# Laboratory Scale Assessment of the Fate of CMP Nanoparticles Through Standard Waste Water Treatment Systems *(Customized Project)*

**PIs:**

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**Other Researchers:**

- **Antonia Luna, Postdoctoral Fellow, Chemical and Environmental Engineering, AA**
- **Jim Field, Professor, Chemical and Environmental Engineering, AA**

**Cost Share (other than core ERC funding):**

- **Graduate Incentives for Growth Awards (GIGA) ($25 K)**
- **Student Fellowship (Mexican Science Foundation, CONACyT) ($20 K)**

# Objectives

- Investigate removal of CMP nanoparticles by interactions with the biosolids (*i.e.*, entrapment in sludge flocs, adsorption to cells, cell internalization).
- Assess the impact of municipal wastewater composition (eg. organic matter, salts, surfactants, pH, etc) on the aggregation behavior of CMP nanoparticles.
- Evaluate the removal of nanoparticles (NP) present in CMP effluents in a bench-scale wastewater treatment plant.

# ESH Metrics and Impact

*Reduction in emission of ESH-problematic material to environment*

This study will lead to new insights on the interactions of NPs with typical components in semiconductor effluents, municipal wastewaters, and natural aquatic environments over a wide range of physicochemical conditions.

It will also provide information on the fate of NP present in CMP waste streams in municipal wastewater treatment systems. The knowledge gained can be utilized to determine if additional treatment steps are required to reduce environmental emissions of ESH-problematic chemicals, if any.

# Materials and Methods

## Commercial Slurries

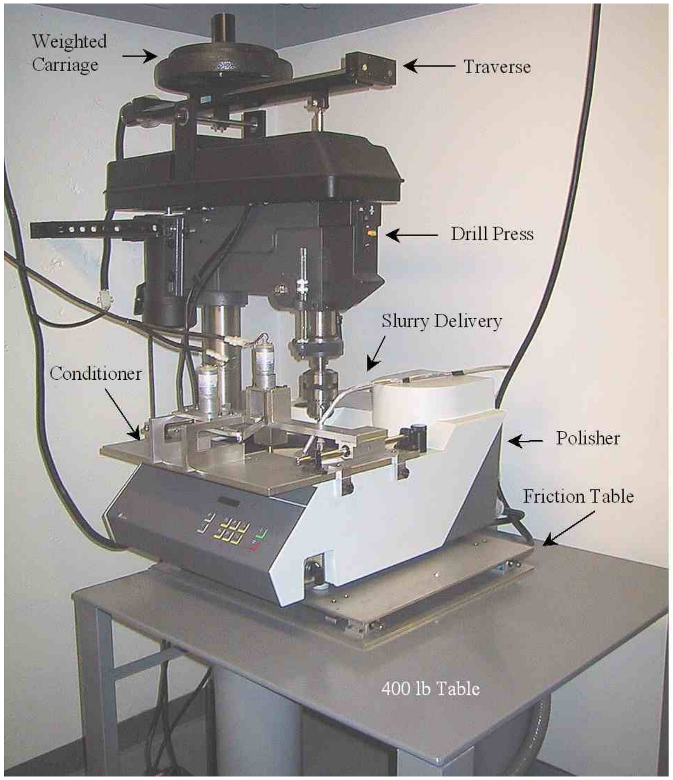
Fumed Silica – Oxide CMP (30 nm)
Alumina – Cu CMP
Ceria – Oxide/STI CMP

## Virgin Nanoparticles

Silica: 10-20 nm
Alumina: 50 nm
Ceria 20 or 50 nm

## CMP waste:

Prepared at the pilot-scale CMP tool available at the UA



*Polisher (100-mm) that will be used to prepare CMP waste effluents*

## Particle size and Zeta potential:

Malvern Zeta Sizer Nano ZS

# Tasks

1. Impact of wastewater components on the aggregation behavior of CMP nanoparticles.
   - Organic compounds: eg proteins, aminoacids, humus, etc.
   - Polyelectrolytes
   - pH, Salts, divalent cations

2. Removal of CMP nanoparticles by biosolids
   - Adsorption isotherm experiments
   - Electron microscopy examination

3. Removal of nanoparticles in CMP effluent a lab-scale wastewater treatment plant
   - Lab-scale experiments with ceria slurry

# Significant Aggregation of $CeO_2$, $SiO_2$ and $Al_3O_2$ Nanoparticles in Aqueous Solution

| NP | Average Particle Size (nm) | |
|---|---|---|
| | Powder (Using TEM) | Aqueous medium (Using ZetaSizer) |
| $CeO_2$ | 20 | 139 |
| $Al_2O_3$ | 50 | 175 |
| $SiO_2$ | 10-20 | 368 |

$CeO_2$, $Al_2O_3$ and $SiO_2$ NPs showed significant aggregation in aqueous solutions even at pH values considerably different from their respective isolectric point.

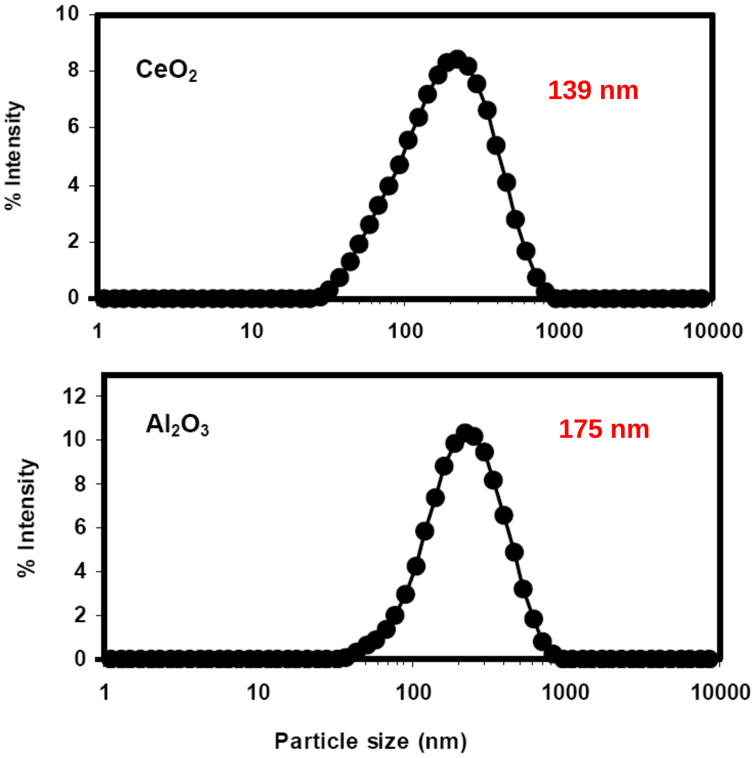
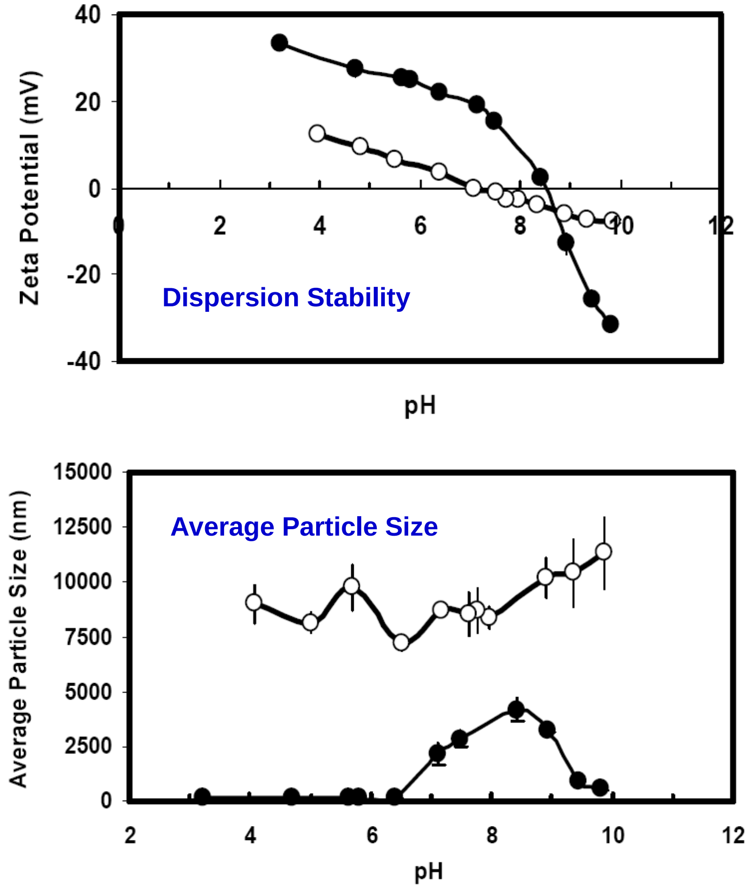


**Fig.** Particle size distribution of nano-$CeO_2$ and $Al_2O_3$ in pH-5.2 and pH-4.5 aqueous solutions, resp. Titration experiments showed that the dispersions exhibit high stability at these pH values.

# Impact of pH and Dilution with Municipal Waste on the Stability of $Al_2O_3$ NP Dispersions

*Z-pot: -20 to 20 mV*

*Dispersion is unstable*



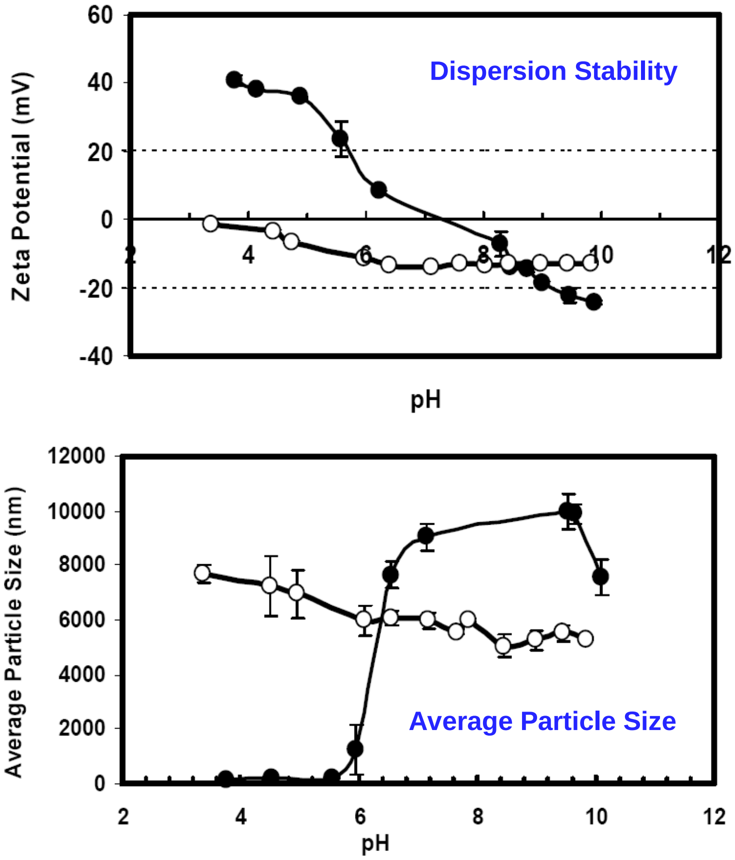
**Dilution with municipal wastewater and circumneutral pH values promotes aggregation of alumina NPs.**

**Fig**. Impact of pH on the zeta potential & average diameter of $Al_2O_3$ dispersions mixed with demineralized water (●) or filtered (20 nm) municipal wastewater (○).

# Impact of pH and Dilution with Municipal Waste on the Stability of $CeO_2$ NP Dispersions

*Z-pot: -20 to 20 mV*

*Dispersion is unstable*



**Dilution with municipal wastewater and increasing pH promotes the aggregation of $CeO_2$ nanoparticles**

**Fig.** Impact of pH on the zeta potential & average diameter of **$CeO_2$** dispersions mixed with demineralized water (●) or filtered (20 nm) municipal wastewater (○).

# Impact of pH and Dilution with Municipal Waste on the Stability of $SiO_2$ NP Dispersions

**The stability of $SiO_2$ NP dispersions was little affected by changes in pH or dilution with municipal wastewater**

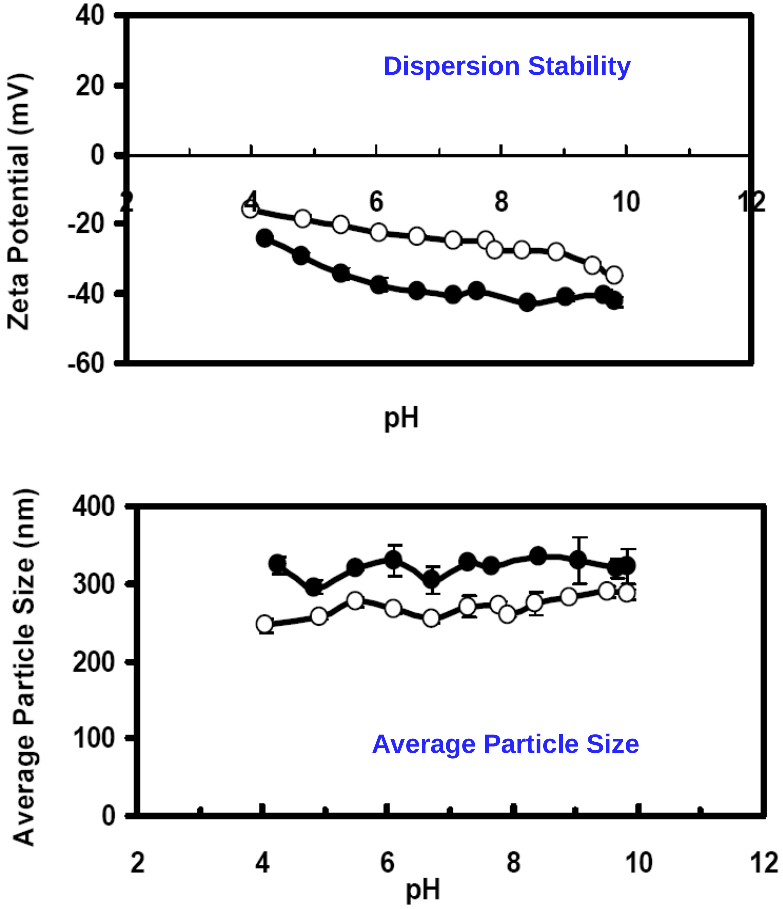


**Fig.** Impact of pH on the zeta potential & average diameter of **$SiO_2$** dispersions mixed with demineralized water (●) or filtered (20 nm) municipal wastewater (○).

# Impact of Dilution with Municipal Waste on the Stability of $Al_2O_3$, $CeO_2$, and $SiO_2$ NP Dispersions

Dilution of **CMP waste** with domestic wastewater (1:1) only caused a moderate decrease in the dispersion stability, probably due to high levels of surfactants in the slurry.

Considerably higher wastewater dilution resulting in increased destabilization of the NP dispersion is expected in the sewer.

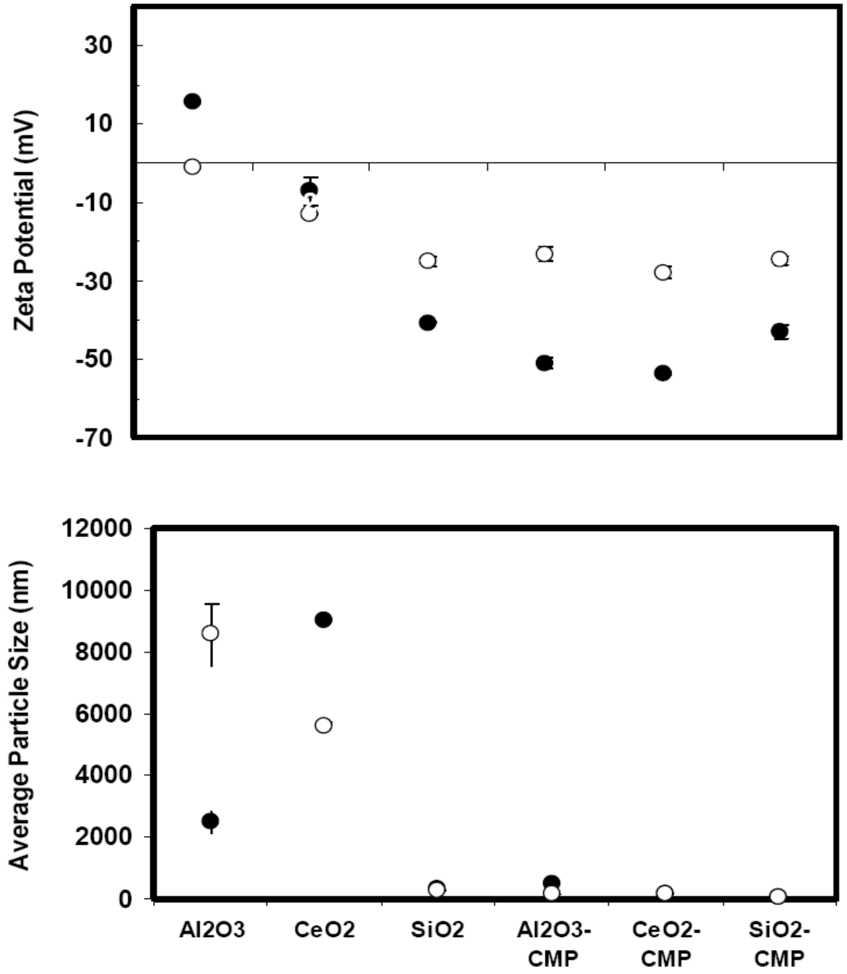


**Fig.** Stability of nano-sized $CeO_2$, $Al_2O_3$ and $SiO_2$ dispersions, and $CeO_2$, $Al_2O_3$ and $SiO_2$ –based CMP slurries diluted (1:1, v/v) with deionized water (●) and membrane-filtered (20 nm) municipal wastewater (○) at circum-neutral pH values.

# Wastewater Components and NP Stability

Constituents in municipal wastewater alter the stability of the inorganic oxide dispersions. Some proteins, humic substances and synthetic dispersants stabilize NP dispersions ($CeO_2$, $Al_2O_3$, $SiO_2$) in the neutral to mildly alkaline range which is typical of municipal wastewaters.

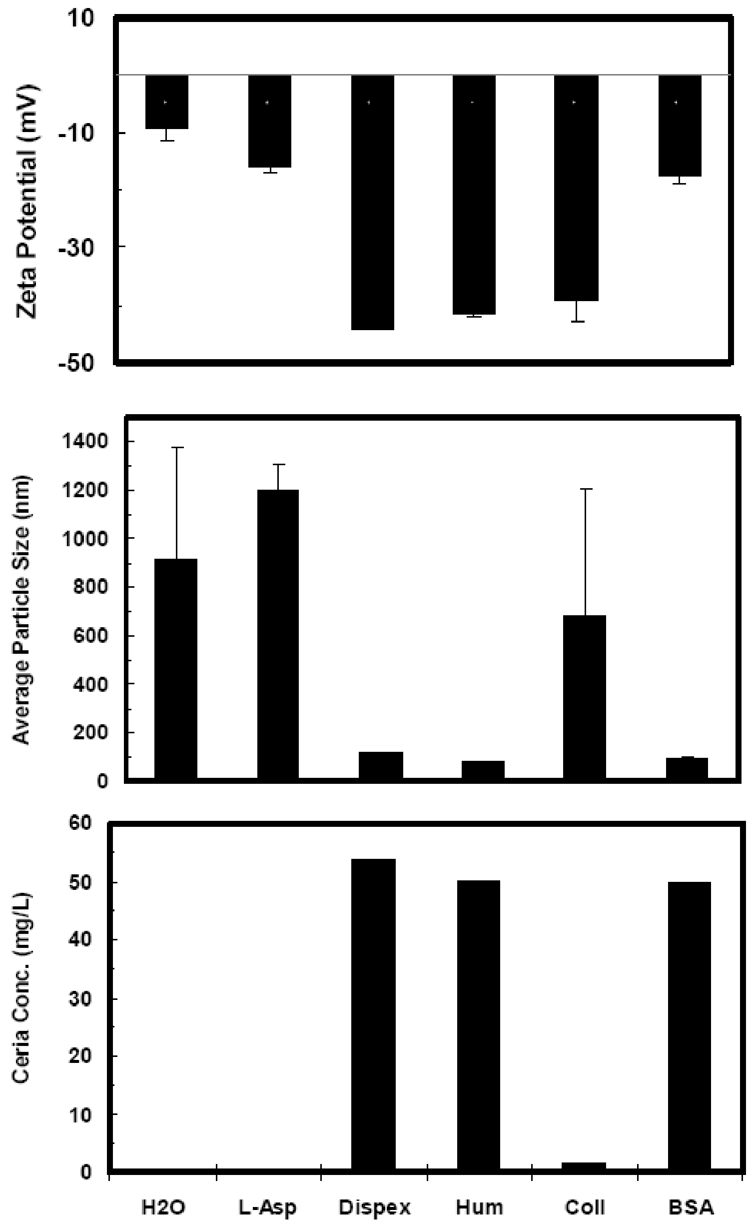


**Fig.** Zeta potential (Top panel), average particle size (Middle panel), and residual ceria concentration in dispersions (Lower panel) after dilution (1/1, v/v) of a nano-sized ceria dispersion with solutions of different additives (200 mg/L).The final pH of the diluted dispersions was 6.8. Additives: L-Asp= L-aspartic acid; Dispex= Ammonium polyacrylate dispersant; Hum= Humic acid; Coll= Collagen; BSA= Bovine serum albumin.

# Removal of CMP Nanoparticles by Activated Sludge

Aerobic activated sludge has a relatively high affinity for $CeO_2$ and $Al_2O_3$ NPs

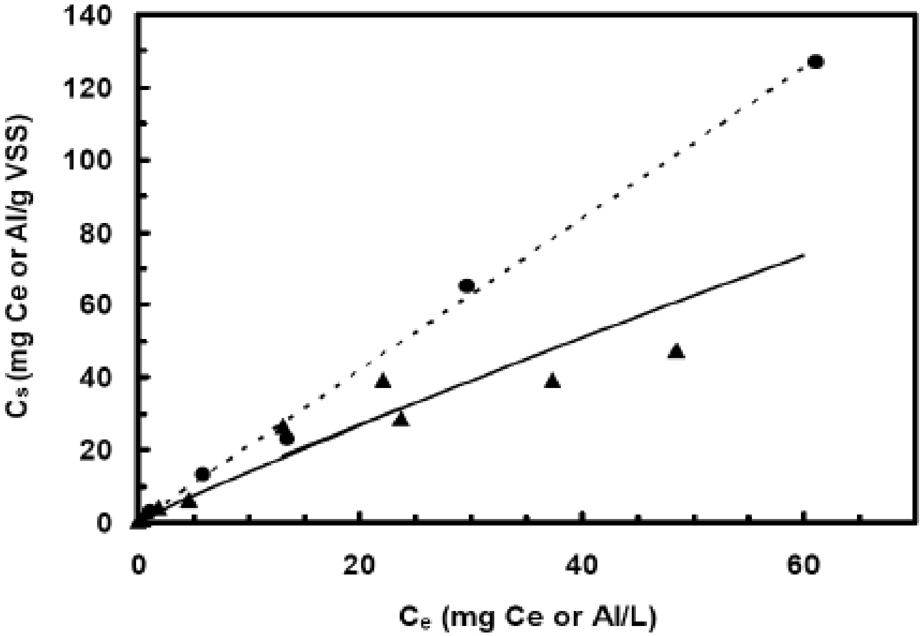
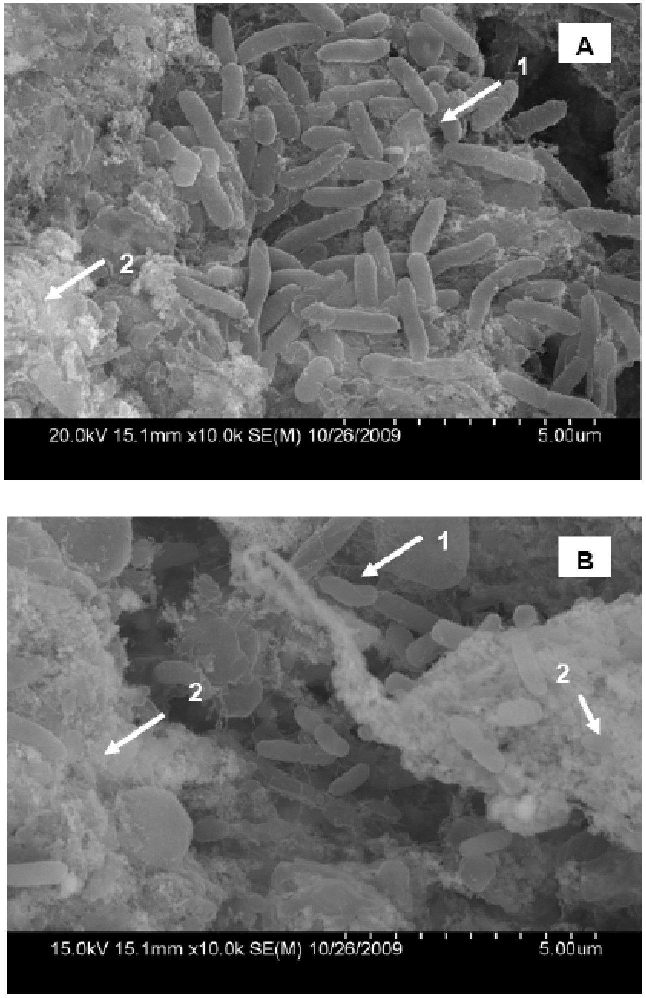


**Fig**. Partitioning of ceria (●) and alumina (▲) onto activated sludge collected from a municipal wastewater treatment plant. Experimental data fit to Freundlich model for ceria (dashed line) and alumina (solid line).

# Removal of CMP Nanoparticles by Activated Sludge



SEM images of activated sludge collected from the bioreactor system fed with a wastewater containing $CeO_2$ NPs. The arrows indicate areas with bacterial cells (labeled 1), and areas where extracellular deposits (labeled 2) that are likely to contain large fractions of agglomerated ceria.

# Removal of CMP Nanoparticles During Conventional Wastewater Treatment (Activated Sludge Process)

Conventional biological treatment provides high removal of $CeO_2$ NP.

NPs removed by adsorption onto the bacterial cell wall and entrapment into sludge flocs.

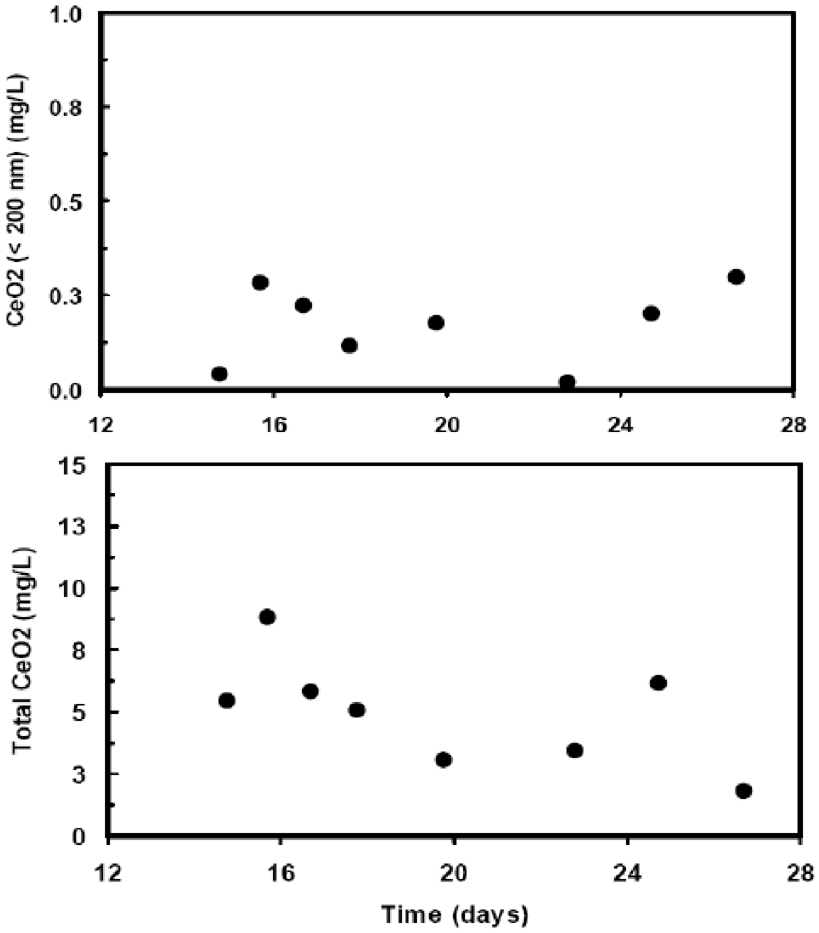


**Fig.** Concentrations of ceria (< 200 nm) (Top panel) and total ceria (Lower panel) in the treated effluent of a continuous lab-scale activated sludge system fed with nano-sized CeO2 (75 mg/L)

# Conclusions

- Treatment of effluents containing ceria or alumina NPs in conventional wastewater treatment plants is expected to result in a significant removal of the inorganic oxides from the treated effluent.

- Destabilization of the NP dispersions by constituents in the wastewater as well as association of the inorganic oxides with the activated sludge appears to be implicated in the removal mechanisms.

- $SiO_2$ NP dispersions were considerably more stable, even when diluted with municipal wastewaters or solutions containing proteins or amino acids that promoted aggregation of ceria and alumina NPs. These results suggest that a high fraction of $SiO_2$ NPs could escape wastewater treatment. Additional research is needed to test this hypothesis.

# Industrial Interactions and Technology Transfer

- **Laurie Beu (ISMI / Sematech)**
- **Steve Brown (Intel)**
- **Reed Content (AMD)**
- **Art Fong (IBM)**
- **Peter Maroulis (Air Products)**
- **Brian Raley (Global Foundries)**
- **Tim Speed (IBM)**
- **Steve Trammel (ISMI / Sematech)**
- **Tim Yeakly (TI)**

# Future Plans

## Next Year Plans

- **Writing scientific publications resulting from the project**
- **This 7-month project was completed on Nov. 2009**
- **Funding is being sought to continue research work on:**
    - **Fate and transport of $SiO_2$ and $CeO_2$ nanoparticles in aquatic environments, including wastewater and surface water**
    - **Innovative methods for the removal of abrasive nanoparticles from CMP wastewaters.**

# Publications, Presentations, and Recognitions/Awards

- Sierra-Alvarez, R., F. Shadman, A. Philipossian. 2009. Laboratory-Scale Assessment of the Fate of Chemical Mechanical Polishing (CMP) Nanoparticles Through Standard Wastewater Treatment Systems FATE Technology Transfer 09115058A-ENG. International SEMATECH Manufacturing Initiative, Inc. Austin, TX. Dec. 14, 2009.

- Three papers accepted for presentation by students at the 32nd Annual SESHA International High Technology ESH Symposium and Exhibition. Scottsdale, AZ, April 26-29, 2010.

- Sierra-Alvarez, R et al. 2010. Removal of $CeO_2$ Nanoparticles in Semiconductor Manufacturing Effluents during Activated Sludge Treatment. 2010. 7th Leading Edge Conference on Water and Wastewater Technologies, Phoenix, AZ (June 2-4). (Accepted for presentation)

- Sierra-Alvarez, R., Barbero, I., M. Rodriguez, J. Rottman, F. Shadman, J.A. Field, R. Fate of Chemical Mechanical Polishing (CMP) Nanoparticles in Activated Sludge Processes (Paper in preparation)

- Field JA, Sierra-Alvarez. 2010. Nanoparticle Interaction with Biological Wastewater Treatment Processes. Brown Bag Water Sustainability Series, UofA Maricopa County Cooperative Extension. Phoenix, AZ. Jan 20.

- Barbero, I., M. Rodriguez, J. Rottman, F. Shadman, J.A. Field, R. Sierra-Alvarez. 2009. Evaluation of the Fate of Nanoparticles in CMP Wastewater during Standard Wastewater Treatment. 2009 Graduate Symposium, Dept Chemical and Environmental, UA, Oct. 10 (Poster, 1st prize)

# Reducing Water and Energy Usage in Batch and Single-Wafer Rinsing Tools

**Jun Yan[1], Kedar Dhane[1], Davoud Zamani[1], Omid Mahdavi[1], Xu Zhang[2], Junseok Chae[2], Bert Vermeire[2] and Farhang Shadman[1]**

[1] University of Arizona
[2] Arizona State University

**Co-Sponsored by:**
**ERC, Environmental Metrology Corp (EMC),**
**Freescale Semiconductor Inc., and Samsung Electronics**

# Objective and Approach

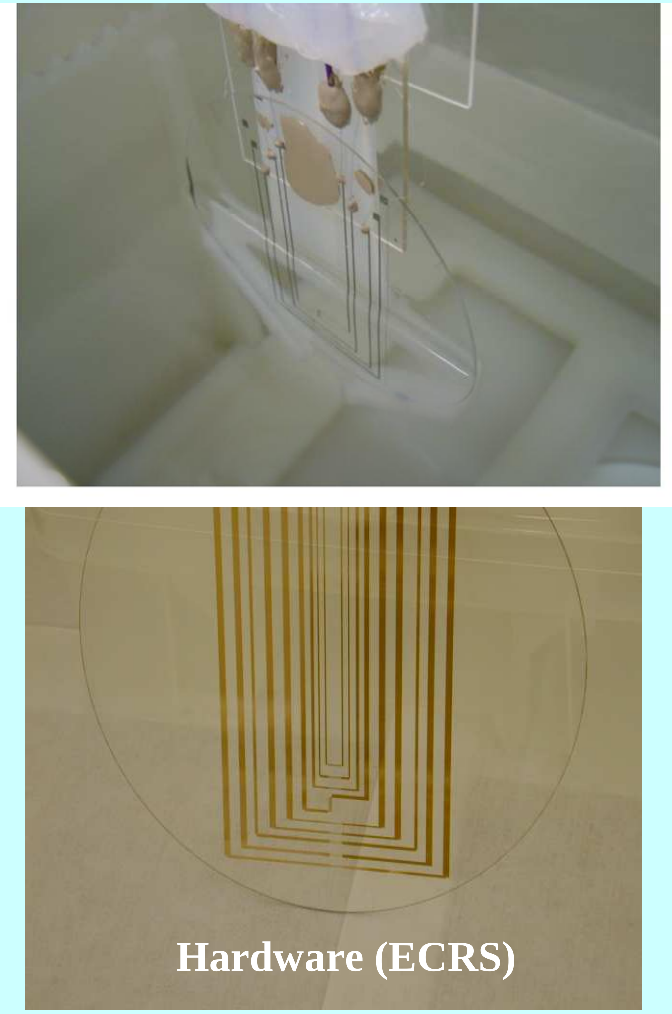
## *Objective:*

- Investigate the fundamentals of cleaning, rinsing, and drying of micro- and nano-structures; develop new technologies (hardware, process models, and process recipes) to reduce water, chemicals, and energy usage during these processes.

## *Method of Approach:*

- Apply the novel Electro-Chemical Residue Sensor (ECRS) metrology method for in-situ and real-time monitoring of the dynamics of batch and single-wafer surface preparation.
- Combine metrology with process modeling to identify the controlling steps (bottlenecks) in the cleaning, rinsing, and drying of micro- and nano- structures.

