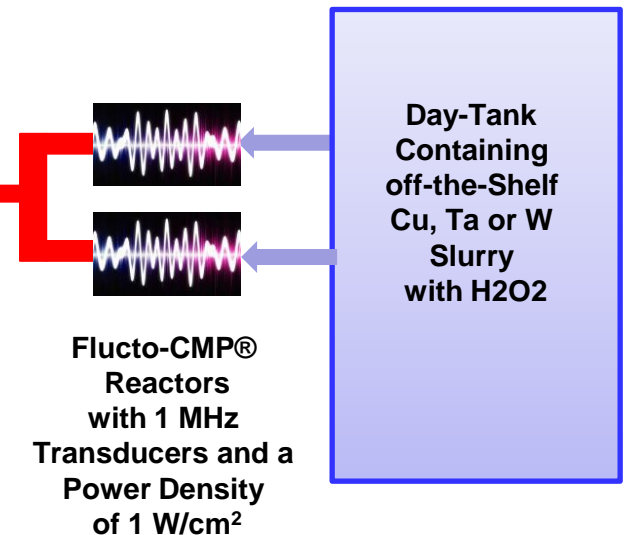
Sono-Activation® of the Reactive Oxidizing Species (ROS)



● = ROS ● = Cu^{2+} ● = Complexing Agent

The Flucto-CMP® Setup at Araca

- The new Araca-Fujikoshi RDP-500® and APD-800 tools are the POR in-house polishers for Flucto-CMP®.
- Equipped with two highly-confidential continuously flowing closed megasonic reactors connected in parallel.
- Flucto-CMP® can be easily retrofitted on any HVM AMAT or Ebara polisher.

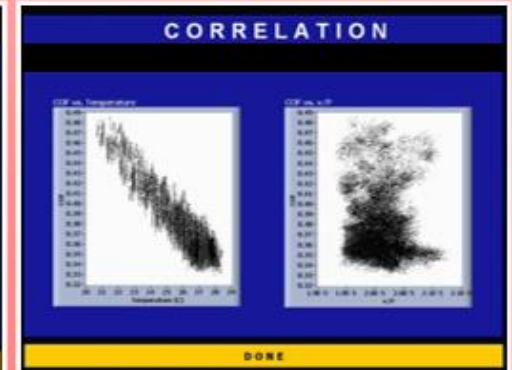
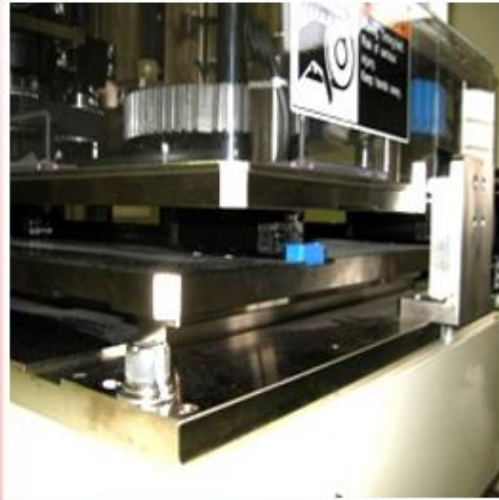




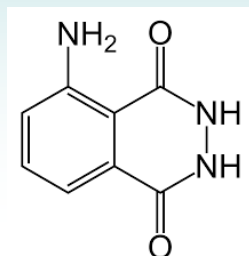
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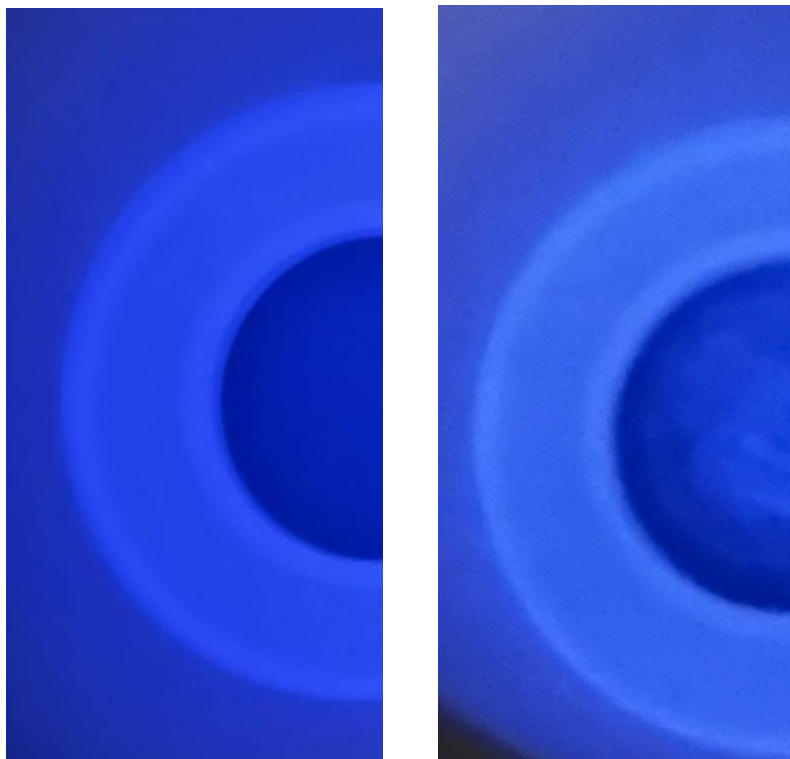
APD-800 Polisher and Tribometer for R&D and Low-Volume Manufacturing



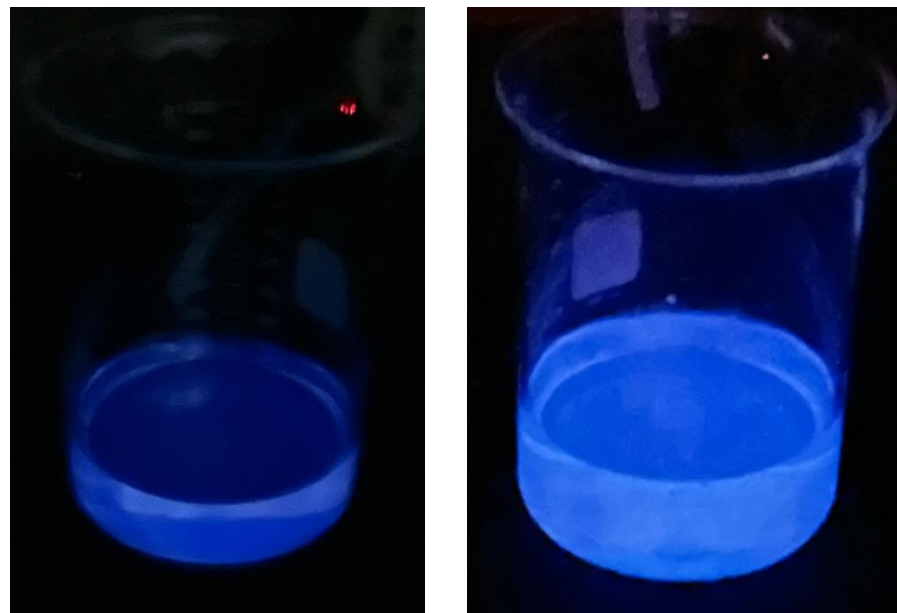
Reactive Oxidizing Species Creation – Luminol® Tests



**Supplier A – Bulk Copper Slurry
with H₂O₂ – After 5-sec (left) and
60-sec (right) exposure to Flucto-CMP**



**Supplier A – Bulk Copper Slurry Post
Sono-Activation Reactor –
Without H₂O₂ (left) and with H₂O₂ (right)**



RR with Flucto-CMP® on Blanket Substrates – Off-the-Shelf Slurries

- Early results (on 100-mm wafers):
 - ✓ Bulk Cu RR increase – **40%** (Supplier A, C, D)
 - ✓ TSV Cu RR increase – **15%** (Supplier A)
 - ✓ W RR increase – **25%** (Supplier A, B)
 - ✓ Ta RR increase – **25%** (Supplier A)
 - ✓ ILD RR increase – **100%** (Supplier A STI CeO₂)
- APD-800 polisher with **one** or **two** Flucto-CMP® reactor (on 300-mm wafers):
 - ✓ Bulk Cu RR increase – **15%** (Supplier A)
 - ✓ W RR increase – **10%** (Supplier A)
 - ✓ Great RTR repeatability →
 - ✓ DRACO hard mask – **35%** (Supplier C)
- RDP-500 polisher (on 200-mm wafers) with **two** Flucto-CMP® reactors:
 - ✓ Bulk Cu RR increase – **35%** (Supplier A)
 - ✓ W RR increase – **15%** (Supplier A)
 - ✓ Great RTR repeatability →

