Process Characterization of CMP Consumables

by

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Outline

- Why is CMP process characterization important?
- Levels in typical project execution order
  - Level 1: Screening
  - Level 2: First pass optimization
  - Level 3: Baseline performance
  - Level 4: Fine tuning and process sensitivities
- Examples
- Comments and conclusions

Why Bother?

- Historical approach ...
  - Consumables companies focused on just the product … let the fabs figure out how to use it on their devices
  - Only required a small data package for "proof of concept"
  - Partnered with an "alpha site" to finish debugging
- Today …
  - Marketplace is demanding more complete data packages
  - Fabs are less willing to commit long-term engineering resources to unproven products
  - Fewer fabs are willing to "be the first"
  - Strong competition for nearly every aspect of consumables

CMP Process Complexity

- **Wafer Parameters**
  - Size / Shape / Flatness
  - Film Stack Composition
    - Metals (Al, Cu, W, Pt, etc.)
    - Oxide (TEOS, PSG, BPSG, etc.)
    - Other (polysilicon, low-k polymers, etc.)
  - Film Quality Issues
    - Stress (compressive or tensile)
    - Inclusions and other defects
    - Doping or contaminant levels
  - Final Surface Requirements
    - Ultralow surface roughness
    - Extreme planarization, esp. Copper
    - Low defectivity at <0.12 um defect size

- **Pad Issues**
  - Materials (polyurethane, felt, foam, etc.)
  - Properties must be chosen for the job
  - Conditioning method must be optimized
  - Lot-to-lot consistency

- **Slurry Issues**
  - Chemistry optimization often required
  - Mixing and associated inconsistency
  - Shelf life and pot life sometimes very short
  - Slurry distribution system (design, cost, upkeep)
    - Agglomeration and gel formation
    - Filtration is often required
  - Cleaning method specific to slurry and film
  - Waste disposal and local regulations

- **Process Issues**
  - Long list of significant input variables
    - Downforce
    - Platen speed
    - Carrier speed
    - Slurry flow
    - Conditioning method
      - Disk used (material, diamond size, spacing, etc)
      - Force
      - Speed
      - Sweep profile
  - Highly sensitive to local pattern variation
  - Must maintain consistency at high throughput
  - Must optimize for variation of incoming films

- **Integration Issues**
  - Materials Compatibility
    - Electrochemical interactions with two or more metals
    - Film integrity and delamination, esp. low-k
    - Film stack compressibility
  - Interactions with adjacent process modules
    - Photolithography
    - Metal deposition and metal etch
    - Dielectric deposition and etch
  - Electrical design interactions
    - Feature size constraints
    - Interactions with local pattern density
    - Line resistance variation, esp. damascene copper
    - Dielectric thickness variation
    - Contact resistance variation

Level 1: Screening

Typical Project Status	Early screening trials New pad or slurry formulations New materials or device integration schemes
Typical Metrics	Removal rate Visual indication of surface quality
Testing Inputs and Constraints	Choose 1 or 2 primary metrics Focus on rapid cycles of learning Keep iterations low to minimize cost per trial Simplest test conditions to still give valid comparison
Goal	Sufficient data to determine most likely candidates to continue with targeted 1st round optimization

Level 2: First Pass Optimization

Typical Project Status	Initial screening complete Top two alternatives chosen for further development
Typical Metrics	Removal rate and uniformity Microscopic surface quality (roughness, scratches, etc.) Initial patterned wafer response (if applicable)
Testing Inputs and Constraints	Broader range of metrics Measure all metrics under same process conditions Include issues of process implementation (breakin, etc.) Expect iterations with formulation
Goal	Data that meets all required targets for at least a small series of wafers and justifies time/expense of a baseline marathon run

Level 3: Baseline Performance

Typical Project Status	All formulations frozen (even if temporarily) Process stability implied and remaining to be proven
Typical Metrics	Removal rate and uniformity plus selectivities (if needed) Microscopic surface quality (roughness, defects, etc.) Patterned wafer or prime wafer response over time Defect performance and detailed characterization
Testing Inputs and Constraints	Full range of metrics that a target customer will expect Measure all metrics under same process conditions Maintain formulation and process settings throughout run Benchmark against commercial standard (if applicable) Length of run in context of pad life or slurry pot life
Goal	Consistent process performance on all metrics across a reasonable marathon run

Level 4: Fine Tuning and Process Sensitivities

Typical Project Status	**All formulations frozen** **Process stability reasonably proven** **Looking for specific interactions or responses**
Typical Metrics	**Same as Level 3, but often targeted to highlight specific interactions or customer-driven process responses**
Types of Tests	**Repeatability across multiple batches or lots** **Process sensitivity to variation in key raw ingredients** **Time study: staged response through slurry shelf life** **Wear study: staged response to pad wear** **Wafer sensitivity to various test wafer sources** **Residual contamination** **Etc.**
Goal	**Data showing clear relationship between input variables and output response**

