University of Arizona e-Seminar Series

A Review of Variability Reduction Strategies: Intrinsic Advantages of e-Sulfuric and Single Wafer Cleaning

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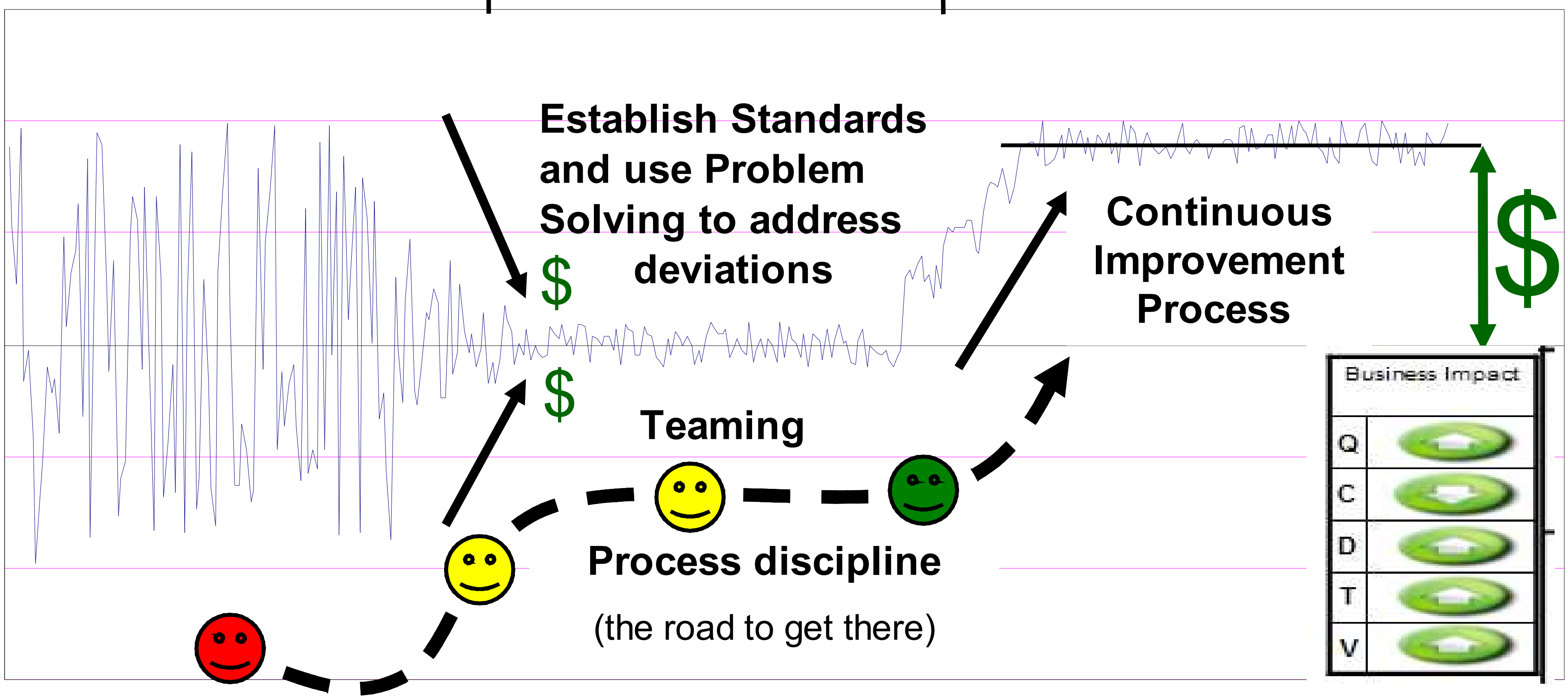
October 9th, 2011

The Power of Lean Transformation

Ability to see waste and identify variability

Remove waste and reduce variability

Continuous improvement allows improved performance from a stable baseline



Reduction in Wets Variability

- <u>Goals of Presentation</u>:

1) Review Sources of Wets Variability & Variability Reduction Strategies

2) Briefly introduce electrolyzed sulfuric acid as a pollution prevention technology. (in context of Variability Reduction)

3) Describe how single wafer cleaning incorporates many variability reduction strategies intrinsically.

Variability in Wets Processing

Types of Variability	Typical Effect of Variability
1. Bathlife effects (Time driven)	Etch rate (resist strip) variation.
2. Bath loading effects (Wafer driven)	Degraded FM (foreign material), etch rate
3. Poor wetting	Unetched films->missing silicide, missing sigma shapes.
4. High particle addition	Multiple defects. HF etches (hydrophobic wafers) most challenging.
5. Dissolved gas	Particle removal efficiency (megasonics) Unwanted metal etch
6. Charge/electrochemical	Contact / Via Opens
7. Poor particle removal	Multiple defects (blocked implant, embedded contam, blocked silicide…)
8. Metallic impurities	Polysilicon bumps, crystallographic etch, polysilicon etch, gate oxide relability.