# Background: In-situ Metrology
# Electro-Chemical Residue Sensor (ECRS)



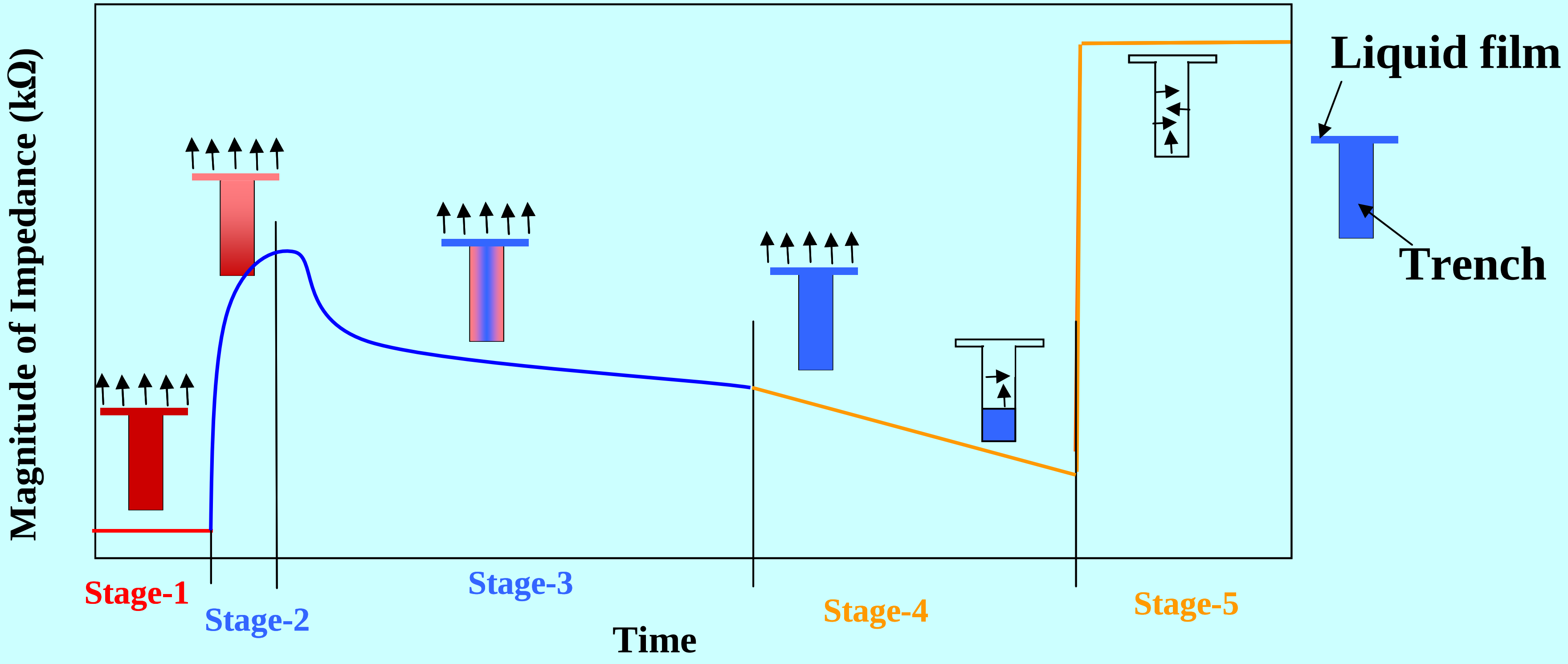
Hardware (ECRS)

| Solution (pH) | UPW (pH=7) | HCl(pH=6) | HCl(pH=5) |
|---|---|---|---|
| Resistivity (MΩ) | 18 | 2.3 | 0.23 |
| Resolution (ppt) | 5 | 30 | 400 |

## *Key Features*

- **Real Time**
- **In-situ**
- **Online**
- **High Sensitivity**
- **Non-destructive**
- **Quick Response**

# Monitoring Capabilities of ECRS



**Stage-1: Chemical Exposure**

**Stage-2: Rinsing -Purging of the Trench**

**Stage 3: Rinsing: Surface Reaction**

**Stage-4: Bulk Drying**

**Stage-5: Surface Drying**

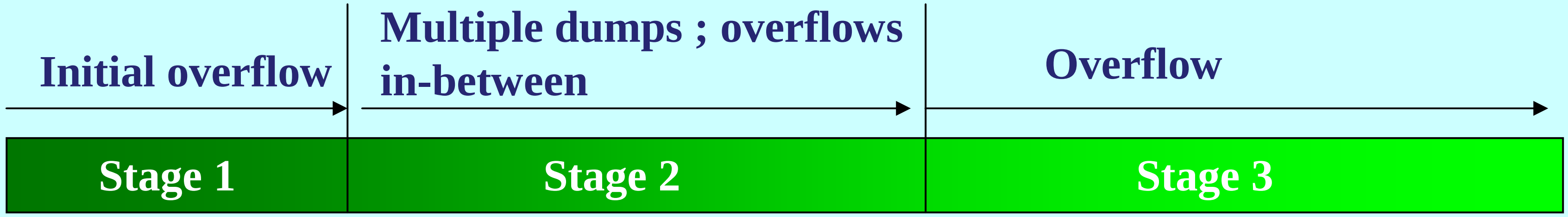
# ECRS Application in Over-Flow and Quick- Dump Rinse Tools

**Joint work with Freescale and EMC* on development of new low-water rinse processes using ECRS and process modeling.**

**Co-Investigators and Liaisons: Hsi-An Kwong, Marie Burnham, Tom Roche, Amy Belger, Stuart Searing, and Georges Robert**

**** EMC is a Engineering Research Center spin-off company that is formed for tech transfer and commercialization of ECRS technology***

# Sample Results: Optimization of Rinse Recipe in Over-Flow and Quick- Dump Rinse Combination

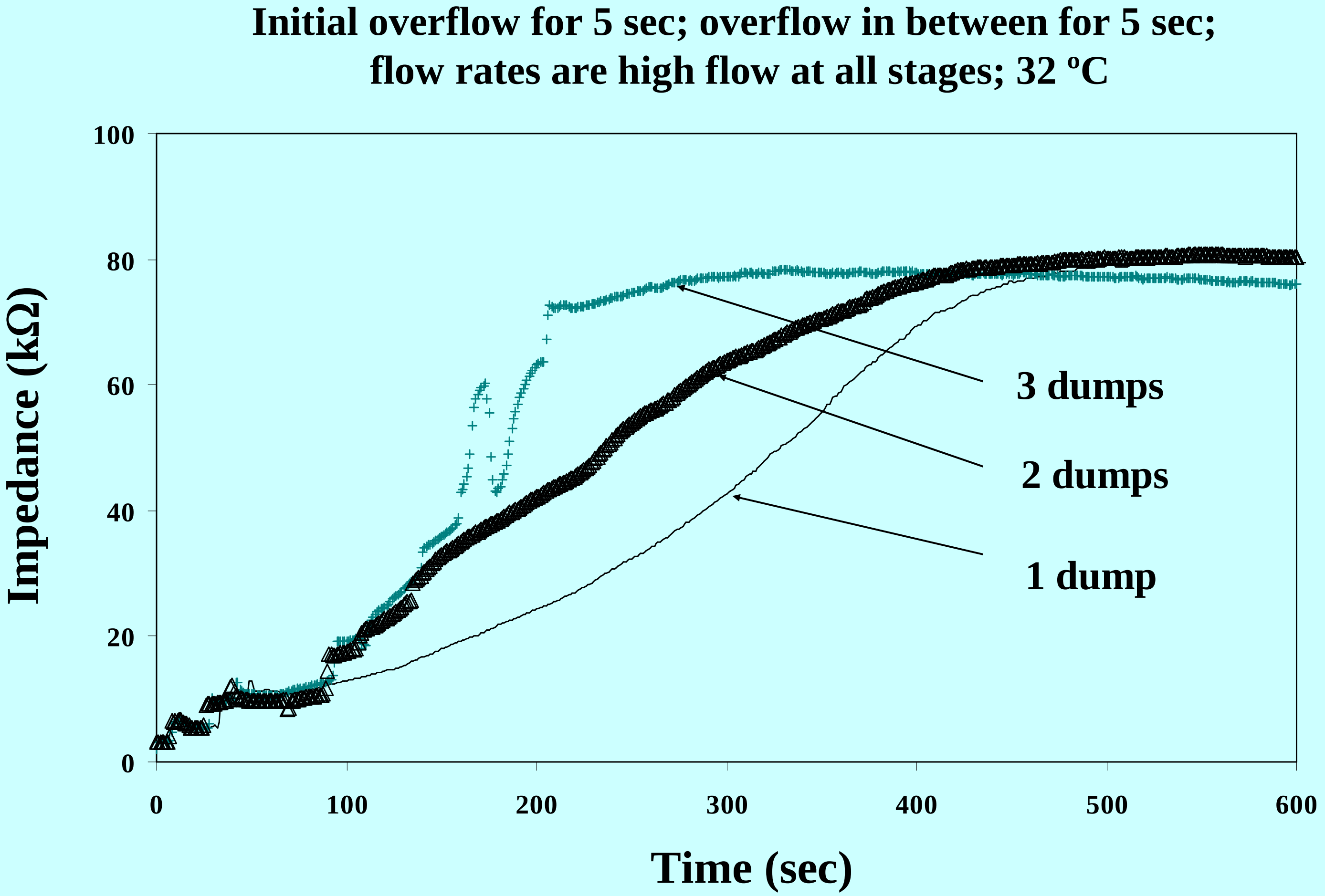


## Process Parameters

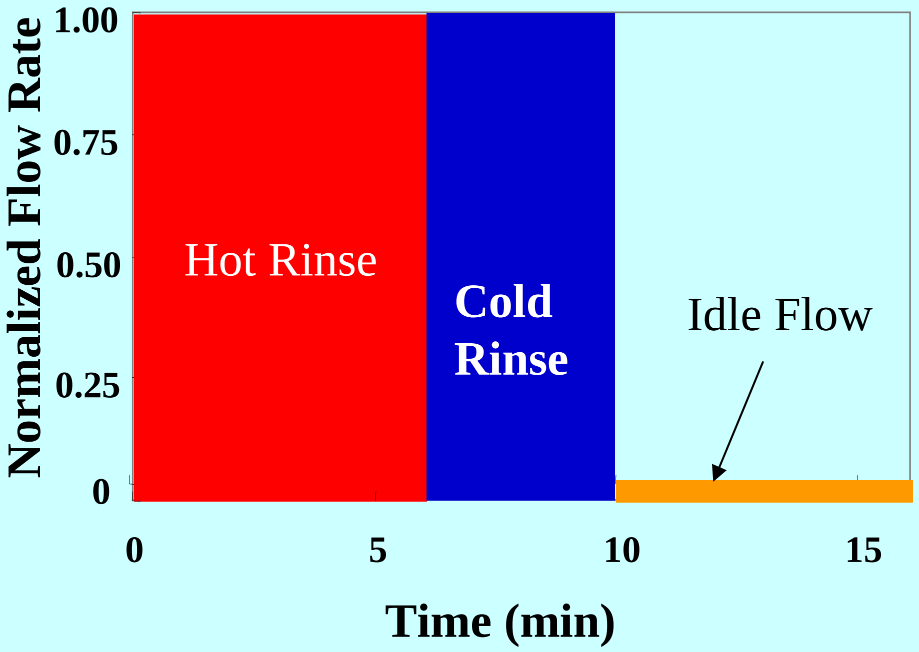
- Flow rates at different stages
- Time for every session of overflow rinse
- Number of quick dumps
- Water temperature at every session

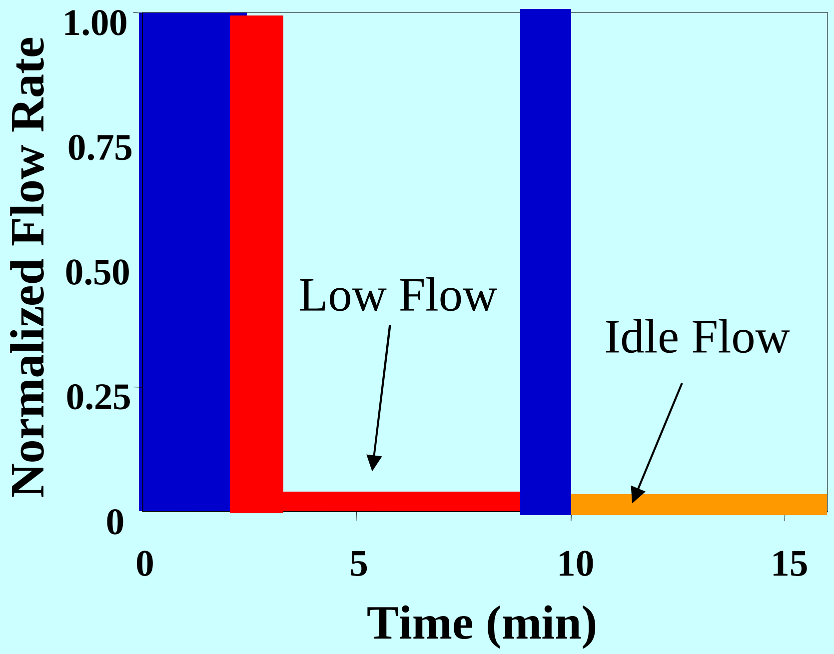
**Collaboration with Freescale to optimize existing rinse recipes is ongoing.**

# Effect of the Number of Dumps on the Post-APM Rinsing



# Example of a New Hot Rinse Schedule


Conventional Rinse


ECRS Enabled Rinse

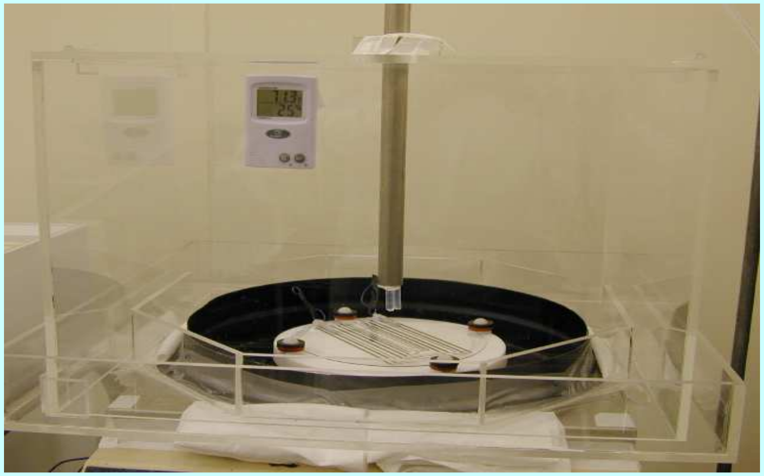
- **Use initial cold rinse to flush tank**
- **Use hot water to finish flush and heat wafers**
- **Cycle time is not increased**
- **Savings: ~ 25% cold water and ~ 80% hot water**

# ECRS Application in Single-Wafer Rinsing and Drying

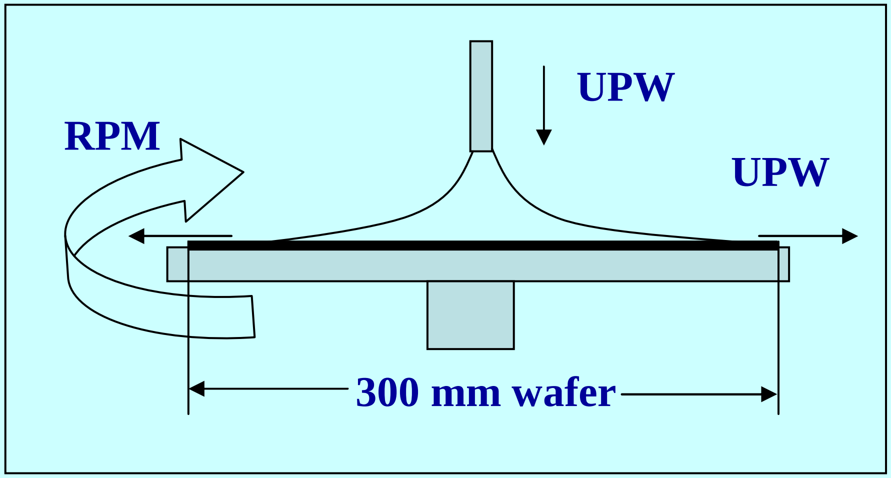
**Joint work with Samsung and EMC on analysis of the dynamic of spin rinse and development of new low-water rinse processes.**

**Samsung Co-Investigators and Liaisons:**
**Jeongnam Han, Seung-Ki Chae, Pil-Kwon Jun**

# Application of ECRS to Single-Wafer Spin Rinsing



**Experimental Setup**



**Process Model Schematic**

- *A single wafer tool equipped with ECRS is designed and set up.*
- *Combination of experiments and process model is used to study the effect of various process parameters.*

# Process Model for Spin Rinsing

- Convection
- Surface Charge
- Diffusion
- Surface reaction
- Ionic transport

**Multi-component species transport equations :**

$$\frac{\partial C_i}{\partial t} = \nabla \cdot (D_i \nabla C_i + z_i F \mu_i C_i \nabla \varphi) - u \nabla C_i$$

$$u_r = \frac{\rho\omega^2 r h^2 (1-(1-\frac{z}{h})^2)}{2\mu} \qquad h = 0.782(\frac{Q\mu}{\rho\omega^2 r^2})^{1/3}$$

**Surface adsorption and desorption:**

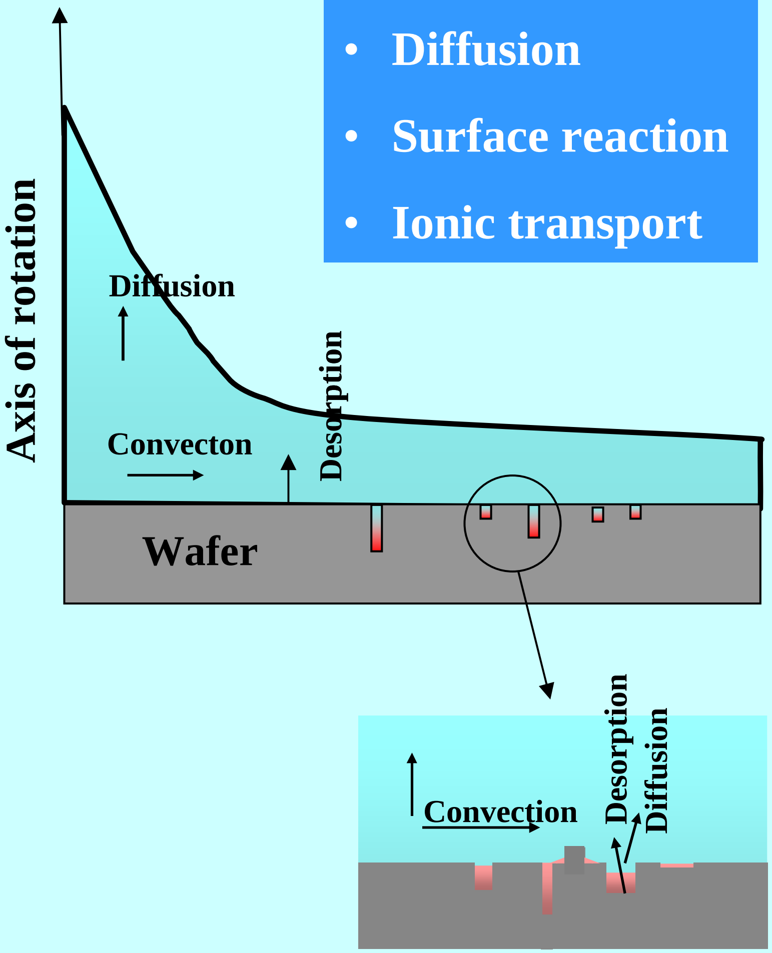
$$\frac{\partial C_{S2}}{\partial t} = k_{a2} C_2 (S_{02} - C_{S2}) - k_{d2} C_{S2}$$

**Poisson equation:** $\nabla^2 \varphi = -\frac{\rho}{\varepsilon}$

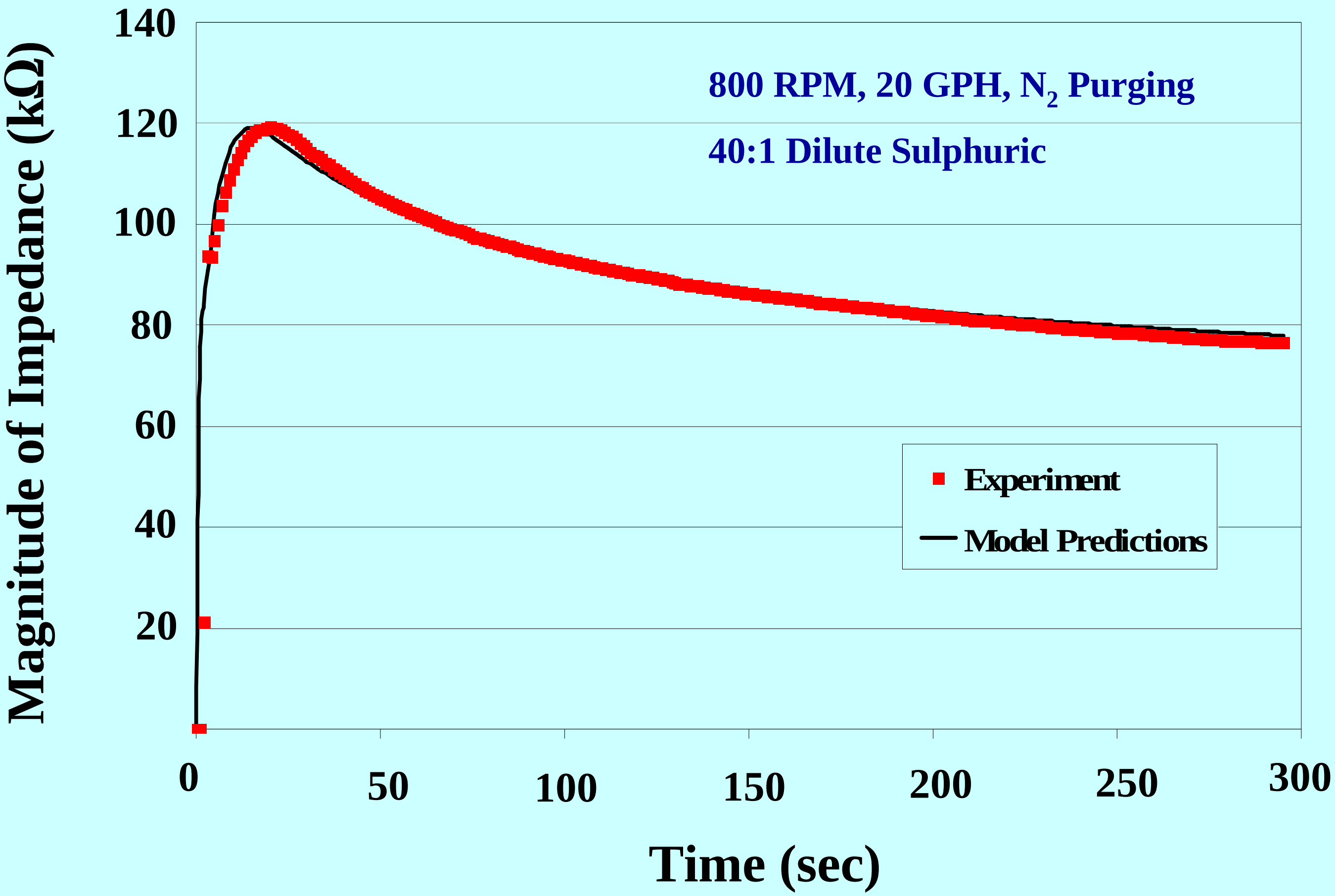
**where charge density:** $\rho = F \sum_i z_i C_i$

**Ohm’s law:** $\vec{J} = \sigma \vec{E}$ $\qquad \nabla \times \vec{E} = 0$

**where electrical conductivity:** $\sigma = \sum_i \lambda_i C_i$



# Validation of Process Simulation

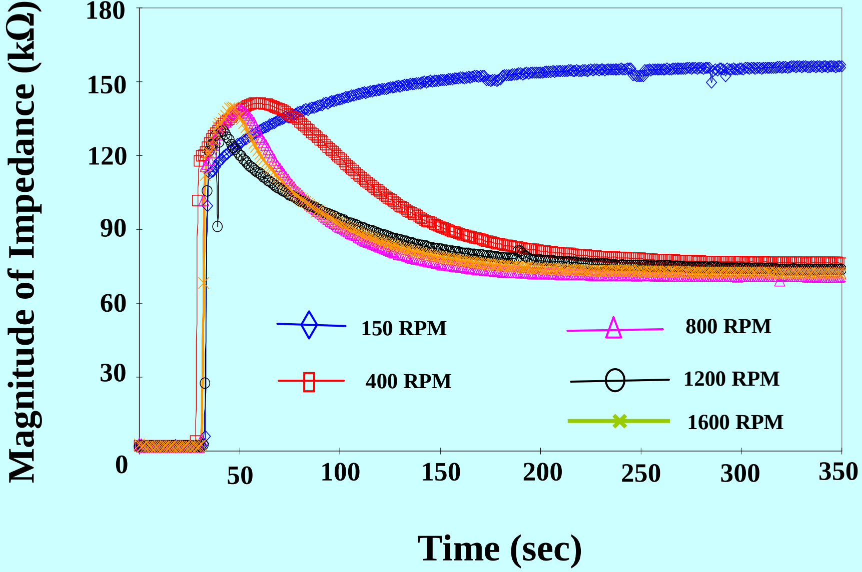


*Simulation results are in good agreement with the experimental data*

# Effect of Process Parameters

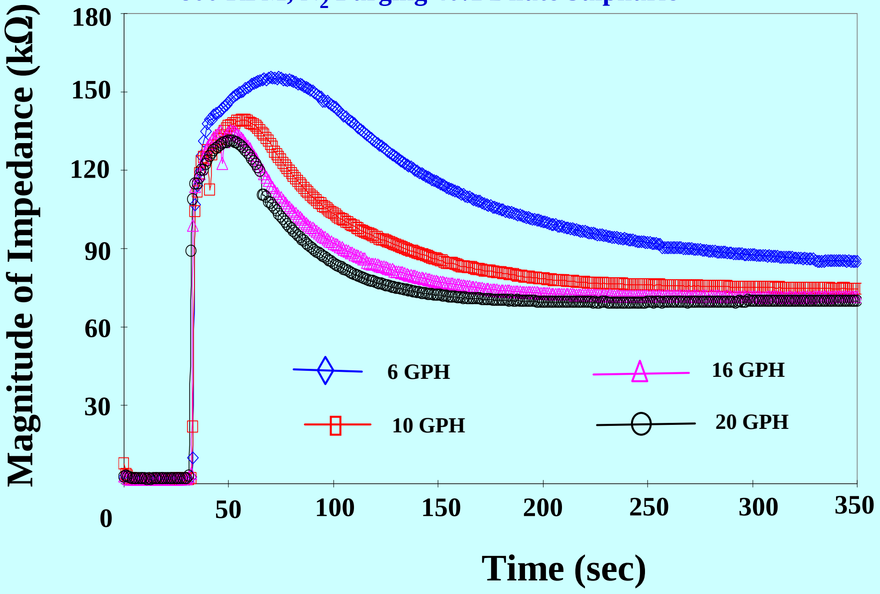
## Effect of Speed of Rotation

20 GPH, $N_2$ Purging 40:1 Dilute Sulphuric



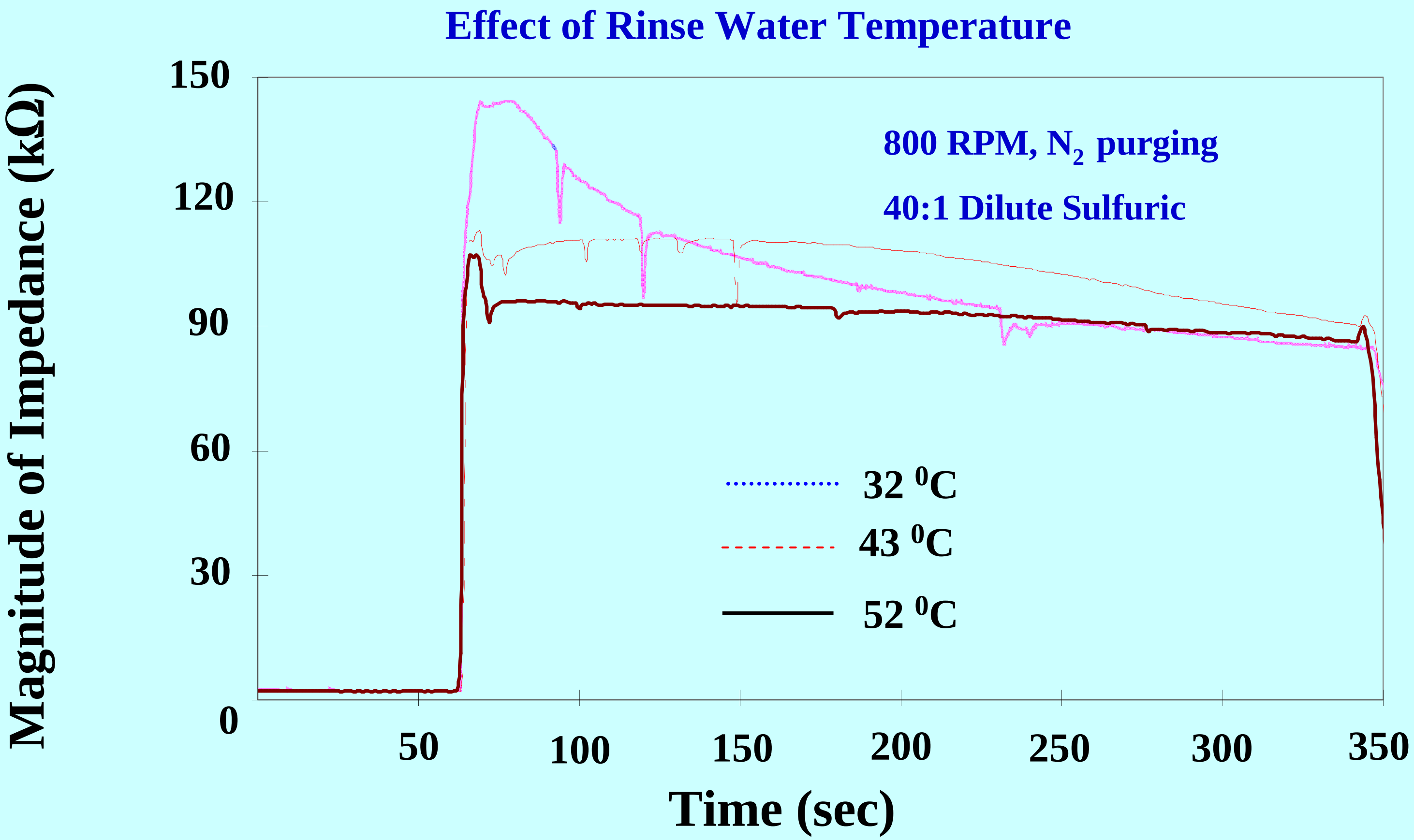
## Effect of Flow Rate

800 RPM, $N_2$ Purging 40:1 Dilute Sulphuric



- *Gain in rinse efficiency diminishes as we reach an optimum speed of rotation and rinse-water flow rate.*
- *Speed of rotation and water flow rate can be optimized to reduce rinse time and increase throughput.*

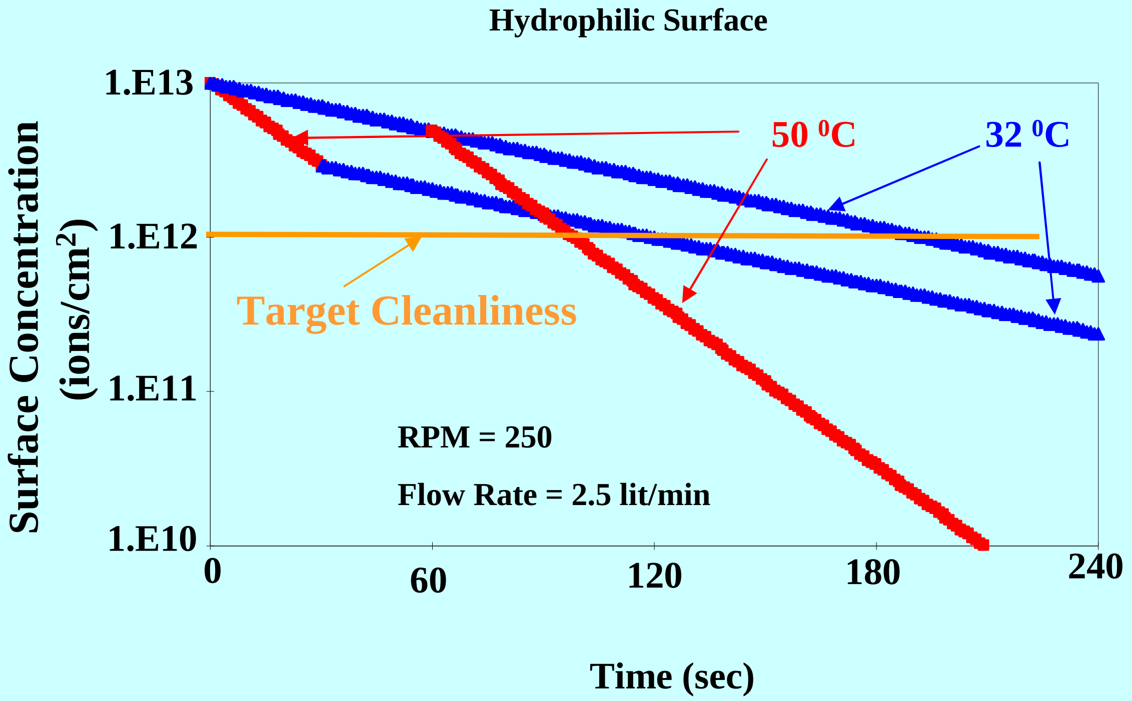
# Effect of Process Parameters

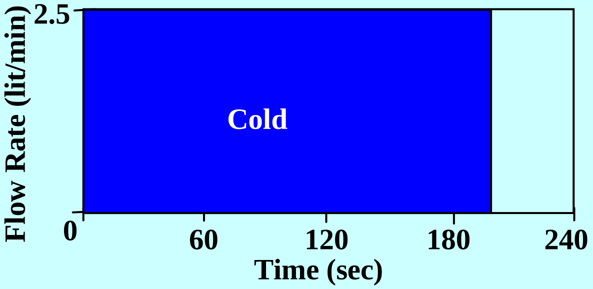


*Temperature has significant effect on enhancing both the early stage and the final stage of the rinse process.*

# Benefits of Staged Rinsing

## Post SC-1 Rinsing





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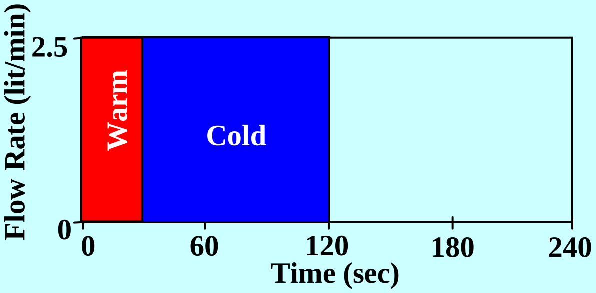

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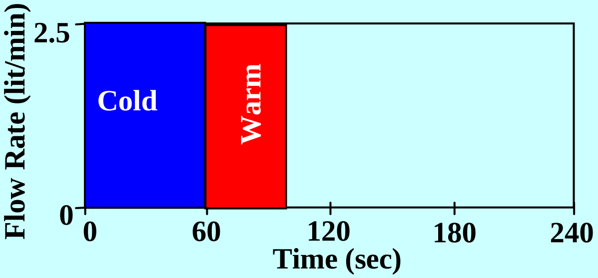
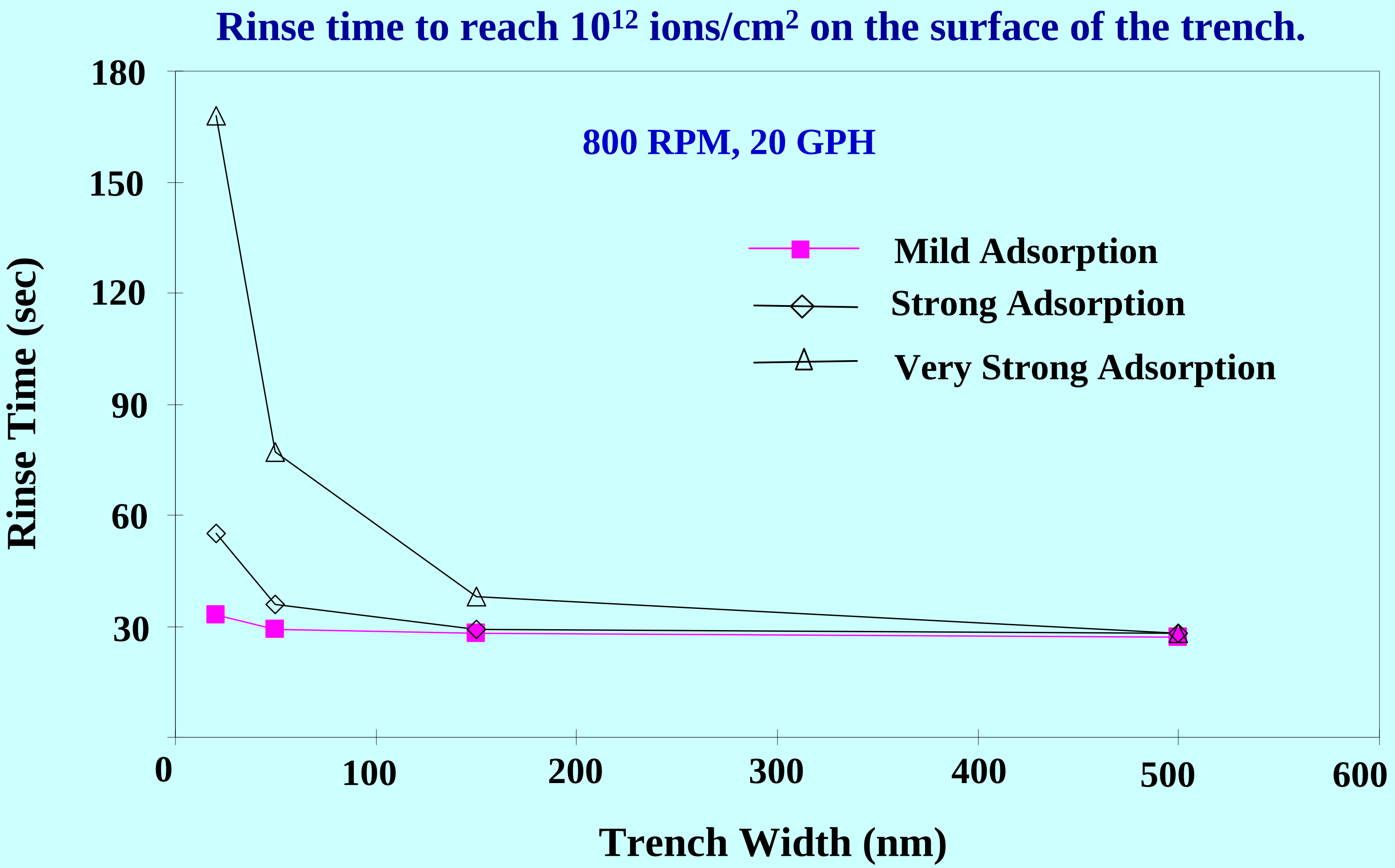


- *Staging temperature of UPW decreases rinse time without sacrificing cleanliness*
- *To reach 1.E12 ions/cm², staged rinsing leads to water savings of 40% for staged rinse "1" and 50% for staged rinse "2".*

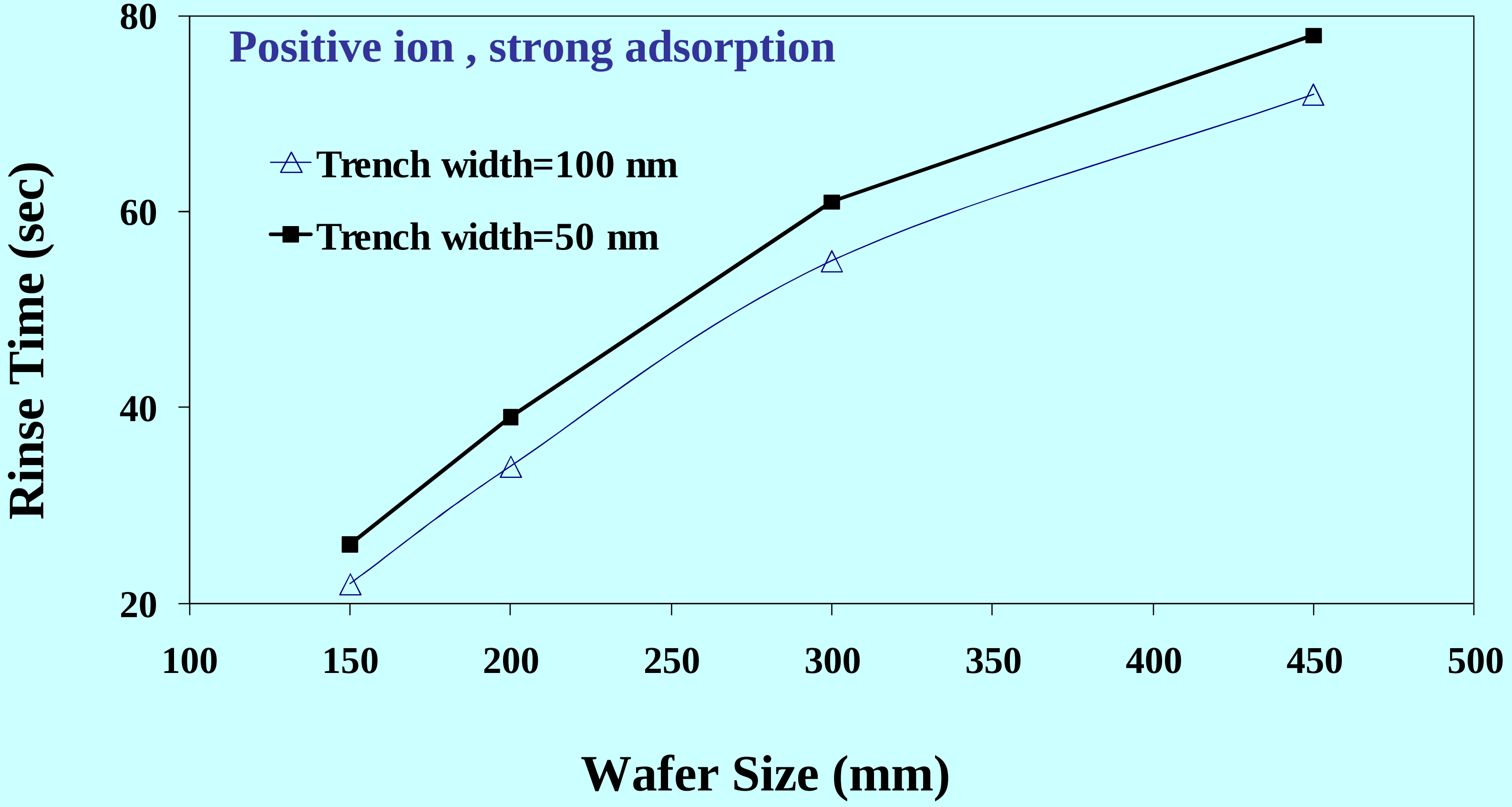
# Effect of Feature Size



***Required rinse time increases as feature size decreases.***

# Effect of Wafer Size

Rinse time to reach $10^{12}$ ions/cm$^2$ on the surface of the trench.