Intro to Examples

- A few examples will help illustrate the groupings of characterization levels just described
- Note that all examples represent live data taken on various materials polished at TFS
- Deliberate mix of internal and external data
- No customer identity is or will be provided
- Examples are for reference only and do not imply the ultimate capabilities of any of the products or processes used … they are only for illustration

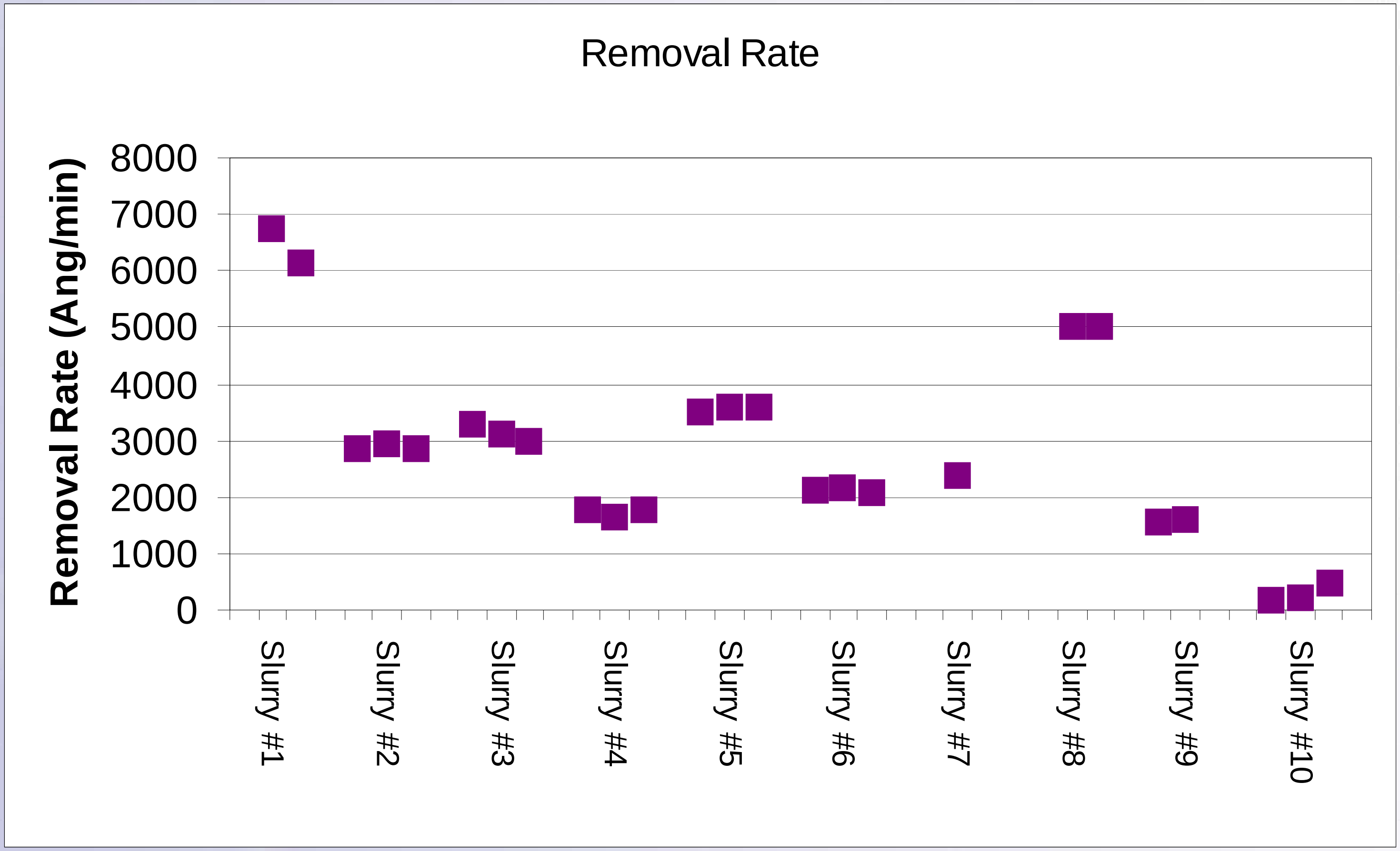
Screening Example: High rate Cu slurry formulas