Example of Time-Driven Variability (Bathlife) in Wets: H2O2 Decomposition in Sulfuric/Peroxide Baths (Resist Strip)

- Sulfuric / Peroxide used for resist strip
- Active species in Sulfuric / Peroxide requires H2O2 to make:

$$H_2O_2 + H_2SO_4 \rightarrow H_2SO_5 \text{ (Caro's Acid)} + H_2O$$

Variability Problem: Rapid decomposition of H_2O_2 .

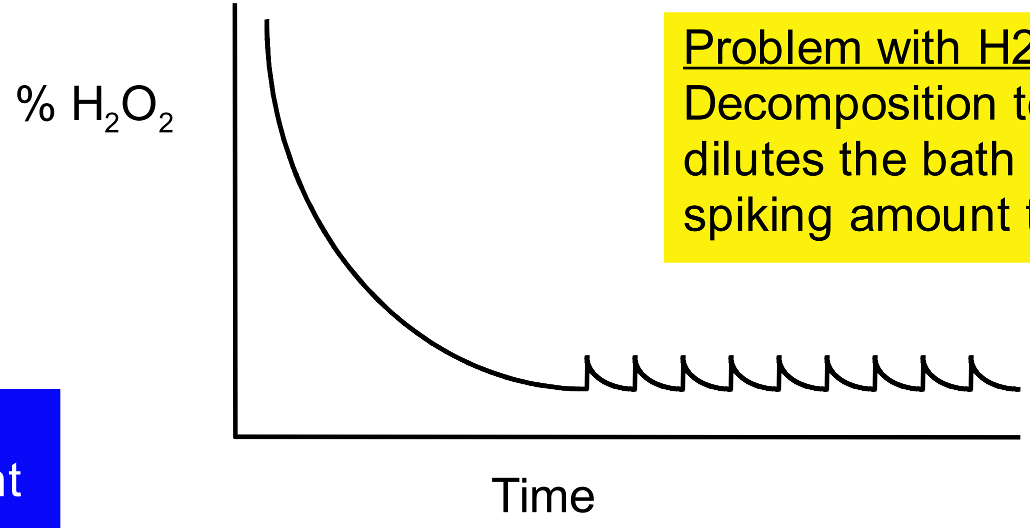
$$H_2O_2 \rightarrow \tfrac{1}{2} O_2 + H_2O$$

Sample	% H_2O_2	% H_2SO_4
New Bath #1	1.18	82.09
New Bath #1 After 235 Wafers	0.09	82.46
New Bath #2	1.15	80.85
New Bath #2 After 378 Wafers	0.07	83.09

(Data with H2O2 spiking turned on)

Example of Time-Driven Variability (Bathlife) in Wets: H_2O_2 Decomposition in Sulfuric/Peroxide Baths (Resist Strip)

Variability Mitigation: 1) H2O2 Spiking



Problem with H2O2 spiking: Decomposition to water dilutes the bath if H2O2 spiking amount too much

Solution: Target high dose implant resist strip for single wafer with fresh chemistry to entirely eliminate bathlife.

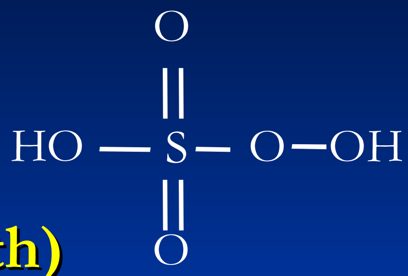
2) Containment: Run high dose implant resist strips (only) in short bathlife S/P.

Time-Driven Variability (Bathlife) in Wets: e-Sulfuric as a Solution to H2O2 Decomposition

Variability Reduction Approach: Remove the variability source altogether. (Eliminate Peroxide)

SPM Chemistry

$$H_2SO_4 + H_2O_2 \longrightarrow H_2SO_5 + H_2O$$

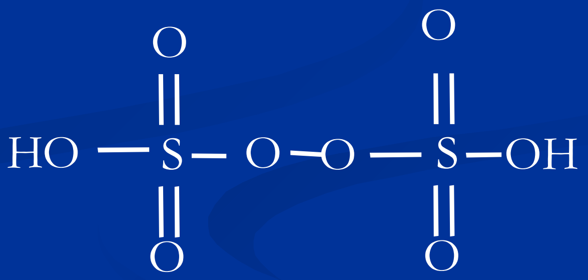


Problem: $H_2O_2 \longrightarrow \frac{1}{2} O_2 + H_2O$ **(Dilution of bath)**

Electrolyzed Sulfuric Acid

$$2\ H_2SO_4 \longrightarrow H_2S_2O_8 + 2\ H^+ + 2\ e^-$$

$$H_2SO_4 + H_2O \longrightarrow H_2SO_5 + 2\ H^+ + 2\ e^-$$



Side Reactions

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

$$3\ H_2O \longrightarrow O_3 + 6\ H^+ + 6\ e^-$$

"e-Sulfuric Qualification at IBM", Charles Taft, David Hilscher, Sandi Merritt (IBM), Tatsuo Nagai, Toru Otsu (Kurita Water Industries LTD), David Harris (Kurita America Inc.) dharris@kuritaamerica.com/972-484-4438 ISMI Proceedings Sept 2011.