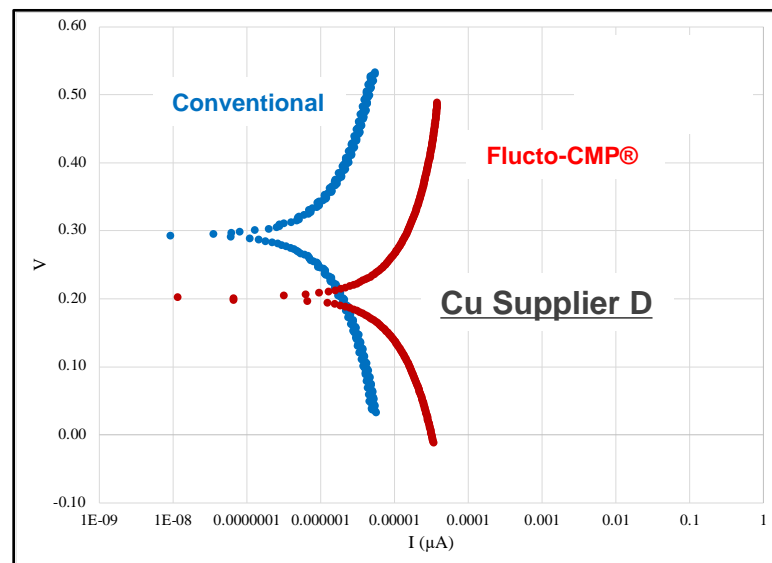
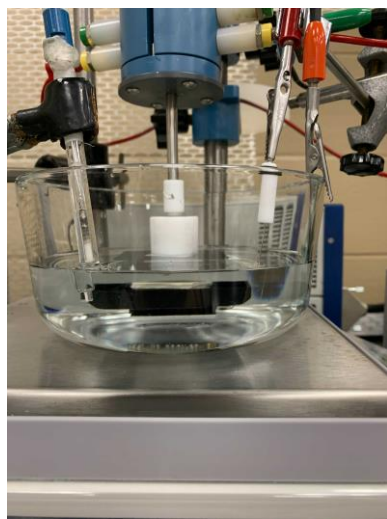
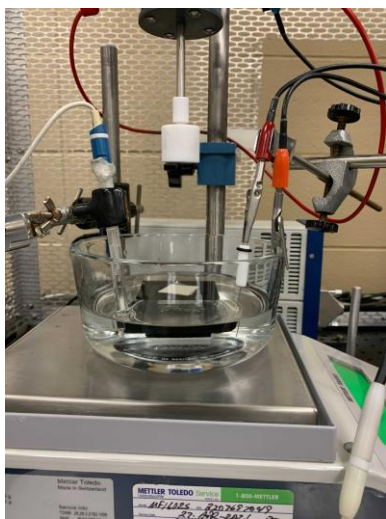
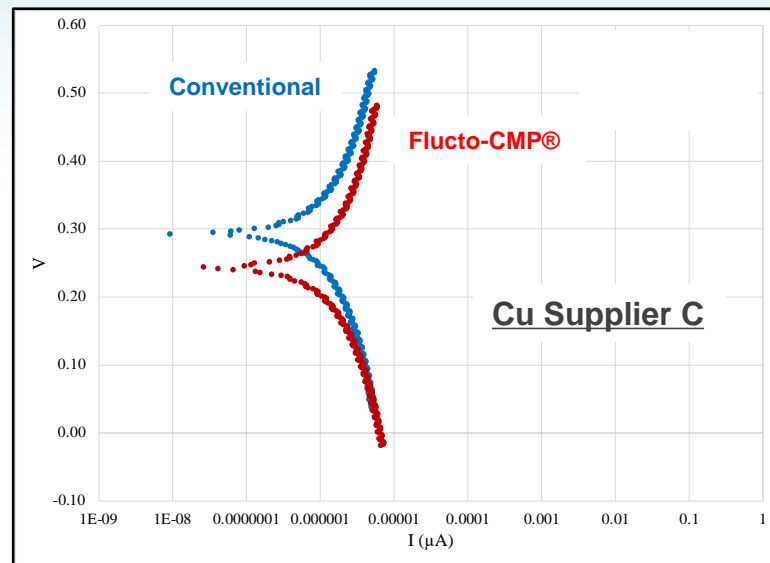
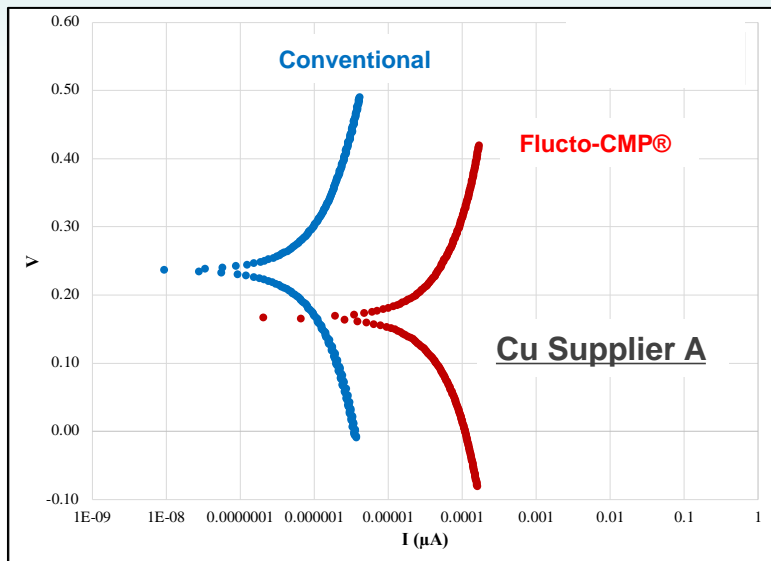
COPPER

Run	Mean COF	Mean Pad Temp. (°C)	Mean Removal Rate (Å/min)
1	0.56	25.5	9190
2	0.532	25.8	8844
3	0.571	25.8	9025
4	0.543	25.7	8858
5	0.551	25.6	9175
6	0.562	26	9215
7	0.548	25.6	8957
8	0.542	25.7	9041
9	0.562	26.2	9038
10	0.554	26.2	8854
11	0.539	25.9	8958
12	0.565	25.5	9124
Average	0.552	25.8	9023
Standard Deviation (%)	2.2%	0.9%	1.5%

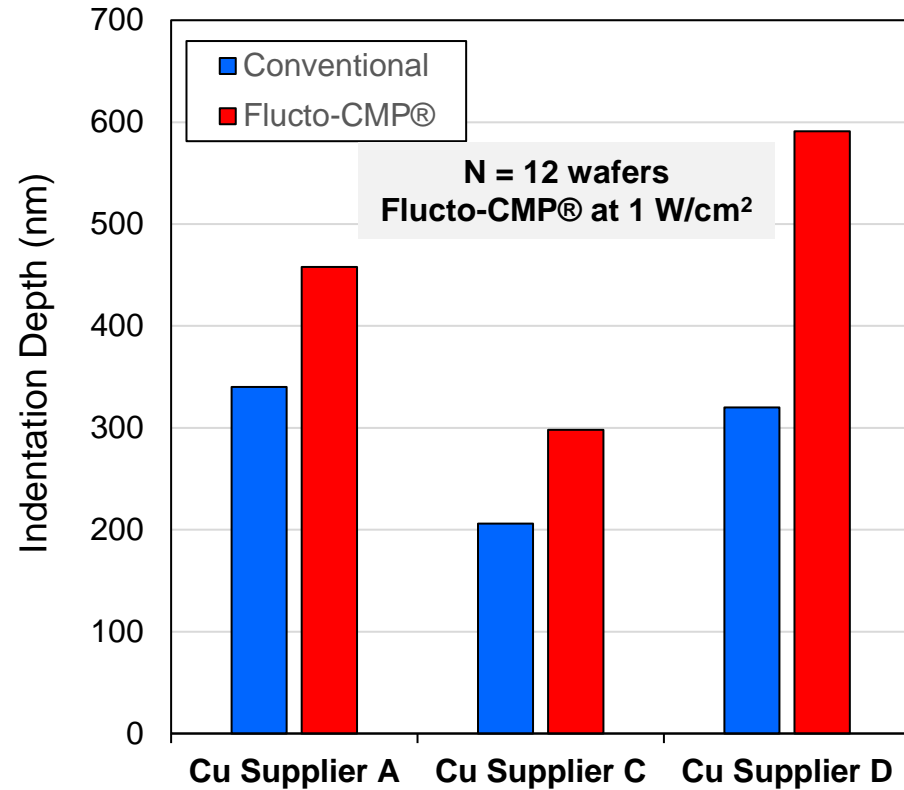
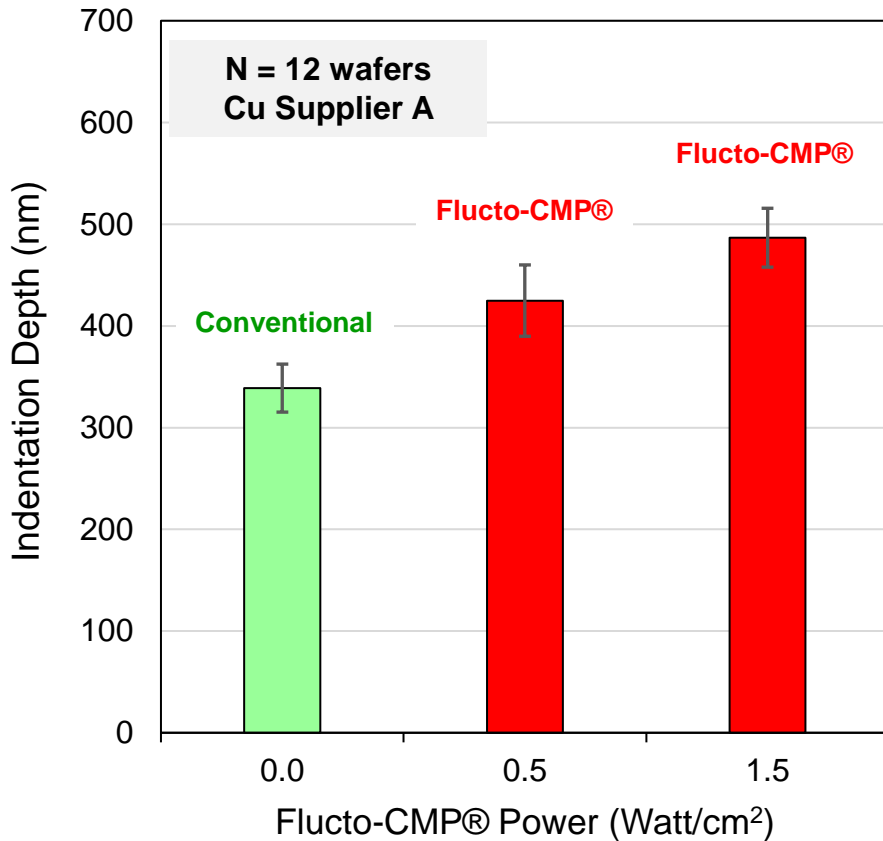
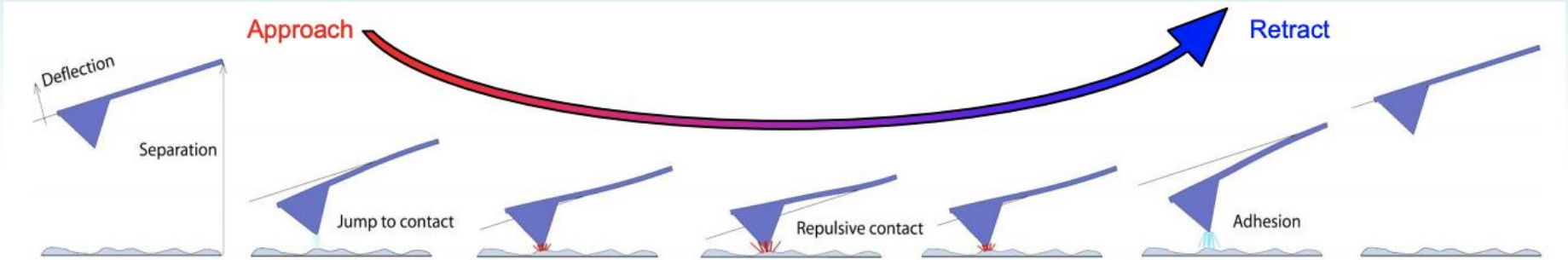
TUNGSTEN