- Slurry formulation trials on IPEC polisher

CMP Data Summary Table

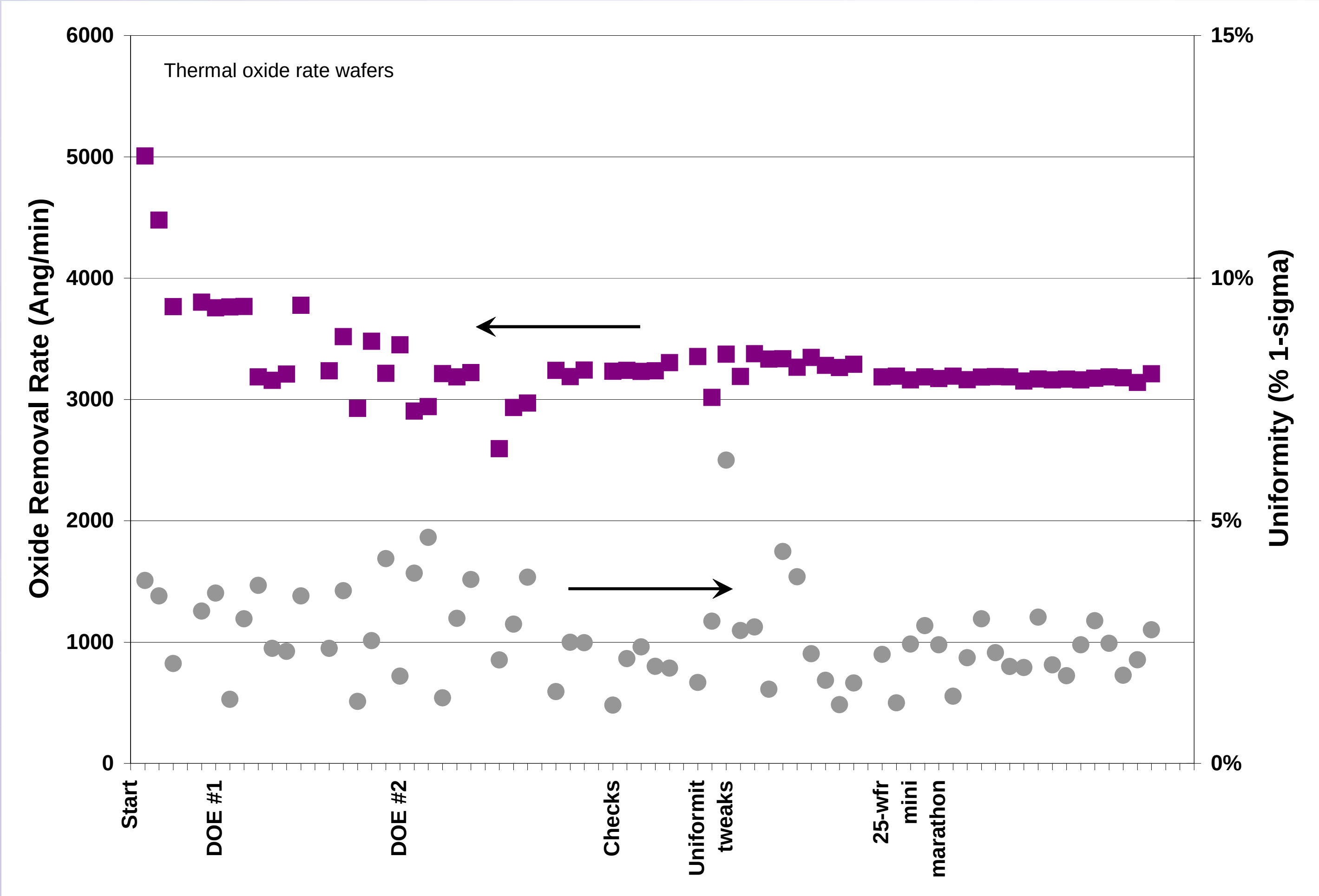
Slurry #	Copper CMP Results			
	Rate	Unif.	Ra (Ang)	Comments
1	6440	7.75%	30	
2	2880	7.85%	10	
3	3132	9.26%	11	
4	1725	10.59%	6	Excellent Ra, low rate
5	3556	5.06%	8	
6	2130	7.98%	74	
7	2385	4.94%	14	
8	4995	5.60%	459	Excessive Ra
9	1590	3.60%	11	Ra ok, low rate
10	479	9.63%	66	