***Required rinse time increases as wafer size increases.***

# Summary

- **Developed a new method for integrating ECRS with single-wafer tools.**
- **Developed a comprehensive process simulator and verified it for single-wafer rinsing; the simulator is applicable to rinsing and cleaning of fine structures on patterned wafers.**
- **Applied ECRS to determine the effect of key process parameters such as speed of rotation, flow rate, rinse water temperature, feature size, and wafer size (a unique and first-time study of these effects).**
- **The ECRS technology and the new process simulator were used to develop rinse recipes that result in *significant reduction in usage of water and energy (hot water) for both batch and single-wafer rinse tools* (joint work with Freescale and Samsung).**
- **Work is continuing on the wireless version of the ECRS (details on the poster)**
- **Future work will also include applying this new technology to drying processes.**

# ECRS: Winner of "*Best Product 2009*" Award

**Semiconductor International Announces 2009 Editors Choice Best Product Award Winners**

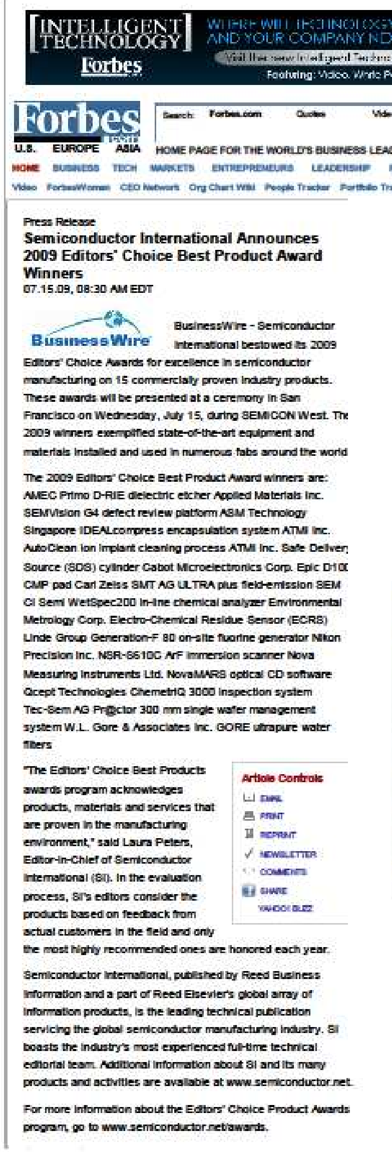
Wed Jul 15, 8:32 AM

OAK BROOK, Ill.--(BUSINESS WIRE)--*Semiconductor International* bestowed its 2009 Editors' Choice Awards for excellence in semiconductor manufacturing on 15 commercially proven industry products. These awards will be presented at a ceremony in San Francisco on Wednesday, July 15, during SEMICON West. The 2009 winners exemplified state-of-the-art equipment and materials installed and used in numerous fabs around the world.

The 2009 Editors' Choice Best Product Award winners are:

| | |
|---|---|
| AMEC | Primo D-RIE dielectric etcher |
| Applied Materials Inc. | SEMVision G4 defect review platform |
| ASM Technology Singapore | IDEALcompress encapsulation system |
| ATMI Inc. | AutoClean ion implant cleaning process |
| ATMI Inc. | Safe Delivery Source (SDS) cylinder |
| Cabot Microelectronics Corp. | Epic D100 CMP pad |
| Carl Zeiss SMT AG | ULTRA plus field-emission SEM |
| CI Semi | WetSpec200 in-line chemical analyzer |
| Environmental Metrology Corp. | Electro-Chemical Residue Sensor (ECRS) |
| Linde Group | Generation-F 80 on-site fluorine generator |
| Nikon Precision Inc. | NSR-S610C ArF immersion scanner |
| Nova Measuring Instruments Ltd. | NovaMARS optical CD software |
| Qcept Technologies | ChemetriQ 3000 inspection system |
| Tec-Sem AG | Pr@ctor 300 mm single wafer management s |
| W.L. Gore & Associates Inc. | GORE ultrapure water filters |

"The Editors' Choice Best Products awards program acknowledges products, materials and services that are proven in the manufacturing environment," said Laura Peters, Editor-in-Chief of *Semiconductor International* (*SI*). In the evaluation process, *SI*'s editors consider the products based on feedback from



Press Release

**Semiconductor International Announces 2009 Editors' Choice Best Product Award Winners**

07.15.09, 08:30 AM EDT

BusinessWire - Semiconductor International bestowed its 2009 Editors' Choice Awards for excellence in semiconductor manufacturing on 15 commercially proven industry products. These awards will be presented at a ceremony in San Francisco on Wednesday, July 15, during SEMICON West. The 2009 winners exemplified state-of-the-art equipment and materials installed and used in numerous fabs around the world

The 2009 Editors' Choice Best Product Award winners are: AMEC Primo D-RIE dielectric etcher Applied Materials Inc. SEMVision G4 defect review platform ASM Technology Singapore IDEALcompress encapsulation system ATMI Inc. AutoClean ion implant cleaning process ATMI Inc. Safe Delivery Source (SDS) cylinder Cabot Microelectronics Corp. Epic D100 CMP pad Carl Zeiss SMT AG ULTRA plus field-emission SEM CI Semi WetSpec200 in-line chemical analyzer Environmental Metrology Corp. Electro-Chemical Residue Sensor (ECRS) Linde Group Generation-F 80 on-site fluorine generator Nikon Precision Inc. NSR-S610C ArF immersion scanner Nova Measuring Instruments Ltd. NovaMARS optical CD software Qcept Technologies ChemetriQ 3000 inspection system Tec-Sem AG Pr@ctor 300 mm single wafer management system W.L. Gore & Associates Inc. GORE ultrapure water filters

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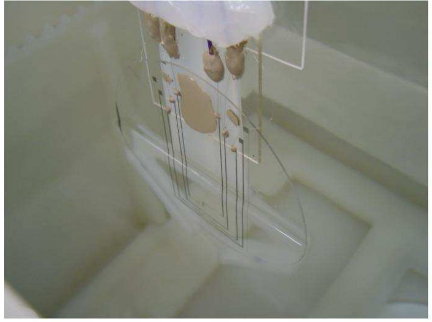
Semiconductor International, published by Reed Business Information and a part of Reed Elsevier's global array of information products, is the leading technical publication servicing the global semiconductor manufacturing industry. SI boasts the industry's most experienced full-time technical editorial team. Additional information about SI and its many products and activities are available at www.semiconductor.net.

For more information about the Editors' Choice Product Awards program, go to www.semiconductor.net/awards.

Semiconductor International
EDITORS' CHOICE
Best Product 2009



# Seed Project: Understanding, Characterizing and Controlling Pad Debris Generation during Copper CMP

**PIs:**

- Takenao Nemoto, New Industry Creation Hatchery Center, Tohoku University
- Ara Philipossian, Chemical and Environmental Engineering, UA

**Graduate Students:**

- Yubo Jiao, PhD candidate, Chemical and Environmental Engineering, UA
- Zhenxing Han, PhD candidate, Chemical and Environmental Engineering, UA

**Other Researchers:**

- Yasa Sampurno, Research Associate, Chemical and Environmental Engineering, UA
- Yun Zhuang, Research Associate, Chemical and Environmental Engineering, UA
- Xun Gu, Ph. D. candidate, Graduate School of Engineering, Tohoku University
- Siannie Theng, Research Technician, Chemical and Mechanical Engineering, UA

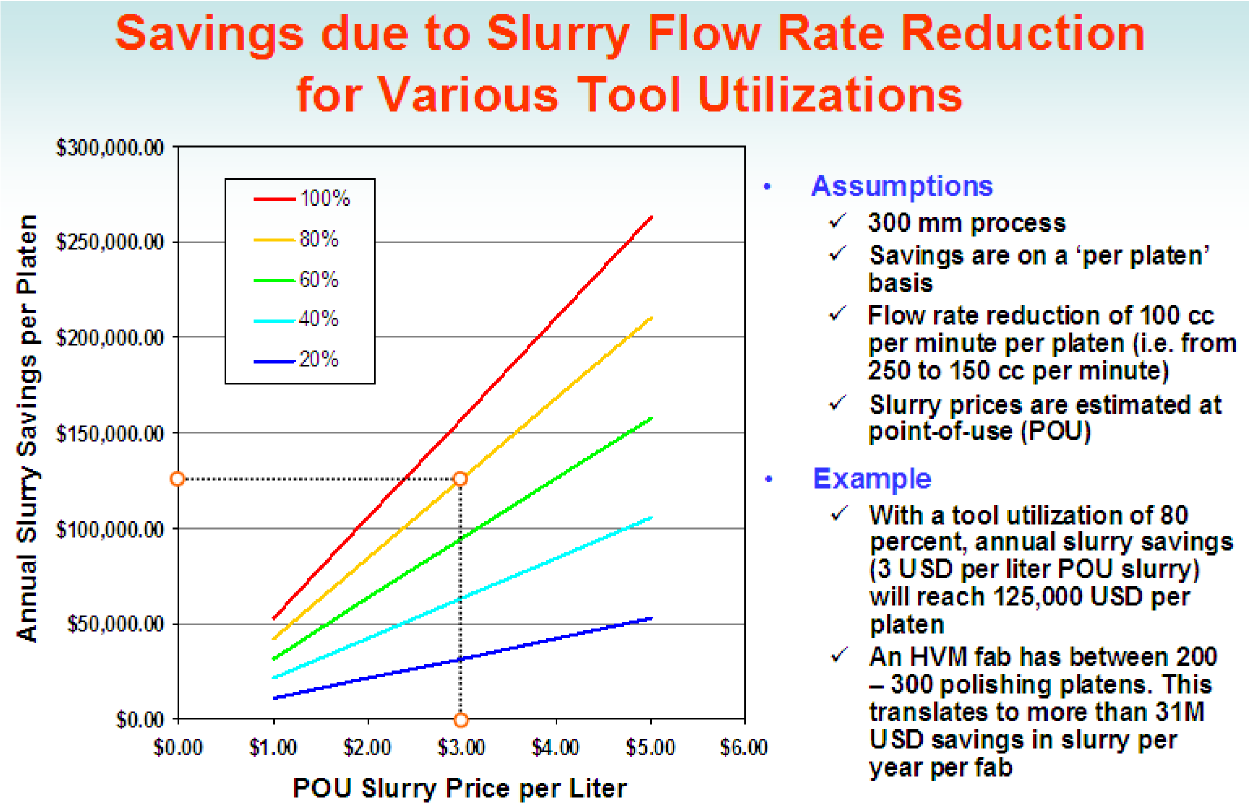
# Objectives

**Reduce consumables in CMP by extending pad life and by reducing slurry flow**

- **Quantify the extent of pad debris generated during conditioning using different industry-standard pads and diamond disc conditioners**
- **Compare the polishing performance of standard vs. novel slurry injection methods on the extent of pad debris resident on the pad surface, polish performance and wafer defects during copper CMP**

# ESH Metrics and Impact

1. **Increase yield by reducing wafer-level defects**
2. **Reduce slurry consumption (and associated waste) by 25 – 50 %**
3. **Increase pad life by more effectively removing conditioner-induced pad debris during polishing**



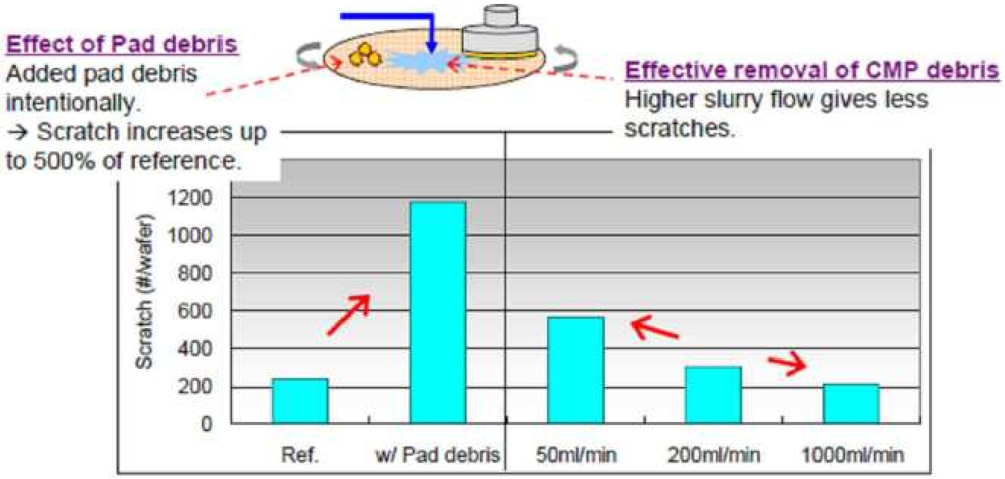
**Savings due to Slurry Flow Rate Reduction for Various Tool Utilizations**

- Assumptions
  - ✓ 300 mm process
  - ✓ Savings are on a ‘per platen’ basis
  - ✓ Flow rate reduction of 100 cc per minute per platen (i.e. from 250 to 150 cc per minute)
  - ✓ Slurry prices are estimated at point-of-use (POU)
- Example
  - ✓ With a tool utilization of 80 percent, annual slurry savings (3 USD per liter POU slurry) will reach 125,000 USD per platen
  - ✓ An HVM fab has between 200 – 300 polishing platens. This translates to more than 31M USD savings in slurry per year per fab

# Approach

- Define and Implement a systematic characterization method for quantifying pad debris generated as a result of conditioning on the pad surface.
- Quantify the extent of pad debris generated during pad conditioning using different industry-standard pads and conditioning discs.
- Select a pad and a disc combination based on the above study. Perform polishing to determine whether extent of pad debris generation is correlated to wafer-level defects.
- Determine whether a novel slurry injection method (that also requires 2X less slurry) is effective in preventing pad debris from entering the pad-wafer interface.
- Determine whether the above novel injection method also reduces wafer-level defects.

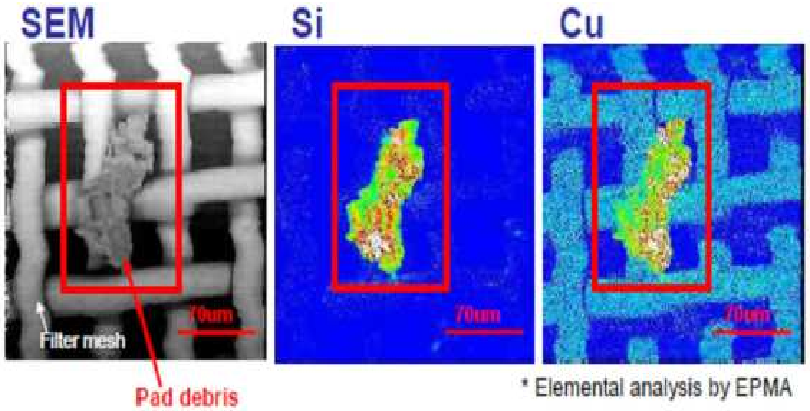
# Effect of Pad Debris on Wafer-Level Defects



**Effect of Pad debris**
Added pad debris intentionally.
→ Scratch increases up to 500% of reference.

**Effective removal of CMP debris**
Higher slurry flow gives less scratches.

- ✓ Pad debris exhibits apparent effect on scratch generation.
- ✓ Scratch count decreases with higher slurry flow. Efficient debris removal would be one of the factors of scratch reduction.



* Elemental analysis by EPMA

Elemental analysis suggests adhesion of silica particle and Cu-complex on the pad debris.

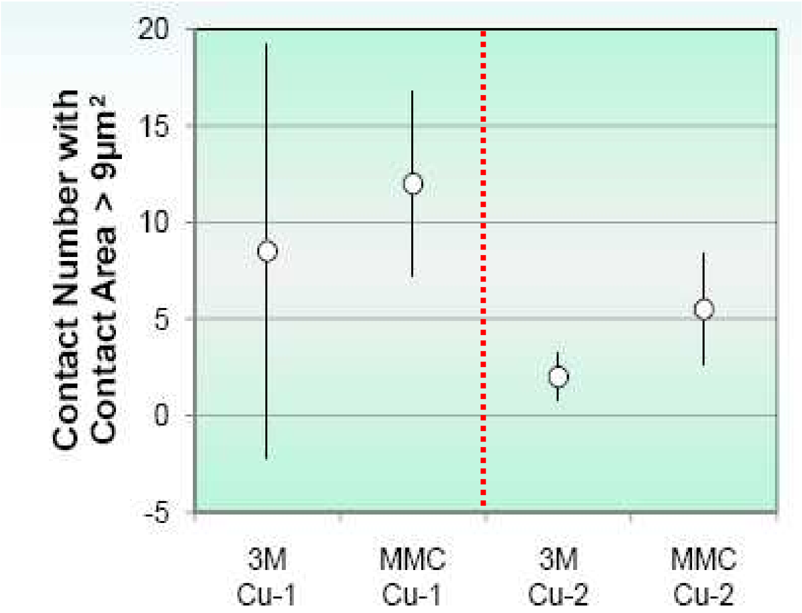
**Source:** **JSR Corporation (2008)**

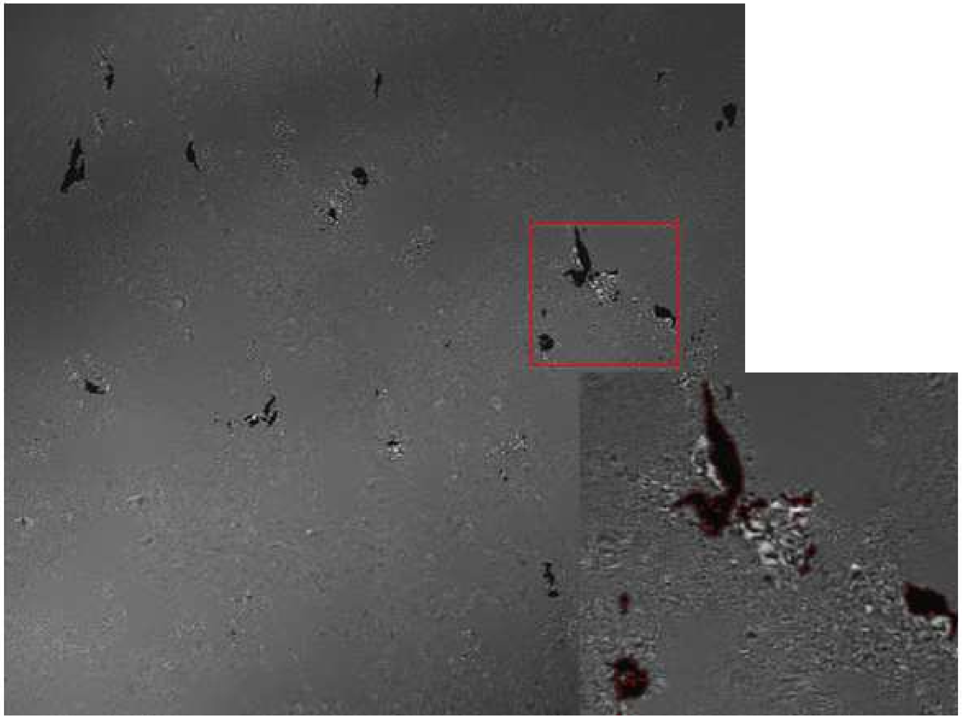
- **Pad debris have been shown to be sources of scratch defects during CMP**
- **JSR’s proposed solution is to reduce pad debris by increasing slurry flow rate by 5X**
- **This goes against EHS and COO objectives**

# Confocal Microscopy Images of Pad Debris

## Based on an earlier joint study by UA and Tohoku University

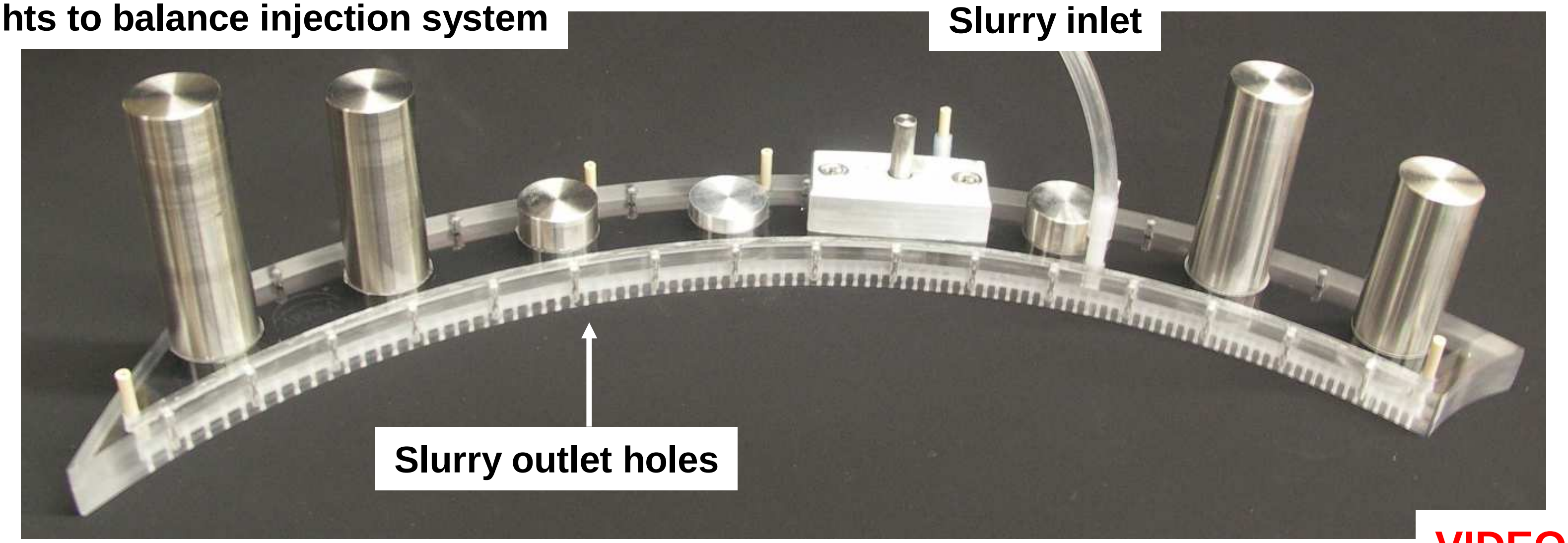
### Pad debris is defined as a contact area greater than 9 micron$^2$





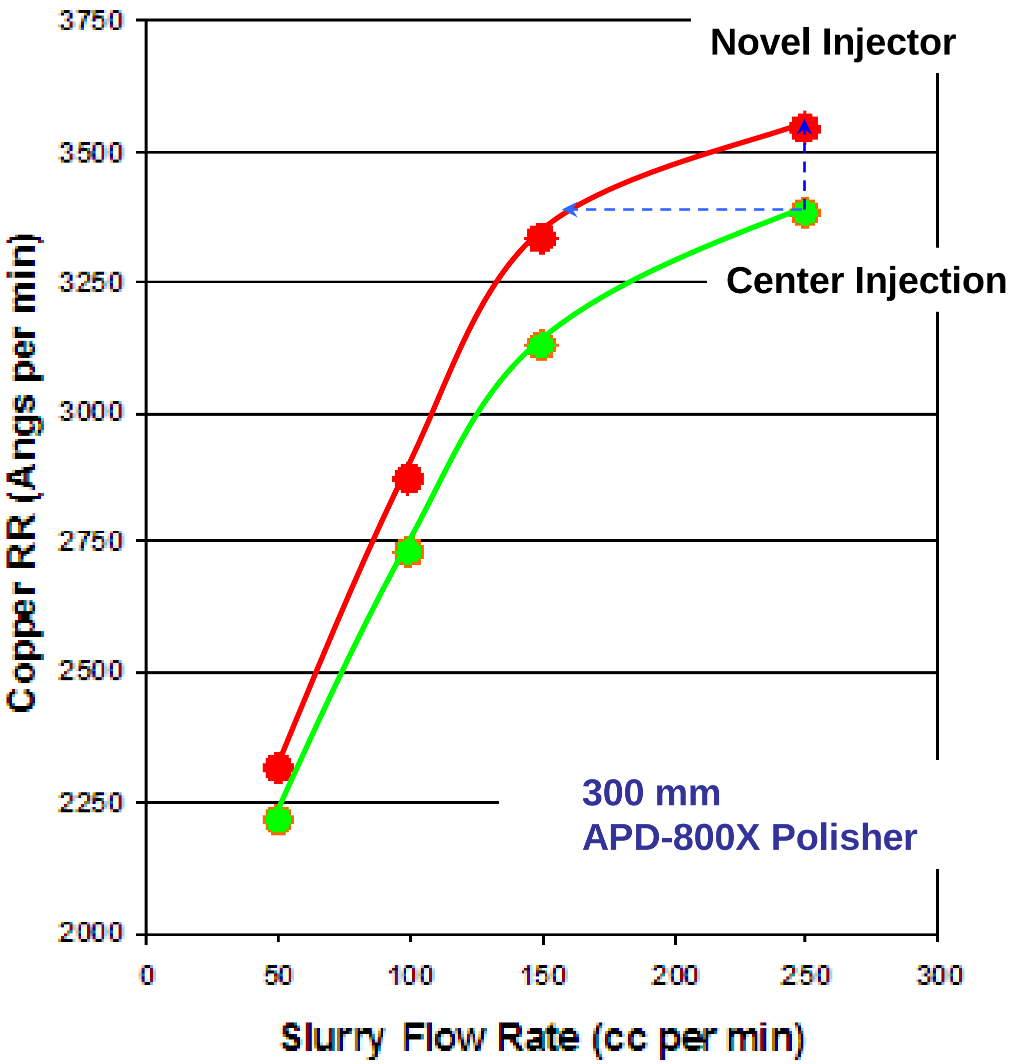
- MMC disc generates more pad debris than 3M disc.
- We believe that pad debris is the source of defects during CMP.
- Cu – 2 process generates less pad debris than Cu – 1.

# Novel Slurry Injection System



VIDEO NO. 1

# RR vs. Flow Rate Data Comparison



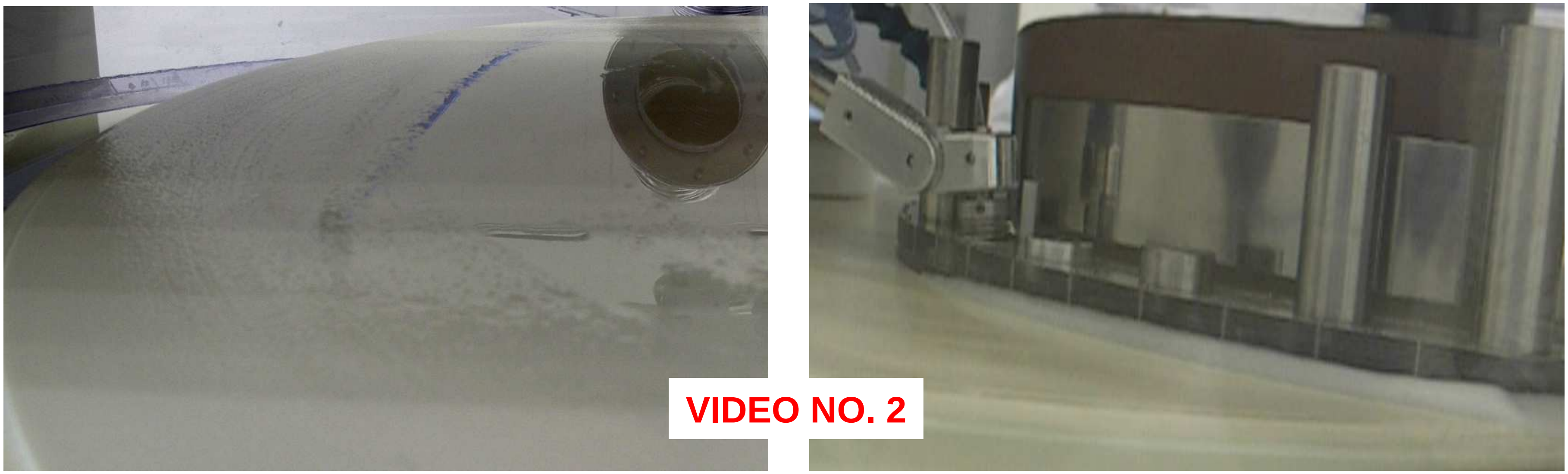
# Benefits of Novel Slurry Injection System

- **Fresh slurry is applied exactly where it is needed**
- **The application method minimizes fresh slurry loss from the wafer or the retaining ring bow wave**
- **The device minimizes mixing of rinse water and used slurry with fresh slurry**
- **Preliminary results show that wafer-level defects are reduced**
- **The device can partially block foamed slurry from getting in the pad-wafer interface during polishing**
- **The design reduces slurry residue build-up on the pad**

**It is not clear if the injection method will also be effective in preventing pad debris from getting into the pad-wafer interface during polishing – This study aims to address this matter**

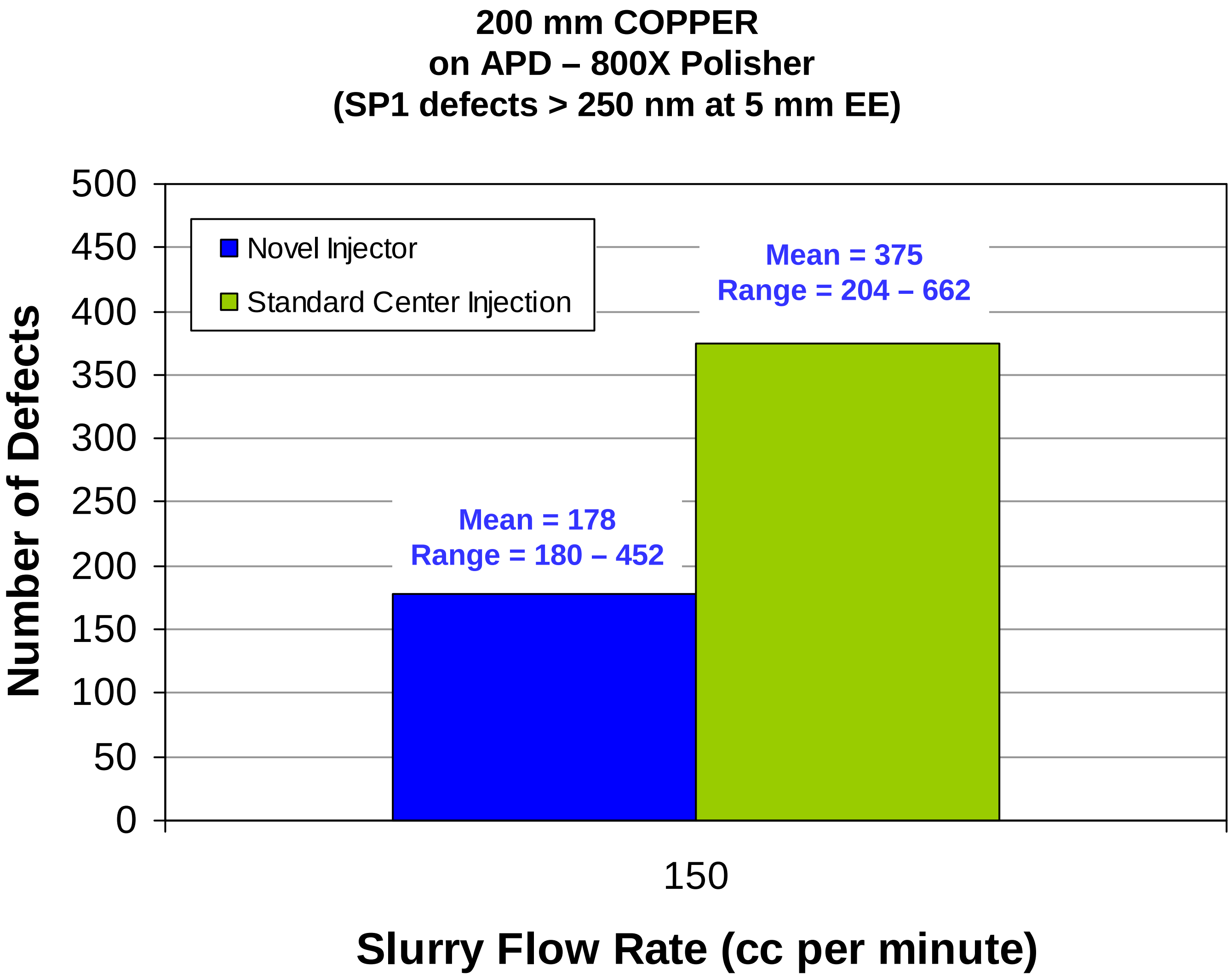
# Novel Slurry Injection System

## Removing Slurry Foam to Improve Defects



- **Slurry foam is formed throughout polishing process**
- **Slurry foam is a major issue in IC manufacturing since most fabs are forced to change polishing parameters to suppress foam formation**
- **Novel slurry injection system can effectively screen out the foam from entering the polishing region without modifying polishing parameters**

# Wafer-Level Defects Comparison



# Industrial Interactions and Technology Transfer

**Industrial mentors and contacts:**

- **Leonard Borucki (Araca Incorporated)**
- **Tadahiro Ohmi (Tohoku University)**
- **SK Lee and Peter Ojerholm (Ehwa)**
- **Shiro-san (Toray)**
- **Chris Wargo (Entegris)**
- **Cliff Spiro (CMC)**

# Plans (Only 1 Year Project)

- Define and Implement a systematic characterization method for quantifying conditioner-induced pad debris.
- Quantify the extent of conditioner-induced pad debris using different industry-standard pads and conditioning discs.
- Select a pad and a disc combination based on the above study and perform polishing studies to determine whether pad debris generation correlates to wafer-level defects.
- Determine whether a novel slurry injection method (that also requires 2X less slurry) is effective in preventing pad debris from entering the pad-wafer interface.
- Determine whether the above novel injection method also reduces wafer-level defects.

# ERC – Intel
# Customized Joint Pilot Program

## *Expected Outcome: New Technologies on Environmentally–Friendly High-Volume Nano-Manufacturing*

**Gopal Rao, Intel**

**Intel/ERC Steering Committee:** Gopal Rao (Co-Chair), Prof Farhang Shadman (Co-Chair), Prof Ara Philipossian, Avi Fuerst, Jim Jewett, Mansour Moinpour, Don Hooper, Carl Geisert, Dan Hodges, John Harland, David Harman

# Acknowledgements

**Executive Initiative:**

Dr. Robert Shelton (President of UA)

Josh Walden (VP/GM of FSM)

Gabe Quenneville (Plant Manager, FSM)

Intel FSM Research Management Review Committee

**PIs Team:**

Intel : Avi Fuerst, Don Hooper, Mansour Moinpour, Carl Geisert, Dan Hodges

UA: Farhang Shadman, Ara Philipossian, Srini Raghavan, Jim Baygents, Jim Farrell

# Current Intel/ERC Customized Research Projects

| No | Project | Lead ERC PI | Lead Intel PI | Research Duration | |
|---|---|---|---|---|---|
| 1. | Investigation of the Relationship between Planarization & Pad Surface Micro-Topography | Ara Philipossian | Mansour Moinpour | 3 yrs | |
| 2. | Retaining Ring and Conditioner Interactions | Ara Philipossian | Don Hooper | 2 yrs | |
| 3. | Contamination Control in Gas Distribution Systems of Semiconductor Fabs | Farhang Shadman | Carl Geisert | 1.5 yrs | |
| 4. | Develop an AFM based methodology to determine the optimal APM composition to remove particles from surfaces | Srini Raghavan | Avi Fuerst | 2 yrs | |
| 5. | Integrated Electrochemical Treatment of CMP waste streams for water reclaim and conservation | James Baygents<br>James Farrell | Don Hooper | 2 yrs | |

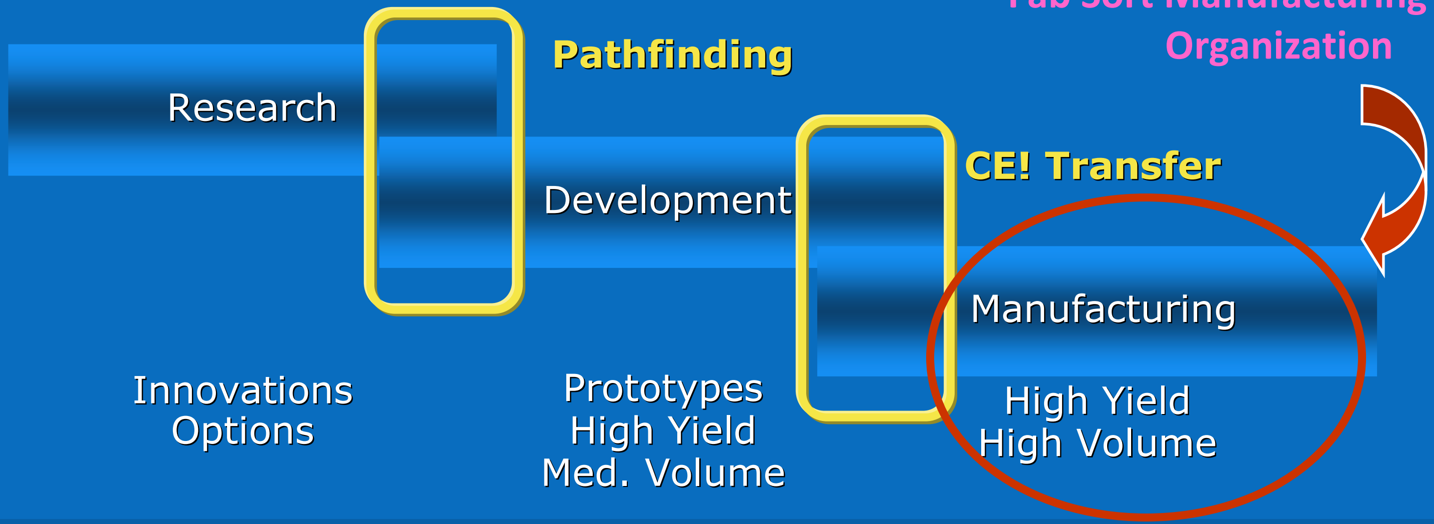
# Intel's Process Technology R-D-M Flow

## Traditional R-D-M Method:

**Phase:** Research → Development → Manufacturing

**Output:**
Publications
Prototypes
High Yield
High Volume

## Intel's R-D-M Method:



Fab Sort Manufacturing (FSM)
Organization

**Phase:**
Research
Pathfinding
Development
CE! Transfer
Manufacturing

**Output:**
Innovations
Options

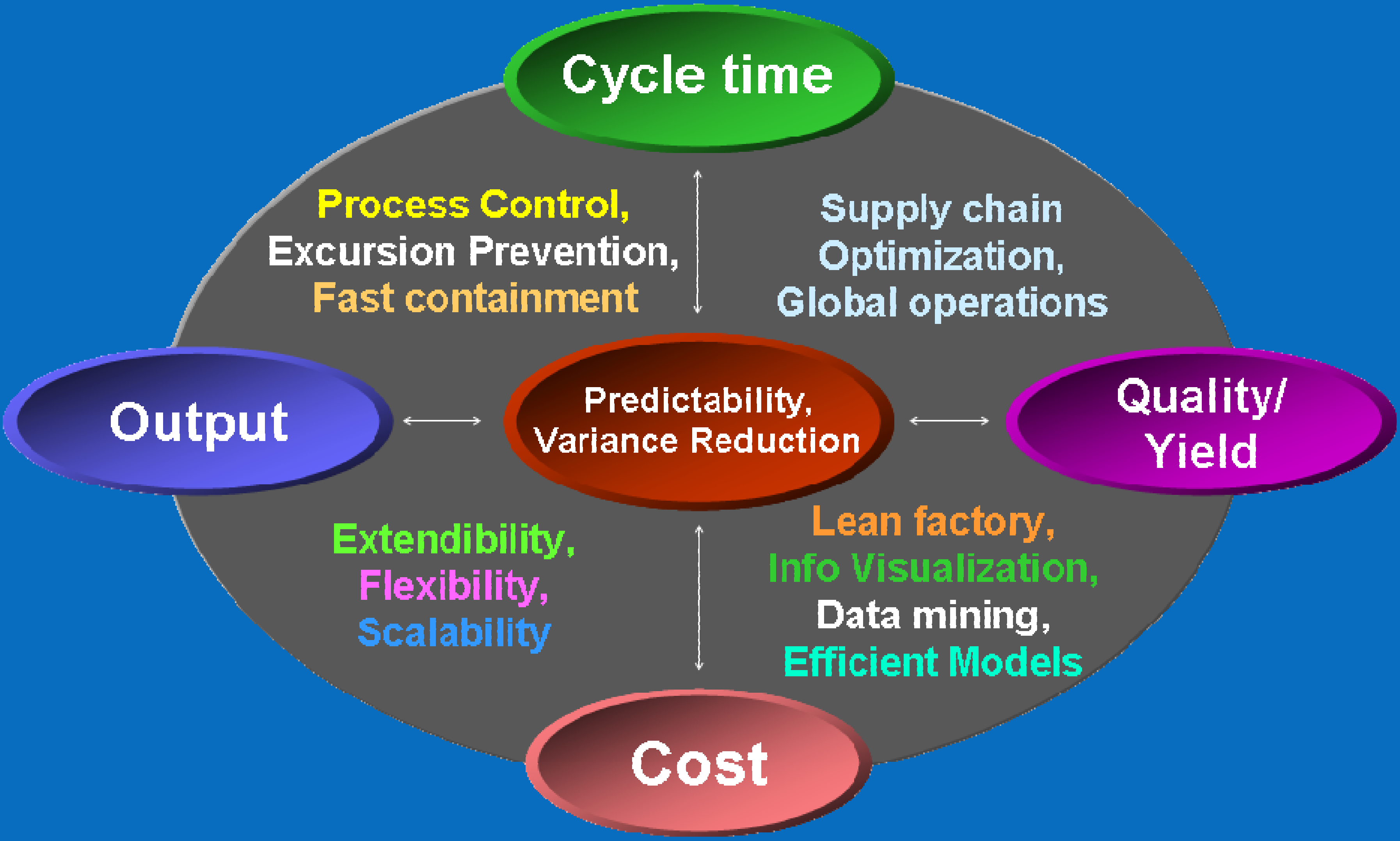
Prototypes
High Yield
Med. Volume

High Yield
High Volume

# Justification for Research in Manufacturing

- Moore's Law enabling significant technology development
- Manufacturing methods, techniques and innovation must keep pace with our technology roadmap
- Leveraging universities for manufacturing research is a good option to explore fundamental and innovative concepts and theories
- FSM resources optimized for performing research in manufacturing