Run	Mean COF	Mean Pad Temp. (°C)	Mean Removal Rate (Å/min)
1	0.318	37.8	2435
2	0.299	37.2	2503
3	0.309	36.6	2453
4	0.308	36.9	2579
5	0.316	37.8	2471
6	0.301	36.9	2402
7	0.307	36.5	2475
8	0.294	37.1	2527
9	0.302	36.4	2481
10	0.294	36.9	2446
11	0.302	36.7	2490
12	0.301	37.6	2538
Average	0.304	37.0	2483
Standard Deviation (%)	2.5%	1.3%	2.0%

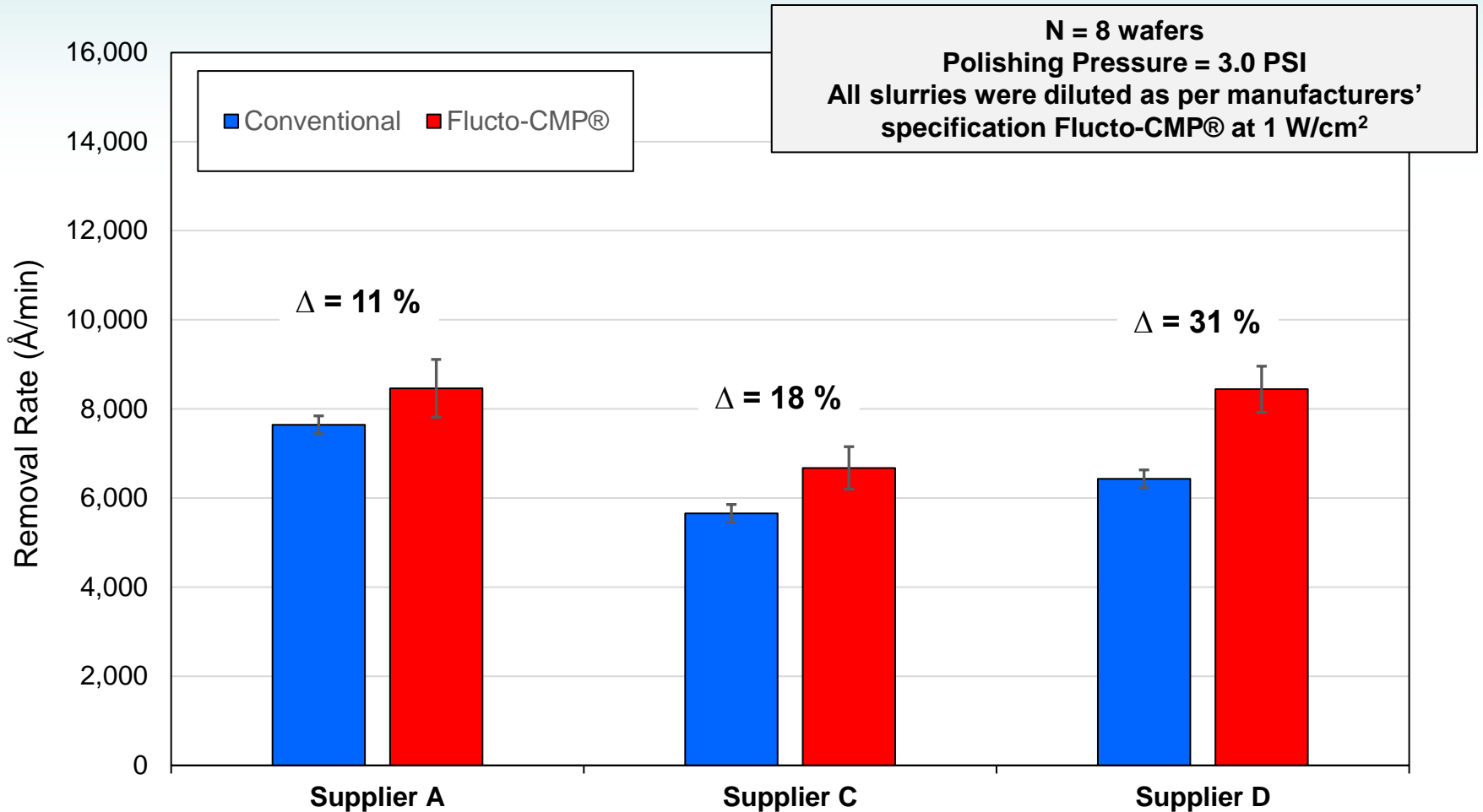
Electrochemical Analysis of Flucto-CMP®



AFM Tip Indentation Depth of the Passivation Layer



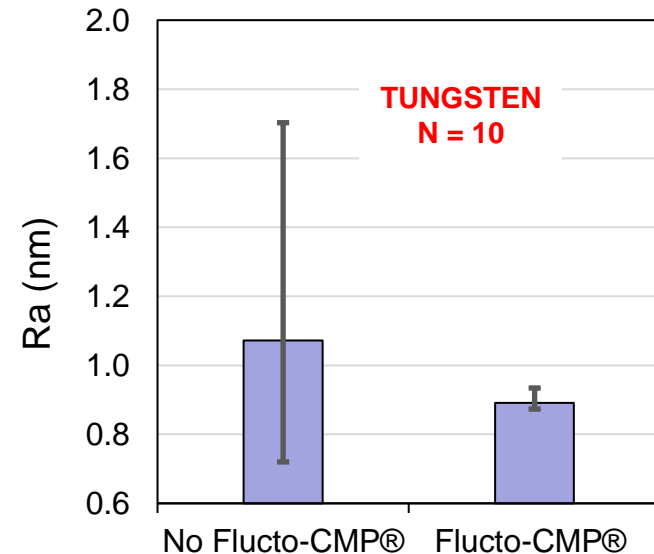
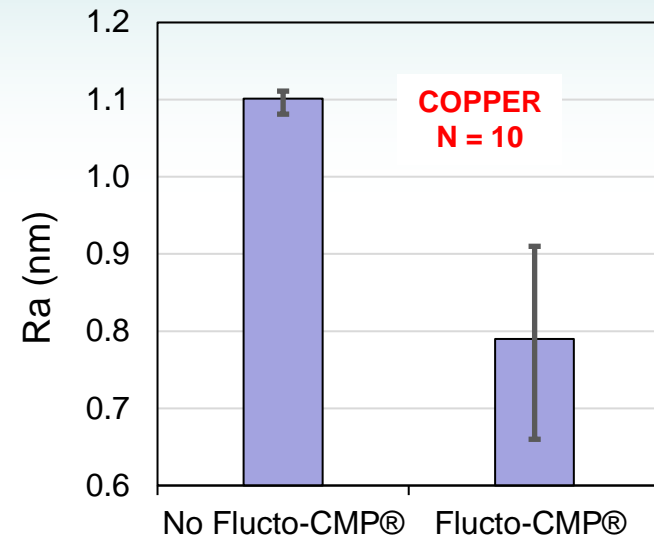
Slurry Supplier Performance Comparison



REMEMBER – THE FASTER YOU POLISH, THE LESS SLURRY YOU USE AND THE LESS WASTE YOU HAVE TO DEAL WITH –
Flucto-CMP® CAN OFFER ATTRACTIVE ENVIRONMENTAL BENEFITS!