Screening Example: High rate Cu slurry formulas



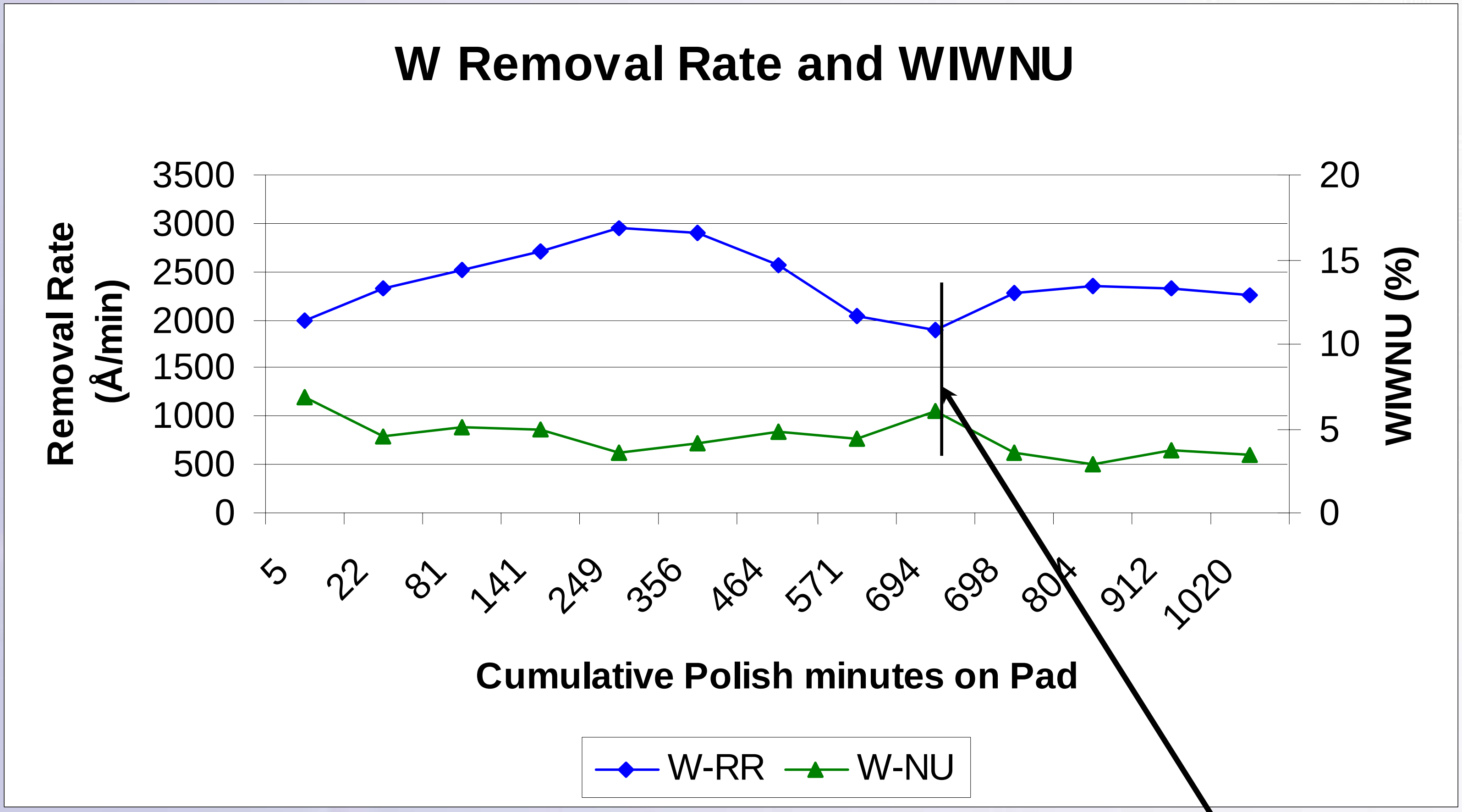
If goal is >4kA/min rate, most of these can be eliminated