# FSM Research Themes



Cycle time

Process Control,
Excursion Prevention,
Fast containment

Supply chain
Optimization,
Global operations

Output

Predictability,
Variance Reduction

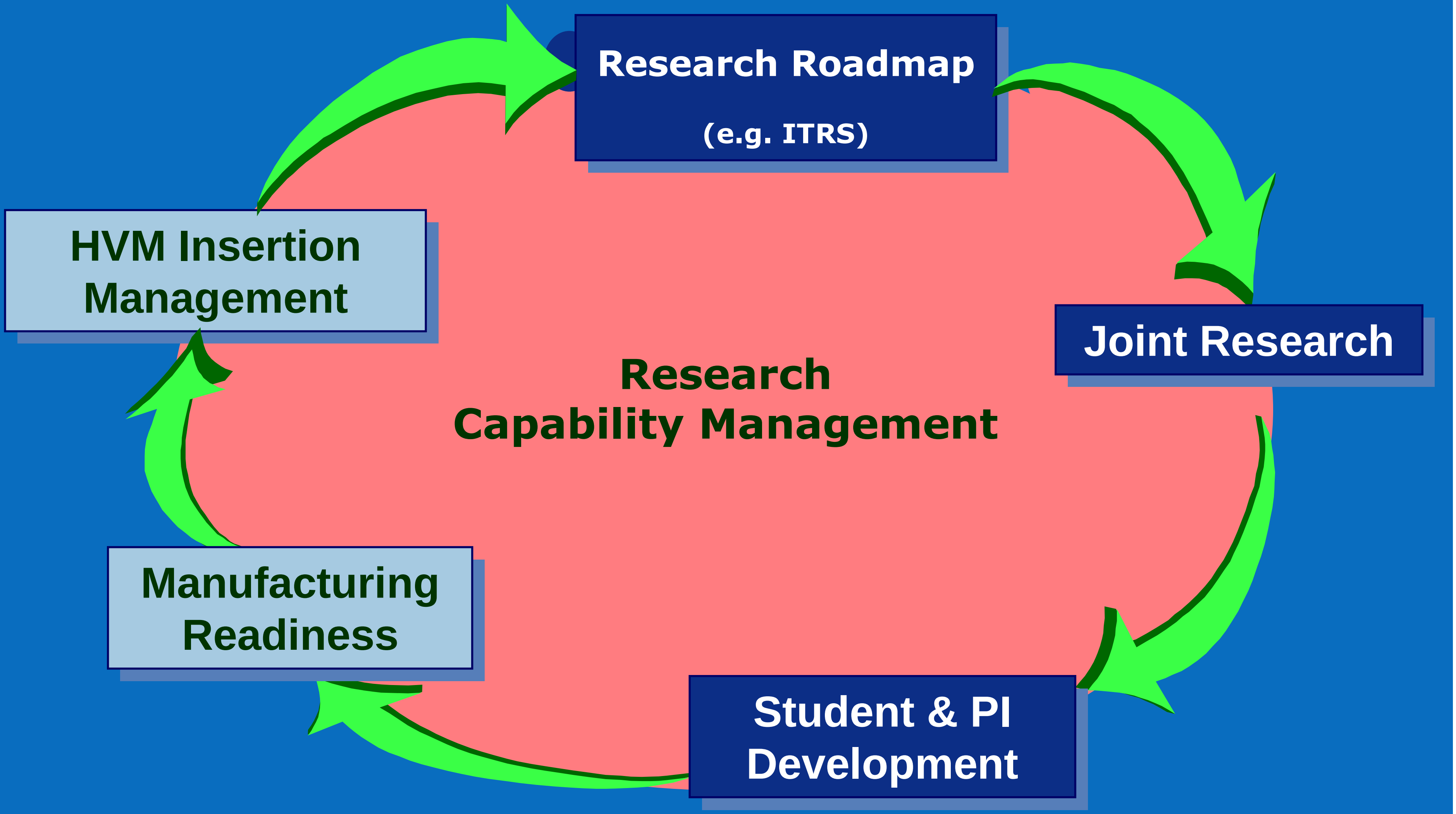
Quality/
Yield

Extendibility,
Flexibility,
Scalability

Lean factory,
Info Visualization,
Data mining,
Efficient Models

Cost

# Intel/ERC Initiative Scope



Research Roadmap

(e.g. ITRS)

Joint Research

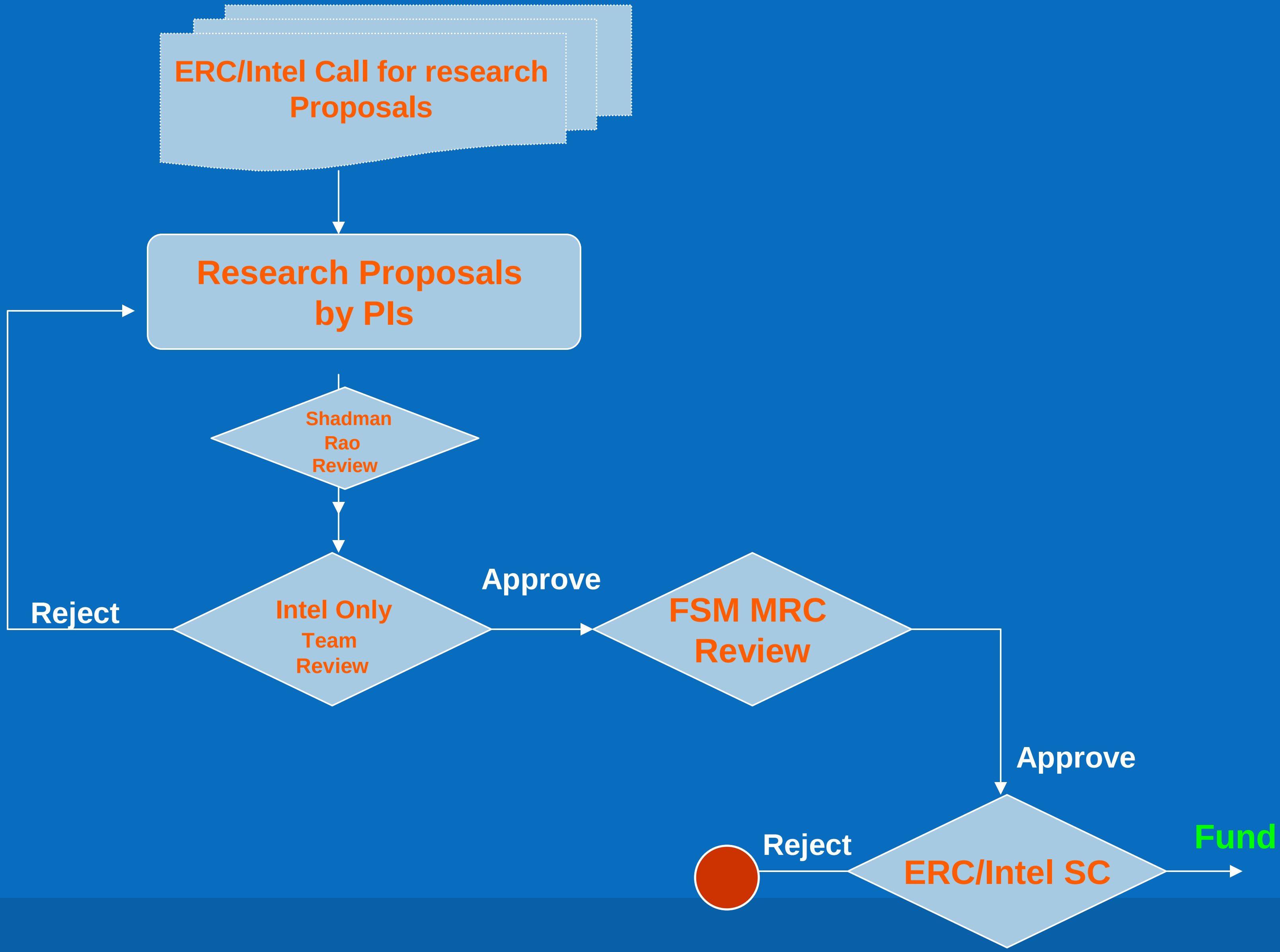
Student & PI Development

Manufacturing Readiness

HVM Insertion Management

Research Capability Management

# Research Proposal Ratification Process



ERC/Intel Call for research Proposals

Research Proposals by PIs

Shadman Rao Review

Intel Only Team Review

Reject

Approve

FSM MRC Review

Approve

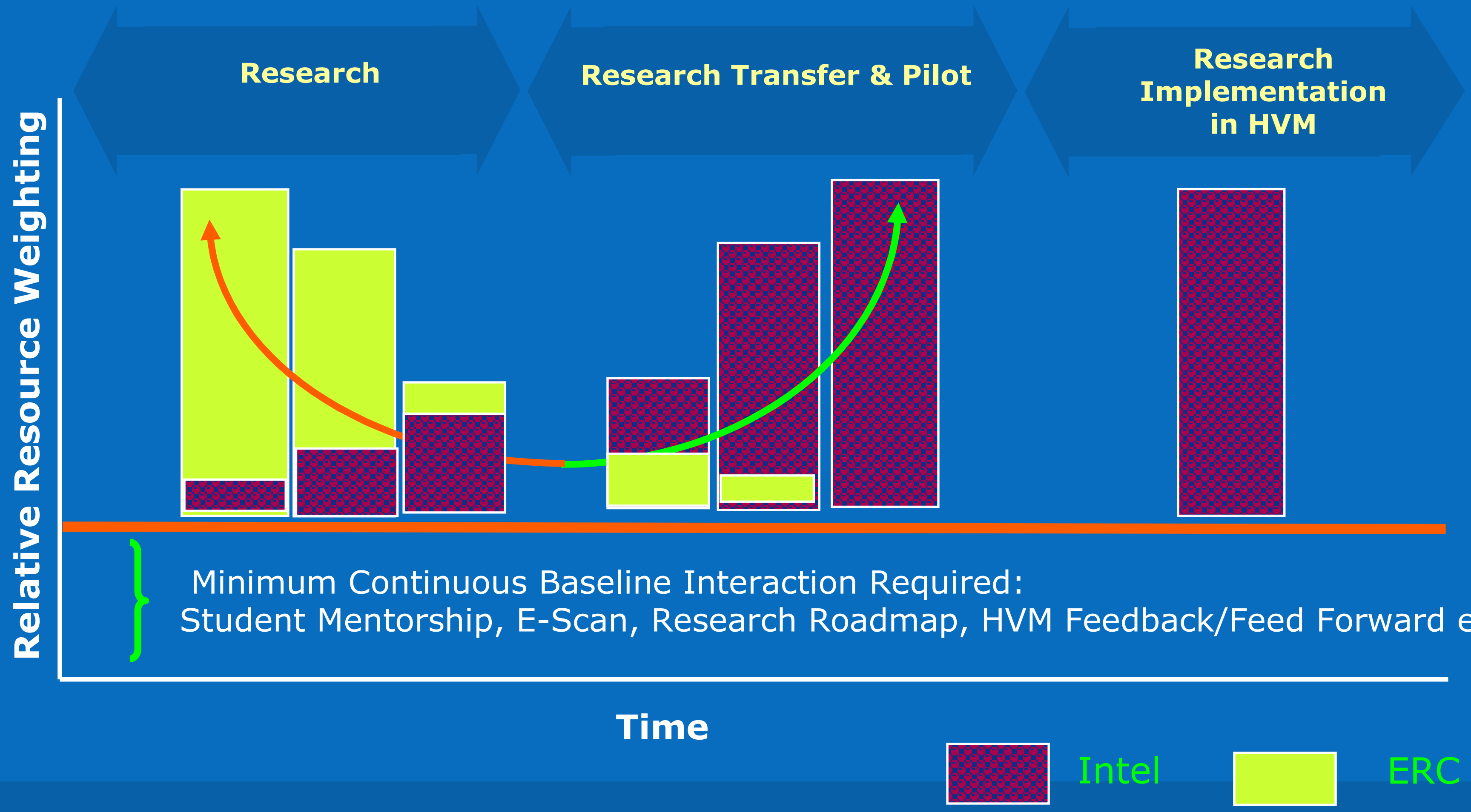
ERC/Intel SC

Reject

Fund

# Joint Intel/ERC Collaborative Research Model Resource Weighting

***"Focusing on Research With HVM Implementation is Critical to Effectively Managing the Research/Student Supply Chain"***



Minimum Continuous Baseline Interaction Required:
Student Mentorship, E-Scan, Research Roadmap, HVM Feedback/Feed Forward etc..

# Conclusions

- Total Value of Intel/ERC Customized Research: ~$1.3M
- Good collaboration between Intel and ERC PIs
- Research Program managed well by Intel/ERC Steering Committee
- Research Projects on track
- ‘For FSM’, ‘By FSM’, ‘In FSM’ Concept applied to harvesting research gaining traction

Thank You!

# Retaining Ring Induced Frictional Pad Heating and its Effect on Pad Wear

**PIs:**

- Ara Philipossian, Chemical and Environmental Engineering, UA

**Graduate Students:**

- Zhenxing Han, Ph. D. student, Chemical and Environmental Engineering, UA
- Yubo Jiao, Ph. D. student, Chemical and Environmental Engineering, UA
- Xiaoyan Liao, Ph. D. student, Chemical and Environmental Engineering, UA

**Other Researchers:**

- Yasa Sampurno, Research Associate, Chemical and Environmental Engineering, UA
- Yun Zhuang, Research Associate, Chemical and Environmental Engineering, UA

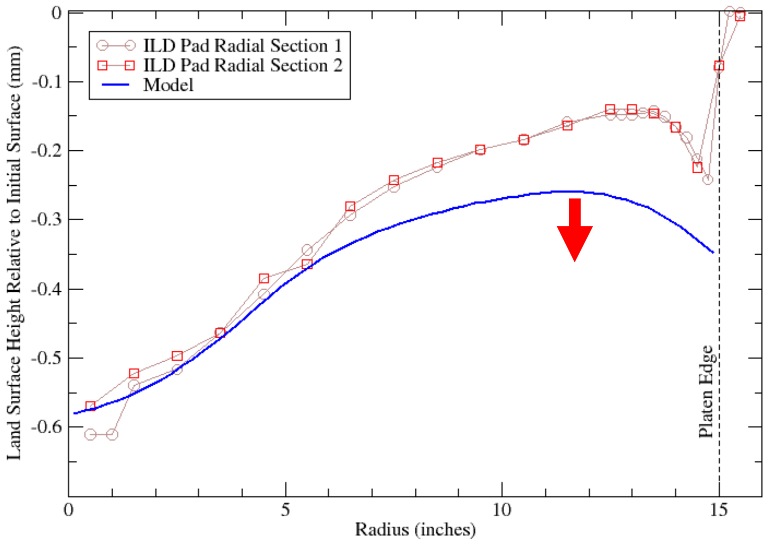
# Retaining Ring Induced Frictional Pad Heating and its Effect on Pad Wear

**Cost Share (other than core ERC funding):**

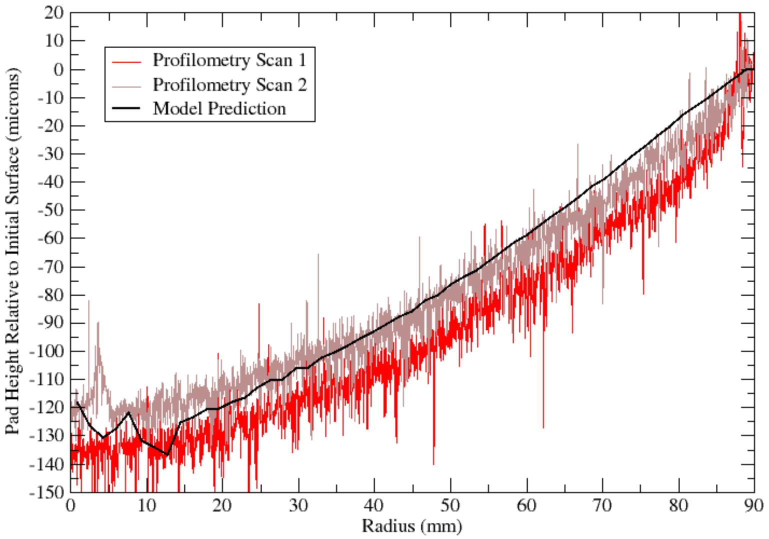
- In-kind donation (retaining rings) from Entegris
- In-kind donation (slurry) from Fujimi
- In-kind donation (conditioner disc) from Shinhan
- In-kind donation (conditioner disc) from 3M
- In-kind donation (polishing pad) from Dow
- In-kind donation (polishing pad) from Cabot Microelectronics
- In-kind donation (wafer) from Intel
- In-kind support from Araca

# Project Essence

- **Evidence suggests that retaining rings have a significant effect on macroscopic pad wear rates depending on polishing time.**
- **Pad cut rates in the presence of a ring are lower than expected from models that otherwise explain such data well.**



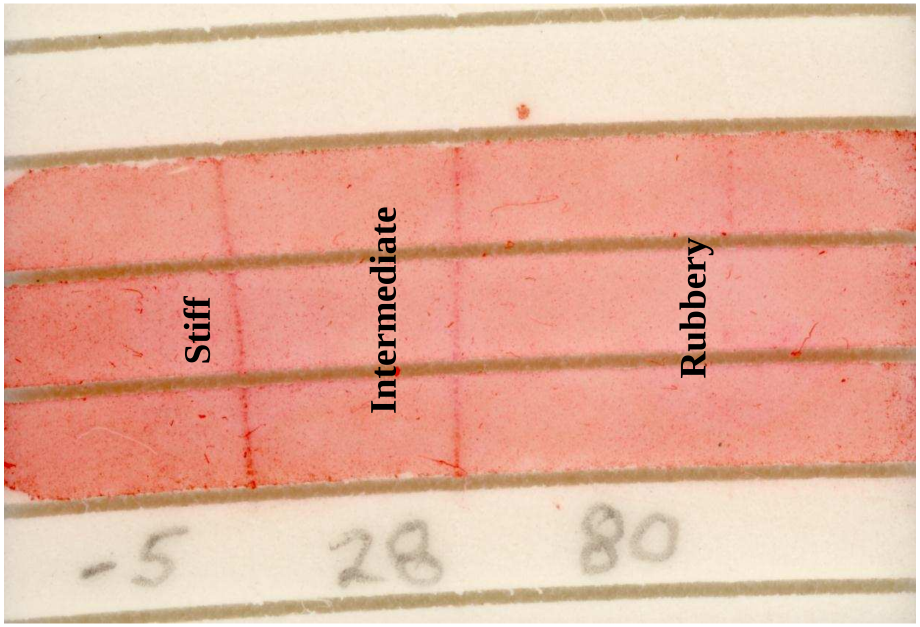
**Model wear profile vs. data with a ring**



**Model wear profile vs. data without a ring**

# Project Essence

- **Qualitative experiments suggest that pad cut rate reduction is thermal in origin and that it depends on how the material properties of the pad change with temperature.**



**Stylus scratches in IC pad at different temperatures at constant load.**
**Scratches appear to heal behind the stylus at 80 C, where the material is rubbery.**

# Specific Objectives and EHS Impact

- **Quantify the effect retaining ring materials, diamond disc conditioners, polishing pads and process conditions (i.e. pad temperature and polishing time) on pad cut rate and pad wear profile**
- **Determine whether or not temperature and/or time effects are the full explanation for pad wear profile differences in different processes**

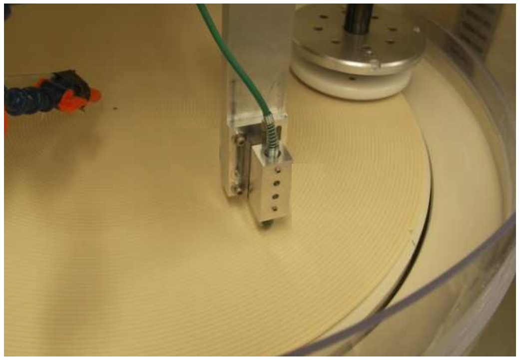
**Reduce slurry, pad and energy consumption by 15 percent**

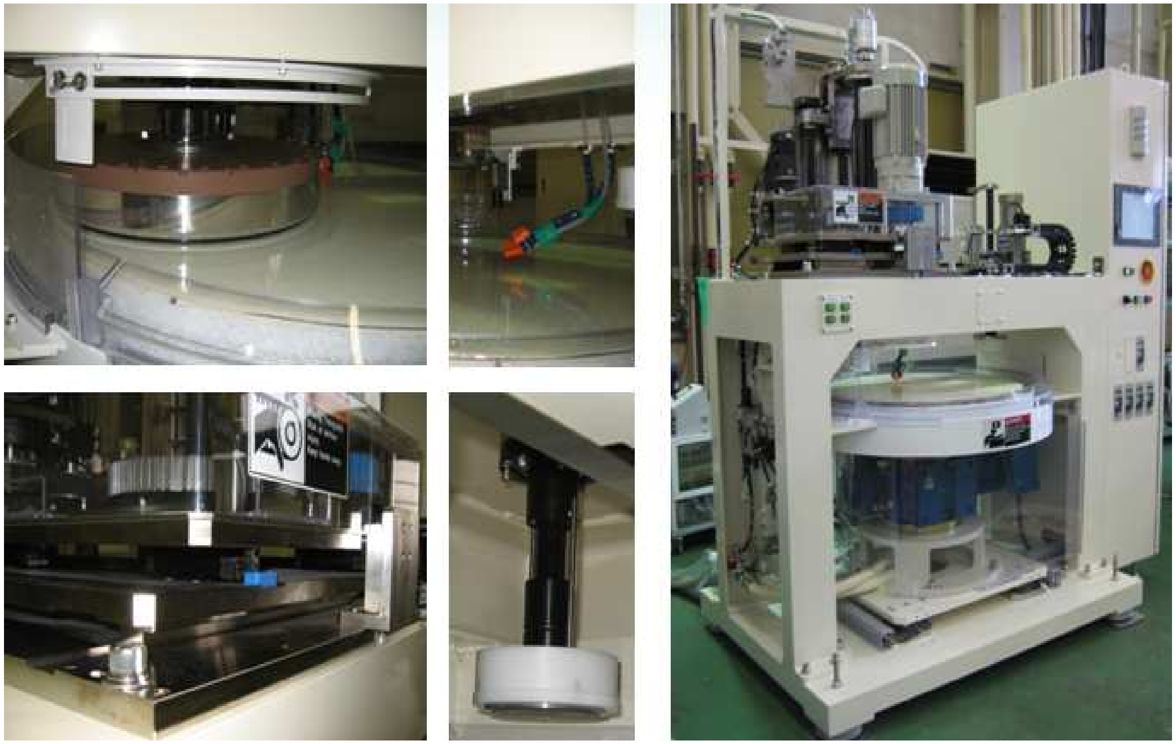
# Approach

**Our approach for this 2 – year program (6/2008 to 5/2010) is as follows:**

- **Modify and integrate a previously built in-situ offline pad cut rate measurement device for UA’s 300 mm polisher**
- **Measure pad wear at three platen temperatures for two different pads, two retaining ring materials and two retaining ring design using a 300 mm polisher equipped with platen heating/cooling**
  - **CMC D100 and Dow IC1000 pads**
  - **PEEK1, PEEK2 and PPS2 retaining rings**
  - **Platen temperature maintained at 15, 25 and 50 ºC (Note: pad temperature is in between platen and room temperature)**
- **Use micrometry to verify pad cut rate (PCR) measurements obtained from the in-situ device**

# Equipment for 300-mm Polisher





**Pad cut rate measurement device (top) … Neslab heater & chiller (center) … Araca APD – 800 platen heating and cooling interface hardware (bottom)**

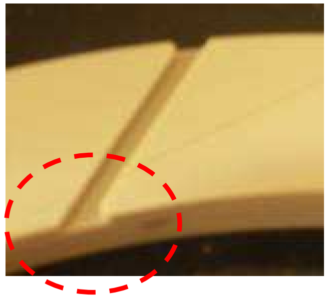
**APD – 800 (300-mm polisher with automatic platen heating and cooling, 10-zone conditioner and in-situ frictional and pad temperature sensor)**

# Retaining Ring Materials and Slot Designs

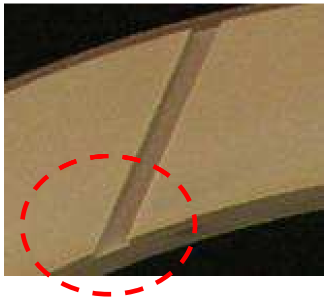
**PEEK**

**PPS**

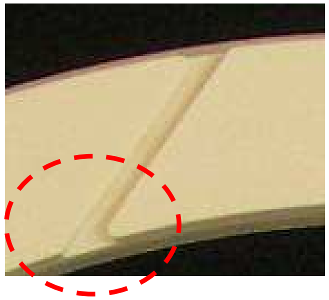
**Design 1**



**Design 2**

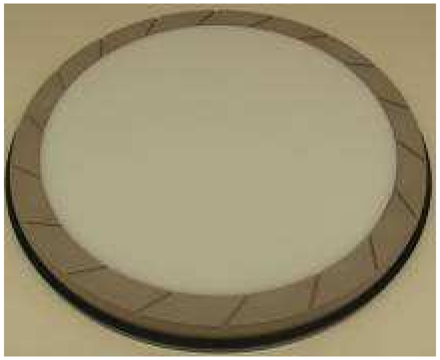


**Design 1**



# Retaining Ring Adaptor

**Adaptor**



**Adaptor with the retaining ring installed**

**Overall setup on the APD – 800 carrier head**

**Retaining ring adaptor (courtesy of Araca and Entegris) has been successfully implemented. The adaptor enables the use of 300 mm industry standard retaining ring (i.e. for the AMAT Reflexion polisher) on APD – 800 300 mm polisher**

# Pad Cut Rate at Platen Temperature 25 ºC

## From Pad Cut Rate Measurement Device

| Ring – Pad | Local Pad Cut Rate* ( µ m/hr) | | | | Average Local Pad Cut Rate ( µ m/hr) |
|---|---|---|---|---|---|
| | 0 – 2 hr | 2 – 4 hr | 4 – 6 hr | 6 – 8 hr | |
| PPS1 – IC1000 | 14.7 | 12.1 | 10.0 | - | 12.2 |
| PEEK1 – IC1000 | 36.6 | 19.4 | 20.5 | - | 25.5 |
| PEEK2 – IC1000 | N/A | N/A | 19.9 | 25.6 | 22.8 |
| PPS1 – D100 | 17.5 | 12.1 | 4.7 | - | 11.4 |
| PEEK1 – D100 | 17.0 | 16.6 | 7.1 | - | 13.5 |
| PEEK2 – D100 | 23.9 | 13.7 | 10.3 | - | 16.0 |

*** Measured by the pad cut rate measurement device at R = 12.25” every 2 hours.**

# Pad Cut Rate at Platen Temperature 50 ºC

## From Pad Cut Rate Measurement Device

| Ring – Pad | Local Pad Cut Rate* (µm/hr) | | | Average Local Pad Cut Rate (µm/hr) |
|---|---|---|---|---|
| | 0 – 2 hr | 2 – 4 hr | 4 – 6 hr | |
| PEEK1 – IC1000 | 33.7 | 13.0 | 4.4 | 17.0 |
| PPS1 – IC1000 | 32.9 | 27.9 | 21.3 | 27.4 |
| PPS1 – IC1000 (Repeat Run) | 22.3 | 27.9 | 10.8** | 21.8 |
| PEEK1 – D100 | 5.3 | 7.9 | 6.4 | 6.5 |
| PPS1 – D100 | < 4.0*** | < 4.0*** | < 4.0*** | < 4.0 |

* Measured by the pad cut rate measurement device at R = 12.25” every 2 hours.
** Measured between 4 and 5.2 hours.
*** Within experimental error.

# Pad Cut Rate Comparison

## Platen Temperature at 25 and 50 $^{o}$C

| Ring – Pad | Local pad cut rate from pad cut rate measurement device (µm/hr) | | Local pad cut rate from micrometry (µm/hr) | | Global pad cut rate from micrometry (µm/hr) | |
|---|---|---|---|---|---|---|
| | 25 C | 50 C | 25 C | 50 C | 25 C | 50 C |
| PEEK1 – IC1000 | 25.5 | 17.0 | 29.6 | 23.8 | 27.5 | 20.3 |
| PPS1 – IC1000 | 12.2 | 27.4 | 17.5 | 33.2 | 16.5 | 29.4 |
| PPS1 – IC1000 (Repeat Run) | 12.2 | 21.8 | 17.5 | 27.4 | 16.5 | 23.5 |
| PEEK1 – D100 | 13.5 | 6.5 | 17.6 | 7.0 | 16.4 | 6.1 |
| PPS1 – D100 | 11.4 | < 4.0* | 8.8 | 5.3 | 7.8 | 5.1 |

*** Within experimental error.**

**The pad surface contained moisture when the pad cut rate device was used to measure local pad thickness during the wear tests. The pad was dry when a micrometer was used to measure local pad thickness after the wear tests. This contributed to different local pad cut rate measurements obtained by the pad cut rate measurement device and micrometer.**

# Summary of Year – 1 Results

## Platen Temperature 25 ºC

- For both IC1000 and D100, global PCRs of the PEEK rings were significantly higher (by appx. 62 – 110 percent) than PPS
- For both IC1000 and D100, global PCRs of the PEEK rings were similar, indicating that the slot curvature did not impact PCR
- For both PEEK1 and PPS1, global PCR for IC1000 was significantly higher (by appx. 68 – 112 percent) than D100 (we would expect a much longer pad life when using D100)
- PCR changed as a function of polishing time (possibly due to changes in pad properties in the 'z' direction)

# Summary of Year – 1 Results

## Platen Temperature 50 ºC

- **For IC1000, global PCR of PEEK1 was lower than that of PPS1 by 30 percent**
- **For D100, the trend was opposite: The global PCR of PEEK1 was higher than that of PPS1 by 16 percent (we don’t yet understand the reason for this)**
- **For both PEEK1 and PPS1, global PCR for IC1000 was significantly higher than D100 (by appx. 233 to 476 percent) – This indicates that the D100 will have a much longer pad life**
- **PCR changed as a function of polishing time (possibly due to changes in pad properties in the ‘z’ direction)**

# Industrial Interactions and Technology Transfer

**Industrial mentors and contacts:**

- **Don Hooper (Intel)**
- **Mansour Moinpour (Intel)**
- **Jason Zanotti (Intel)**
- **Cliff Spiro (Cabot Microelectronics)**

# Future Plans

## Next Year Plan

- **Complete PCR tests on Dow IC1000 and CMC D100 pads using PPS1 and PEEK1 retaining rings at a platen temperature of 15 $^{o}$C**

## Long-Term Plan

- **Develop new (or augment existing) theories to explain the results**

# Investigation of the Relationship between Planarization and Pad Surface Micro-Topography

**PIs:**

- Ara Philipossian, Chemical and Environmental Engineering, UA

**Graduate Students:**

- Yubo Jiao, Ph. D. candidate, Chemical and Environmental Engineering, UA
- Zhenxing Han, Ph. D. student, Chemical and Environmental Engineering, UA
- Anand Meled, Ph. D. student, Chemical and Environmental Engineering, UA
- Xiaoyan Liao, Ph. D. student, Chemical and Environmental Engineering, UA

**Other Researchers:**

- Yasa Sampurno, Research Associate, Chemical and Environmental Engineering, UA
- Yun Zhuang, Research Associate, Chemical and Environmental Engineering, UA

# Investigation of the Relationship between Planarization and Pad Surface Micro-Topography

**Cost Share (other than core ERC funding):**

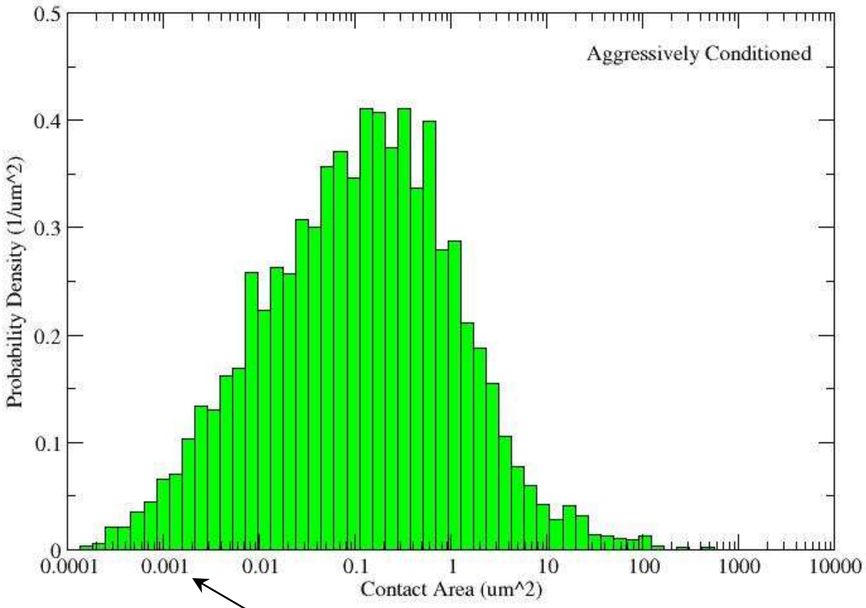
- **In-kind donation (conditioner disc) from Ehwa**
- **In-kind donation (conditioner disc) from Shinhan**
- **In-kind donation (conditioner disc) from 3M**
- **In-kind donation (polishing pad) from Dow**
- **In-kind donation (polishing pad and slurry) from Cabot Microelectronics**
- **In-kind donation (wafer) from Intel**
- **In-kind support from Araca**

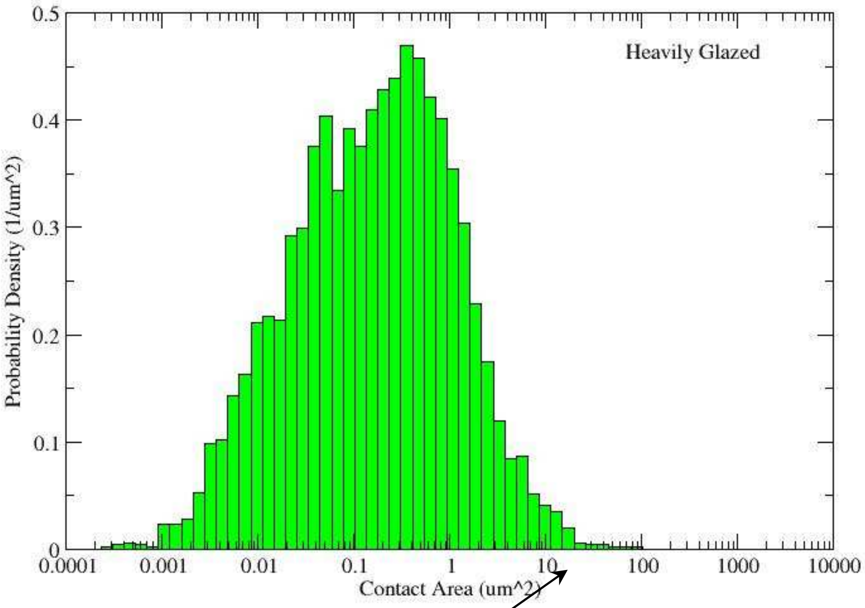
# Project Essence

- Planarization is a common thread across all CMP platforms.
- Planarization behavior depends on the slurry formulation and on the topography of the pad.
- A new method is available for investigating pad/wafer contact, creating an opportunity for deeper understanding and control of the factors that affect planarization.
- The new method, laser confocal contact area microscopy, shows directly which features of the pad topography are capable of reaching into a feature of a given size and reducing planarization efficiency.
- Microscopy data can be supplemented by rough surface contact removal rate modeling to confirm theories suggested by observations.