Approach for e-Sulfuric Introduction

- Qualify monitor wafer reclaim application first
  - Keeps asset productive immediately (Fab loading about 0.5 tools)
  - Demonstrate stability while product qualifications take place.

- Validate both post-ash and "wet only" resist strip operations
  - 45nm & 90nm spacer level wet cleans are primarily post-ash
  - 45nm & 90nm pre gate oxidation deep well levels are primarily "wet-only"

  Groundrule: Implant dose levels 1E15 or less for "wet-only".
  (Wet benches with S/P themselves were ineffective above those levels.)
- Avoid "novel" materials for initial qualifications

<u>**Success Criteria**</u>:

- Equivalent monitor FM
- Equivalent TXRF
- Equivalent product PLY
- Equivalent wafer final test yield
- Device Equivalence sufficient to allow "Mix and Match" of S/P & e-Sulfuric

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Benefits of e-Sulfuric

- Reduced chemical exchanges improve sulfuric tank availability.

  (Incremental capacity increase possible without new tool add)

- Reduced sulfuric acid and hydrogen peroxide use.

- Reduced chemicals for waste treatment.

  (NaOH)

- Variability reduction – more consistent performance than S/P.

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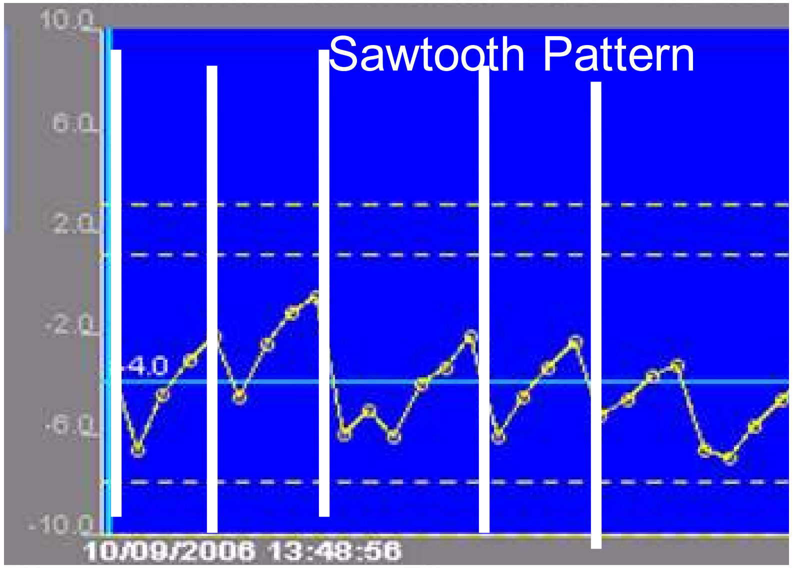
Example of Wafer-Driven Variability in Wets: Hot Phosphoric Acid for Selective Nitride Removal (Etch Rate)

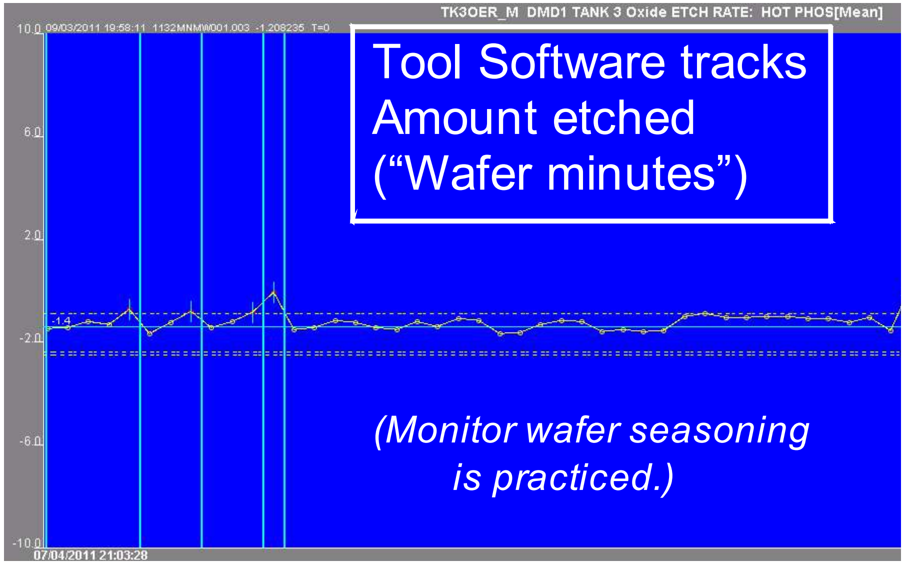
- Used for nitride removal selective to oxides (140:1 Pad Nitride / Pad Oxide)
- Processing done in a boiling liquid (150-170C)
- Variability Problem: Oxide etch rate drops off exponentially with silicate loading