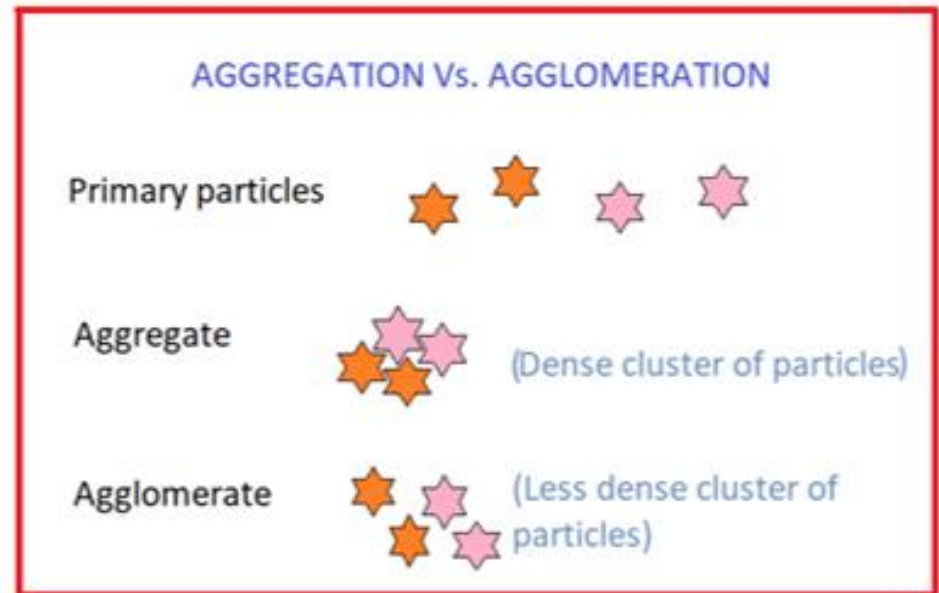
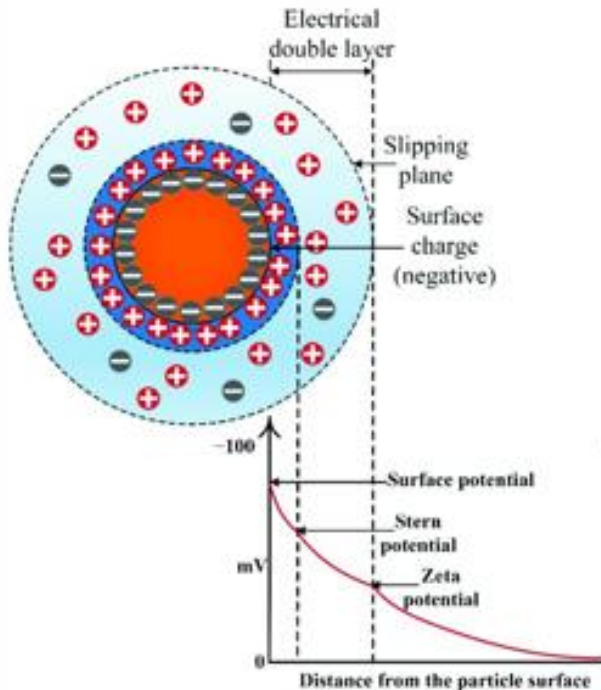
Our Rationale Regarding Defect Reduction

- We believe that defect reduction – **one of the main attractions of our technology** – is due to three separate effects as follows:
 - ❖ **Sonic waves break up agglomerates.** Already proven and patented by Samsung and Micron more than 20 years ago with **ultrasonic** radiation. The next 2 slides demonstrate the effectiveness of Flucto-CMP® on a modern-day copper slurry under **megasonic** waves.
 - ❖ **Megasonic waves increase the concentration of the reactive oxidizing species and result in the formation of a softer passivation layer in which BTA and other molecules are non-covalently bonded on copper.** This softer layer gets removed with greater ease compared to the dense covalently-bonded BTA-copper passivation layer in conventional CMP. Proven by AFM results on the penetration depth into the passivation layer under wet conditions. Dynamic electrochemical results also support our claim.
 - ❖ **Lateral and normal vibrations of the carrier-wafer assembly are dramatically reduced (at times by as much as 80X) with Flucto-CMP® as supported by our real-time shear force and normal force variance results.**



Chemically-Induced Slurry NP Aggregation Theory

- The addition of an electrolyte (i.e., salt) will alter the magnitude of the electric double-layer (at the slurry pH) which will result in a change in the particle zeta potential.
- This change in zeta potential (which is the suppression of charge) will result in greater particle attraction and the formation of either an aggregate (which is hard) or an agglomerate (which is soft).