# Project Essence

## Contact area histograms may be intimately related to polishing behavior





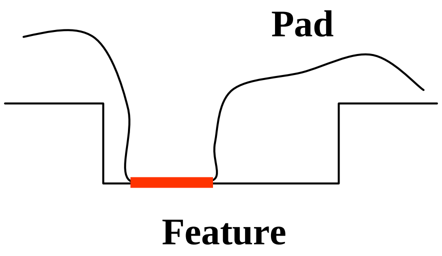
**The aggressively conditioned pad has more contacts in the left-hand tail from tall "thin" asperities (i.e. 10 – 30 nm wide features). These presumably can reach into small features and reduce planarization efficiency. The heavily glazed pad by contrast has relatively few such contact areas.**

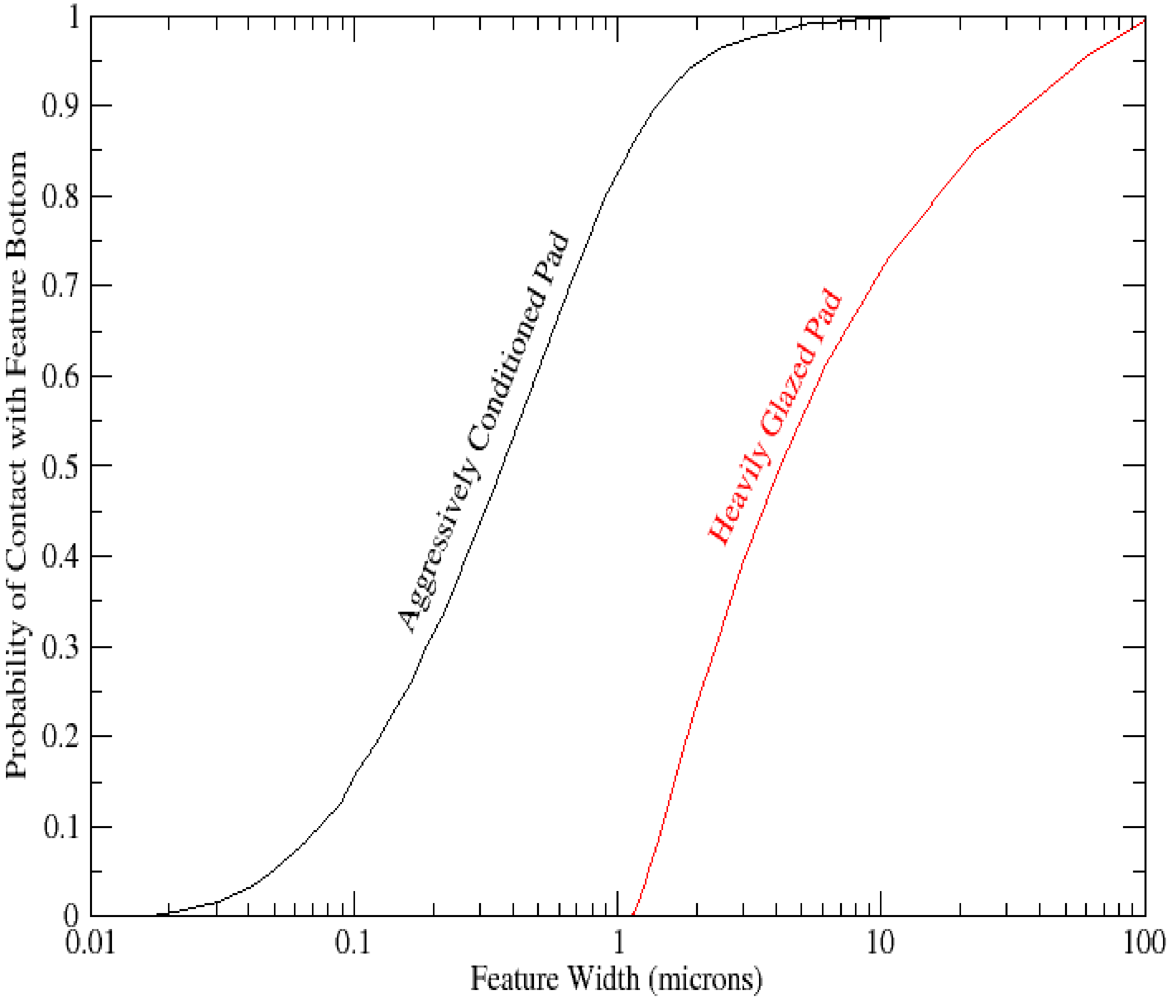
**The heavily glazed pad also has a deficit of large area contacts from tall "fat" asperities (i.e. 3 – 10 micron wide) relative to the aggressively conditioned pad. This may be responsible for a lower removal rate.**

# Project Essence

## CONNECTION WITH PLANARIZATION

**In this graph, the histograms from the previous slide have been processed to estimate the probability that a randomly chosen contacting asperity will be capable of contacting the bottom of a feature of a given width. While illustrated here for trenches, similar estimates can be made for other kinds of features.**





# Objectives and EHS Impact

- **Gain a deeper understanding and control of factors related to pad topography that affect planarization**

- **Prove that contact area can predict planarization behavior**

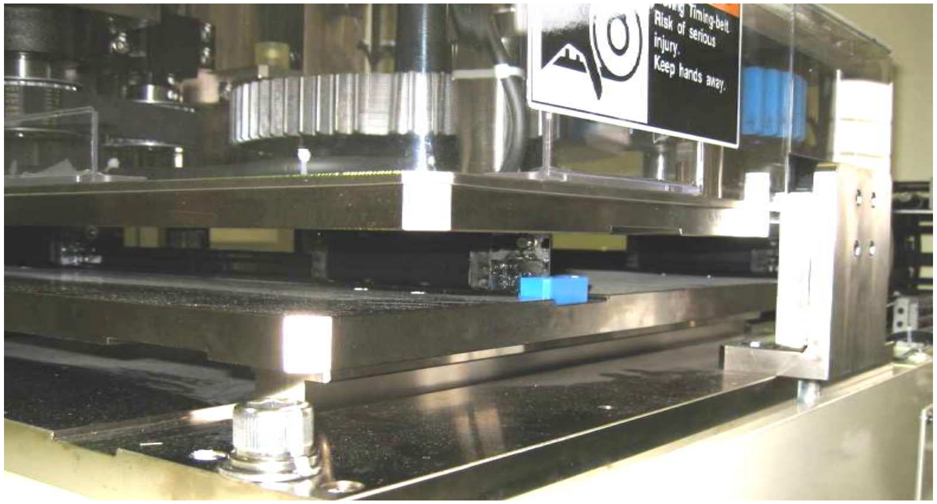
**Reduce slurry, pad and energy consumption by 30 percent**

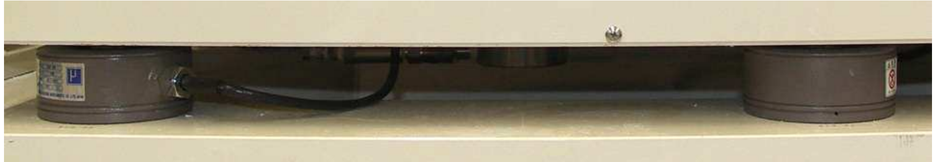
# Approach

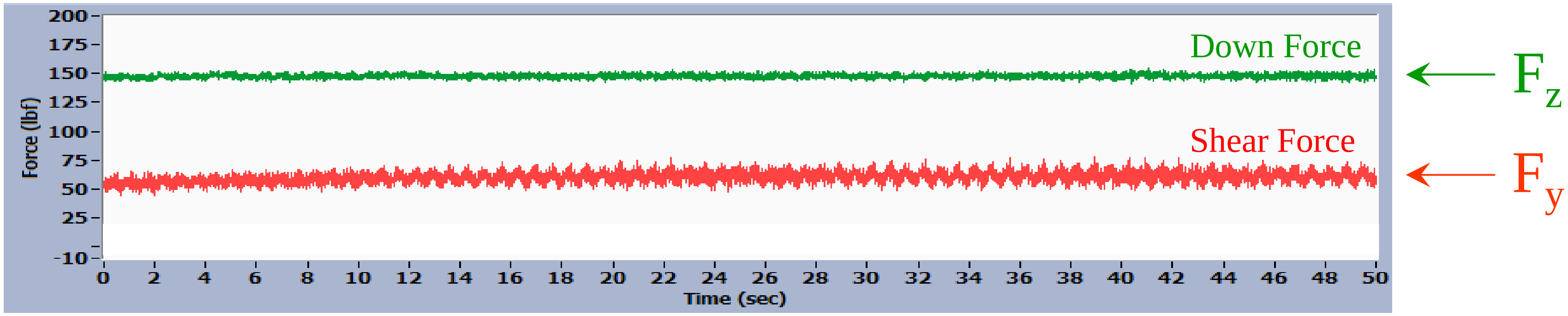
**Our approach for this 3 – year program (6/2008 to 5/2011) is as follows:**

- **Polish 300-mm wafers using a variety of conditions and consumables (i.e. pads with different hardness and porosity and diamonds with different levels of aggressiveness) known or expected to improve or degrade planarization efficiency**
- **Examine pad samples under static loading (at CMP-relevant pressures) using flat, and possibly patterned, sapphire windows (patterned windows would replicate the contact conditions on patterned wafers and would make it feasible to actually see which pad features affect planarization)**
- **Correlate planarization behavior with contact area characteristics**
- **Tie observational data together with rough surface contact and removal rate models**

# APD – 800 Polisher and Tribometer

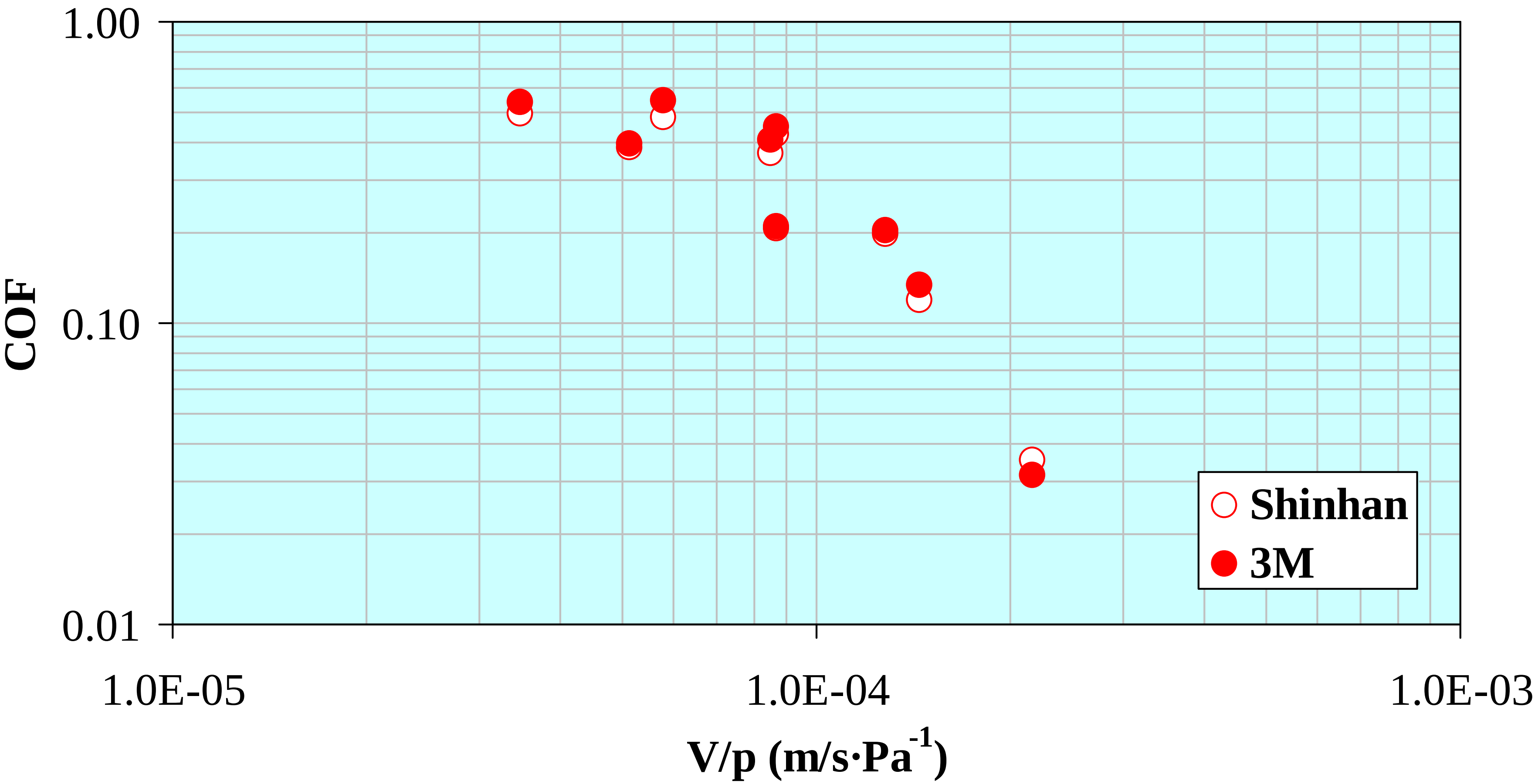






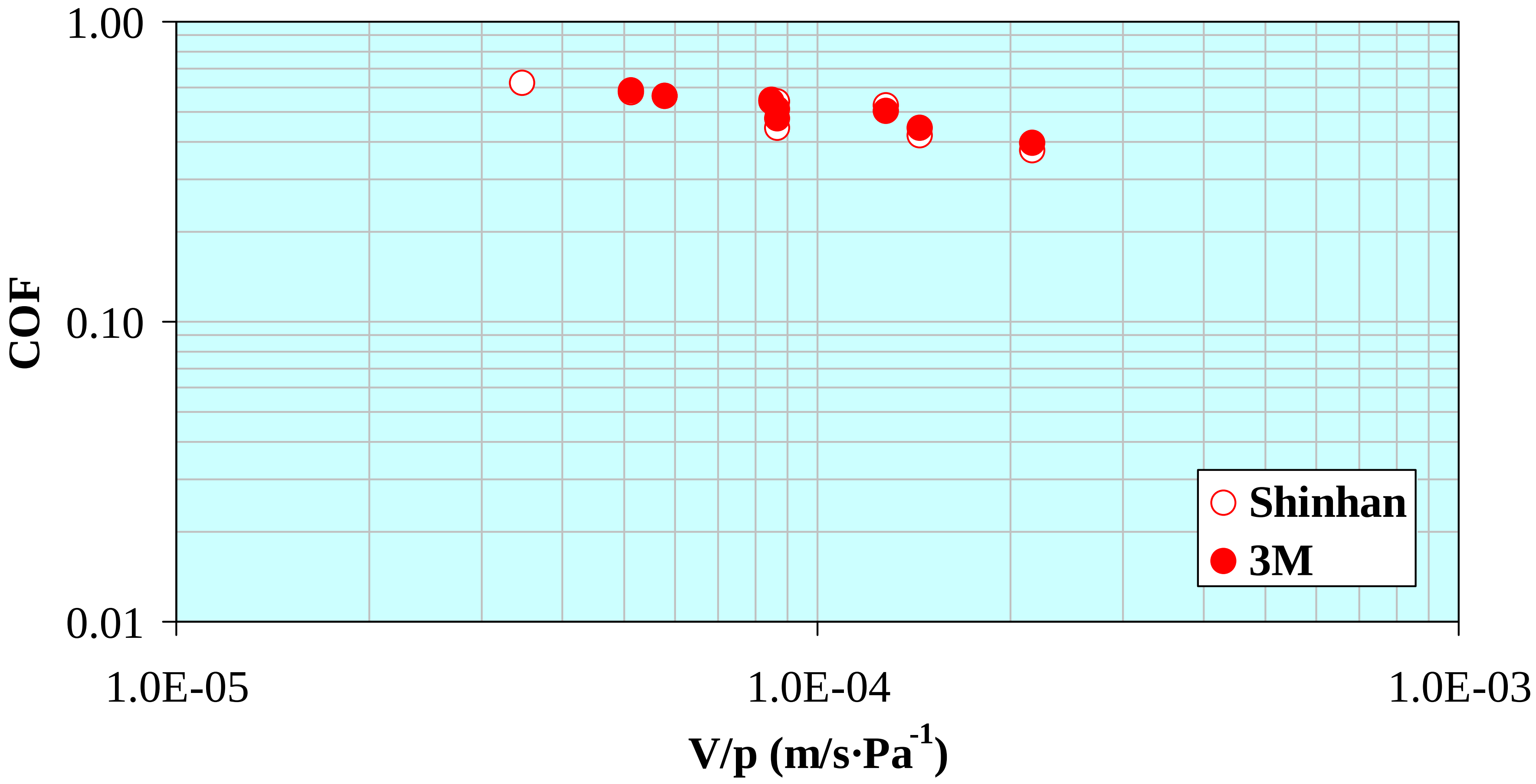
# COF vs. V/p

## IC1000



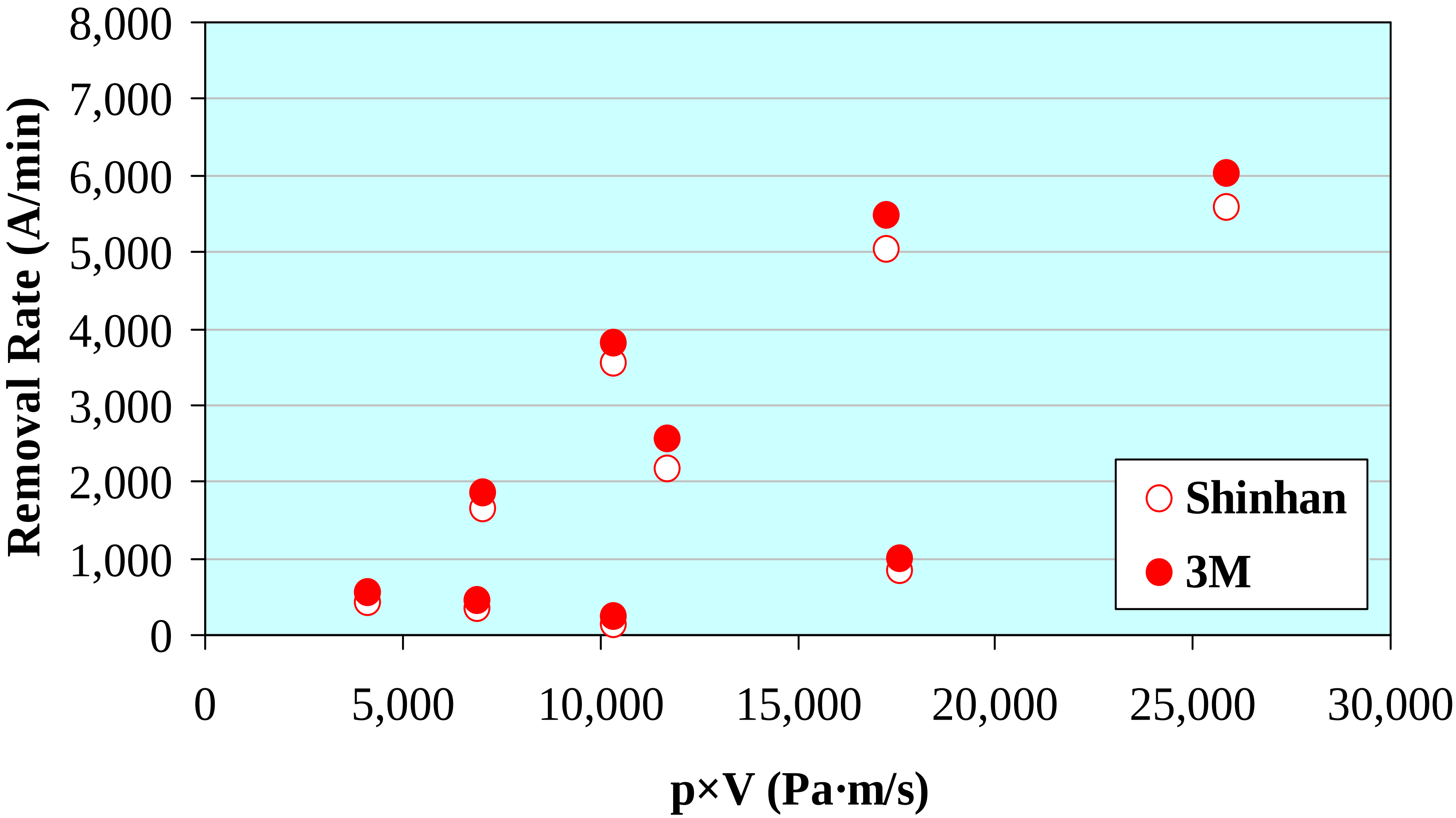
# COF vs. V/p

## D100



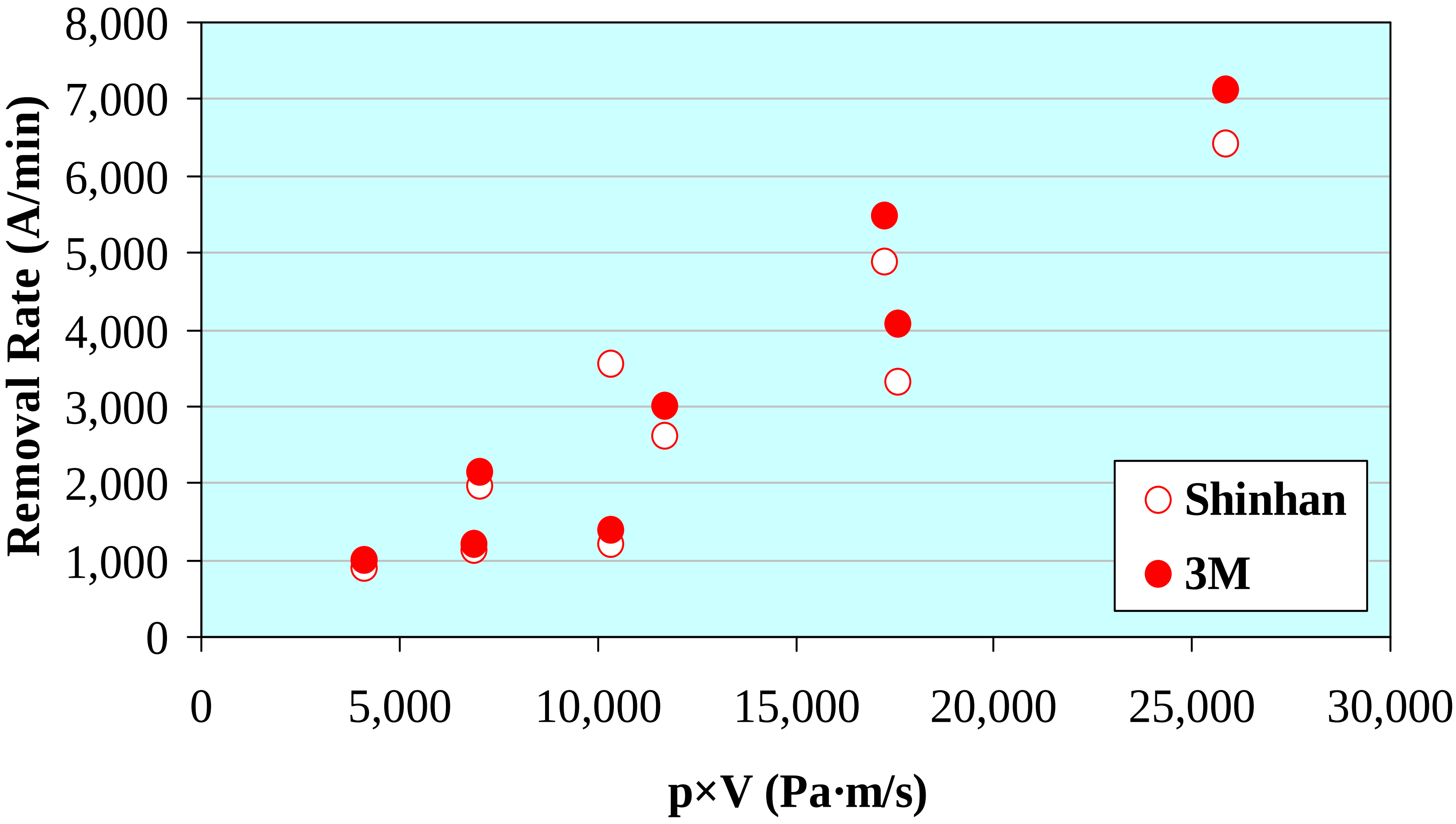
# Removal Rate vs. p × V

## IC1000



# Removal Rate vs. p × V

## D100



# 2-Step Removal Rate Model

- **Modified Langmuir-Hinshelwood model:**
  - **n moles of reactant R in the slurry react at rate $k_1$ with copper film on the wafer to form a product layer L on the surface**

$$\underline{Cu} + nR \xrightarrow{k_1} \underline{L} \qquad \boxed{k_1 = A \times \exp(-E_a / kT)} \qquad \boxed{T = T_p + \frac{\beta}{V^{0.5+e}} \times COF \times p \times V}$$

  - **Product layer $\underline{L}$ is subsequently removed by mechanical abrasion with rate $k_2$**

$$\underline{L} \xrightarrow{k_2} L \qquad \boxed{k_2 = C_p \times COF \times p \times V}$$

  - **Abraded material $L$ is carried away by the slurry**

- **The removal rate in this sequential mechanism therefore <u>is a function of both thermal and mechanical attributes of the process</u>**

$$\boxed{RR = \frac{M_w}{\rho} \frac{k_1 k_2}{k_1 + k_2}}$$

# Fitting Parameters

| | |
|---|---|
| $E_a$ | Activation Energy (eV) |
| A | Pre-exponential factor of chemical rate constant<br>(mole $\times$ $m^{-2}$ $s^{-1}$) |
| $C_p$ | Proportionality constant of mechanical rate constant<br>(mole/J) |
| e | Exponential factor of sliding velocity derived from pad heat partition fraction |
| $\beta$ | A constant that depend on wafer size, tool geometry and properties of pad surface and bulk material<br>($10^{-3}$ K/Pa(m/s)$^{0.5-e}$) |

# Summary of Optimized Parameters

## Based on Two Level Optimization Process

| Fitting Parameters | IC1000 Shinhan | IC1000 3M | D100 Shinhan | D100 3M |
|---|---|---|---|---|
| $E_a$ (eV) | 1.267 | 1.267 | 1.267 | 1.267 |
| A ($10^{17}$ mole $\times$ $m^{-2}$ $s^{-1}$) | 7.734 | 7.734 | 7.734 | 7.734 |
| $C_p$ ($10^{-7}$ mole/J) | 1.640 | 1.536 | 1.550 | 1.667 |
| e | 1.562 | 1.901 | 1.006 | 0.740 |
| $\beta$ ($10^{-3}$ K/Pa(m/s)$^{0.5-e}$) | 1.967 | 2.133 | 1.143 | 1.176 |
| RMS (A/min) | 145 | 176 | 84 | 74 |

# Summary of $k_1/k_2$

| Pressure (PSI) | Velocity (m/s) | $k_1/k_2$ | | | |
|---|---|---|---|---|---|
| | | IC1000 Shinhan | IC1000 3M | D100 Shinhan | D100 3M |
| 1.0 | 0.6 | 3.6 | 5.2 | 2.2 | 2.1 |
| 1.7 | 0.6 | 8.0 | 17.6 | 3.0 | 2.8 |
| 2.5 | 0.6 | 41.3 | 206.1 | 5.7 | NA |
| 1.0 | 1.0 | 2.3 | 2.5 | 1.3 | 1.5 |
| 1.7 | 1.0 | 2.4 | 3.4 | 1.7 | 2.1 |
| 2.5 | 1.0 | 7.0 | 14.5 | 2.9 | 3.7 |
| 1.0 | 1.5 | 3.6 | 4.7 | 1.0 | 1.1 |
| 1.7 | 1.5 | 1.1 | 1.2 | 1.3 | 1.8 |
| 2.5 | 1.5 | 2.7 | 3.6 | 2.3 | 3.3 |

# Summary of Year – 1 Results

- RR results for all combinations of 2 pads and 2 discs showed gross non-Prestonian behavior
- Compared to D100, the IC1000 pad exhibited a much faster transition from boundary lubrication to partial lubrication mode
- The 2-step Langmuir-Hinshelwood model successfully simulated the non-Prestonian RR results thus indicating that the observed scatter could be fully explained theoretically
- Wilcoxon Signed Rank test of simulation results showed that:
    - D100 exhibited a more chemically-controlled process (CCP) than IC1000
    - Shinhan exhibited a more CCP than 3M

# Industrial Interactions and Technology Transfer

**Industrial mentors and contacts:**

- **Don Hooper (Intel)**
- **Mansour Moinpour (Intel)**
- **Cliff Spiro (Cabot Microelectronics)**
- **Peter Ojerholm (Ehwa)**

# Future Plans

## Next Year Plans

- **Repeat all of the tests (i.e. effect of pad and process conditions) and simulations performed in Year – 1 with 2 different Ehwa disc (already completed)**
- **Identify consumables and optimum polishing conditions and run 300 mm patterned wafers for pad analysis**
- **Examine pad samples under static loading using a flat sapphire window to determine wafer-level topography, pad-wafer contact and near-contact area, pad asperity shape and density and number of large pad debris**

# Future Plans

## Long-Term Plans

- Examine limited number of pad samples under static loading using a patterned sapphire window to better mimic the contact phenomena that the pad actually sees during patterned wafer polishing
- Determine contact area, pad asperity shape and density and number of large pad debris
- Correlate planarization behavior with contact area data
- Tie observational data together with rough surface contact and RR models
- Propose methodology for using confocal microscopy as part of a screening process or diagnostic technique for new consumables and processes

# Contamination Control in Gas Distribution Systems

## *Customized Project;  Sponsored by Intel*

**PI:**

- **Farhang Shadman, Ph.D., Professor of Chemical and Environmental Engineering, UA**

**Co-PI:**

- **Carl Geisert, Sr. Principal Engineer, Intel**

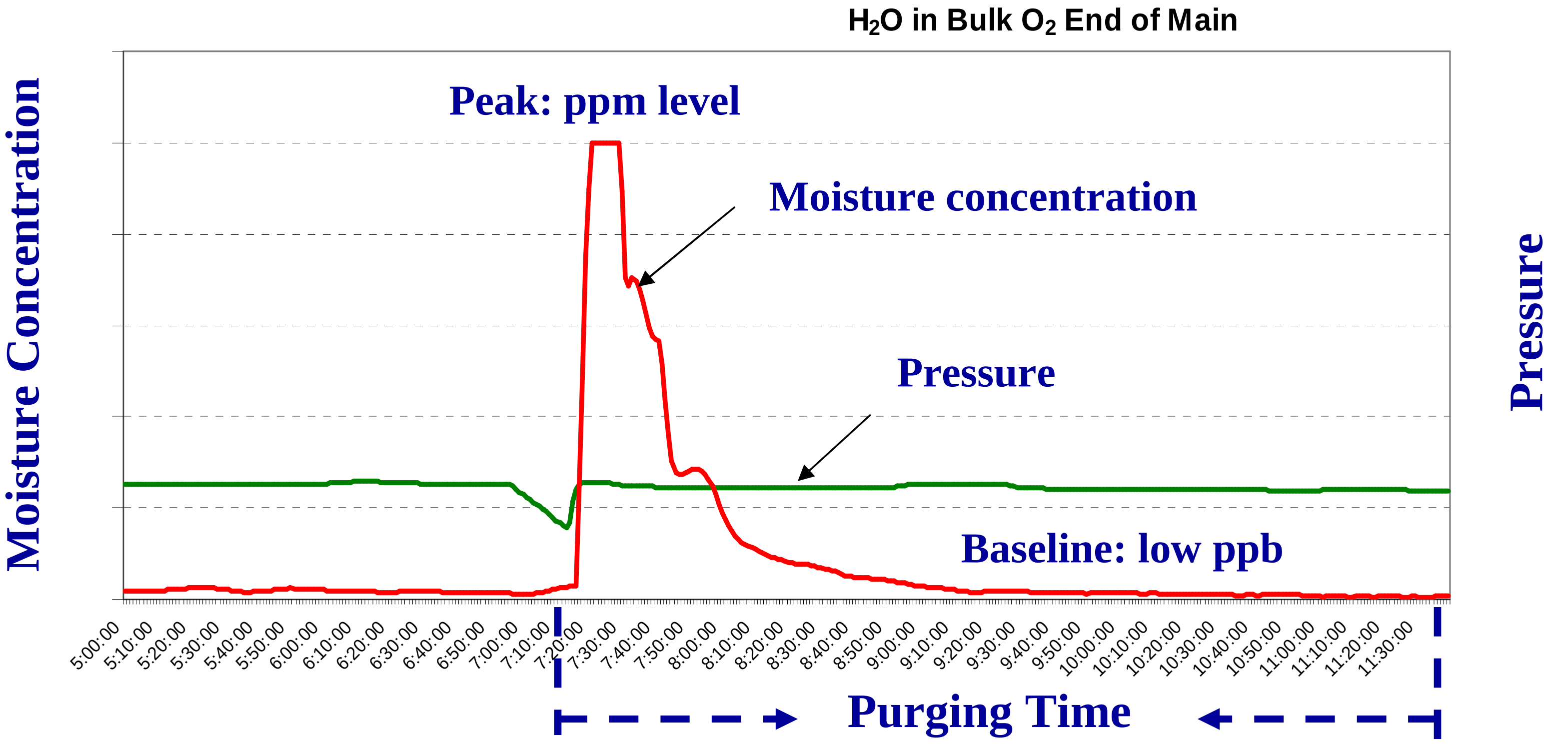
**Research Engineer:**

- **Junpin Yao: Ph.D., Postdoctoral, Chemical and Environ Eng, UA**

**Graduate Students:**

- **Hao Wang: Ph.D. student, Chemical and Environmental Engineering, UA**
- **Roy Dittler: Ph.D. student, Chemical and Environmental Engineering, UA**

# Moisture Contamination & Dry-down



***days ~ several weeks***

***Fab closure due to contamination of the gas distribution system could result in revenue loss between $5M and $15 M/day***

**** Source: Intel***

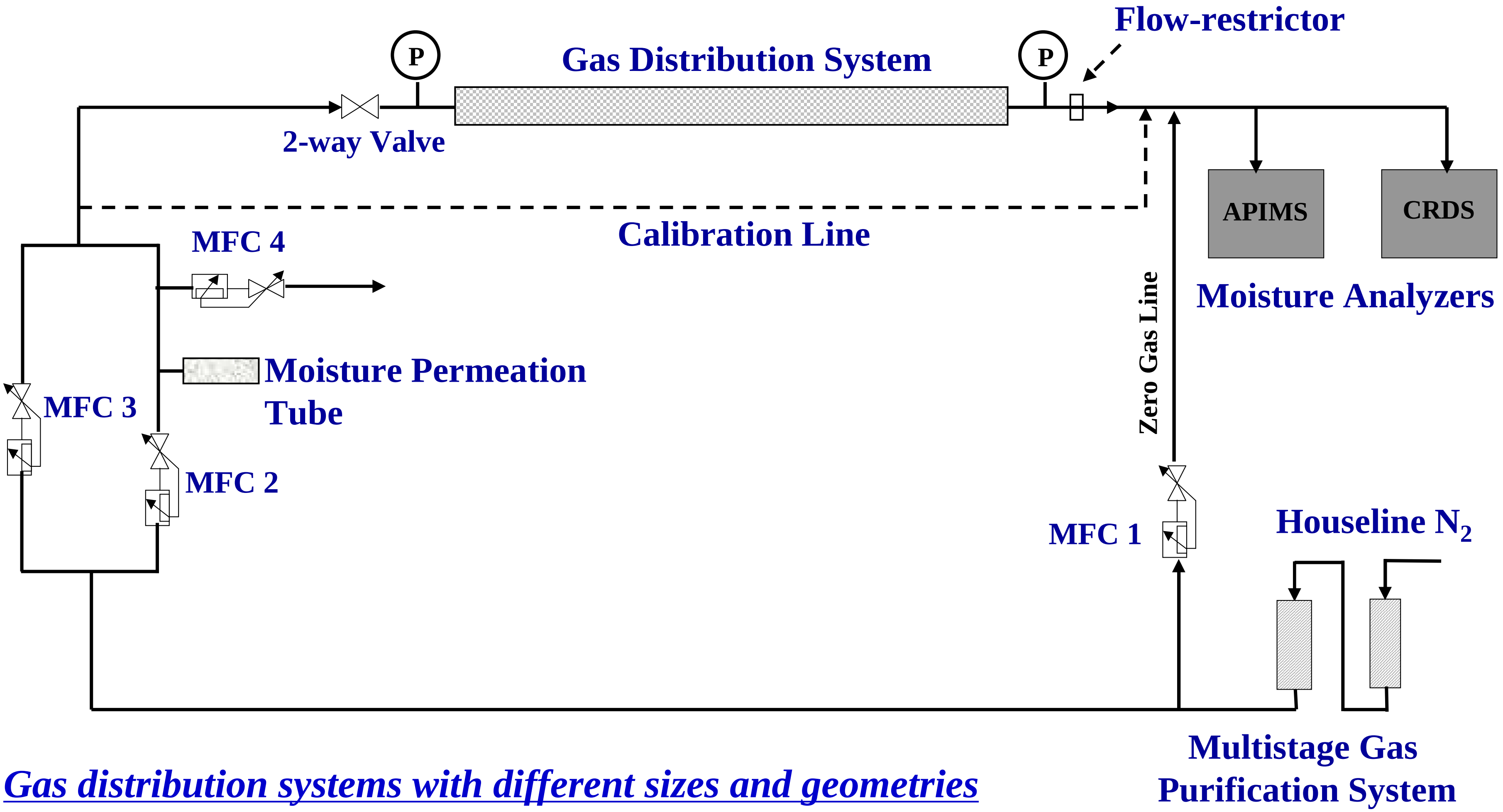
# Objectives

- Develop tools and techniques for analysis of contamination distribution and removal in ultra-pure gas distribution systems.
- Develop and validate a user-friendly process simulator suitable for field application to minimize purge time and gas usage during system start up, system recovery, or during the operation of gas distribution systems.

# ESH Impact

- Significant reduction in the usage of resources (ultra-pure gas and energy) as well as reduction of dry-down time.