Variability Reduction Solution: Partial Drain / Fill (Bleed/Feed)
EAQ (Exchange Adjusted Quantity)

Oxide Removal vs. Time



Oxide Removal vs. Time

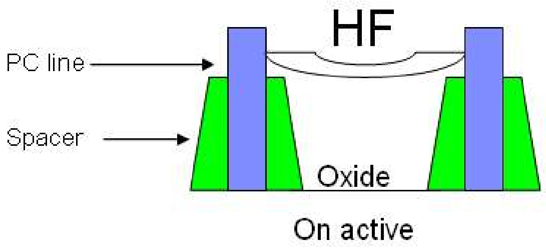


Variability Reduction Solutions/Strategies in Wets Processing

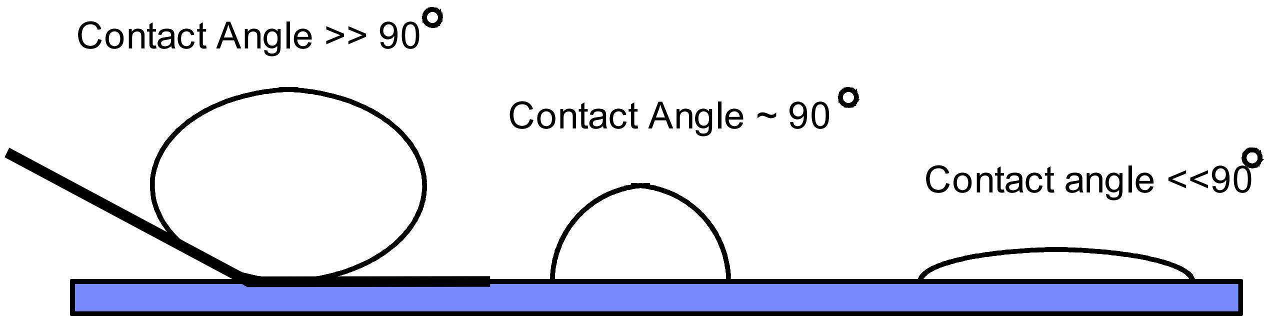
Types of Variability	Variability Solutions Available
1. Bathlife effects (Time driven) 2. Bath loading effects (Wafer driven)	Spiking (Better w/ feedback loop) Partial Drain / Fill or "Bleed & Feed" Change the chemistry Single Use Chemistry

3. Poor wetting
4. High particle addition
5. Dissolved gas
6. Charge/electrochemical
7. Low particle removal
8. Metallic impurities

Poor Wetting: What is it?



Functional Definition: Does liquid (HF) get into all topology?



(contact angles are measured through the liquid)

HF solutions do not like to "wet" polysilicon or nitride

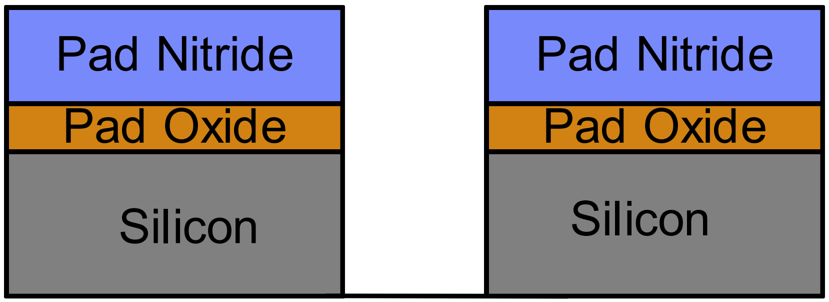
Options to Improve

1. Wet with water first.
2. Use SC1 to wet by growing a chemical oxide.
3. Oxidize with ash or plasma ozone clean
4. Evaluate surfactants.