Process Optimization Example: Thermal Oxide



Optimized process now ready for full marathon, if desired

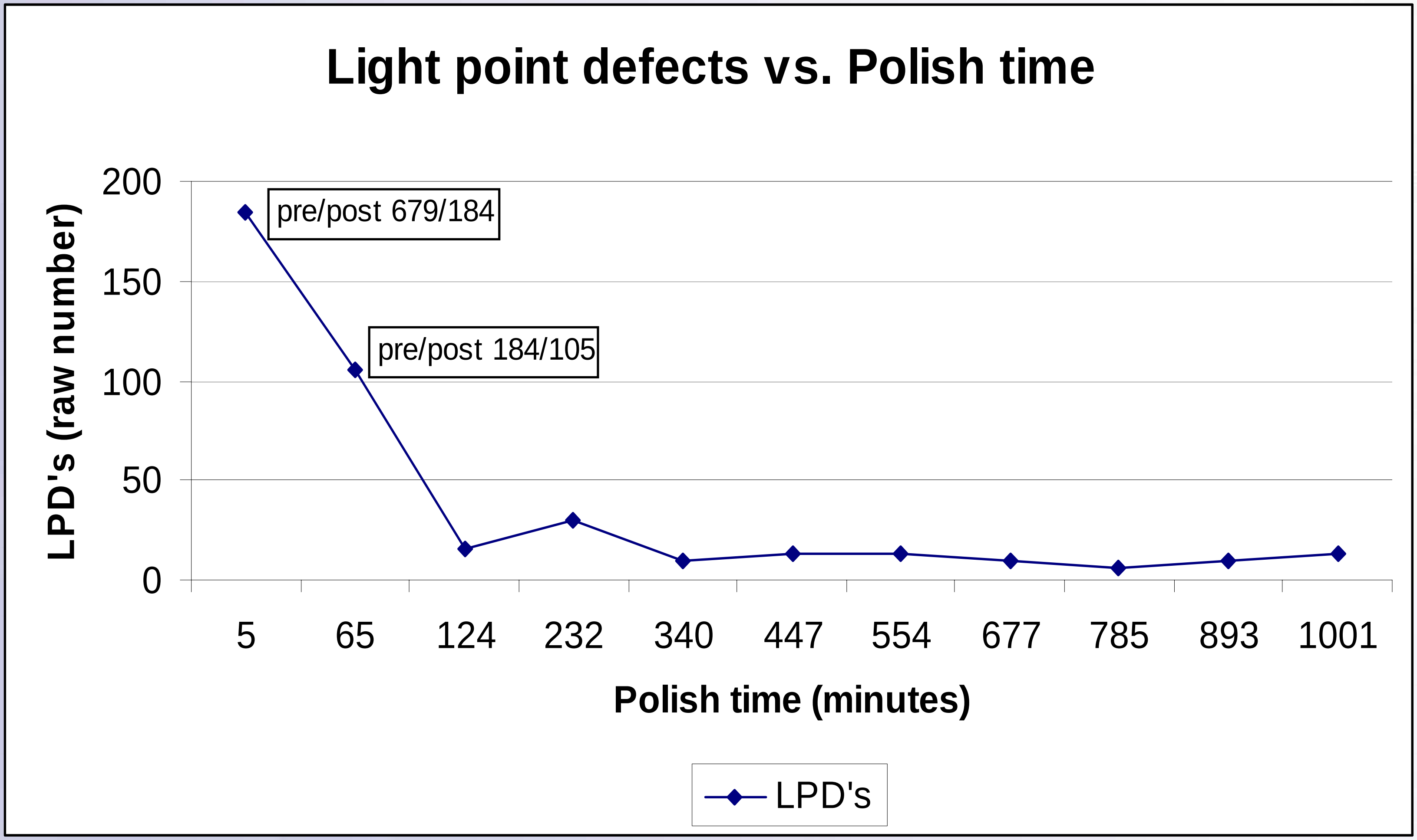
Baseline Example: Tungsten RR/WIWNU



Expt paused to develop brush conditioning then continued with improved process stability

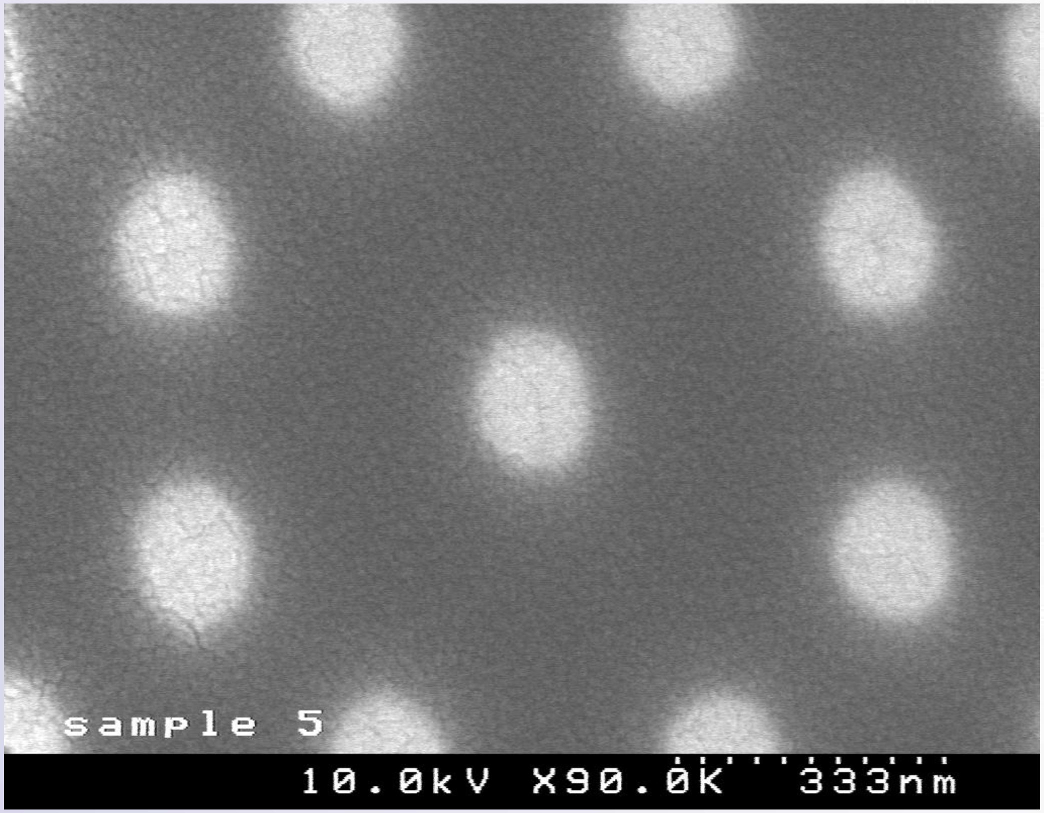
Baseline Example: Tungsten Process Defectivity