# Experimental Set-up and Testbed

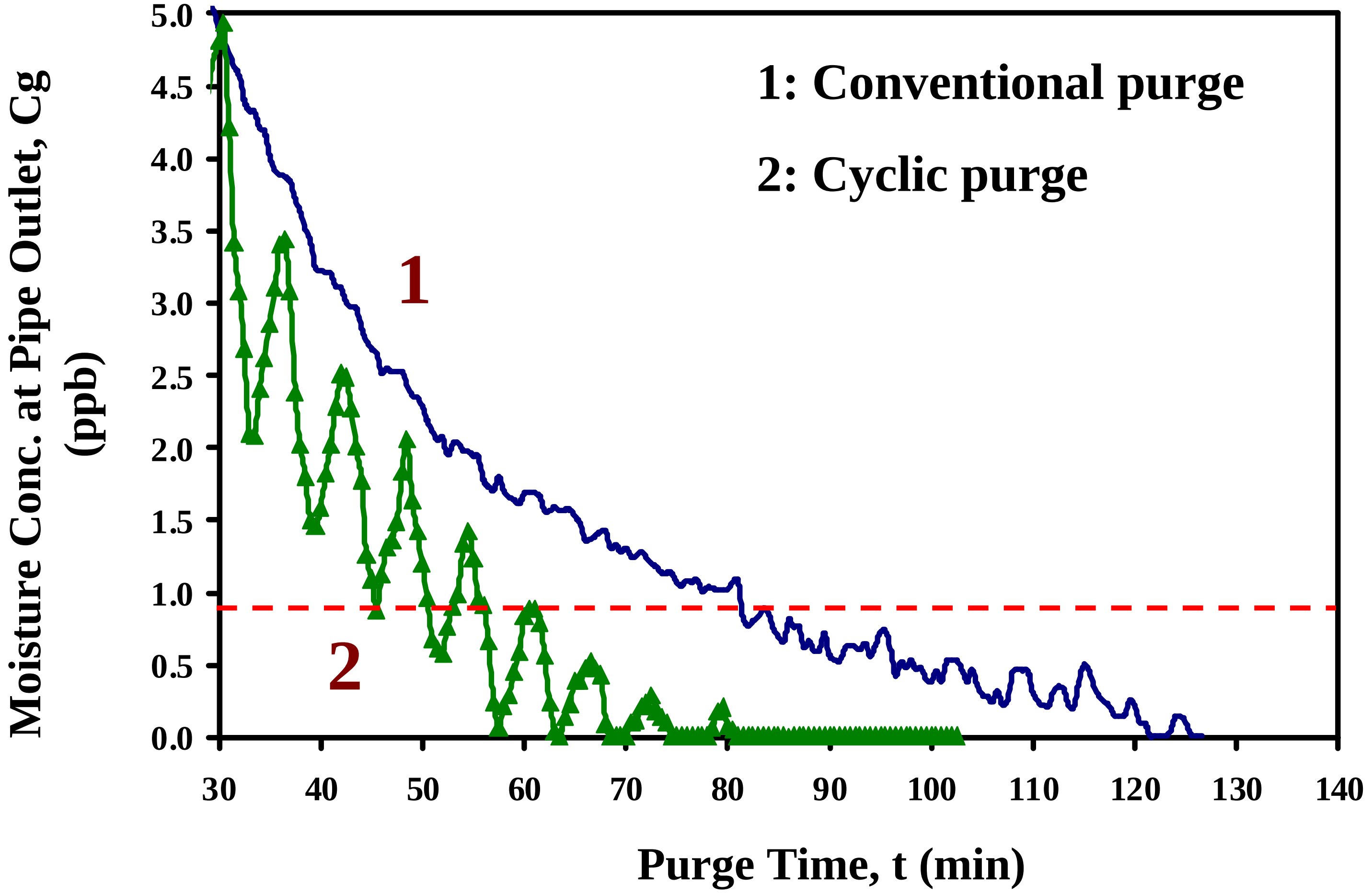


***Gas distribution systems with different sizes and geometries were fabricated and provided by Intel; CRDS (Tiger Optics): middle ppb – low ppm; APIMS: sub ppb – low ppb***

# Cyclic Purge vs. Conventional Purge

*Lab-scale system*

EP SS pipe with 1.5 inch OD and 76 inch length. Initial conc. 90 ppb



***To reach 1 ppb baseline:*** ***conventional purge: 80 minutes; Cyclic purge: 45 minutes ; cyclic purge saves 40% of purge gas.***

# Purge Process Simulator

**System Pressure:**

$$\frac{\partial P}{\partial t} = -P\frac{\partial u}{\partial x} - u\frac{\partial P}{\partial x}$$

**Velocity:**

$$\frac{\partial u}{\partial t} = -\frac{RT}{PM}\frac{\partial P}{\partial x} - u\frac{\partial u}{\partial x}$$

**Absorbed Moisture:**

$$\frac{\partial C_s}{\partial t} = k_a C_g (S_0 - C_S) - k_d C_s$$

**Gas Phase Moisture:**

$$\frac{\partial C_g}{\partial t} = D_L \frac{\partial^2 C_g}{\partial x^2} + \frac{\partial D_L}{\partial x}\frac{\partial C_g}{\partial x} - u\frac{\partial C_g}{\partial x} - C_g\frac{\partial u}{\partial x} + \frac{4}{d}\left[(k_d C_S - k_a C_g (S_0 - C_S))\right]$$

*$C_S$: moisture concentration on pipe wall, mol/cm$^2$; $C_g$: moisture concentration in gas, mol/cm$^3$;*

*$k_{ads}$: adsorption rate constant, cm$^3$/mol/s; $k_{des}$: desorption rate constant, 1/s*

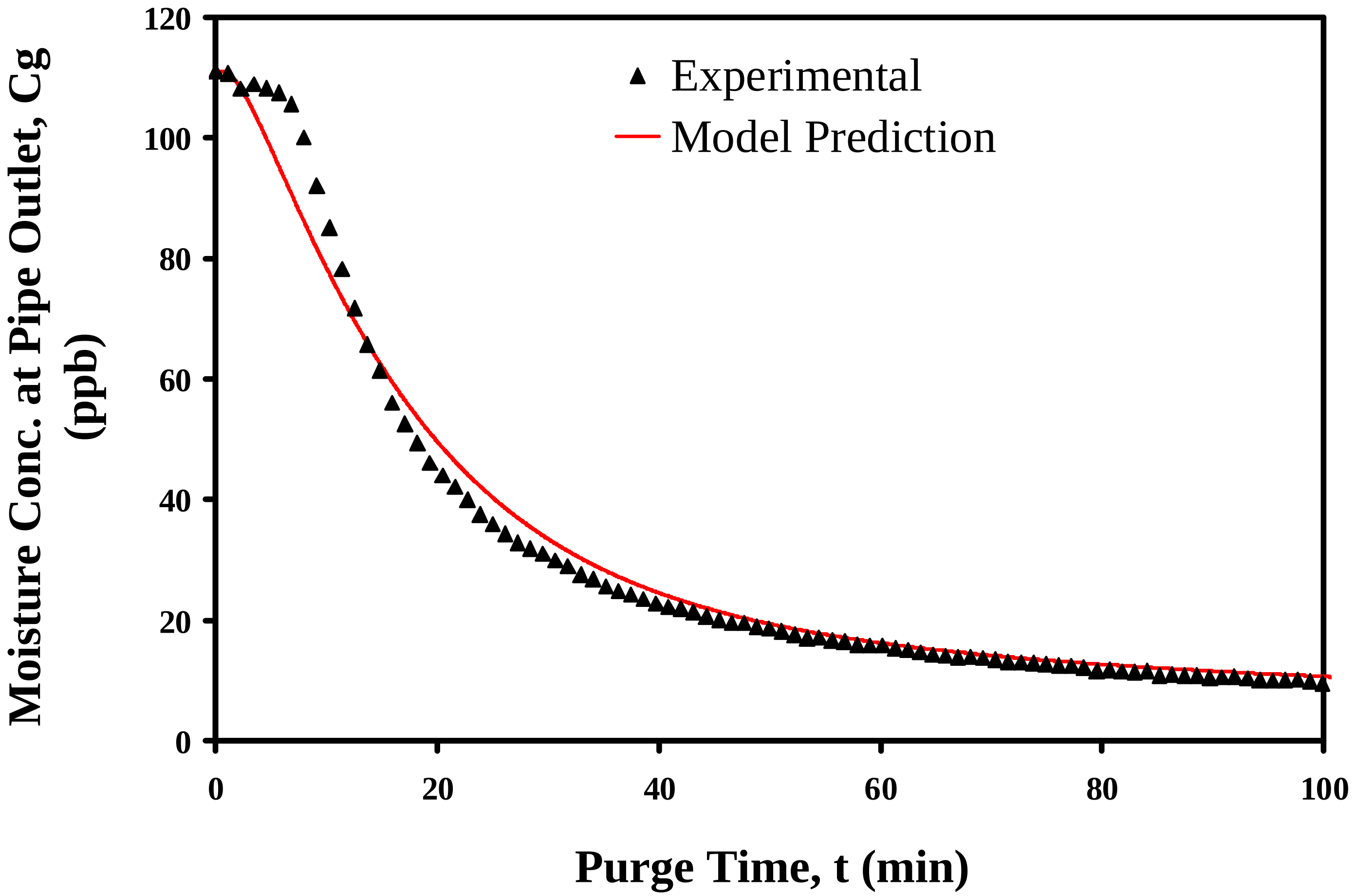
*$S_0$: site density of surface adsorption, mol/cm$^2$; $D_L$: dispersion coefficient, cm$^2$/s;*

*u: velocity, cm/s; d: diameter; P: pressure*

***The simulator is scalable and applicable to various size systems***

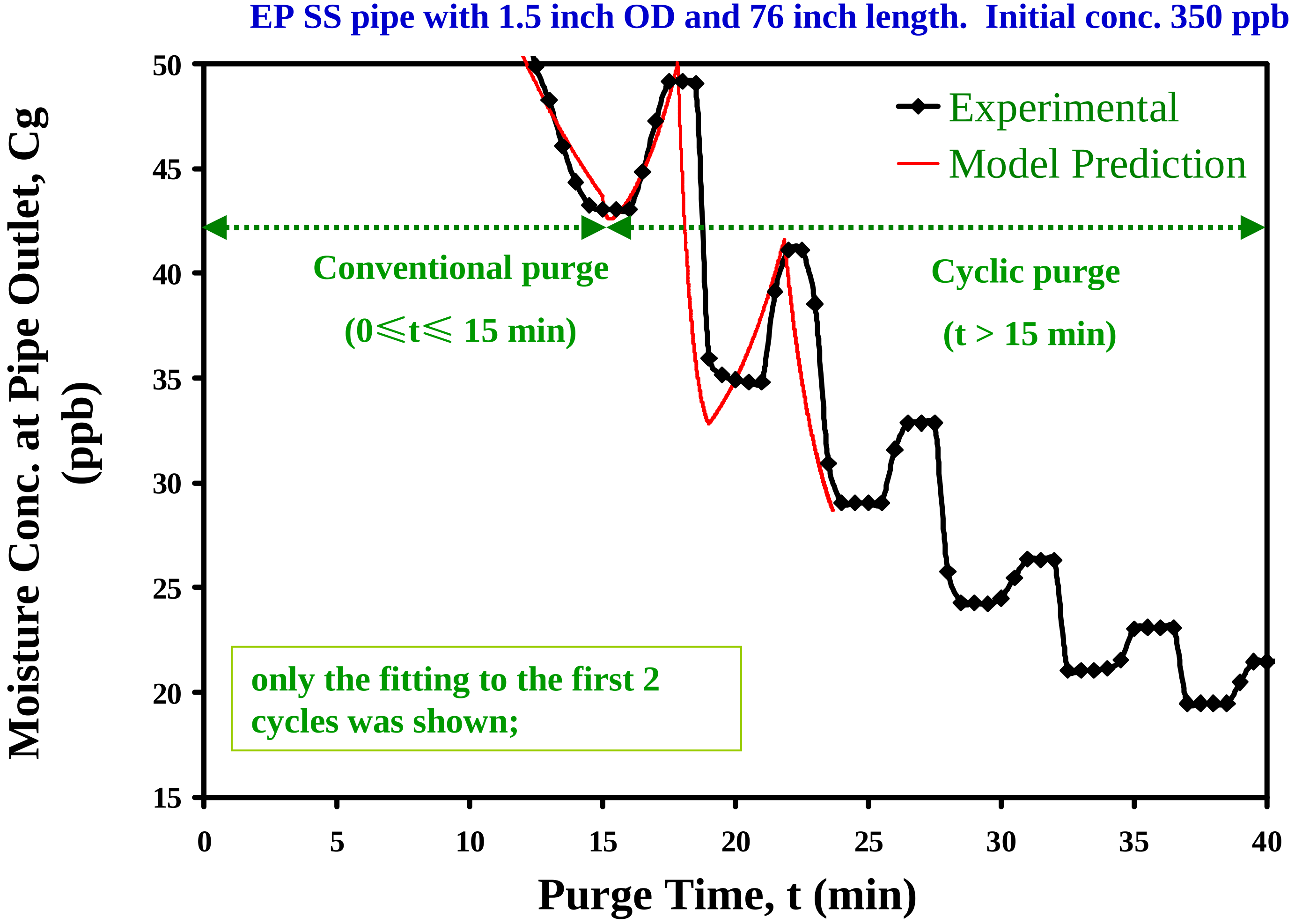
# Simulator Verification- Predicting Conventional Purge

**EP SS pipe with 1.5 inch OD and 76 inch length. Initial conc. 115 ppb**



***The process simulator well predicts conventional purge process***

# Simulator Verification- Predicting Conventional and Pressure-cyclic Purge

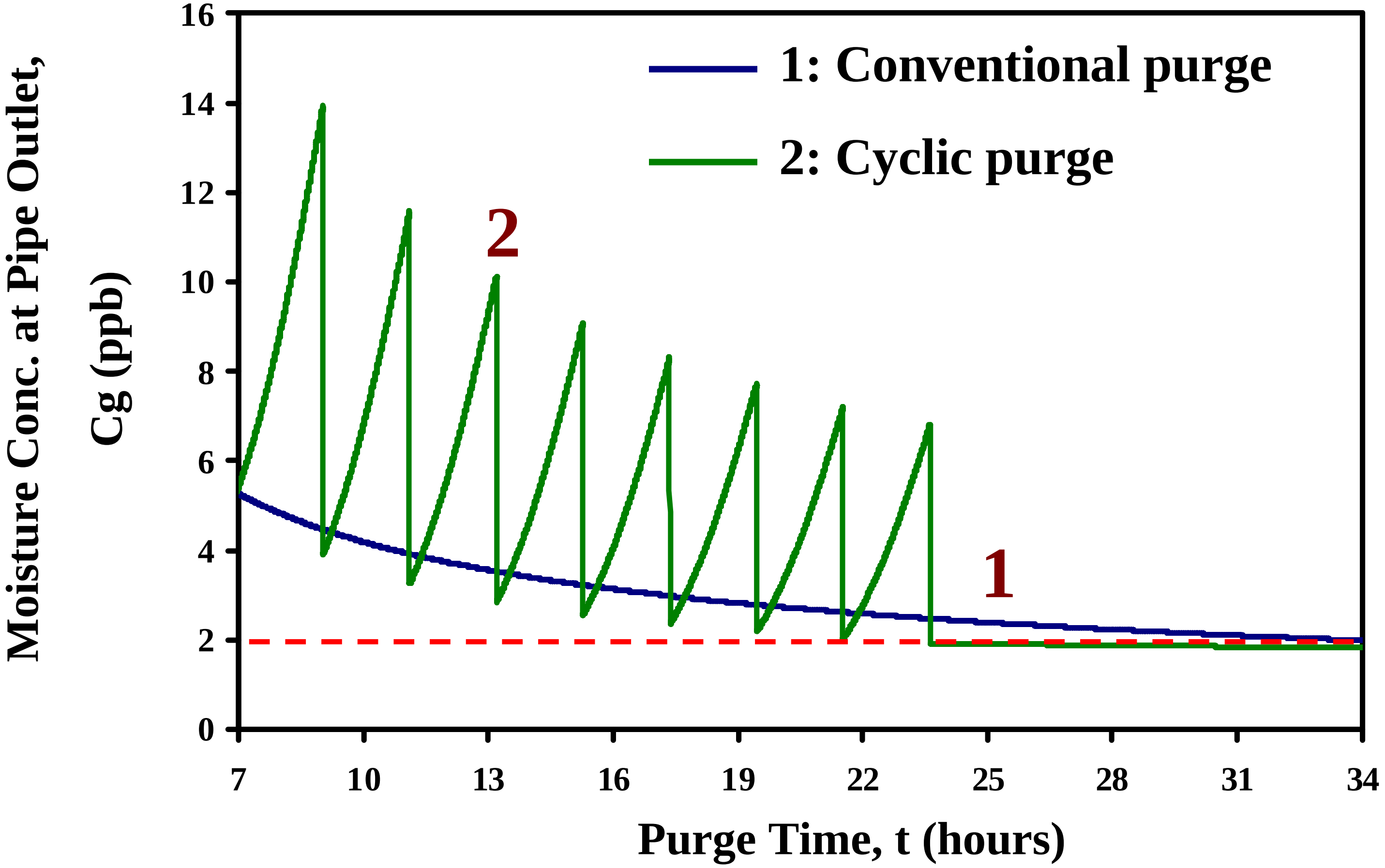


***The process simulator well predicts combination of conventional and cyclic purge processes***

# Cyclic Purge vs. Conventional Purge

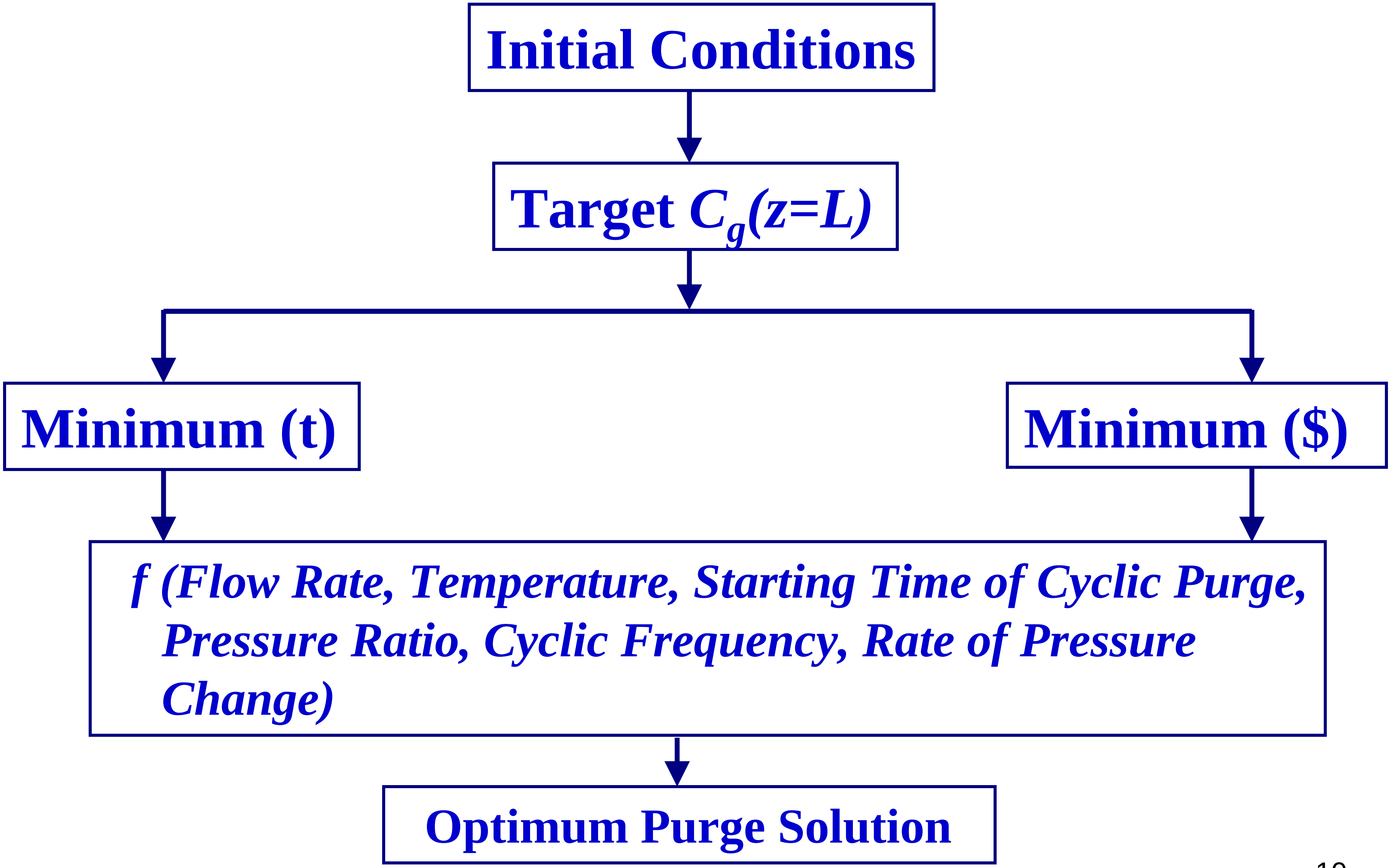
***Industrial-scale system***

**EP SS pipe with 1.5 inch OD and 1640 feet length. Initial conc. 200 ppb; cyclic purge starts when the moisture concentration reaches 5 ppb.**



***To reach 2 ppb baseline:*** ***conventional purge: 34 hours; Cyclic purge: 23 hours; cyclic purge saves 76% of purge gas***

# Optimization of Purging Processes



**Initial Conditions**

**Target $C_g(z=L)$**

**Minimum (t)**

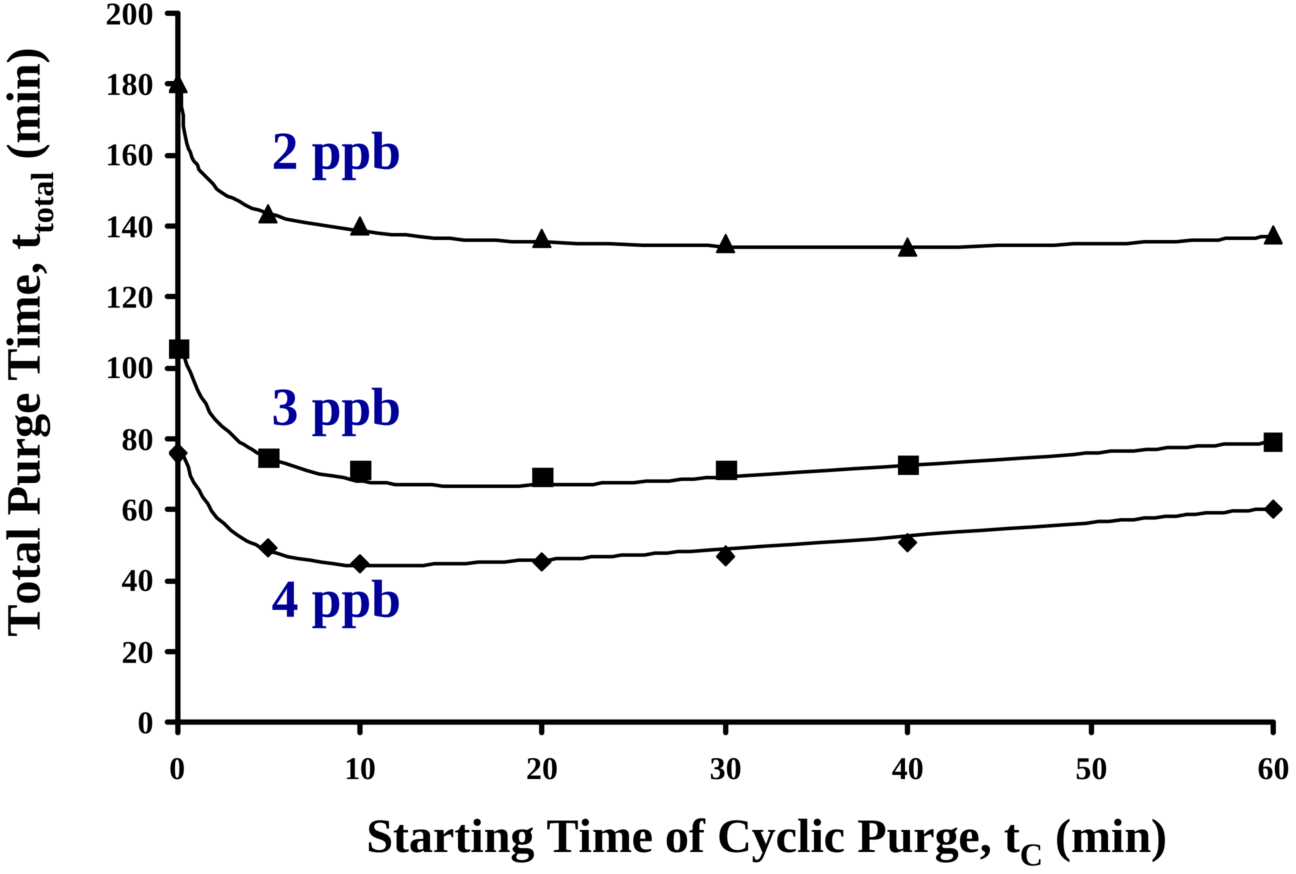
**Minimum ($)**

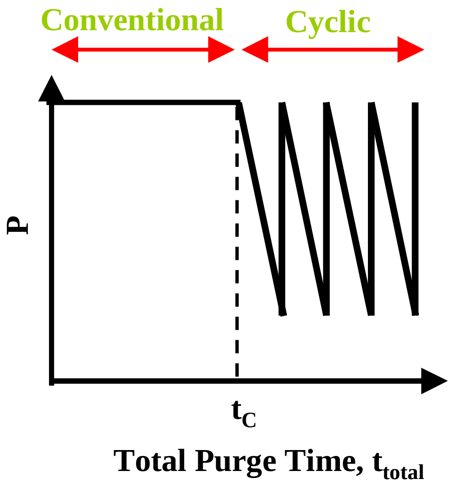
***f (Flow Rate, Temperature, Starting Time of Cyclic Purge, Pressure Ratio, Cyclic Frequency, Rate of Pressure Change)***

**Optimum Purge Solution**

# Optimum Starting Time of Cyclic Purge

**Pipe Length: 10 m, O.D.: 1.5 inch; initial conc.: 200 ppb**





***The starting time of cyclic purge needs to be optimized in order to minimize the total purge time***

*SRC/Sematech Engineering Research Center for Environmentally Benign Semiconductor Manufacturing*

# Highlights

- **Compared with conventional purge with high system pressure and high purging gas flow rate, pressure cyclic purge takes less purge time and consumes less purge gas usage.**
- **The purge process simulator developed in this work well predicts experimental results and can be applicable to various size systems.**
- **Purge process must be optimized in order to minimize the total purge time and gas usage.**

# Interactions and Future Plans

- **Continue working with Intel on this customized joint project; initiate similar applications and studies for other members**
- **Prepare a process simulator for field applications**

# Presentations and Papers

- **Lowering Material and Energy Usage during Purging Ultra-High-Purity Gas Distribution Systems (presenter), AIChE 2009 Annual Meeting, Nov. 2009, Nashville, Tennessee.**
- **Application of Pressure Cyclic Purge (PCP) in Dry-down of Ultra-High-Purity Gas Distribution Systems, under preparation and will be submitted to *Chemical Engineering Sciences***

# Acknowledgements

- **Intel: Val Strazds**
- **Tiger Optics LLC**

# Integrated Electrochemical Treatment of CMP Waste Streams for Water Reclaim and Conservation (Customized Project)

**PIs:**

- **James Farrell, Chemical and Environmental Engineering, UA**
- **James C. Baygents, Chemical and Environmental Engineering, UA**

**Graduate Students:**

- **Francis Dakubo, PhD candidate, Chemical and Environmental Engineering, UA**
- **David Hubler, PhD candidate, Chemical and Environmental Engineering, UA**
- **Mark Brown, MS candidate, Chemical and Environmental Engineering, UA**
- **Pui Foon Lai, MS candidate, Chemical and Environmental Engineering, UA**

**Undergraduate Students:**

- **Jake Davis, Ritika Mohan, Kyle Kryger, Chemical Engineering, UA**

**Cost Share (other than core ERC funding):**

- **GEP Smith Fellowship (D. Hubler), Triffet Prize (D. Hubler), Mining Engineering Fellowship (F. Dakubo), NASA Space Grant Fellowship (K. Kryger), Water Sustainability Program Fellowship (R. Mohan)**
- **Water Resources Research Center ($17K)**

# Objectives

- Develop an electrochemical method for removing $Cu^{2+}$, $H_2O_2$, colloidal abrasives, chelating agents and corrosion inhibitors from wastewater generated during CMP.
- Compare contaminant removal with industry benchmarks for use of reclaimed water.
- Build a prototype reactor and pilot test on real CMP wastewater.
- Compare the economic impact per gallon of water used in semiconductor industry to impact for other water uses.

# ESH Metrics and Impact

1. *Reduction in emission of ESH-problematic material to the environment*

- Eliminate the disposal problems associated with membrane concentrates.
- Eliminate the disposal of Cu-laden nanoparticles into hazardous waste landfills.

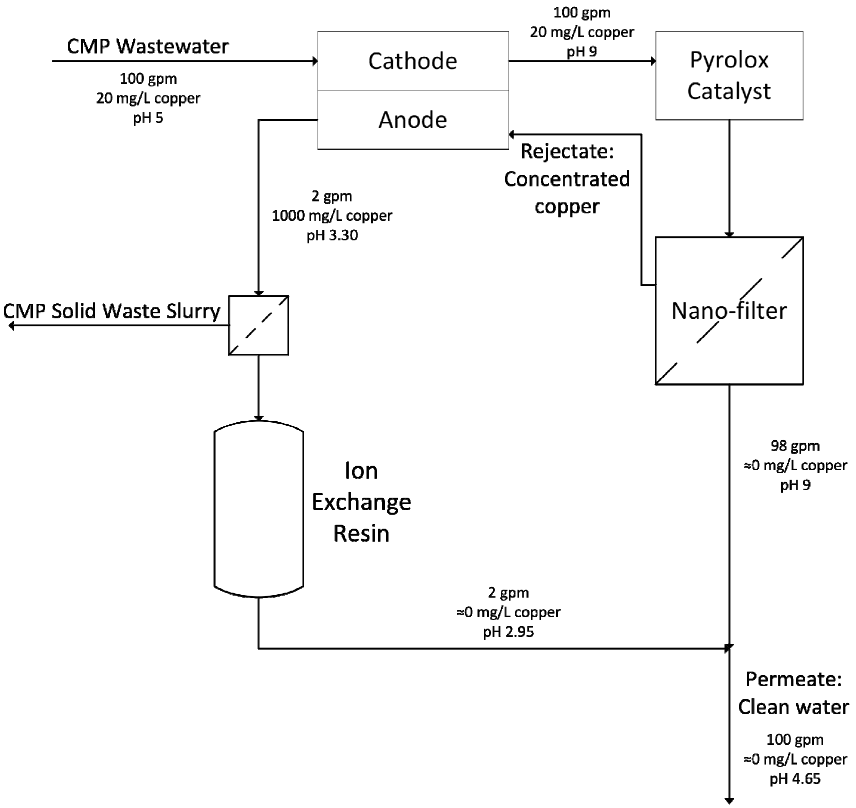
2. *Reduction in the use of natural resources (water and energy)*

- Reclaim CMP wastewater for use in mechanical systems.
- CMP wastewater accounts for up to 30% of fab water use.

3. *Reduction in the use of chemicals*

- Eliminate the need for pH adjusting chemicals and reducing agents that add to TDS load.
- Eliminate the need for activated carbon regeneration.

# Electrochemical Treatment System



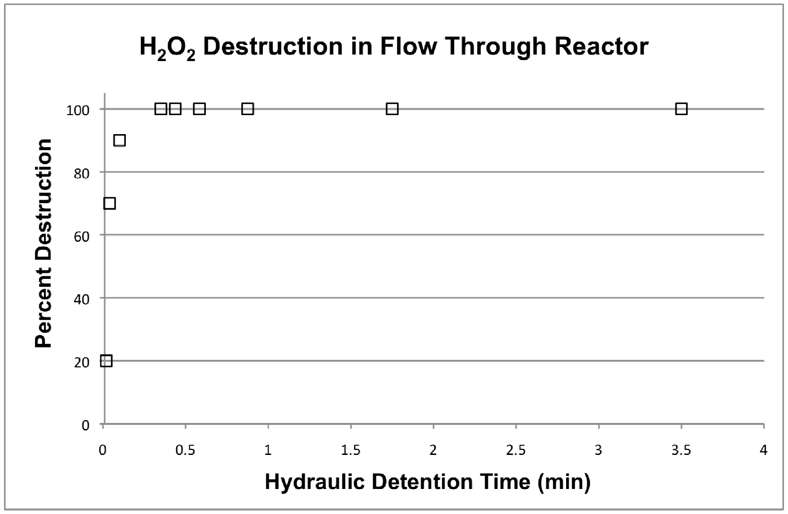
System combines standard filtration unit operations with:

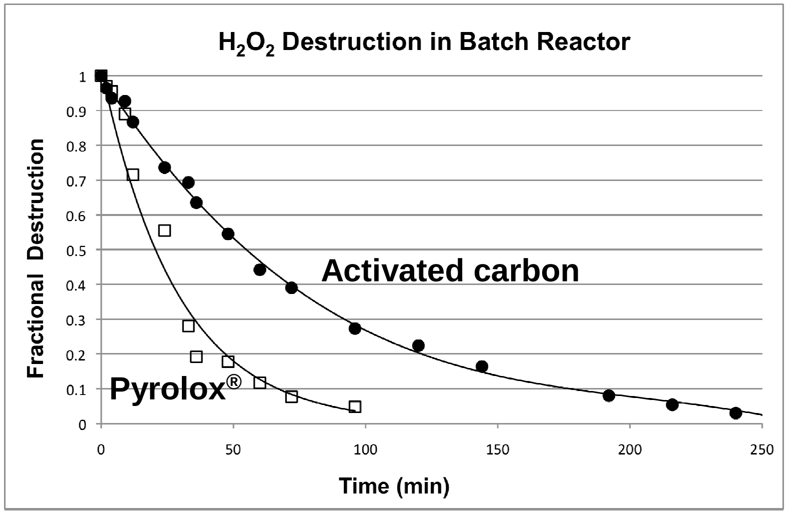
1)novel $H_2O_2$ destruction catalyst
2)electrochemical pH manipulation
3)electrochemical ion exchange regeneration

Advantages of electrochemical treatment:

1) elimination of chemical additives (*e.g.*, pH adjusting chemicals)
2) elimination of secondary waste stream production requiring further treatment or disposal (*e.g.*, ion exchange brines)
3) small footprint, low capital and operating costs

# Peroxide Destruction Catalyst

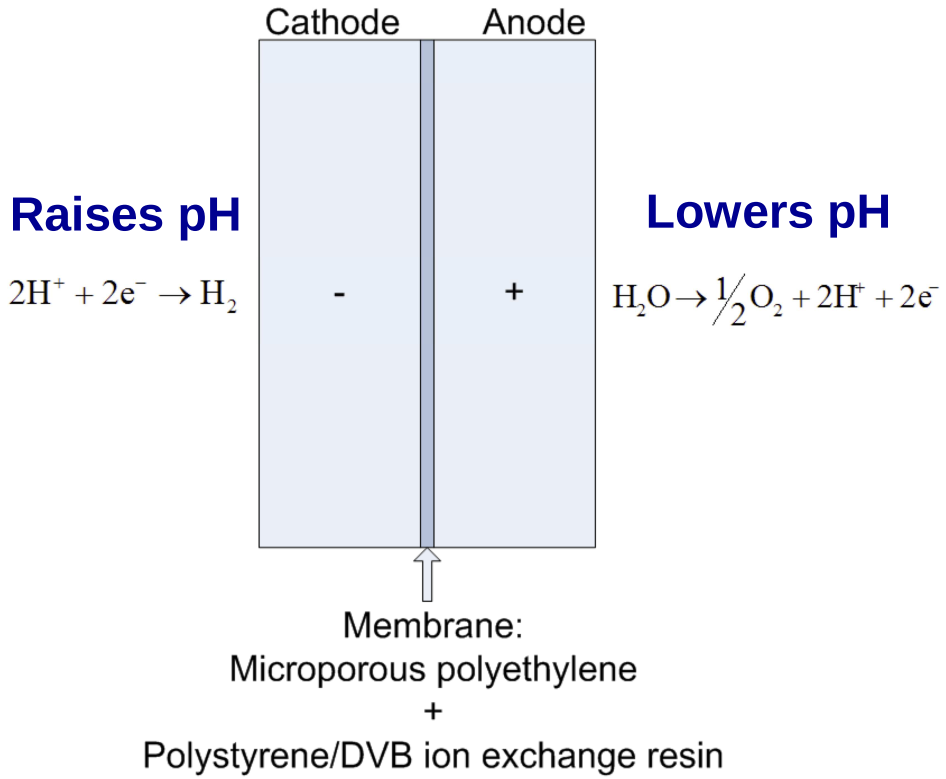




- Conducted tests on six possible peroxide destruction catalysts
- Conducted tests on ultrasonic, $O_3$ and UV-light peroxide destruction

- Pyrolox® (pyrolusite=β-$MnO_2$) catalyst determined to be the most effective
- Pyrolox® is commercially available and used for removing $Fe^{2+}$ from drinking water

# Membrane for Electrochemical pH Manipulation



Cathode

Anode

**Raises pH**

$2H^+ + 2e^- \rightarrow H_2$

-

+

**Lowers pH**

$H_2O \rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^-$

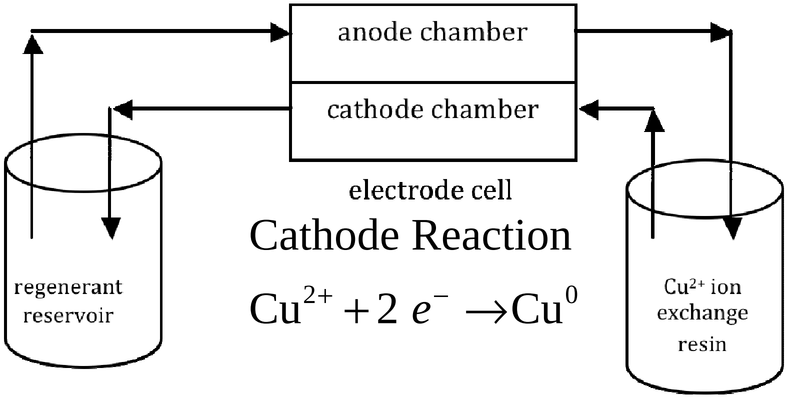
Membrane:
Microporous polyethylene
+
Polystyrene/DVB ion exchange resin

- Developed a novel membrane that is resistant to pinhole leaks common with conventional membranes
- Novel membrane will be useful in other electrochemical applications

# Electrochemical Ion Exchange Regeneration

Anode Reaction

$$H_2O \rightarrow 2\,H^+ + 0.5\,O_2 + 2\,e^-$$



Cathode Reaction

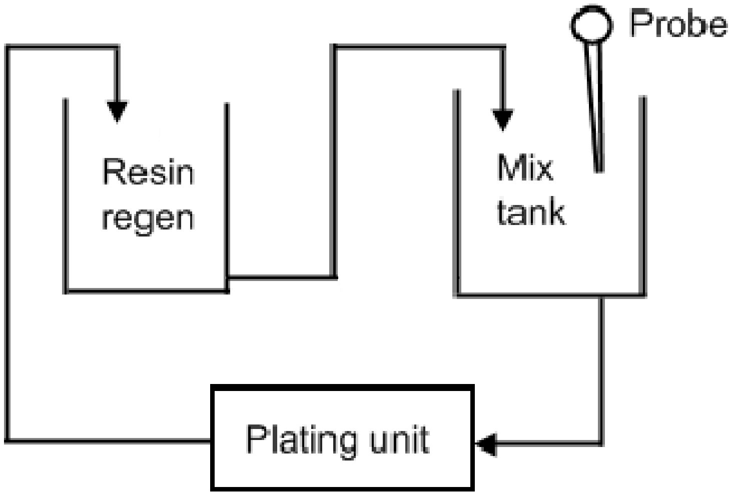
$$Cu^{2+} + 2\,e^- \rightarrow Cu^0$$

**Power cost = \$8.40/m$^3$-resin**

**Cu value = \$240/m$^3$-resin**

# Mathematical Model for Ion Exchange Regeneration

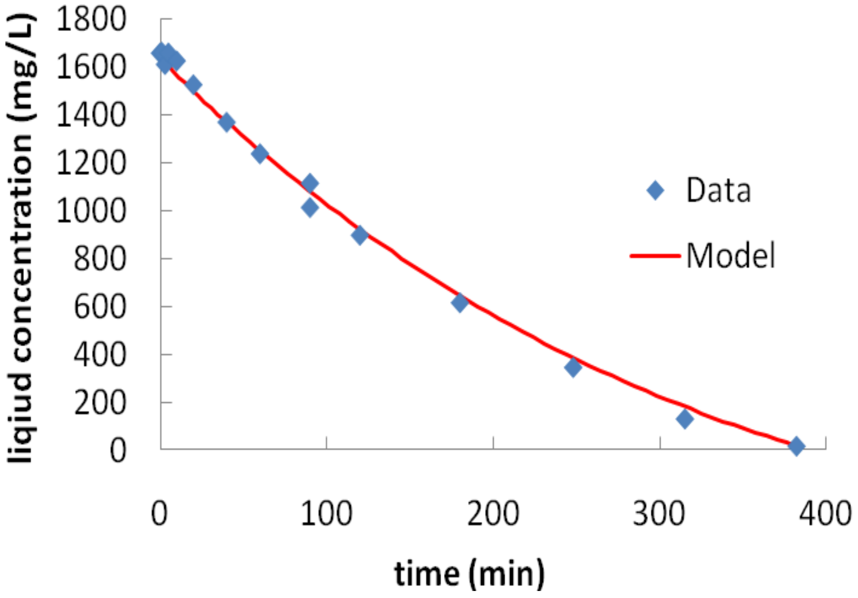
- Cu plating rate can be limited by mass transfer or applied current
- Trade-off between Cu plating rate and Faradaic efficiency
- Mathematical modeling used to optimize the plating rate for cost or time considerations