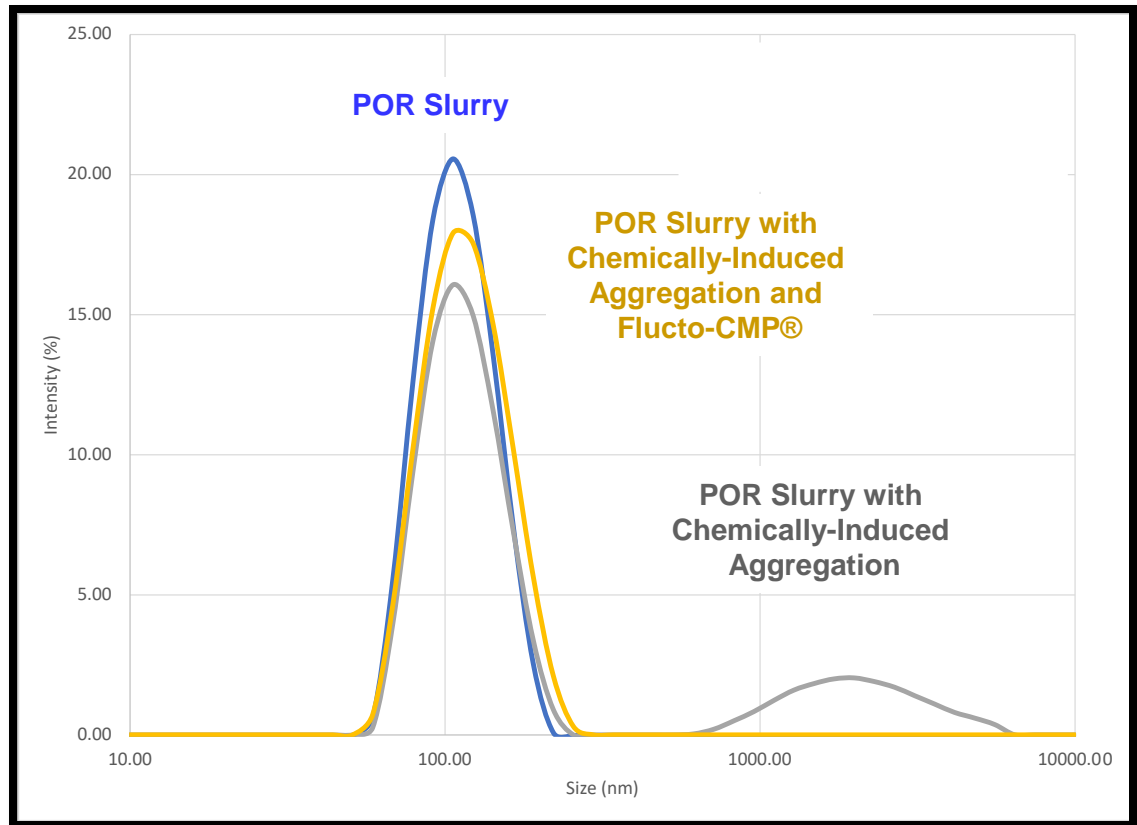


Preliminary Results on Deagglomeration

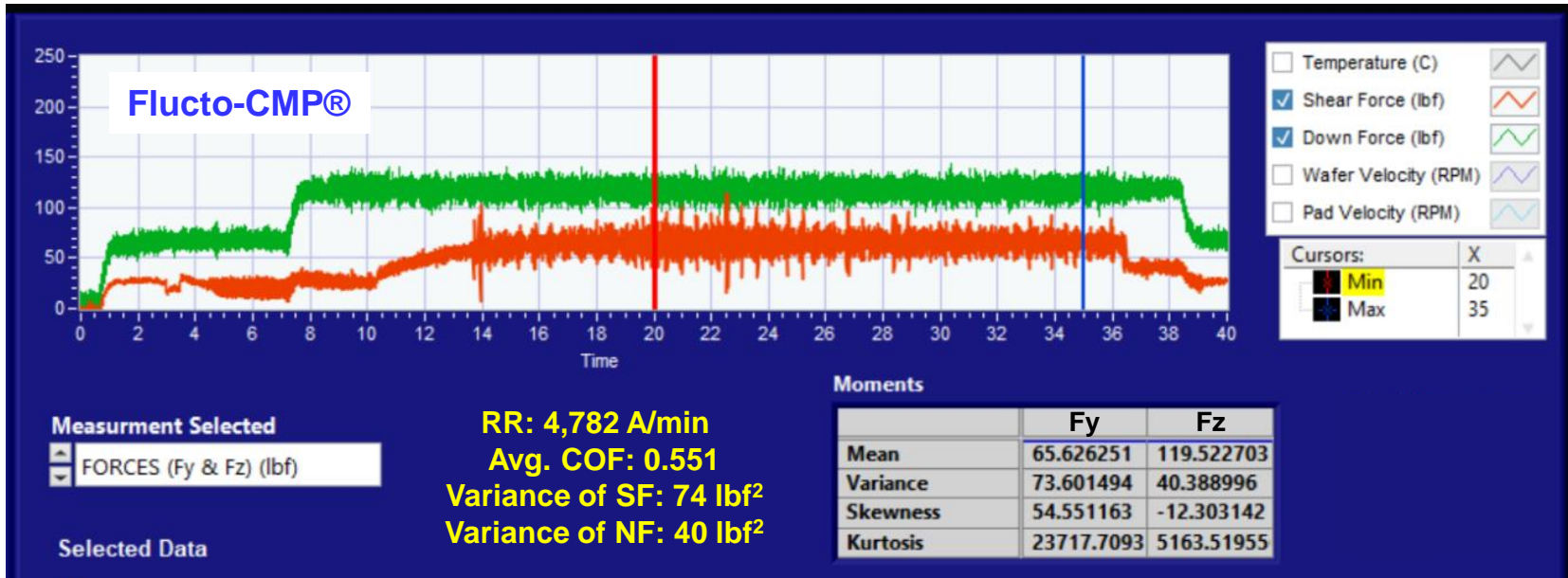
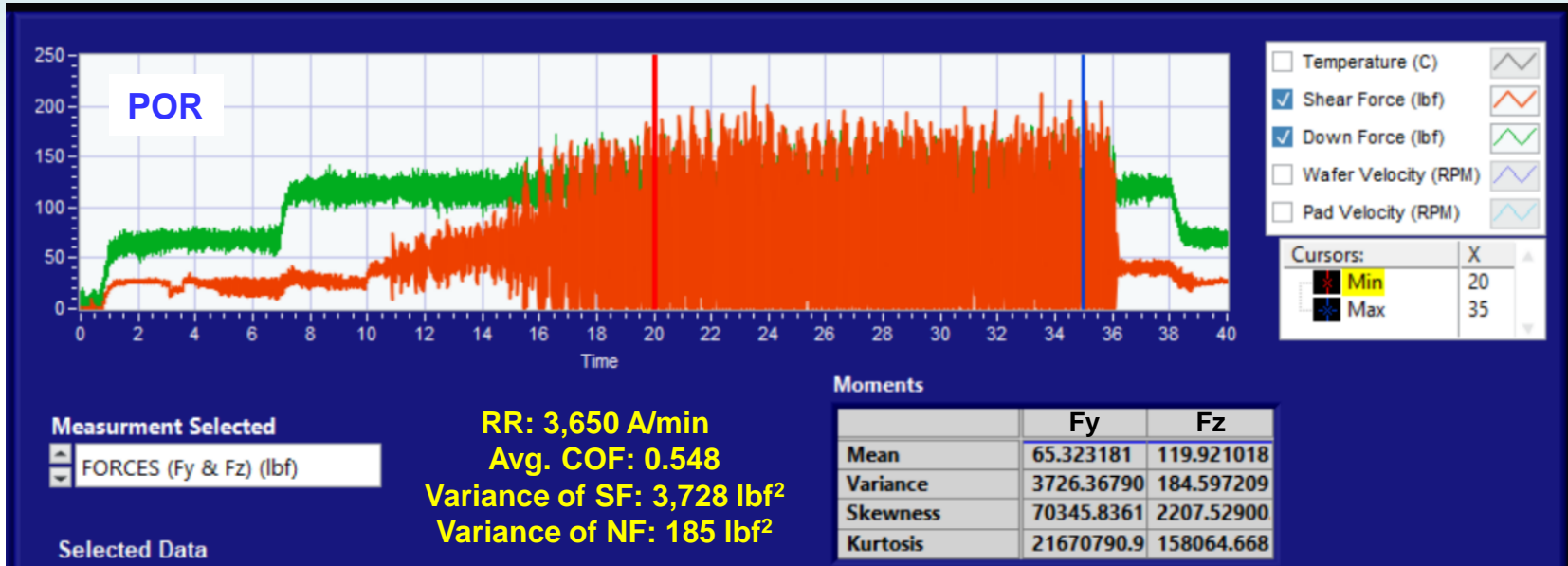
- Effect of Flucto-CMP® technology on slurry nano-particle (NP) health in the case of Cu Slurry Supplier A is shown below. We used a Malvern Zetasizer Nano ZS® particle sizing system.

- Results show that:

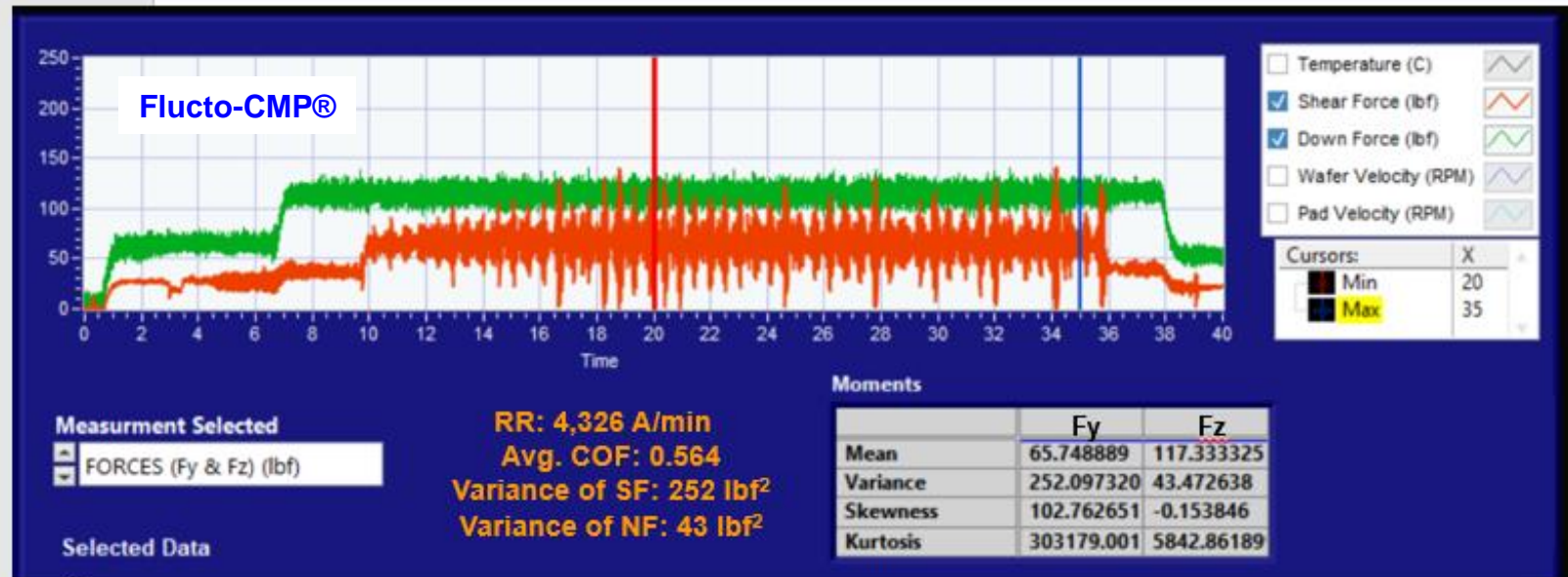
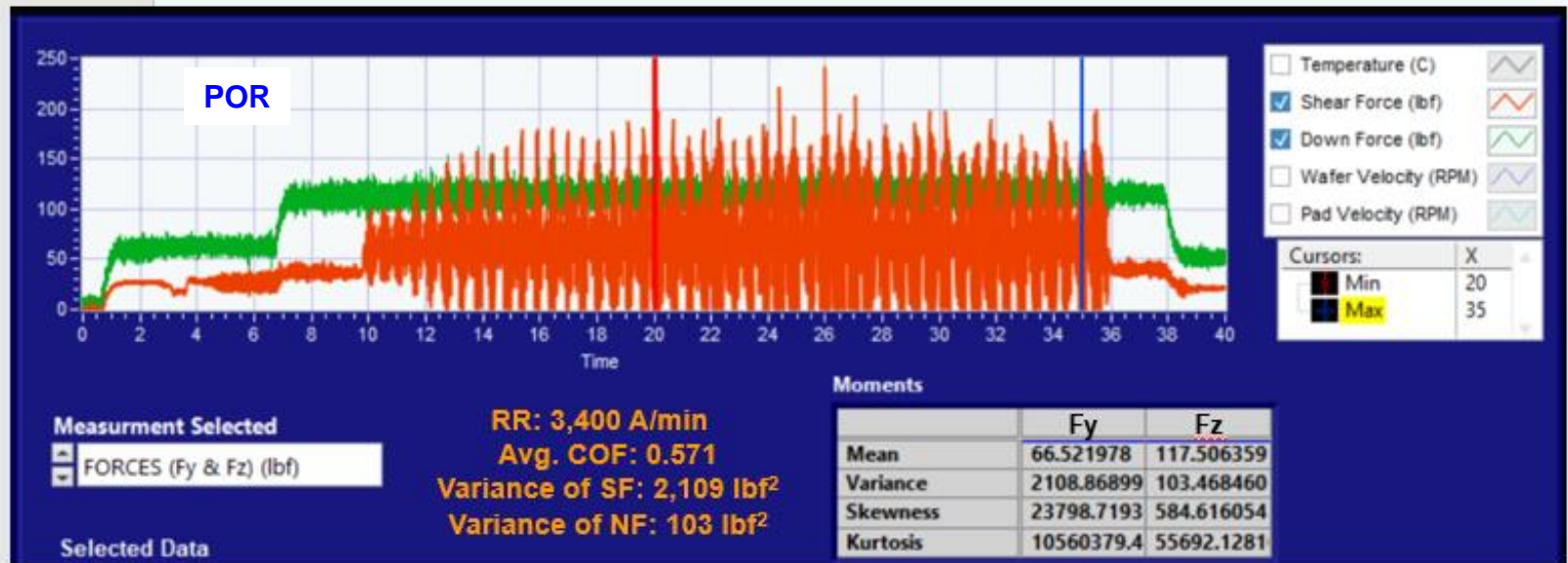
- ❖ Our salt-induced NP aggregation method works as many large aggregates are generated in the copper slurry. An average size of 2 microns!
- ❖ Only after 1 minute of exposure to sound waves, Flucto-CMP® restores the highly-aggregated slurry to its original state.