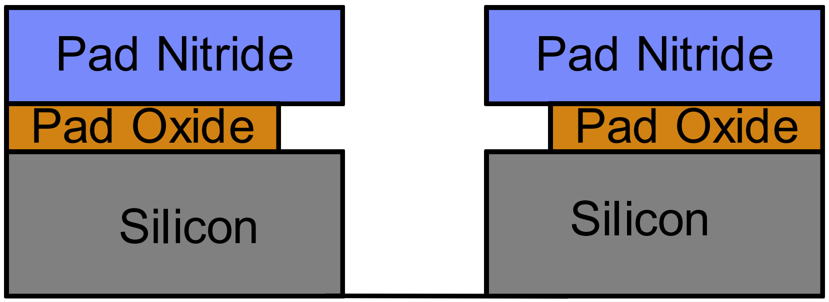
"NPN Yield Improvement with Ozone Surface Treatment Prior to Emitter Poly Deposition" T. Tran-Quinn, N. Bell, R. Cook, M.S. Fung, J.W. Andrews, D. Hilscher, D. Szmyd, V Saikuma, R. Ketcheson, P. Kellawon, S. Cavelli, ASMC Proceedings, 2003.

Influence of Wetting on Electrical Performance
RX Post RIE Clean

After RX RIE



After RX RIE Postclean (with HF)



(Subsequent RX liner oxidation and later etches round the corner of Si for lower leakage.)

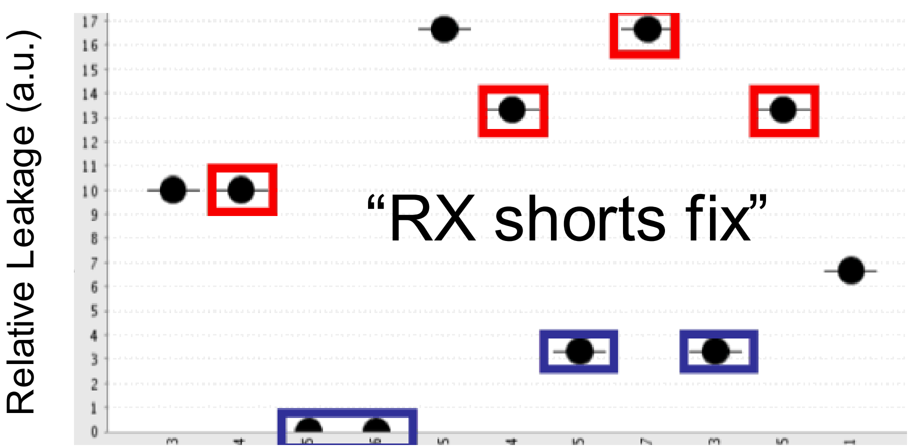
<u>Key to M1 Leakage Chart</u>

Dots Only = POR (Straight into 40:1 BHF)

Red Boxes = Straight into 300:1 DHF

Blue Boxes = Placed into water and then ramped to 300:1 DHF.

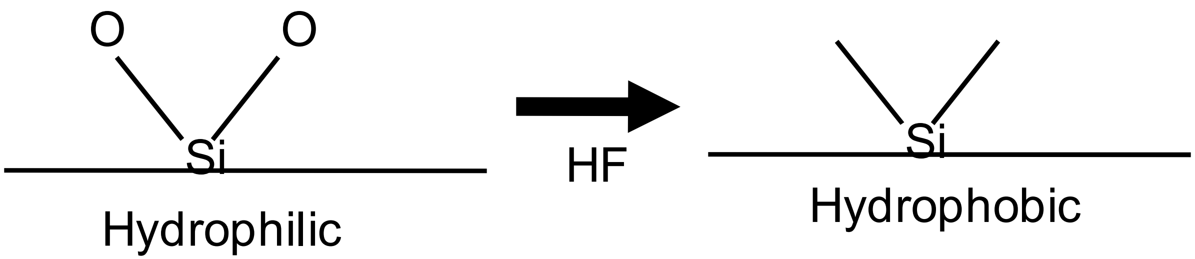
<u>PC_RX Leakage Test</u>



Individual wafer results shown (split lot)

Wets Variability – High Particle Addition

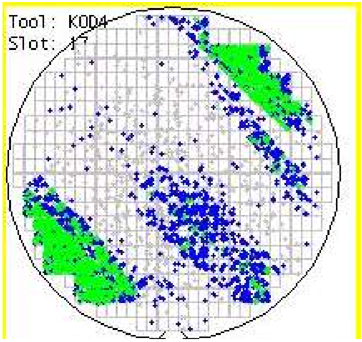
Systematic Exposure: HF / HCl Last Sequences (when possible)