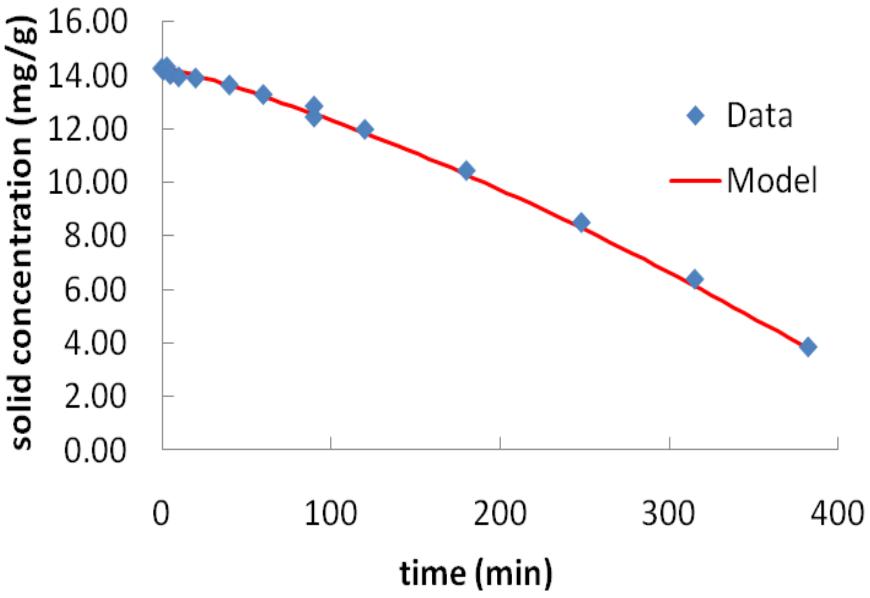


**Liquid mass balance:** $$\left(V_{MIX} + V_P + \varepsilon V_{RR}\right)\frac{dc}{dt} = -k_0 A + V_{RR} K_m \left[c^l_{eq}(c_s) - c\right]$$

**Solid mass balance:** $$V_{RR}\frac{dc_s}{dt} = -V_{RR} K_m \left[c^l_{eq}(c_s) - c\right]$$

# Resin Regeneration Modeling





- Modeling can predict both liquid and solid phase $Cu^{2+}$ concentrations
- Modeling will be used to scale-up from prototype to full scale system

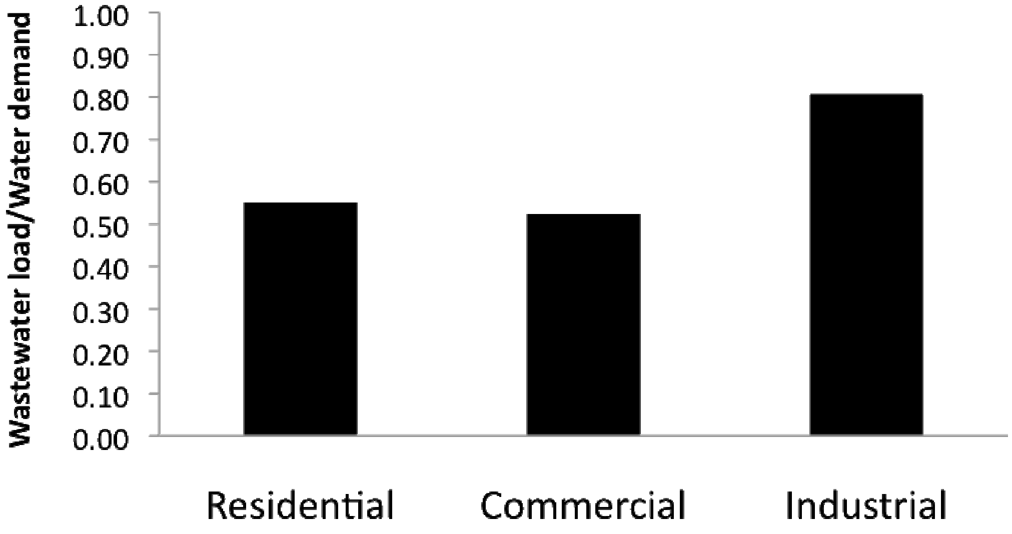
Parameters: $V_{MIX} = 6.0$ L; $V_{RR} = 3.4$ L; $V_P = 3.0$ L; $\varepsilon = 0.3$; $K_m = 0.162$ min-1; $k_0A = 110.7$ mg/min

Isotherm: $c_{liq} = (1/(1.97 \times 10^{-3})) \times (c_{sol}/(18.6 - c_{sol}))$, $c_{liq}$ in mg/L, $c_{sol}$ in mg/g

# Economic Impact of Semiconductor Water Use

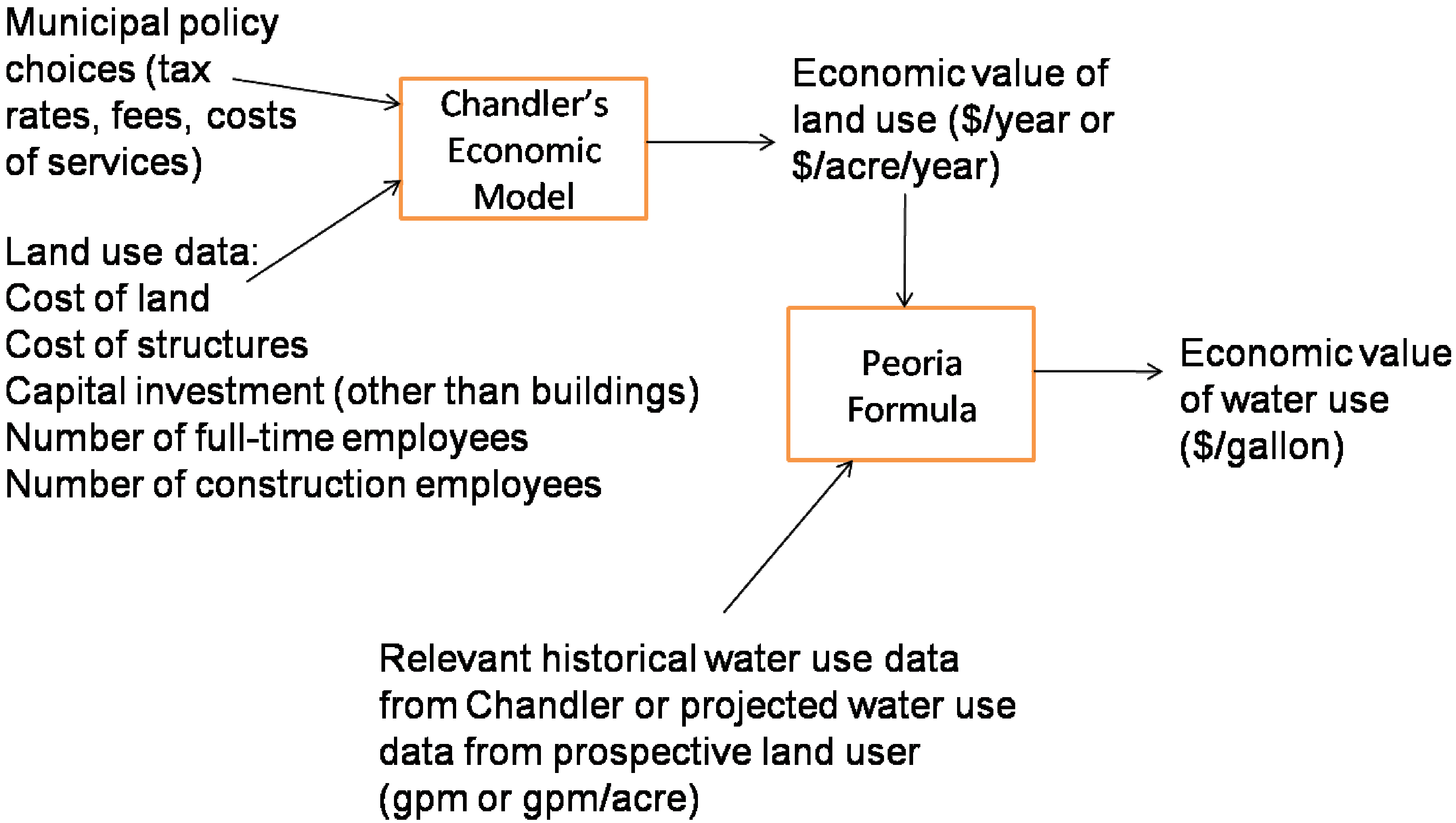
- Evaluate the economic benefits of selected uses of water
- Question: Is high volume semiconductor manufacturing a rational use of water, especially in a semi-arid community?
- Not just a matter of total water use, as industrial users can return more water to the city, and semiconductor HVM can go beyond other industrial users

**Fraction of water returned by different land users:**



# Economic Impact of Semiconductor Water Use

## Method for evaluating economic impact per gallon:



Municipal policy choices (tax rates, fees, costs of services)

Land use data:
Cost of land
Cost of structures
Capital investment (other than buildings)
Number of full-time employees
Number of construction employees

Chandler's Economic Model

Economic value of land use ($/year or $/acre/year)

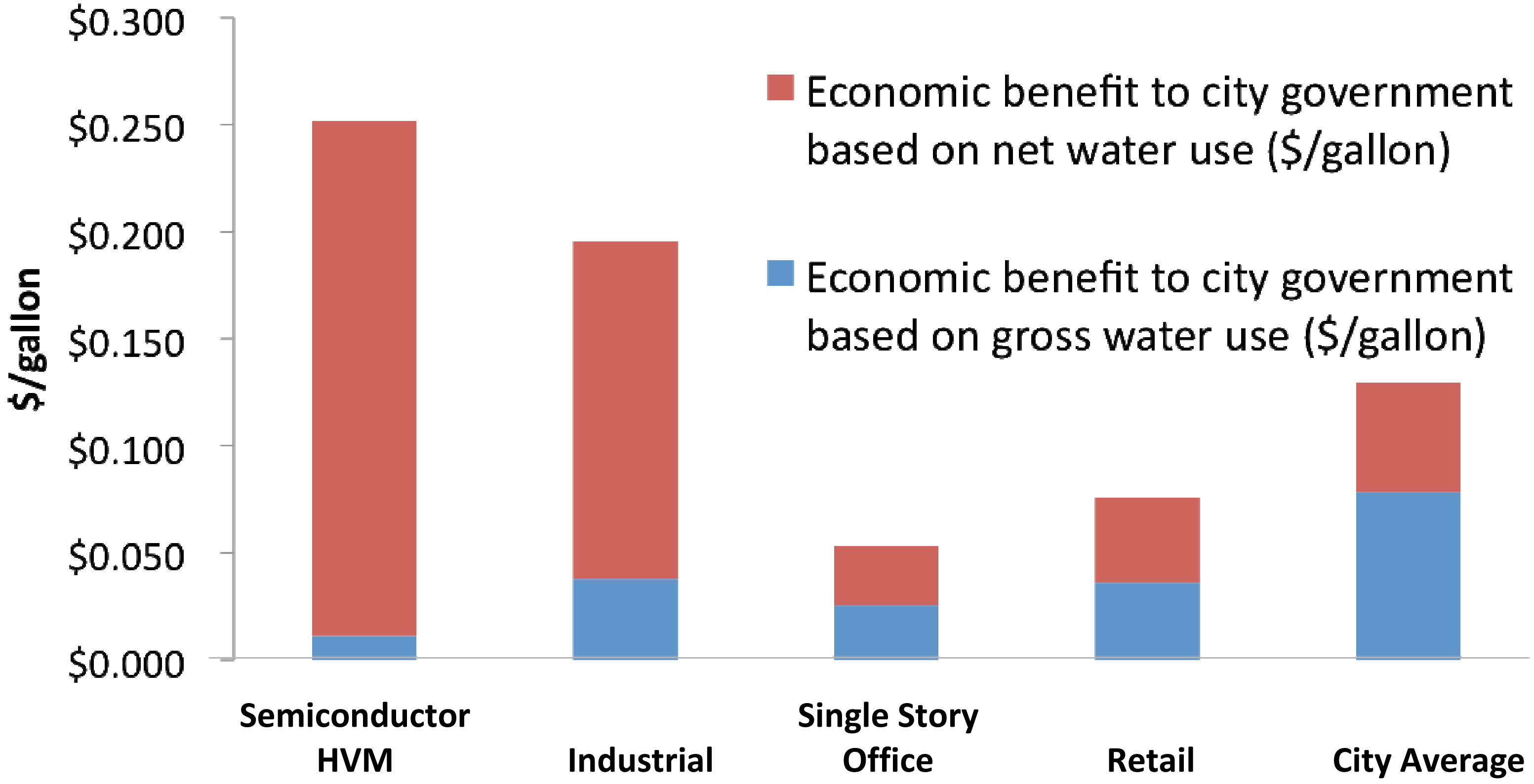
Peoria Formula

Relevant historical water use data from Chandler or projected water use data from prospective land user (gpm or gpm/acre)

Economic value of water use ($/gallon)

# Economic Impact of Semiconductor Water Use

## Economic benefit to city government:



- Semiconductor HVM is a reasonable use of water in semi-arid or arid communities, as long as infrastructure exists to recapture value from wastewater streams.

# Industrial Interactions and Technology Transfer

- **Don Hooper, Intel Corporation**
- **Dan Hodges, Intel Corporation**
- **Allen Boyce, Intel Corporation**
- **Avi Fuerst, Intel Corporation**

- **Sharon Megdal, Water Resources Research Center, UA**
- **Christine Mackay, Economic Development Director, Chandler, AZ**

# Future Plans

## Next Year Plans

- **Pilot test of complete system**

## Long-Term Plans

- **Apply electrochemical treatment methods to other wastewater streams**

# Publications, Presentations, and Recognitions/Awards

- **David Hubler: Triffet Prize and GEP Smith Fellowship**
- **Francis Dakubo: Department of Mining Engineering Fellowship**
- **Kyle Kryger: Ella Philipossian Memorial Scholarship & Pillars of Excellence Award**
- **David Hubler: First Place Award, University of Arizona 2009 Student Showcase, B.P.A. Division, November 6-7, 2009, Tucson, AZ**
- **“Economic Benefit of Commercial and Industrial Water Uses in a Semi-arid Municipality,” presented at the Arizona Hydrological Society/American Institute of Hydrology 2009 Hydrological Symposium, August 30-September 2, 2009, Scottsdale, AZ**
- **“Electrochemical Methods for Water Reclaim in Semiconductor Manufacturing,” presented at the International Conference on Microelectronics Pure Water, November 11-12, 2008, Mesa, AZ**
- **“Electrochemical Water Treatment using Diamond Film Electrodes,” presented at the University of Illinois at Urbana-Champaign, November 7, 2008**

# Optimization of Dilute Ammonia-Peroxide Mixture (APM) for High Volume Manufacturing Through Surface Chemical Investigations
# (Intel Customized Project)

PIs:

- Srini Raghavan, Material Science and Engineering, UA
- Jinhong Zhang, Mining and Geological Engineering, UA

Graduate Students:

- Shariq Siddiqui, PhD candidate, Material Science and Engineering, UA

Cost Share (other than core ERC funding):

- Horiba SC-1 monitor on loan

# Objectives

1) Optimization of ammonia-peroxide mixtures (APM) for particle removal through interaction force measurements using atomic force microscope (AFM).

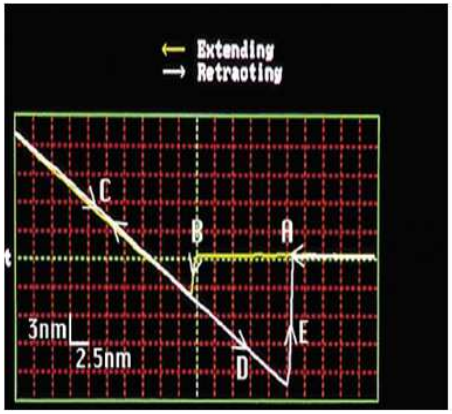
2) Investigate the stability of ammonium hydroxide and hydrogen peroxide in APM solutions as a function of temperature, dilution ratio and trace metal ion.

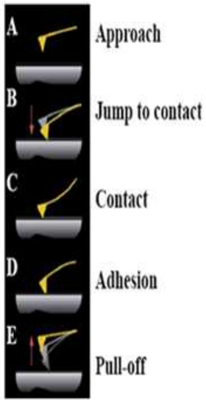
# RESULTS –Part I

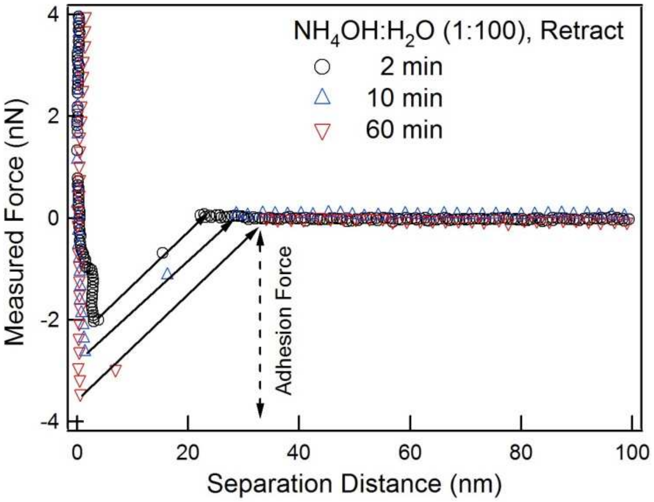
Force measurements between *H-terminated Si surface* and a *H-terminated Si tip* in dilute APM (1:1:100) solution and its components.

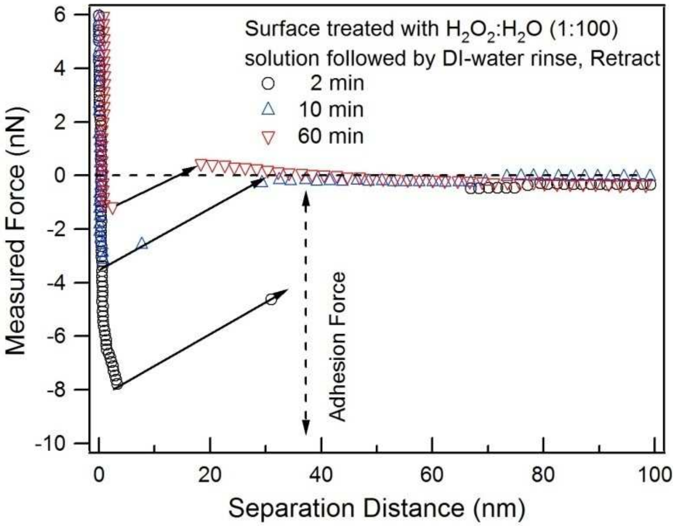
# Adhesion Force Measurements between a H-terminated Si surfaces in a dilute APM Solution & Components

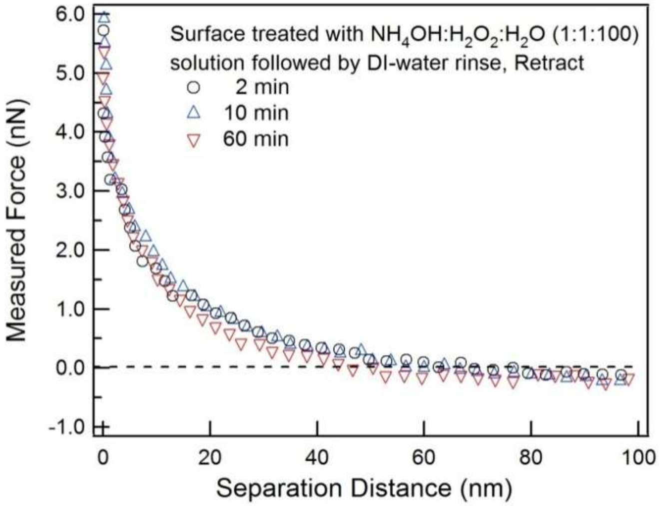
- p-type Si (100) substrate and Si AFM tip.





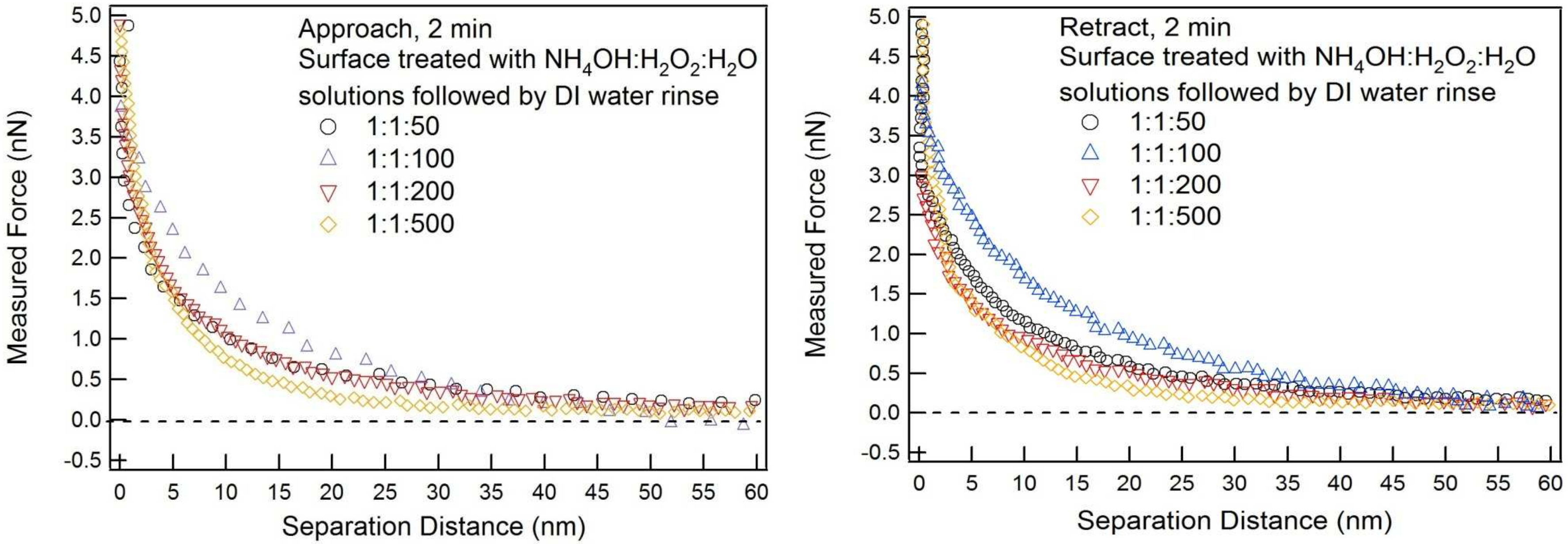






- Adhesion force exists between Si surface and Si tip $NH_4OH:H_2O$ (1:100) and $H_2O_2:H_2O$ (1:100) solutions.
- Only repulsive force was measured between Si surface and Si tip in a dilute APM 1:1:100 solution.

# Effect of dilution on Interaction forces between H-terminated Si surfaces

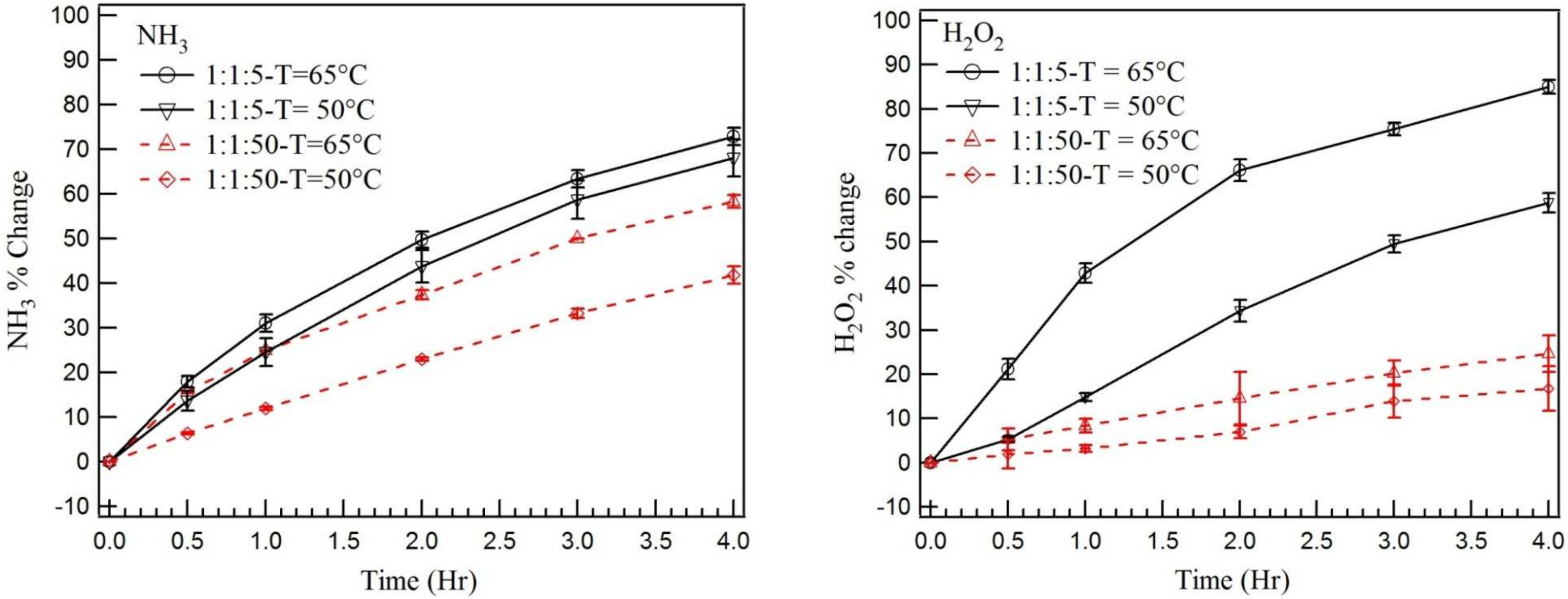


- Both approach and retract curves between Si surface and Si tip show a net repulsive force in APM solutions ranging from 1:1:50 to 1:1:500 within 2 min of immersion.
- *These results indicate that particle re-deposition can be prevented in even very dilute APM solutions*.

# RESULTS –Part II

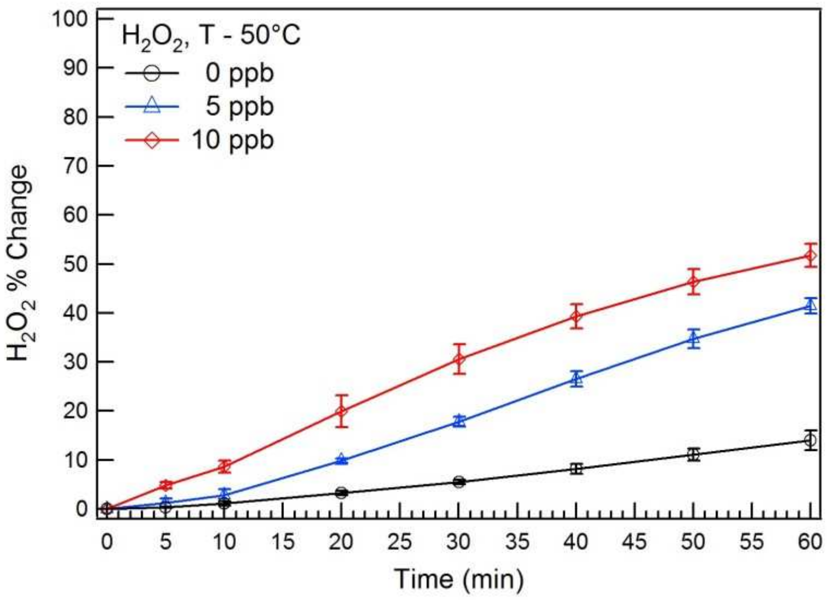
Measurement of the stability of *ammonium hydroxide* and *hydrogen peroxide* in APM solutions using Horiba SC-1 composition monitor.

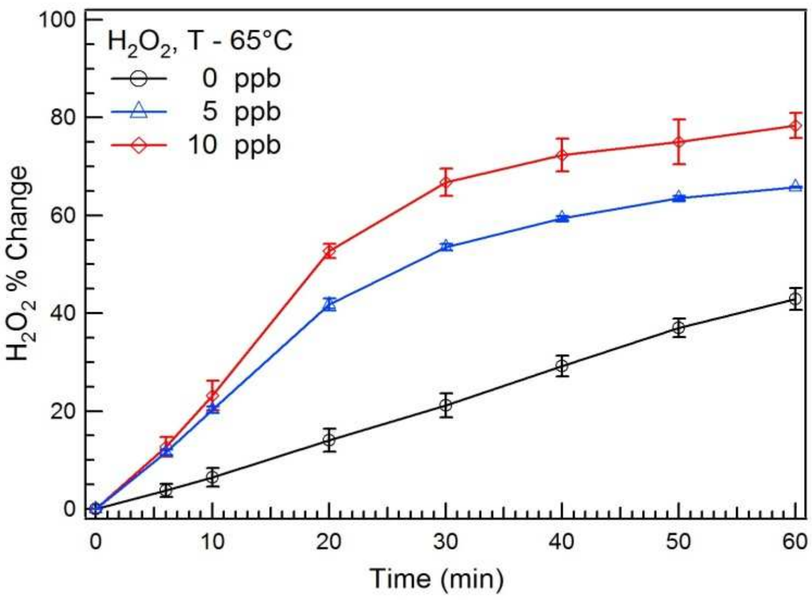
# Effect of Dilution on $NH_4OH$ and $H_2O_2$ Decomposition



- Extent of decomposition of both ammonium hydroxide and hydrogen peroxide decreases with dilution of APM solution.
- In four hours, ammonia concentration decreased by 30% in a dilute (1:1:50) APM solution vs. 65% decrease in a conventional (1:1:5) APM solution at 50°C.
- Hydrogen peroxide decomposition measured to be less than 15% in four hours at 50°C and 65°C for a dilute APM (1:1:50) solution.

# Decomposition of $H_2O_2$ in the presence of $Fe^{2+}$ ions in 1:1:5 APM Solution





- Hydrogen peroxide decomposition increases with $Fe^{2+}$ concentration and temperature.

- Highest peroxide decomposition was measured in the presence of 10 ppb $Fe^{2+}$ ion at 65°C.

  - Time for 50 % decomposition is roughly 30 and 20 min at 5 and 10 ppb of $Fe^{2+}$.

# Highlights

- Adhesion forces prevailed between H-terminated Si surface and a H-terminated Si tip in DI water, ammonium hydroxide and hydrogen peroxide solutions up to 60 min.
- Interaction force measurements in dilute APM solutions showed repulsive forces between Si surface and Si tip within 2 min of immersion.
- Ammonium hydroxide and hydrogen peroxide decomposition increases with temperature for a conventional APM (1:1:5) solution.
- Dilute APM solution (1:1:50) showed less decomposition at elevated temperatures when compared to 1:1:5 solution
- Hydrogen peroxide decomposition increases with $Fe^{2+}$ concentration and temperature.

# Future Plans

- Interaction force measurements at elevated temperatures (40, 50 and 65℃)

- Measurements of stability of ammonium hydroxide and hydrogen peroxide in dilute APM in the presence of trace metal ions.
  - Proposed metal ions are: $Fe^{2+}$ and $Fe^{3+}$

# Industrial Interactions

## Industrial Mentor

- Avi Fuerst, Intel Corporation
- Barry Brooks, Intel Corporation
- Eric Hebert, Horiba Inc.

INTERNATIONAL SEMATECH
ISMI
MANUFACTURING INITIATIVE
ESH Technology Center

**Accelerating Sustainable Manufacturing**

# *Challenges in Semiconductor Energy Reduction and the Progression Towards Idle Mode*

Thomas Huang, P.E.

Project Manager,
ESH Technology Center

# Agenda/Topics

- Challenges in Energy Reduction for Fabs and Equipment
- SEMATECH/ISMI Previous Highlights
- 2008 Case Study: Idle Mode Feasibility
- 2009 Pump Idle Demonstration
- Next Steps

# Agenda/Topics

- **Challenges in Energy Reduction for Fabs and Equipment**
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# Fab Challenges in Energy Reduction

- Rapid changes in fab loading make it difficult to stay optimized for energy efficiency
- Operating well below design capacity usually results in poor efficiency

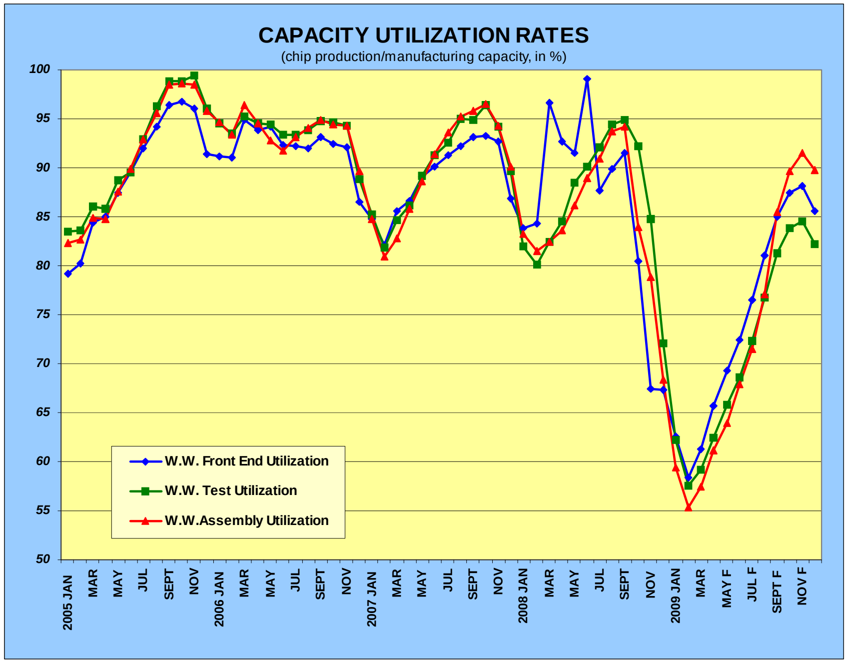


Chart Source: *Industry Pulse*, VLSI Research

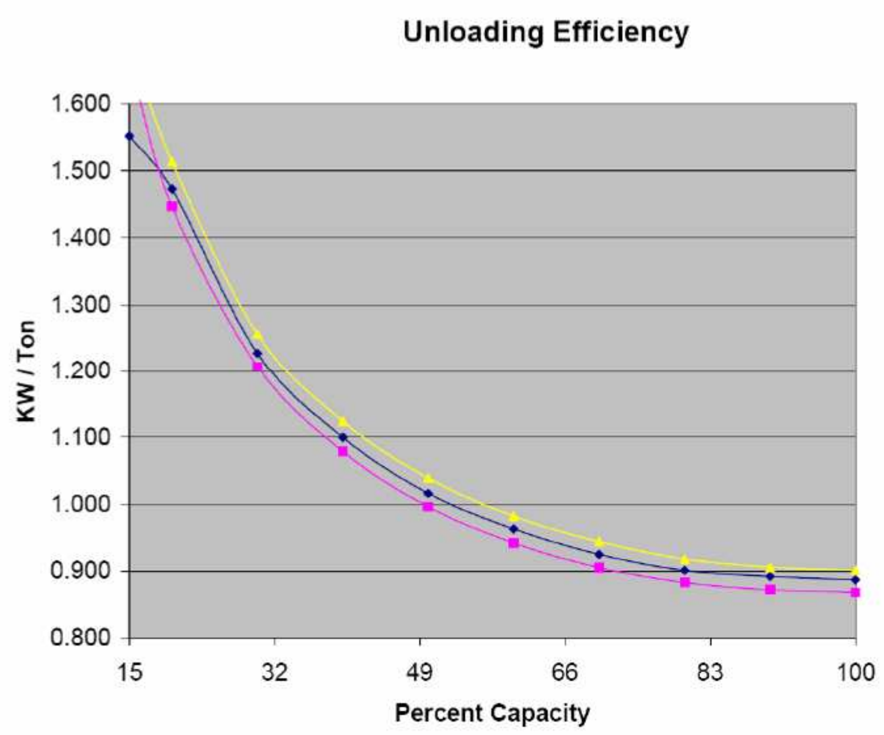


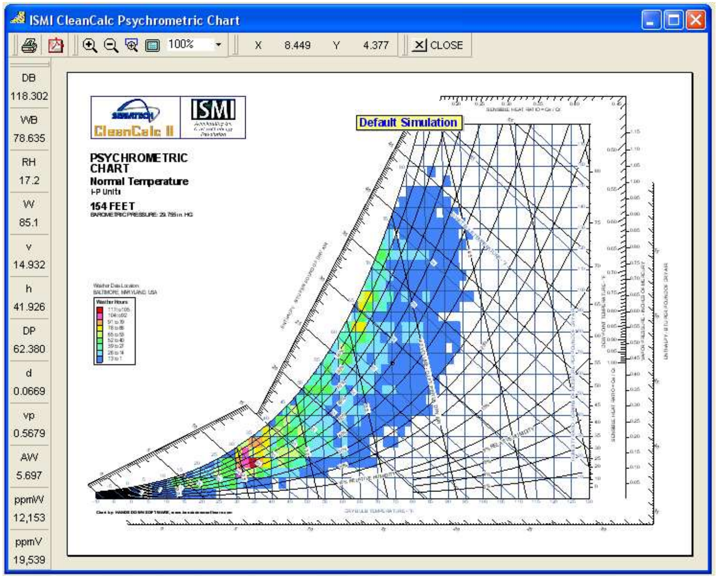
Chart Source: Source: Cascadia Region Green Building Council, "Heat Recovery Chillers" R. Scott Rushing and Eric Vander Mey,

# Facilities E-Reduction Challenges

- Process and production liability far outweighs potential energy savings

Example:

- Approach: increase temperature and humidity tolerances to reduce HVAC energy requirement for tight process control
- Potential annual cost savings $100-250k USD per fab
- Process impact: stepper and scanner focus and alignment issues, critical dimension control


ISMI CleanCalc Psychrometric Chart

100%

X 8.449 Y 4.377

DB 118.302
WB 78.635
RH 17.2
W 85.1
v 14.932
h 41.926
DP 62.380
d 0.0669
vp 0.5679
AW 5.697
ppmW 12,153
ppmV 19,539

PSYCHROMETRIC CHART
Normal Temperature
I-P Units
154 FEET

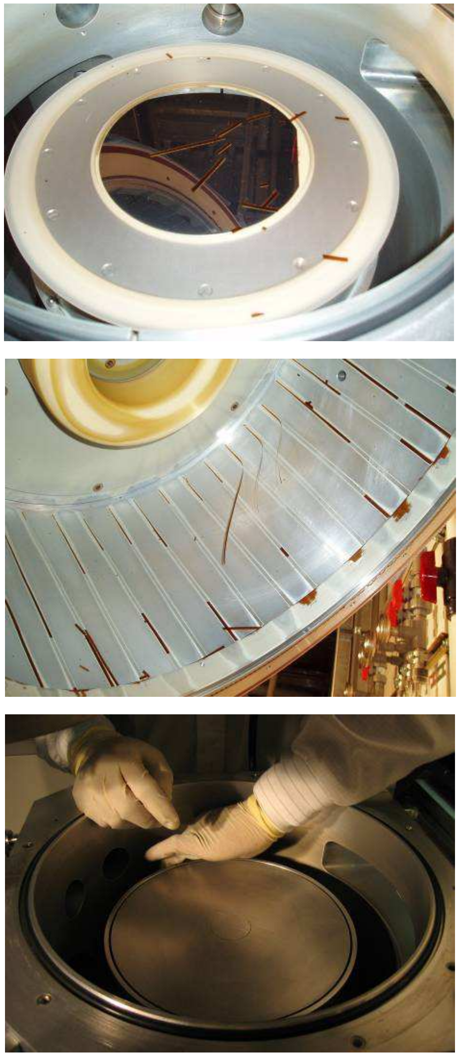
Weather Data Location: BALTIMORE, MARYLAND, USA

# Equipment E-Reduction Challenges

- Process stability and uptime conflicts with energy reduction

Example:

- Approach: reduce chamber heating during tool idle periods
- Potential annual cost savings $5k USD savings per tool
- Process impact: chamber deposition peeling and flaking requiring wet cleans and significant down time