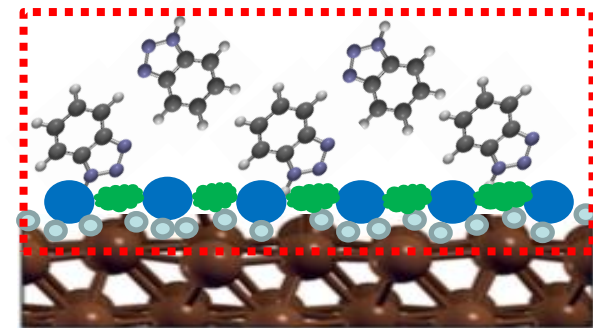
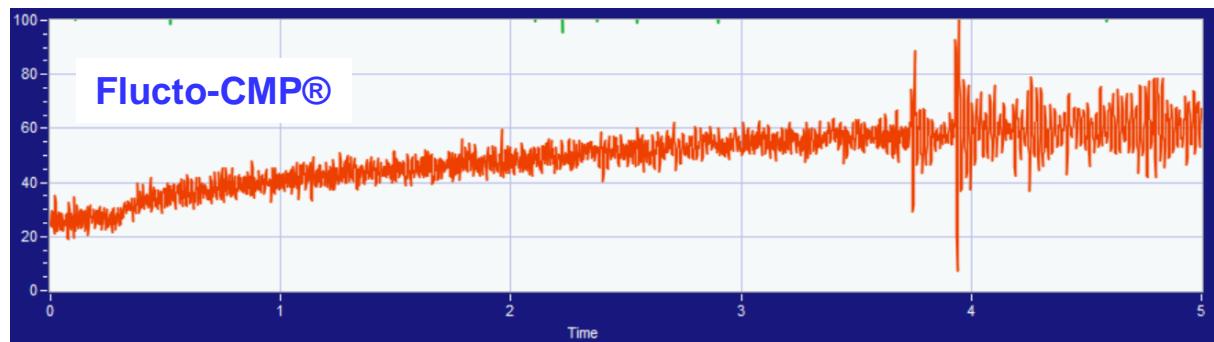
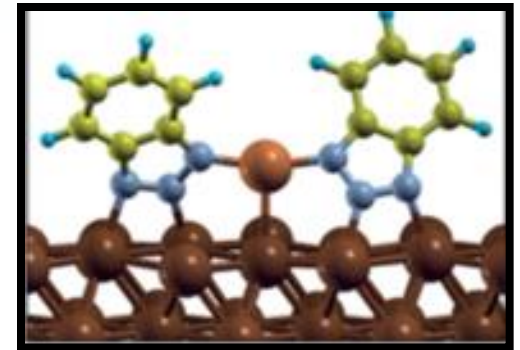
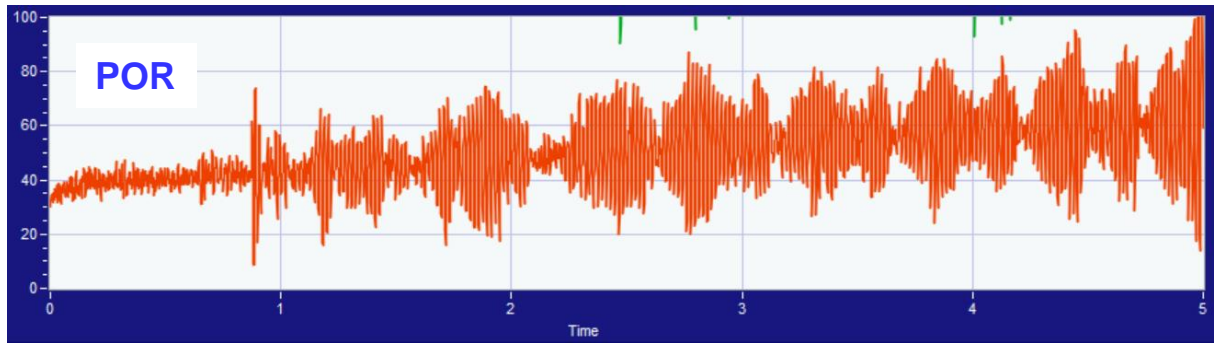
Time Traces – 1.5 PSI – 1.5 m/s – 1% H2O2



Time Traces – 1.5 PSI – 1.5 m/s – 1.5% H2O2 – Copper Supplier A



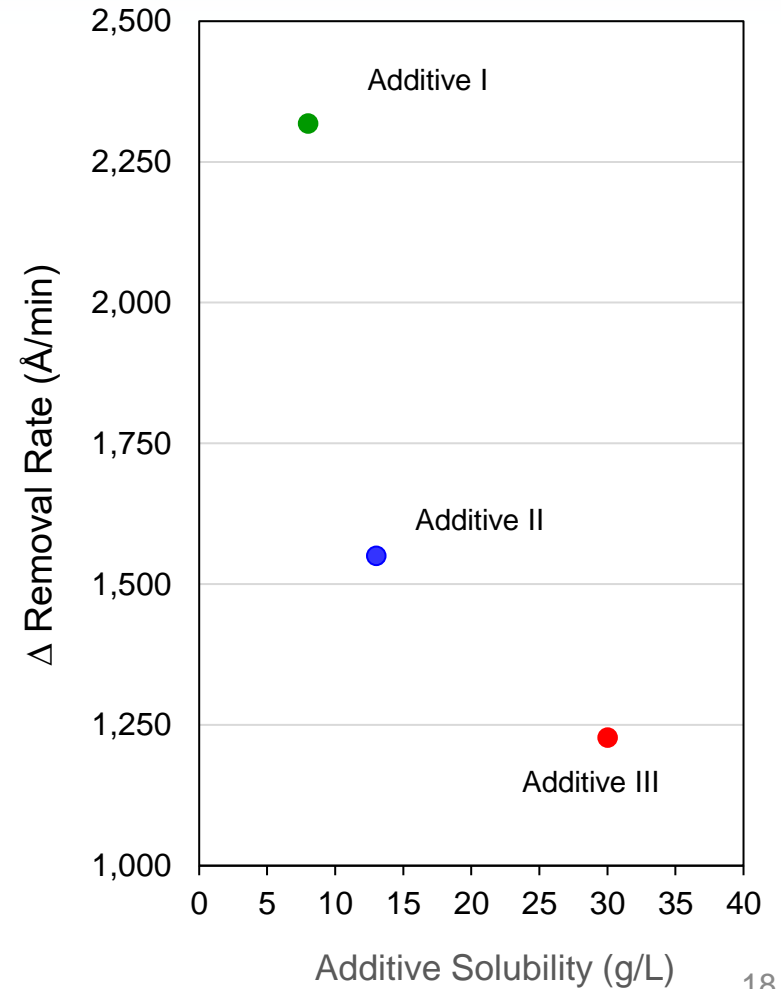
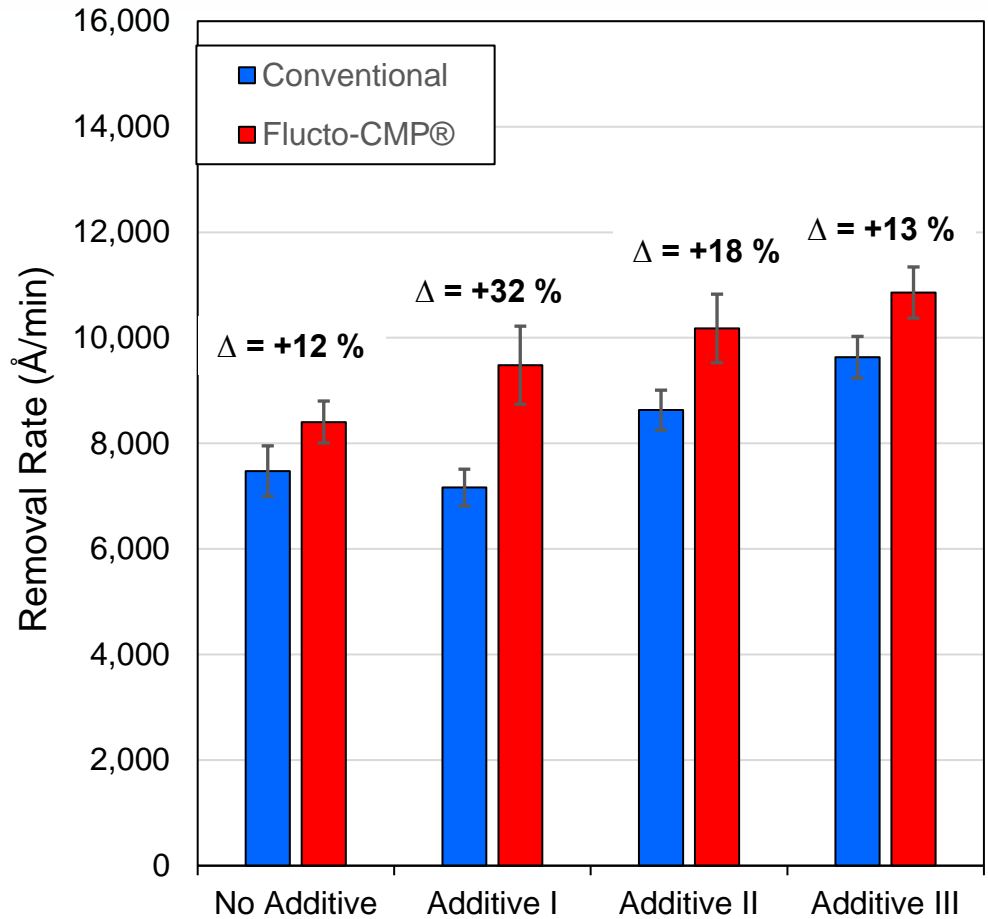
Interfacial Effects with Covalently-Bonded Dense Cu-BTA?