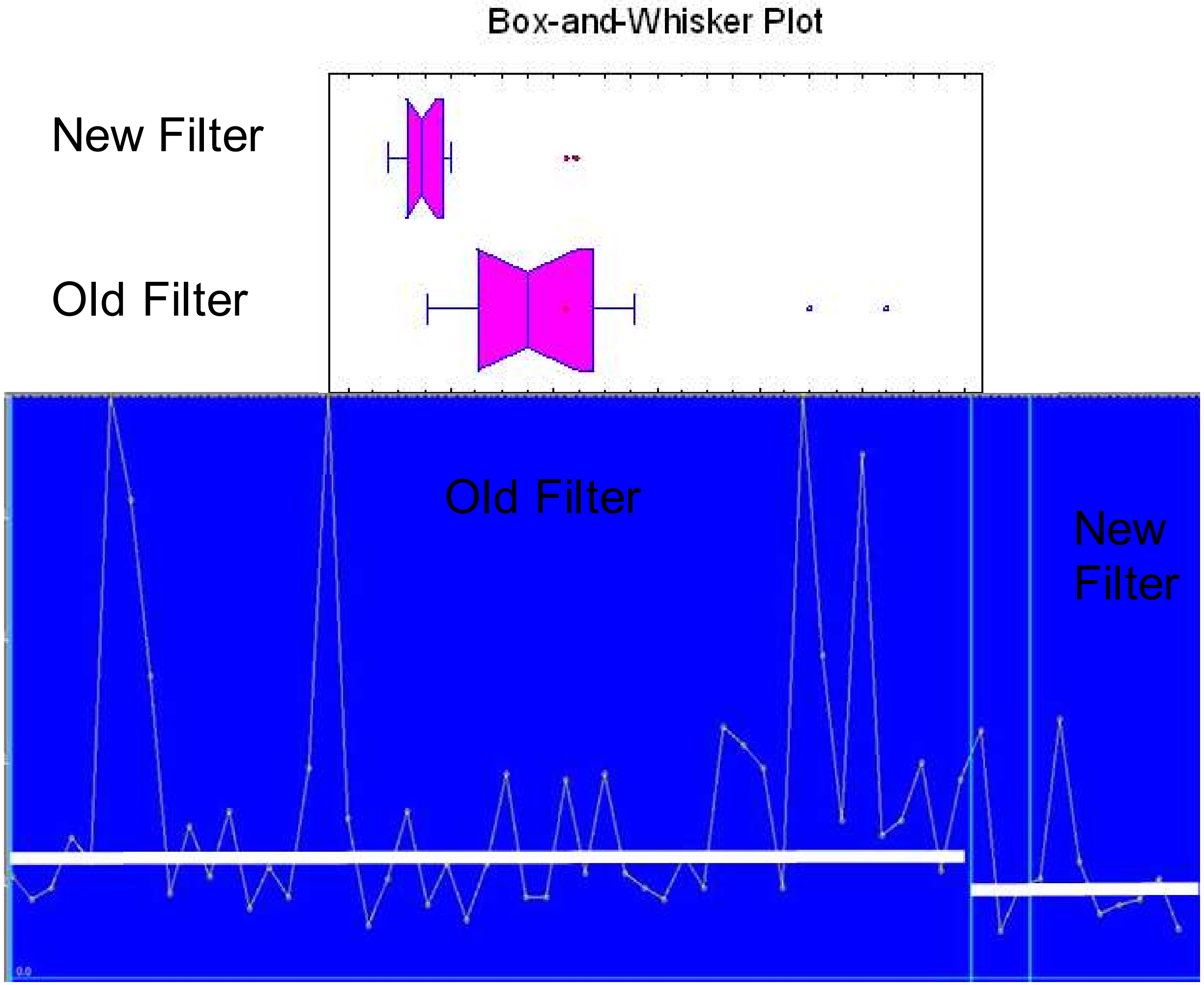
HCl in dryer to avoid Ca deposition. (Gate Ox reliability exposure)

<u>Strategies to Mitigate</u>:

1) Reoxidize surface if possible.
   - SC 1/SC 2 (H_2O_2)
2) Single wafer if clean must be HF-last.



Wets Variability – High Particle Addition (Improved Filtration as a Mitigation Strategy)



Acknowledgement: Richard Henry and Robert Zigner

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4. High particle addition	Avoid HF-last cleans when possible. Improved filtration
5. Dissolved gas	
6. Charge/electrochemical	
7. Low particle removal	
8. Metallic impurities	

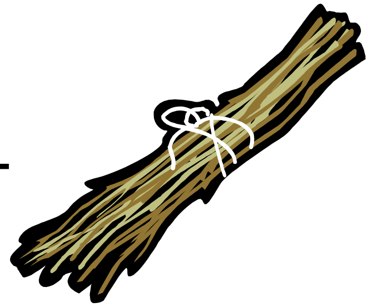
Variability: Dissolved Gas on Megasonic Efficiency

Dissolved gasses are required to get good particle removal efficiency.

Variability: Effect of Dissolved Gas on BEOL Yield (Cu Liner Preclean)

(Charge)

+



(Oxygen)

Cu →

(Cu-oxides blocking Polymer removal & Cu material loss)

Variability: Surface Charge Removal

Problem: Incoming charge from upstream tools.