Blanket film low-defect TEOS wafers

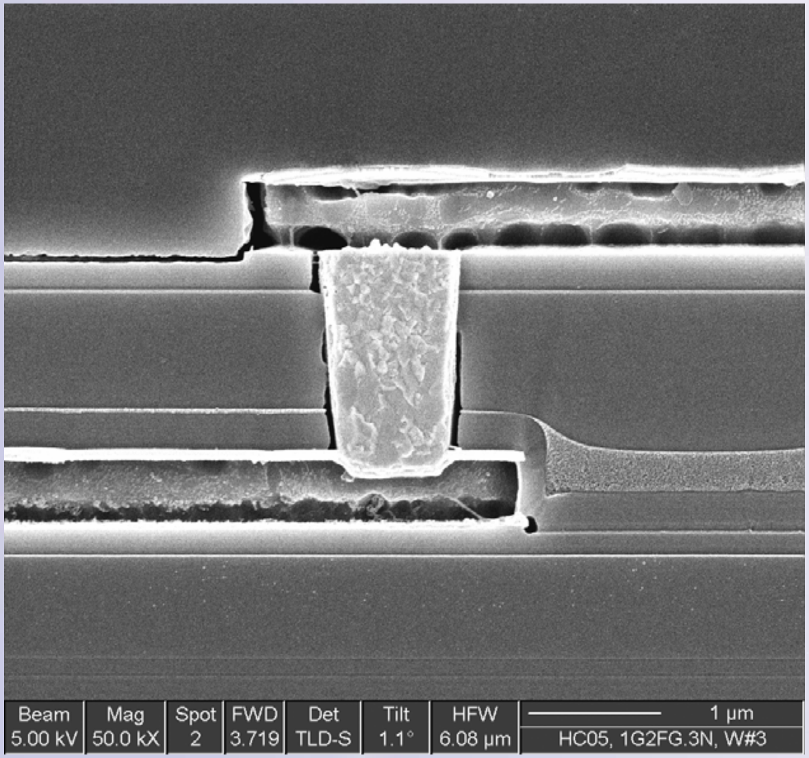


Baseline Example: Tungsten Plugs

FE-SEM picture of 0.15um plugs on SKW-5P test wafer polished with baseline W CMP process



Baseline Example: Tungsten Plugs



Cross section SEM of tungsten plug polished with first generation tungsten baseline CMP process