● = ROS ● = Cu²⁺ ● = Complexing Agent

Addition of Sono-Activated® Additives to Cu Supplier A Slurry

N = 8 wafers
Polishing Pressure = 3.0 PSI
Cu Supplier A
Flucto-CMP® at 1 W/cm²



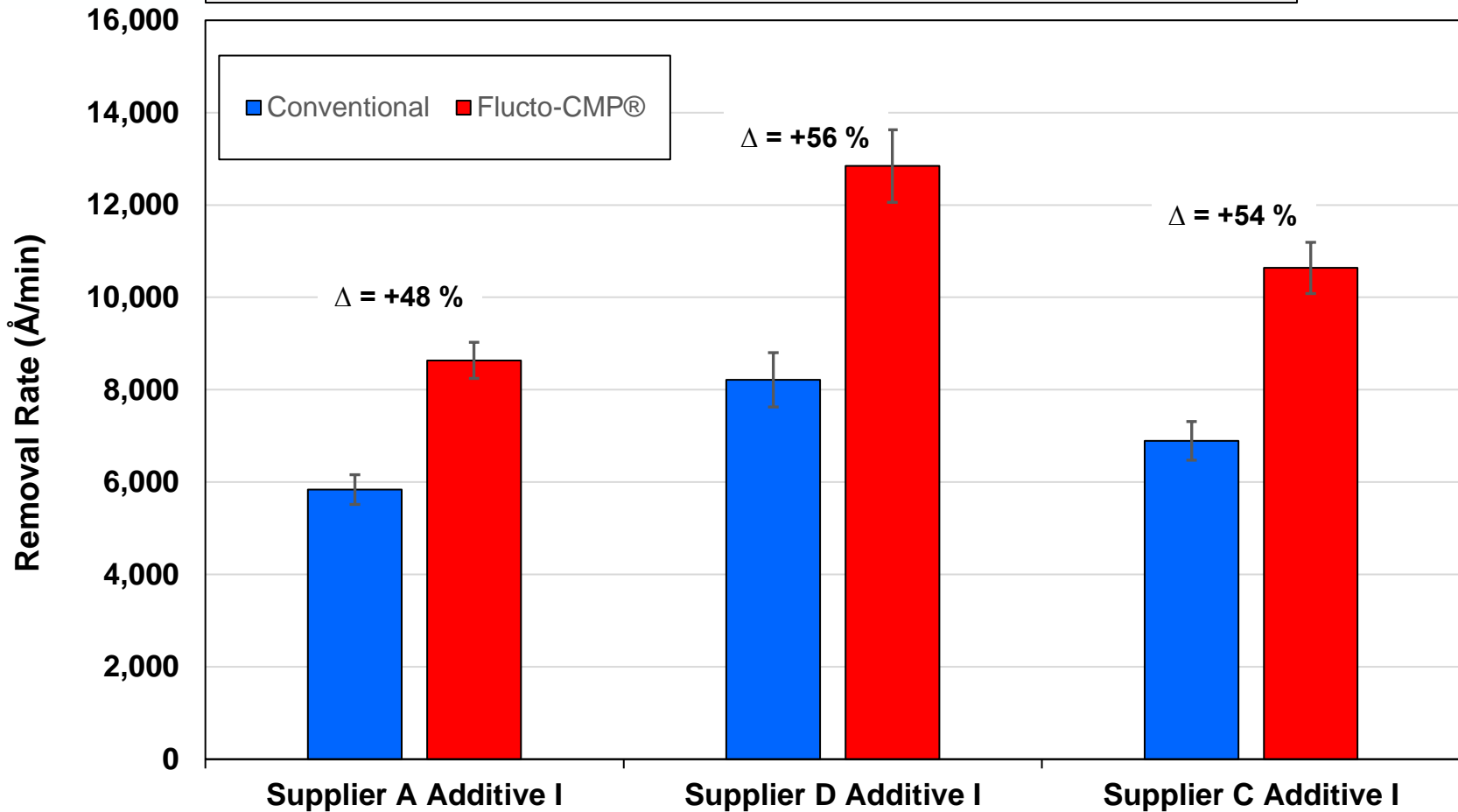
Effect of Sono-Activated® Additive on 3 Slurries