Solutions:

1) DI CO_2.
2) IPA

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Advantages of Single Wafer Tooling

- No wafer to wafer transfer of particles

  - No scraps due to “dirty lot” running with “clean lot”

- Can process only one side of a wafer with chemistry if desired

- Can turn “off” chemistry step ~ 2 seconds vs. ~8 second minimum transfer time chemical tank to rinse tank in batch

- Fine liquid droplets generate significant particle removal efficiency.

- Better mass transfer.

- Process yield. Batching handling can result in large wafer scraps. (Stuck in tank, wafer handling)

Variability: Low Particle Removal

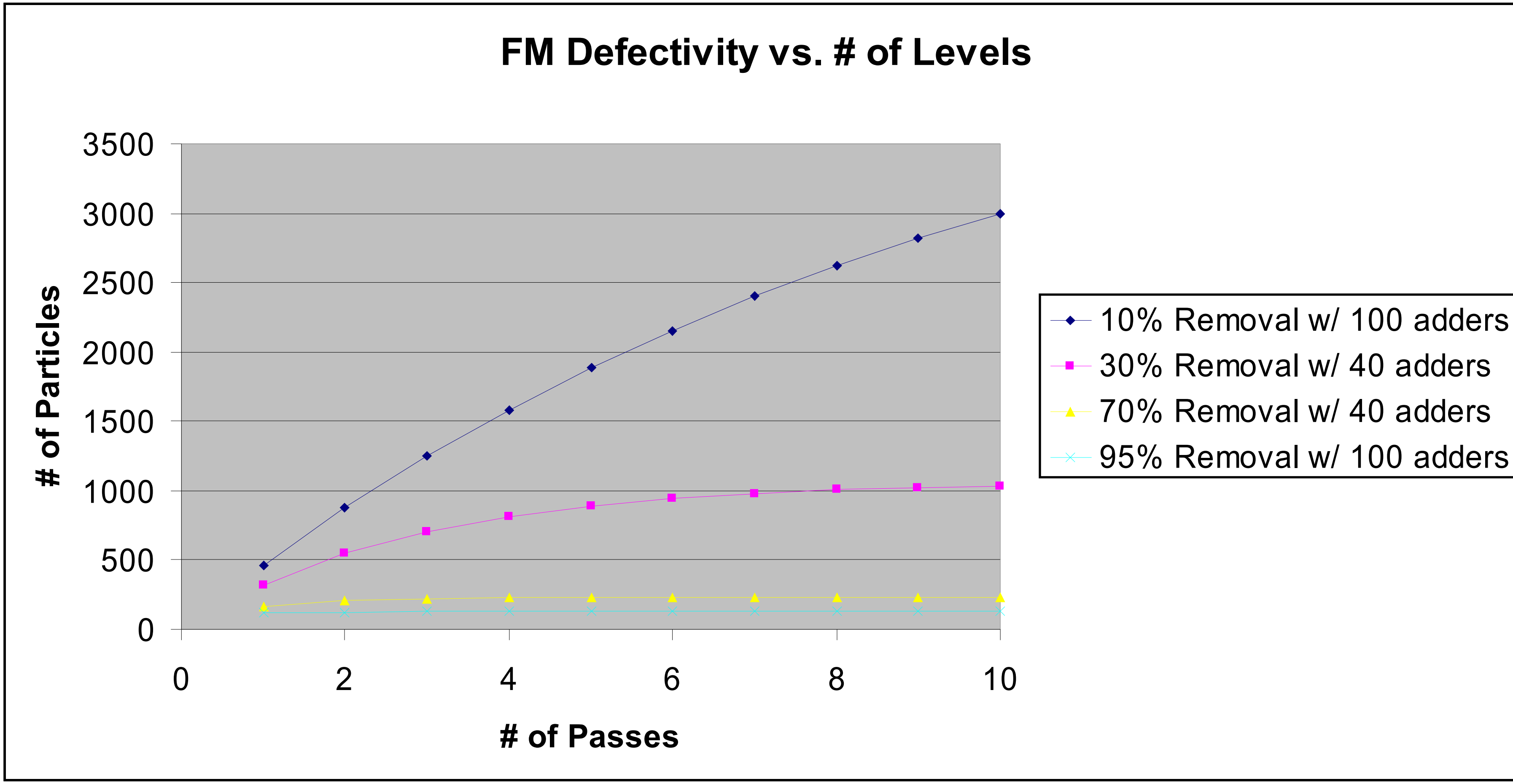
Problem: Cleaning methods must not damage sensitive patterns.
(Post gate stack RIE)

Megasonics generally is too aggressive for sensitive structures.