Baseline Example: Residual Contamination Data

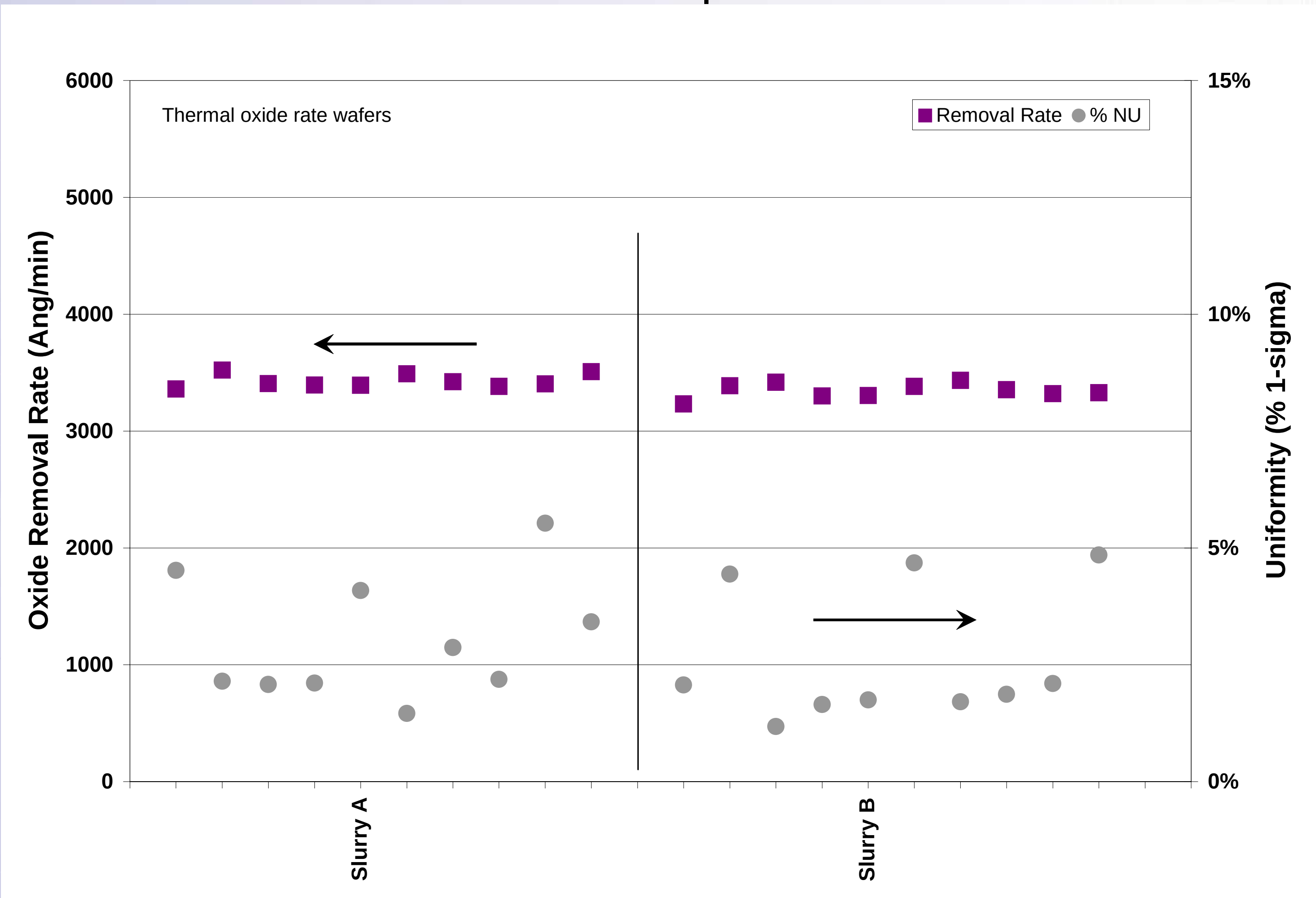
Key Point

- All values from TFS lab are less than or comparable to fab reference

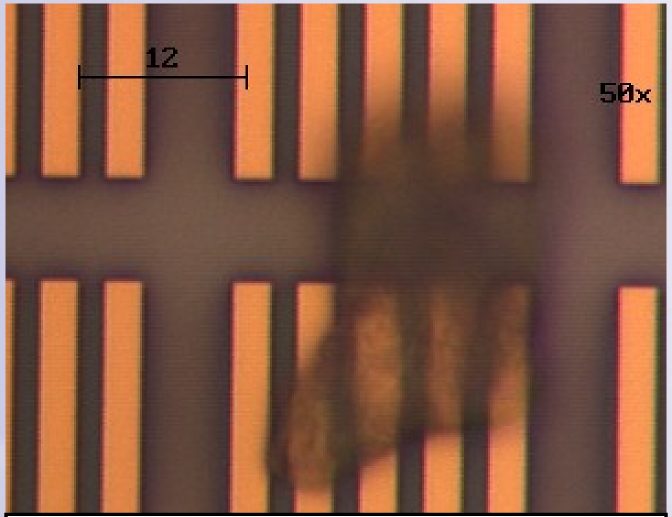
#	Element	Mainstream Fab Reference	Baseline on 472 at TFS	Baseline on 372M at TFS	Scrubber Qual	Second Scrubber Qual
All values represent surface area densities in 1E10 atoms per square cm						
1	P	108.07	96.28	76.24	80.32	84.78
2	S	478.7	368.09	389.6	383.63	384.49
3	Cl	79.84	80.98	66.78	77.42	72.85
4	K	0	0	0	0	0
5	Ca	5.18	7.74	39.96	5.75	3.62
6	Sc	0	0	0	0	0
7	Ti	0.65	0	0	0	0
8	V	0	0	0	0	0
9	Cr	0	0	0	0	0
10	Mn	0	0	0.13	0	0
11	Fe	179.11	95.44	95.03	0.94	0.45
12	Co	0	0	0	0	0
13	Ni	0	0.21	0.08	0.25	0
14	Cu	0.1	0.74	3.93	0	0
15	Zn	0.05	3.38	15.39	0.85	0
16	W	0	0	0	0	0