N = 8 wafers

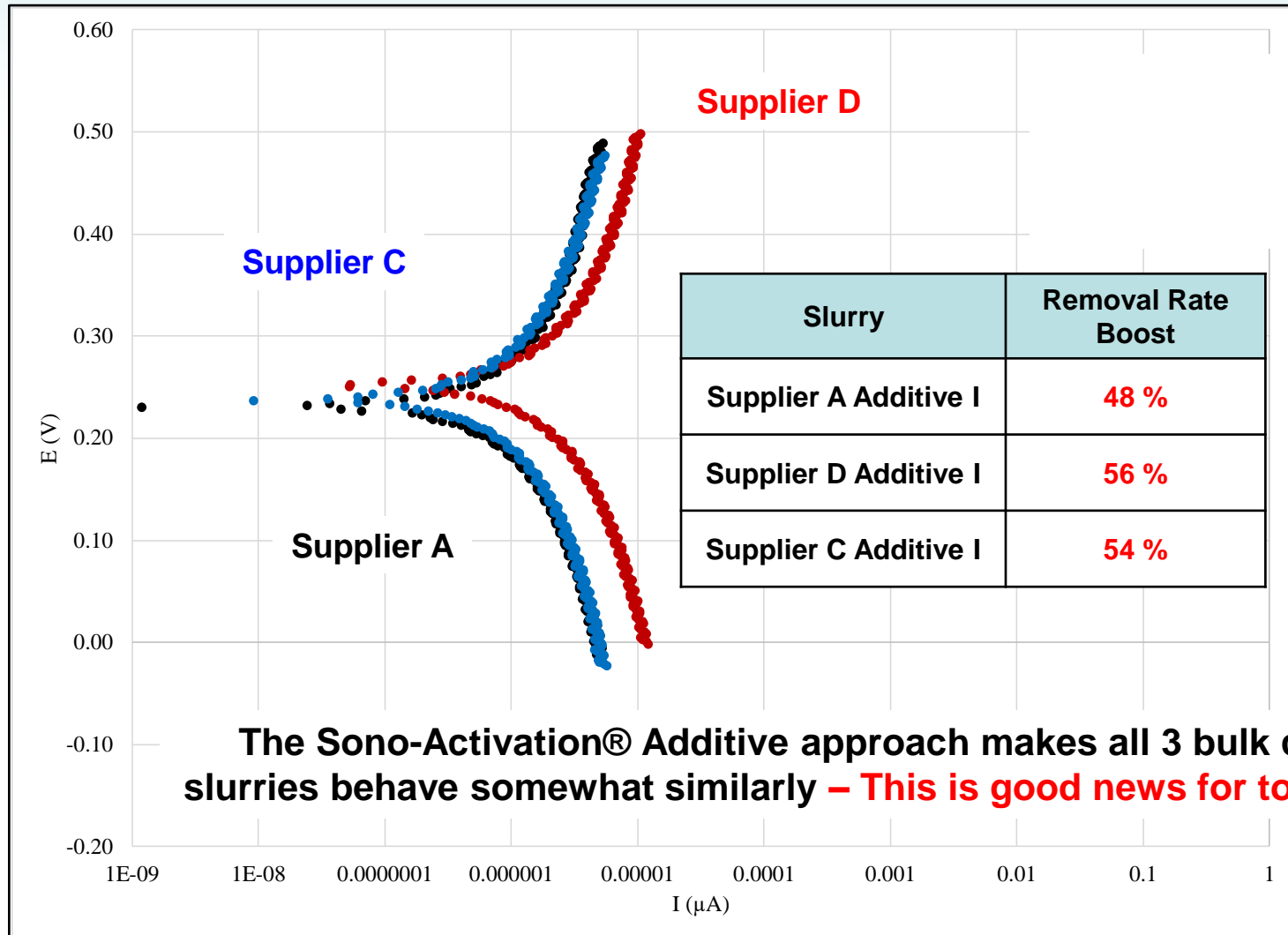
Polishing Pressure = 3.0 PSI

All slurries were diluted as per manufacturer's specification

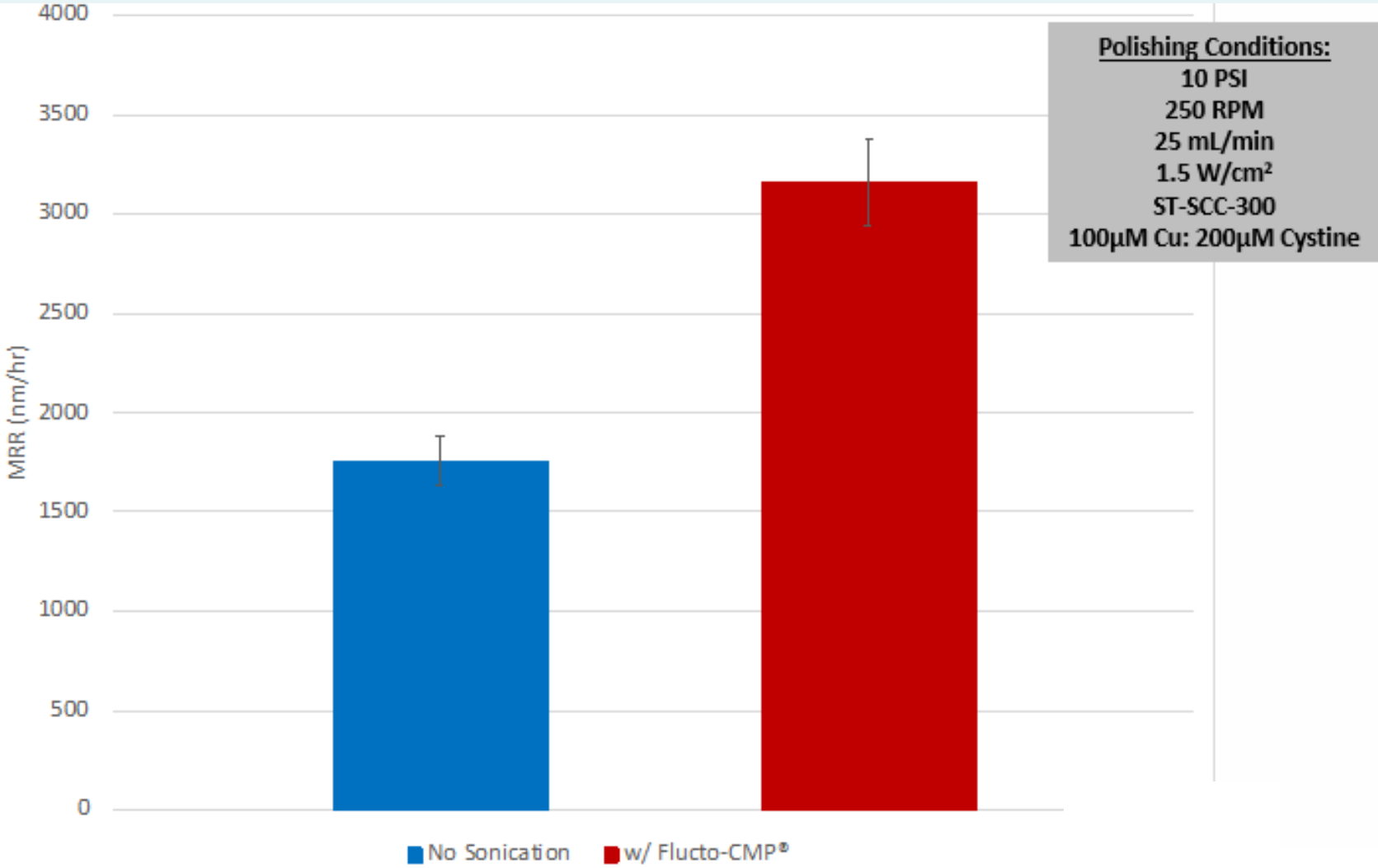
Flucto-CMP® at 1 W/cm²



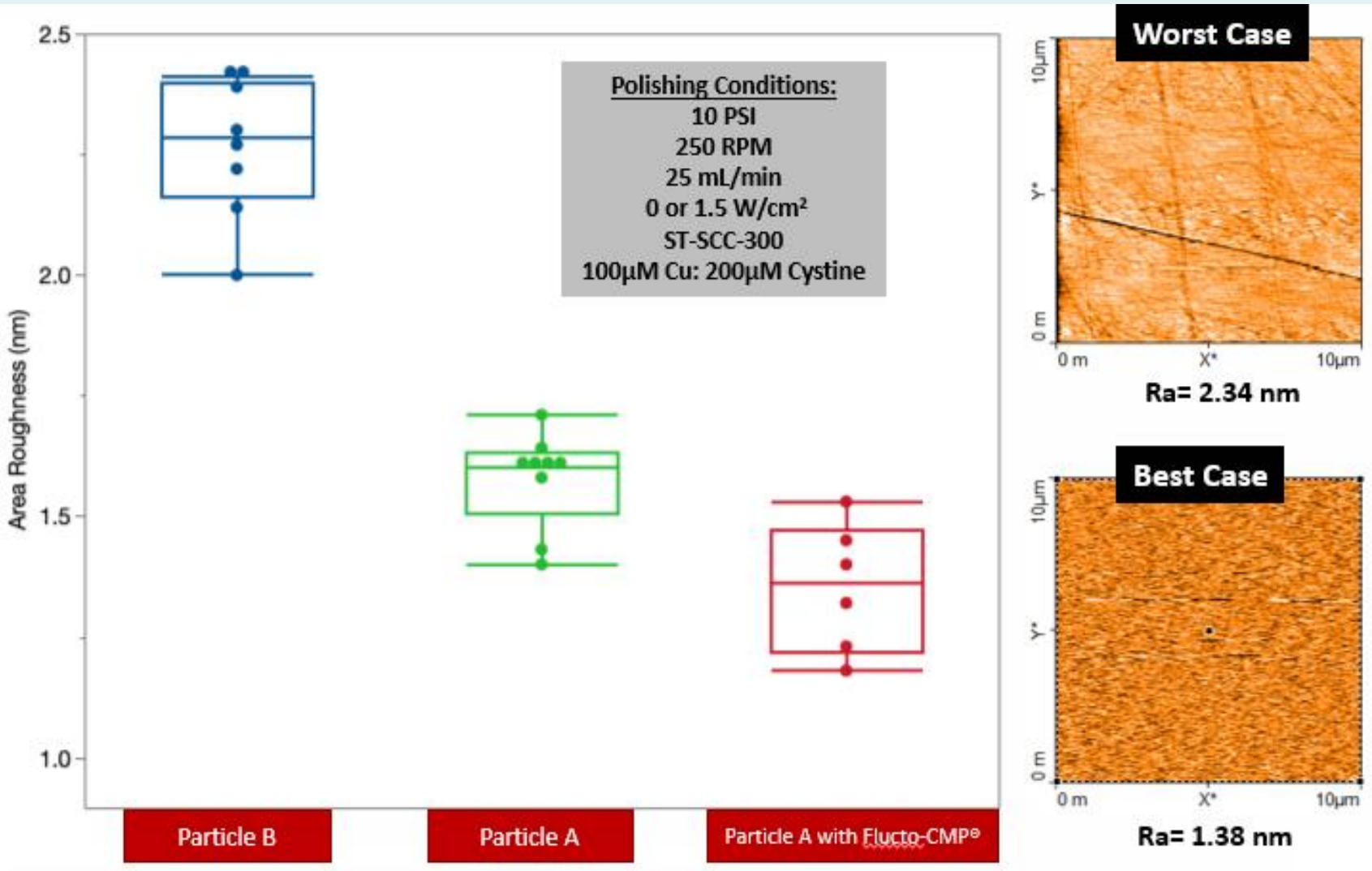
Film Formation Kinetics with Sono-Activated® Additive Approach



Effect of Flucto-CMP® on SiC RR (Non-Permanganate-Based)



Preliminary AFM Surface Finish Analysis post-SiC Polish



Thank You!