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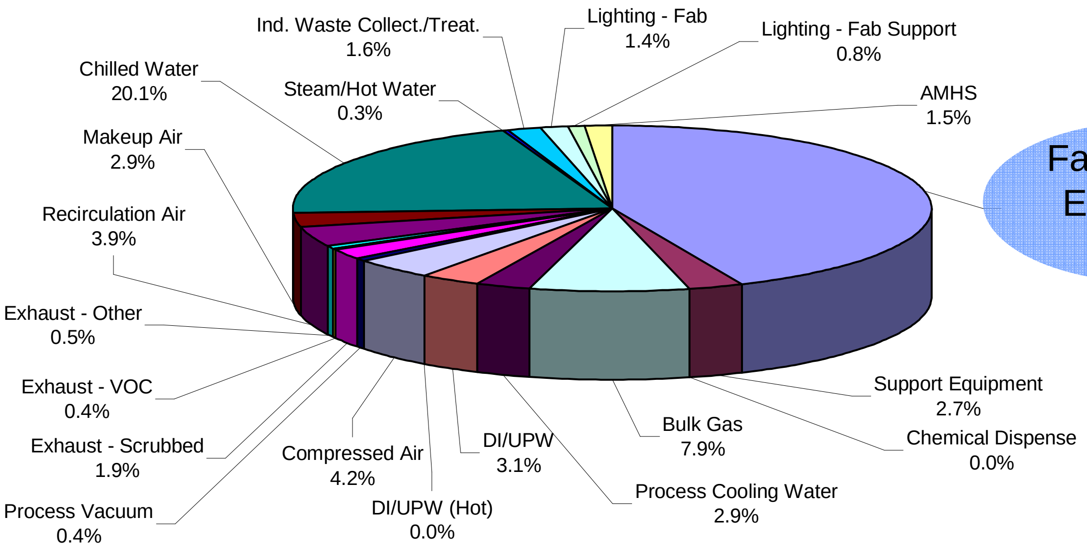
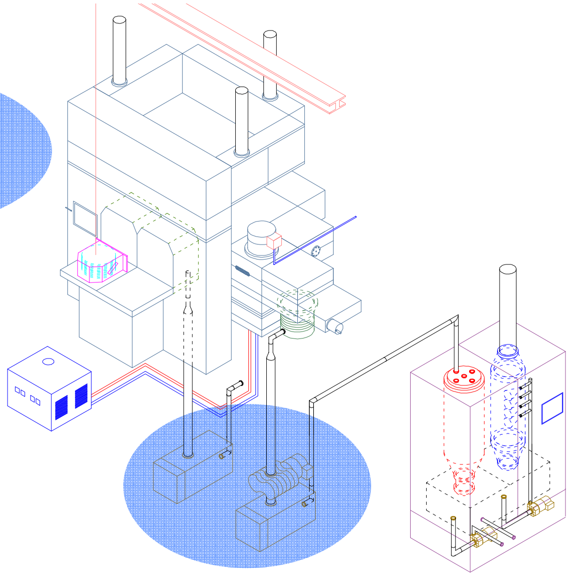
# Previous Fab and Equipment Energy Studies

## 300 mm Fab energy



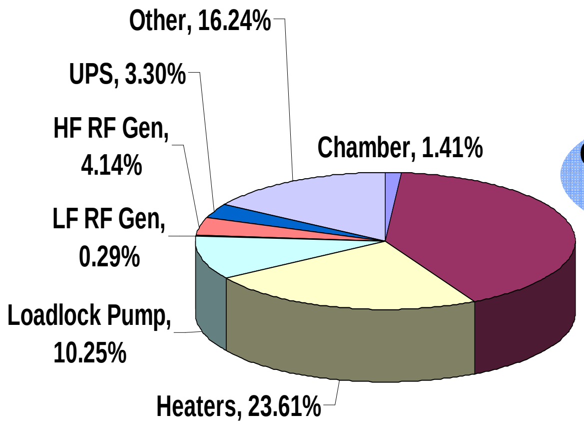
Fab Process Equipment 43.4%

Chamber Pump 40.77%



Focus on Pumps

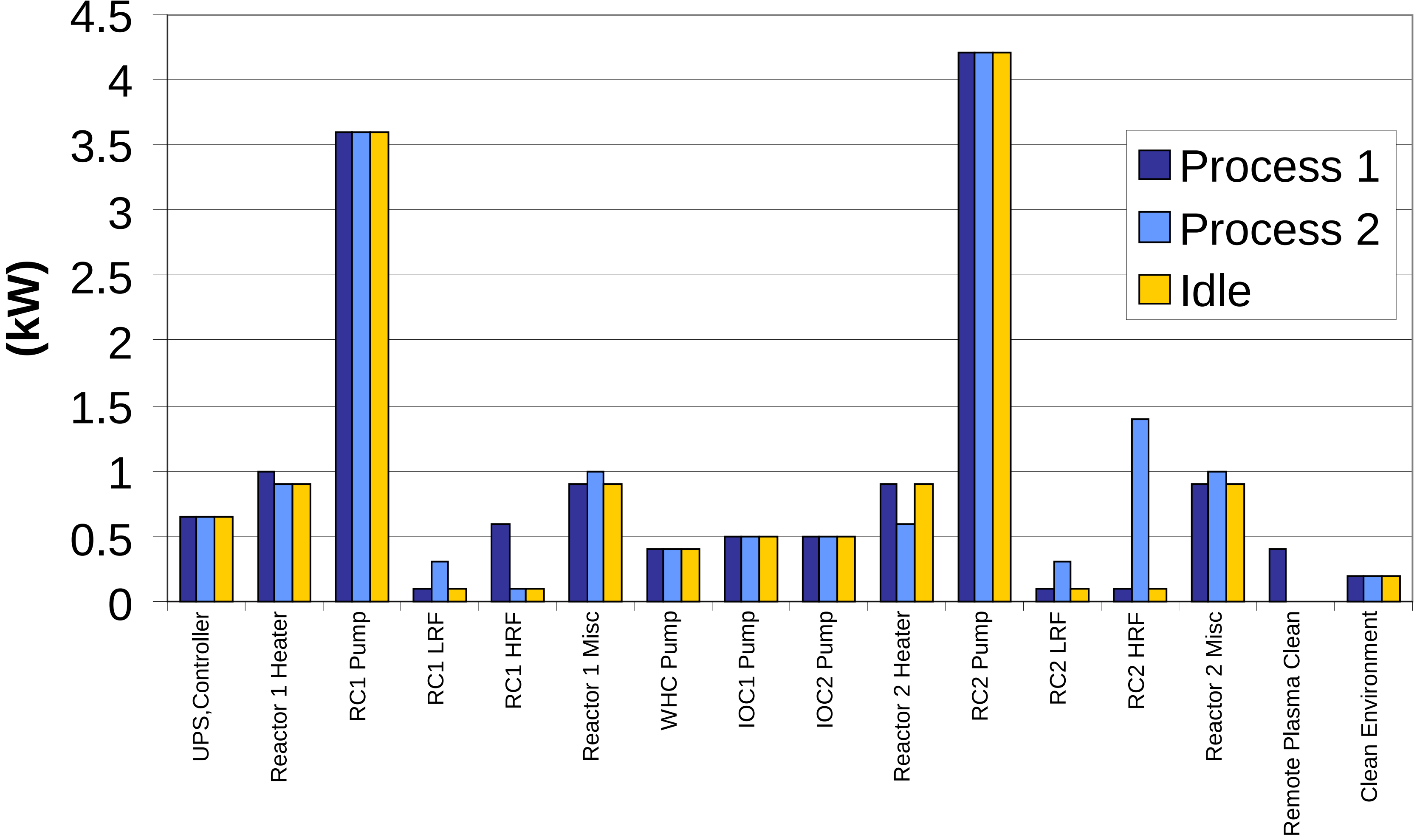
## 300mm CVD tool energy



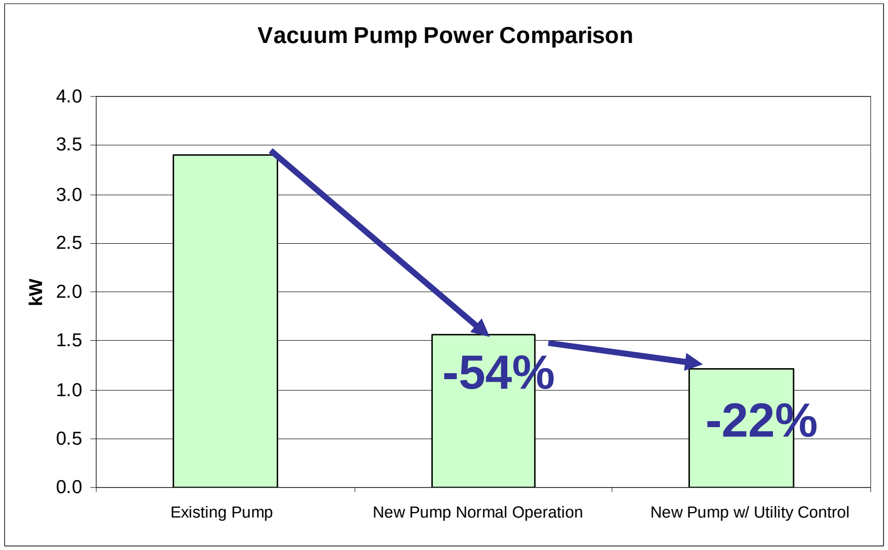
| | |
|---|---|
| Chamber Pump | 40.77% |
| Loadlock Pump | 10.25% |
| Heaters | 23.61% |
| **Total** | **74.63%** |

# Energy Pareto Chart for CVD Processes

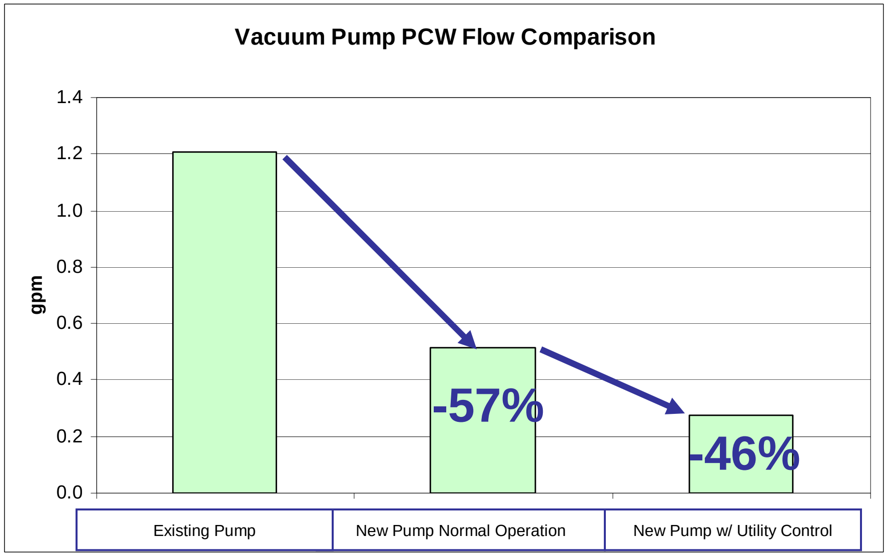
Back in 2000, there was no change from idle to process except in RF

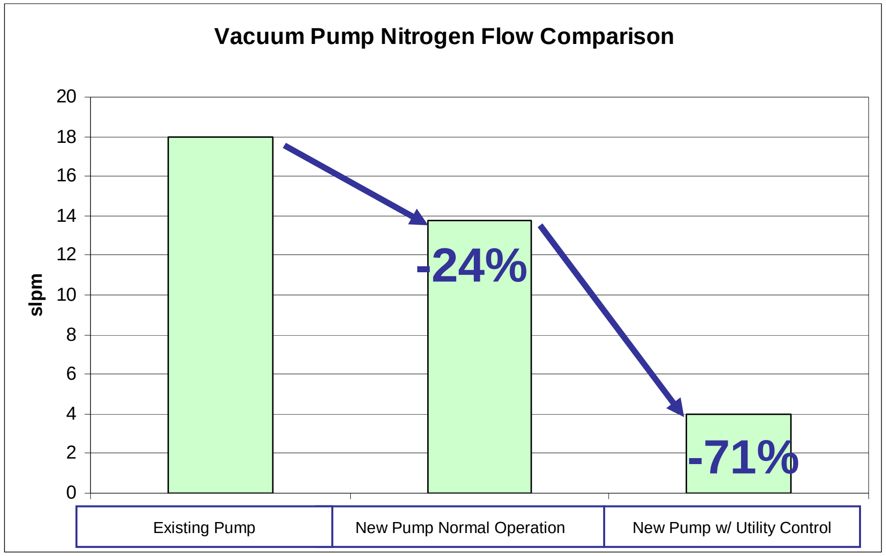


# Vacuum Pump Speed Control Results



- Idle mode power could be further reduced depending on process.
- Nitrogen purge reduction can be reduced an additional 71% if the process allows.





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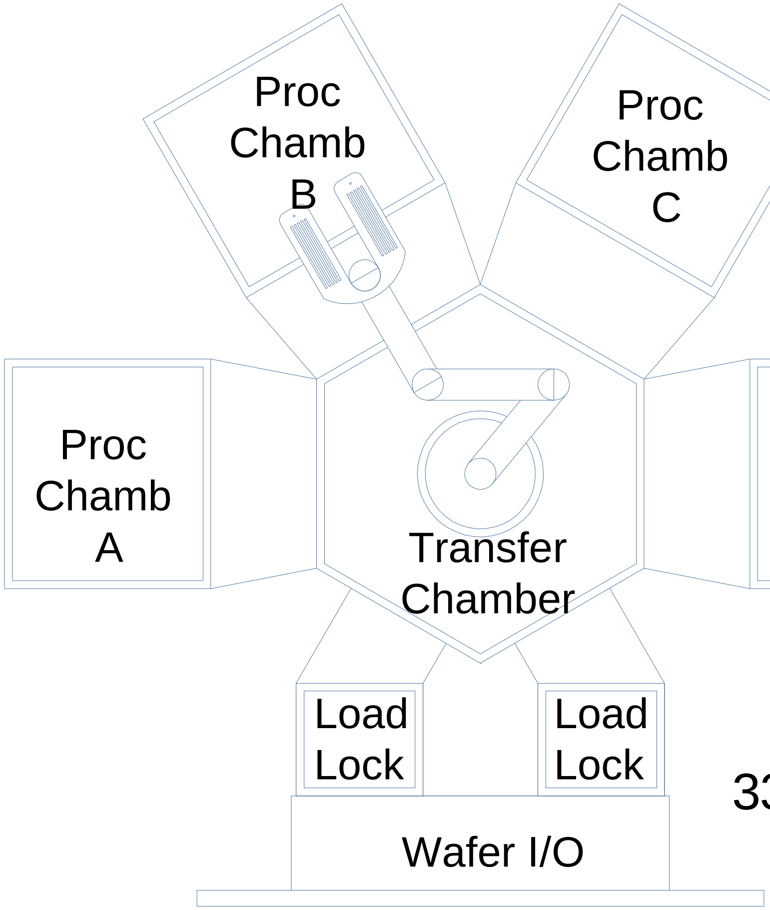
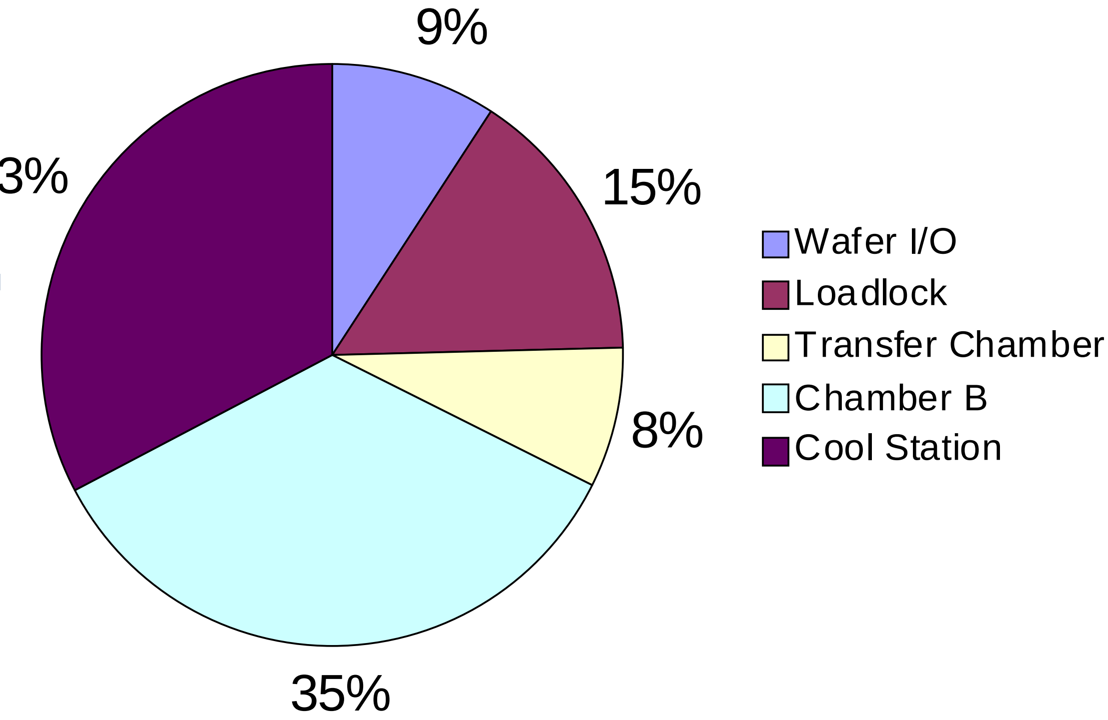
# Wafer Event Analysis – Raw Tool Log Data

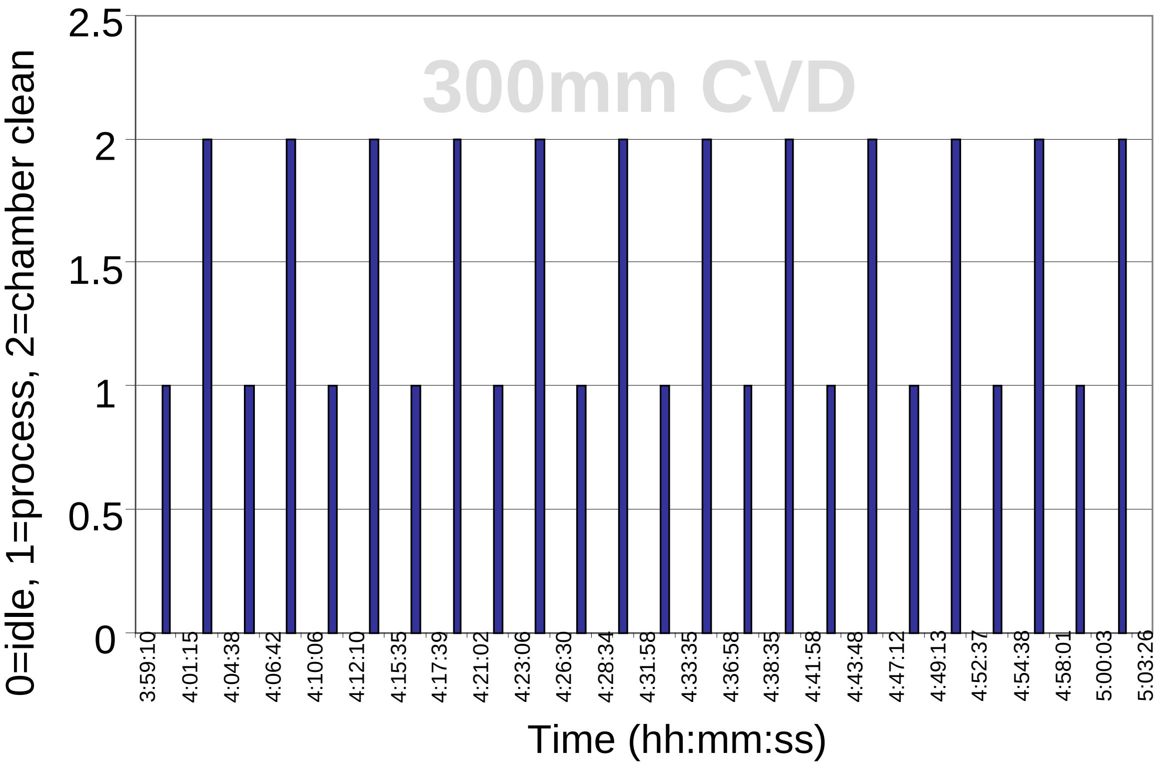
```
#EventID   Severity   Source      CreationTi Text
   3420     147464 AT/LL         56:18.6 Wafer transfer info -  LL Vent finished
   3362     147464 AT/LL/Left    56:20.5 Wafer transfer info - Door Opened
   3362     147464 AT/LL/Righ    56:20.6 Wafer transfer info - Door Opened
    204     147464 AT/System     56:25.2 Wafer CB:15 moved from FIC_1_1 to LL_1_1
    204     147464 AT/System     56:25.2 Wafer CB:16 moved from FIC_2_1 to LL_1_2
     37     147464 AT/System     56:25.2 System/Sequencer.LL_Slot 1_XferCount changed from  244855  to  244856
    204     147464 AT/System     56:31.0 Wafer CB:13 moved from LL_2_1 to FIC_1_1
    204     147464 AT/System     56:31.0 Wafer CB:14 moved from LL_2_2 to FIC_2_1
   3362     147464 AT/LL/Left    56:31.9 Wafer transfer info - Door Closed
   3361     147464 AT/Buffer/    56:33.3 Wafer transfer info - Slit Opened
   3362     147464 AT/LL/Righ    56:33.3 Wafer transfer info - Door Closed
   3417     147464 AT/LL         56:33.4 Wafer transfer info - Start pump down LL
    204     147464 AT/System     56:35.0 Wafer CB:13 moved from FIC_1_1 to COOL_STN_1_1
     37     147464 AT/System     56:35.0 System/Sequencer.COOL_STN_Slot 1_XferCount changed from  158143  to  158144
     37     147464 AT/System     56:35.0 System/Sequencer.COOL_STN_Slot 1_SoFarCount changed from  159210  to  159211
     37     147464 AT/System     56:35.0 System/Sequencer.COOL_STN_Slot 1_CleanOnLoad_SoFarCount changed from  158067  to  158068
     58     147464 AT/COOL_      56:35.0 Slot1 Process recipe  cool-22  started.
    229     147464 AT/COOL_      56:35.0 Recipe step 1 started
    204     147464 AT/System     56:35.3 Wafer CB:14 moved from FIC_2_1 to COOL_STN_4_1
     37     147464 AT/System     56:35.4 System/Sequencer.COOL_STN_Slot 4_XferCount changed from  148089  to  148090
     37     147464 AT/System     56:35.4 System/Sequencer.COOL_STN_Slot 4_SoFarCount changed from  149154  to  149155
     37     147464 AT/System     56:35.4 System/Sequencer.COOL_STN_Slot 4_CleanOnLoad_SoFarCount changed from  148011  to  148012
     58     147464 AT/COOL_      56:35.4 Slot4 Process recipe  cool-22  started.
    229     147464 AT/COOL_      56:35.4 Recipe step 1 started
   3446     147464 AT/Buffer/    56:42.5 Chamber B vacuum robot wafer detect data updated
    204     147464 AT/System     56:42.6 Wafer CA:21 moved from CHB_1_1 to Buffer_1_1
    204     147464 AT/System     56:42.6 Wafer CA:22 moved from CHB_1_2 to Buffer_1_2
     37     147464 AT/System     56:42.6 System/Sequencer.Buffer_Slot 1_XferCount changed from  489224  to  489225
   3446     147464 AT/Buffer/    56:42.9 Chamber B vacuum robot wafer detect data updated
   3361     147464 AT/Buffer/    56:43.2 Wafer transfer info - Slit Closed
     37     147464 AT/System     56:43.3 CHB/Side1/HighFreqRF.cFwdPwrDeviationTmo changed from  5 s  to  10 s
     37     147464 AT/System     56:43.3 CHB/Side2/HighFreqRF.cFwdPwrDeviationTmo changed from  5 s  to  10 s
    229     147464 AT/CHB        56:44.2 Recipe step 1 started
   3418     147464 AT/LL         56:46.2 Wafer transfer info - LL pump down finished
    230     147464 AT/CHB        56:47.2 Recipe step 1 completed
    229     147464 AT/CHB        56:47.5 Recipe step 2 started
    230     147464 AT/CHB        56:47.5 Recipe step 2 completed
    229     147464 AT/CHB        56:47.5 Recipe step 3 started
   3361     147464 AT/Buffer/    56:47.9 Wafer transfer info - Slit Opened
    289     147464 AT/System     56:50.0 Cassette A Wafer 24 Started
    204     147464 AT/System     56:50.0 Wafer CA:24 moved from CASS_A_24_1 to COOL_STN_7_1
     37     147464 AT/System     56:50.0 System/Sequencer.COOL_STN_Slot 7_XferCount changed from  233368  to  233369
    230     147464 AT/CHB        56:50.5 Recipe step 3 completed
   3380     147463 AT/CHB/Si     56:55.8 RF is ON
   3380     147463 AT/CHB/Si     56:55.8 RF is ON
```



During a wafer process cycle, where does the wafer spend most of its time?



|  | Summed Duration | Percent | Event Duration |
|---|---|---|---|
| Clean | 12:03:58 | 38% | 1-6 min |
| Idle | 15:57:08 | 50% | 12s-10min |
| Process | 3:39:52 | 12% | 1.5-2 min |
| Total | 31:40:58 | 100% |  |



# Agenda/Topics

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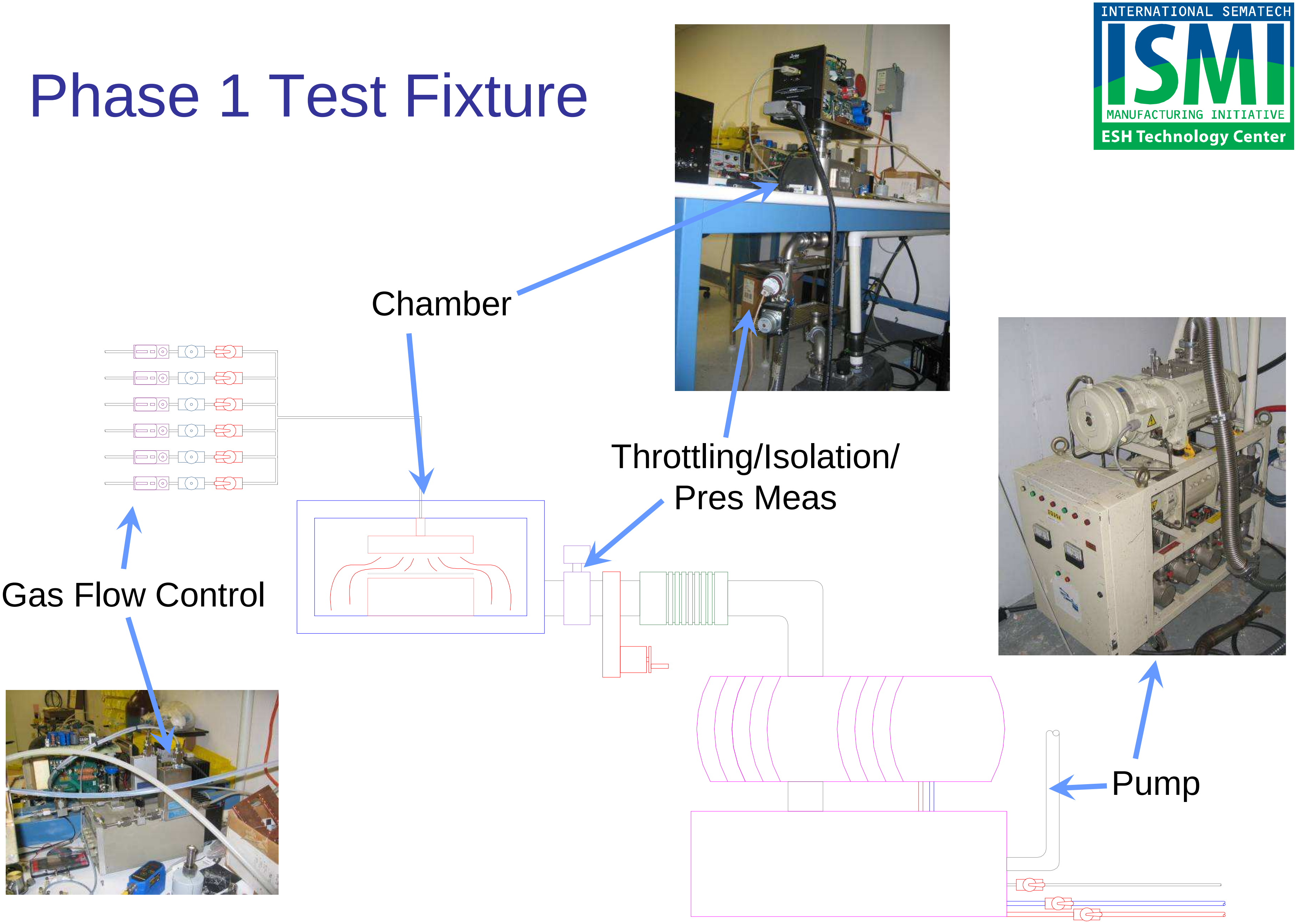
- Next Steps

# 2009 Projects Relating to Energy Reduction

- Resource Conservation
  - Fab Energy and Utility Calculator
  - Energy Star Compatible LEED EB Database
  - Alternative/Renewable Energy for Fabs Feasibility Study
  - Heat Exhaust Recycling Benchmark and Cost Benefit Analysis
  - On-board Total Equivalent Energy (TEE) for Process Equipment
  - SEMI S23 Application Guide and TEE tool Revisions
  - **Vacuum Pump Speed Control Demonstration**
- Technology Development
  - Feasibility of Recycle and Reclaim of Fab and Assembly/Test Process Wastewater
  - Feasibility of Treating and Abatement Solvent-corrosive Mixtures
  - Supplier Leadership Workshops on Energy Reduction

# Phase 1 Test Fixture



Chamber

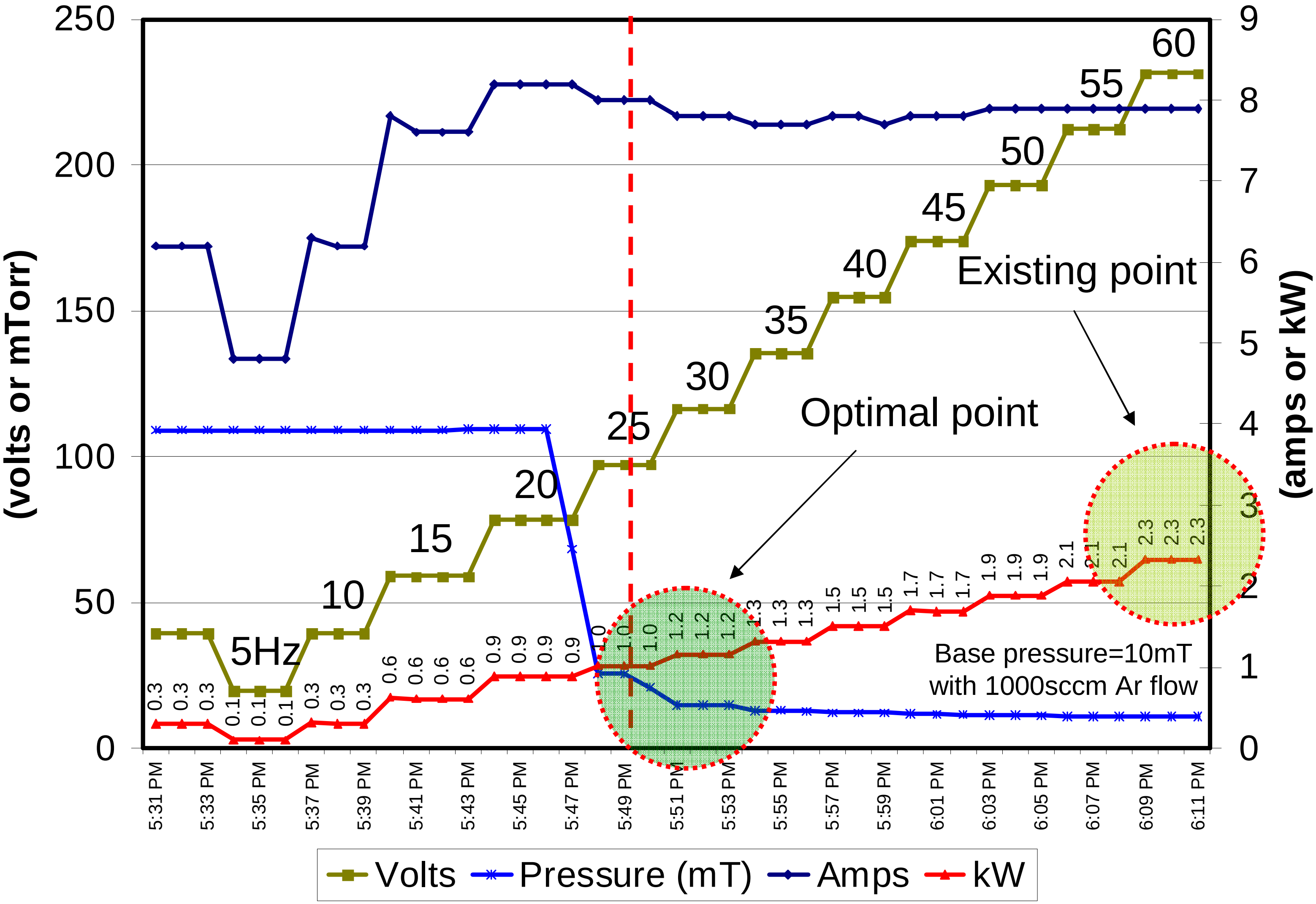
Throttling/Isolation/
Pres Meas

Gas Flow Control

Pump

# Test Data

For this pump and chamber configuration 25Hz is min

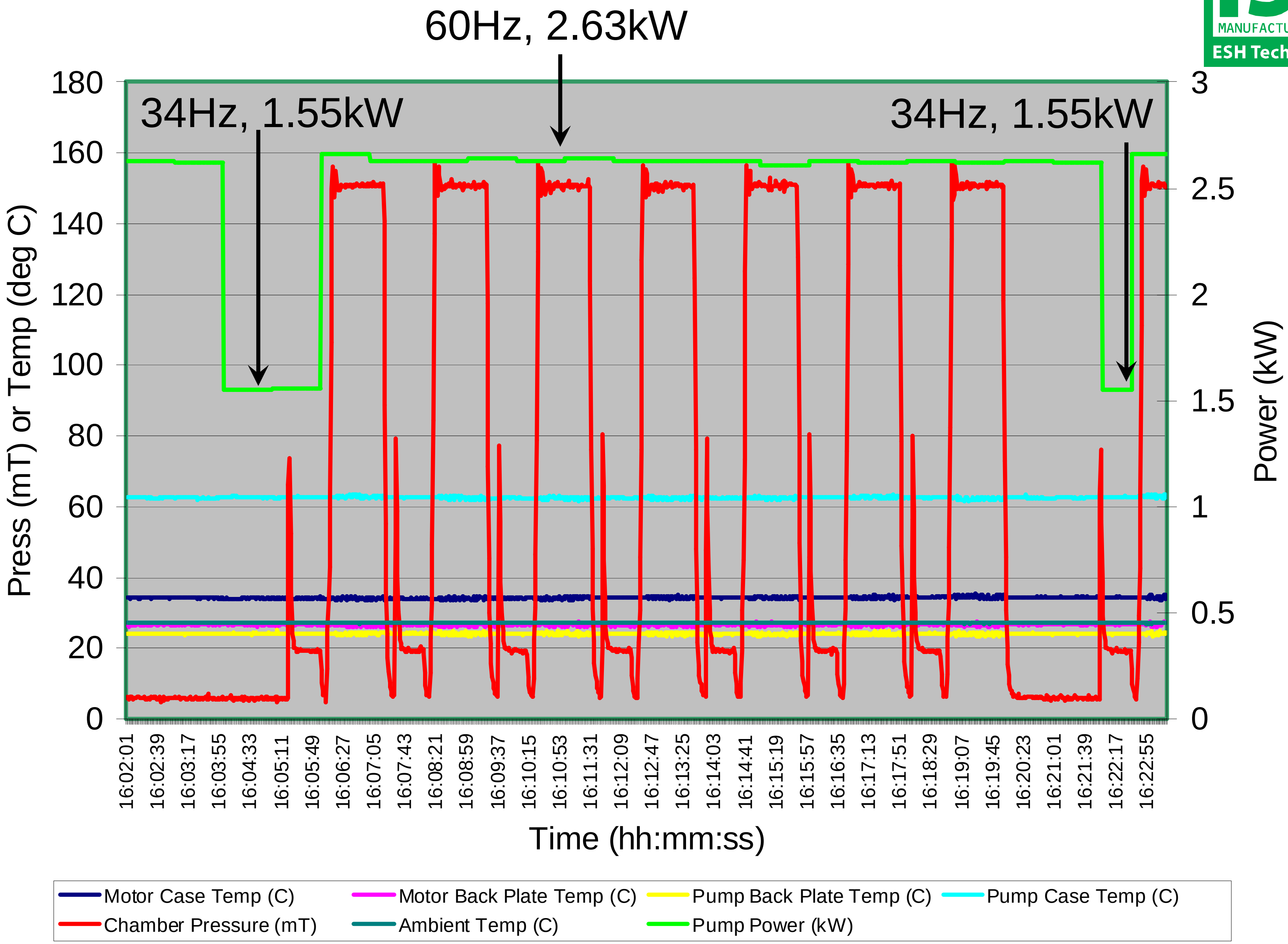


Optimal point

Existing point

Base pressure=10mT
with 1000sccm Ar flow

# Roughing Pump Power Consumption


60Hz, 2.63kW

34Hz, 1.55kW

34Hz, 1.55kW

# Summary

- Data taken on the test stand showed the pump held base pressure while reducing pump frequency from 60 to 25Hz while pumping against a 1000 sccm Ar gas load.  Resulted in pump power reduction from 2.3kW to 1.0 kW.
- Pump VFD and Tool Interface Retrofit was repeated on an oxide etch tool
  - Installed on a process chamber, not loadlock or transfer
- On an oxide etch tool, reduced the roughing pump frequency (speed) from 60Hz to 36Hz with no impact to the turbopump load or speed.  Resulting power reduction was from 2.66kW to 1.55kW

- 144 wafers were run making comparisons with the tool in baseline and idle modes.  ER, PC and Uniformity were monitored via pre/post thickness data and particle counts.  The statistical analysis showed no effects on the process data from running the tool in idle mode.

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# 2010 Projects in Energy Reduction

- Revisit/refresh Facilities Energy BKM's
- Standardize communication interface for support equipment (i.e., pumps, abatement)
- Address over specification of utility specifications for process tools
- ESH assessment on EUV with focus on utility consumption
- Continue efforts to enable reporting and improving process tool energy consumption with Total Equivalent Energy (TEE) software

# Some Suggestions

- Reduce redundancy between facilities and process equipment
  - mini-environment vs room air
  - POU chiller vs facility cooling water
- Improve heat transfer and control to eliminate overcool then trim heat strategy
  - POU chiller with immersion heater in reservoir
- Reduce extreme temperature and vacuum requirements
  - idle temperature for furnace = 600-800°C
  - many vacuum levels are at $10^{-9}$ Torr requiring cryo pumping
  - even a reduction helps
- Increase utilization or recycle percentages
  - single wafer wet tools vs immersion bath tools
  - gas diffusion and plasma utilization
  - source power for EUV, 90kW produces 4W of usable EUV power at intermediate focus