Answer: Fine liquid droplets

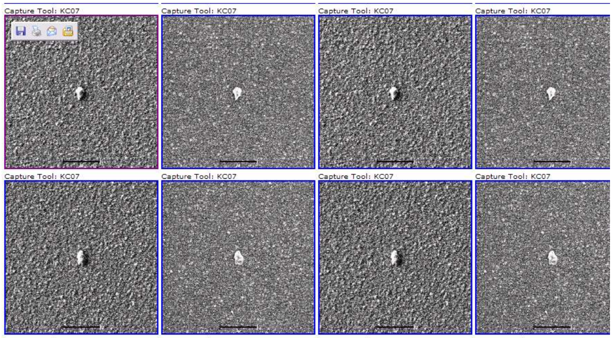
Particle Adders vs. Particle Removal

Assume ~400 particle adders / level from “other tools”

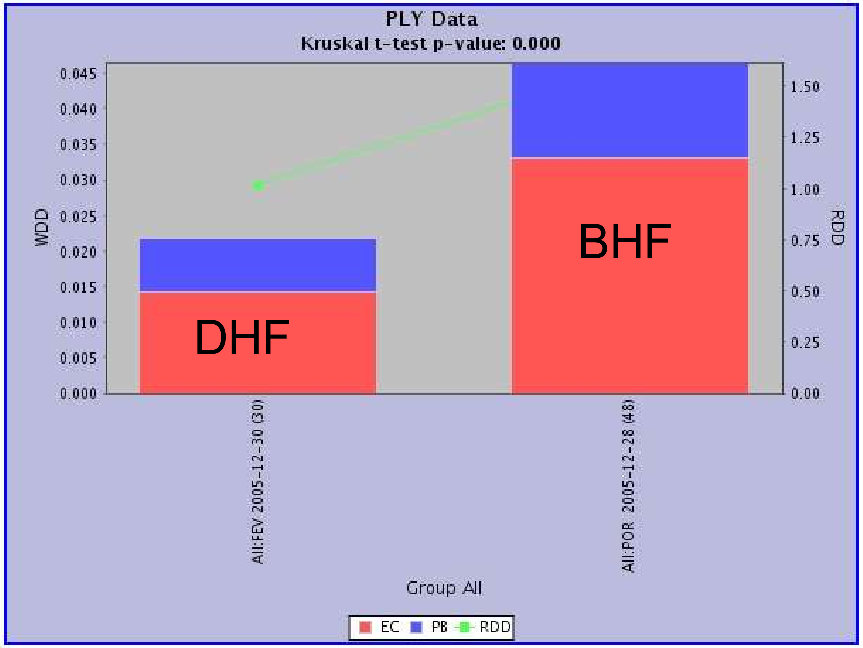


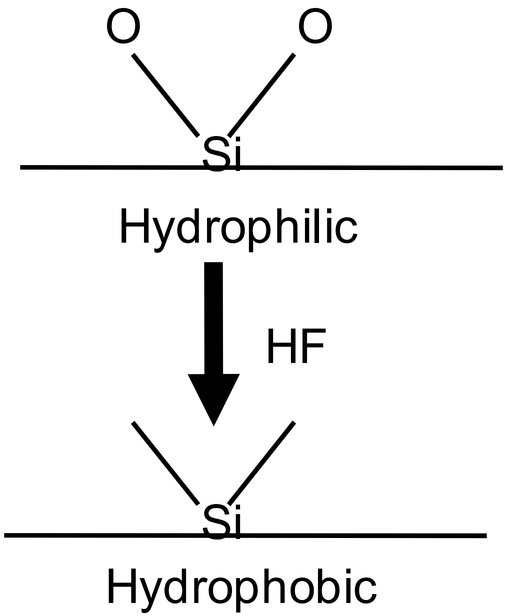
Metallic Impurities Variability: Poly Bumps Defect Learning

Problem: Trace metallics catalyze the deposition of polysilicon locally resulting in a defect known as "poly bumps".



Transition from BHF (recirculated tank w/ shared wafer history) to single use DHF had a 50% reduction in these defects.





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7. Low particle removal	Fine droplet at appropriate time/ pattern sensitivity setting.
8. Metallic impurities	Single use chemistry (especially HF) Ion exchange filtration for solvents

Variability Reduction Solutions/Strategies in Wets Processing

Single Wafer Clean Variability Reduction Elements in Green

Types of Variability	Variability Solutions Available
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2. Bath loading effects (Wafer driven)	Change the chemistry **Single Use Chemistry**
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5. Dissolved gas	Low O2 for HF increasingly important
6. Charge/electrochemical	Needed for megasonics **CO2 rinse** / **IPA rinse**
7. Low particle removal	**Fine liquid droplet at appropriate time/ pattern sensitivity setting**.
8. Metallic impurities	**Single use chemistry (especially HF)** Ion exchange filtration for solvents

Summary

- The key variability reduction strategies in wets have been identified and catalogued for the extended team's reference in thinking about the new applications listed.

- e-Sulfuric is a greener technology than sulfuric/peroxide which reduces variability because it eliminates H2O2.

- Single wafer clean captures a large number of those variability reduction elements intrinsic to the nature of single wafer clean. (Why it is so successful.)