Process Sensitivity Example: Slurry Comparison

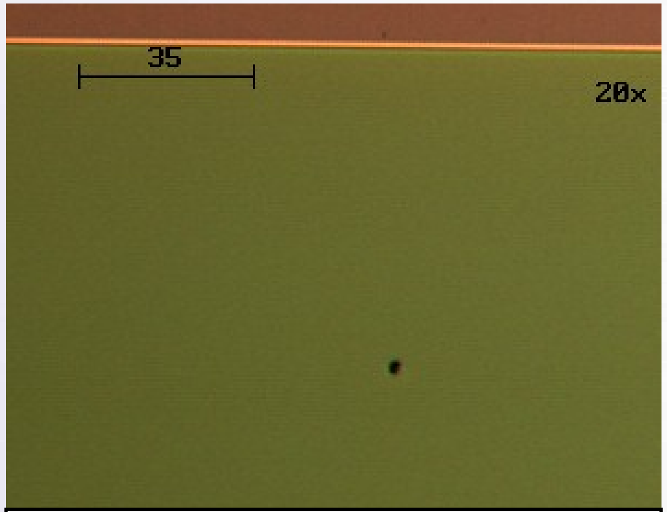
Baseline oxide process



Fine Tuning Example: Copper Wafer Defects

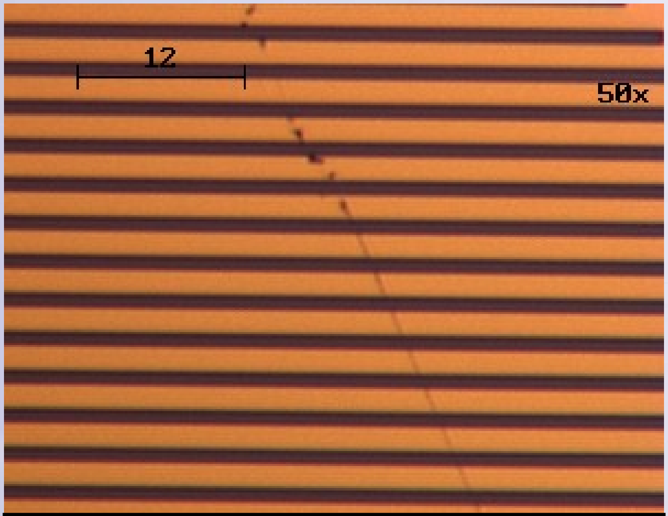


Large particle

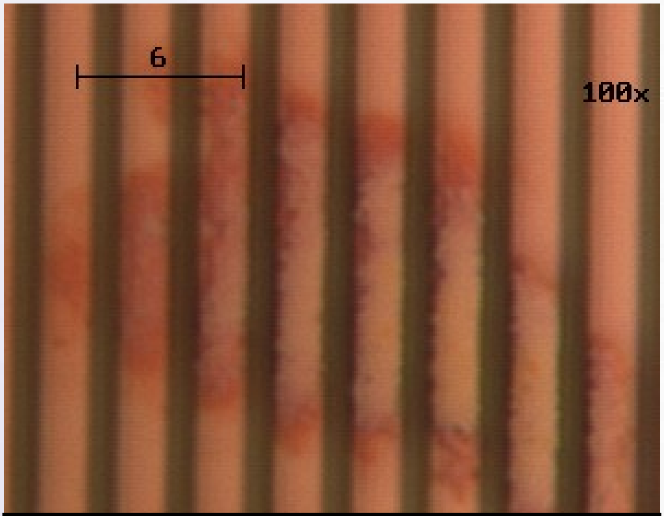


Small particle on oxide

Fine Tuning Example: Copper Wafer Defects

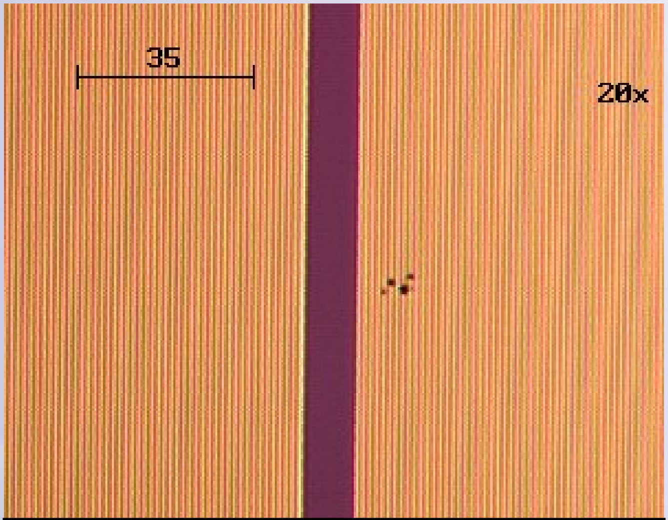


Scratch

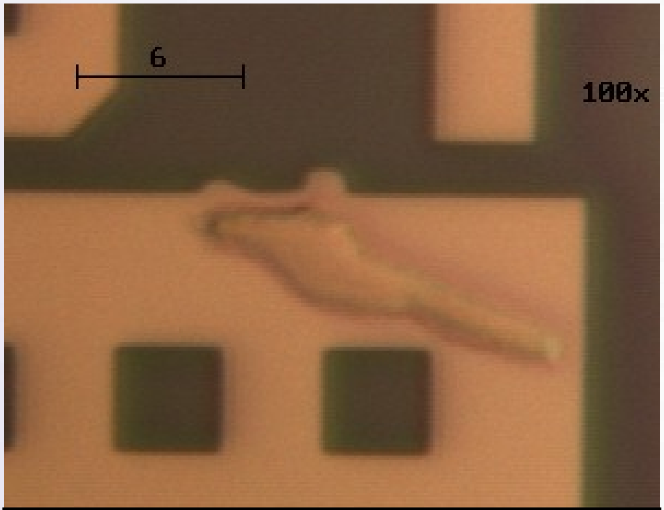


Corrosion

Fine Tuning Example: Copper Wafer Defects



Cluster of pits



Prior layer defect

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Contact info

- Anyone desiring copies of this presentation or wishing to discuss issues related to this talk, please contact one of the following people at TFS:

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Additional Information

The following slides contain additional details related to CMP outsourcing.

Reasons to Outsource CMP

- Lower Risk
  - Immediate access to proven process technology and expertise
  - Minimize complexity associated with polishers, cleaners, chemical delivery, filtration, metrology, consumables, etc.
- Faster Execution
  - Rapid prototyping, development projects or process qualification
  - Reduce implementation time an average of 12 to 18 months
- Substantial Cost Benefits
  - Reduce or eliminate capital expenditures
  - Lower unit costs
- Production Impact
  - Perform engineering trials without taking your polishers off line
  - Flexible manufacturing capacity when you need it

CMP Development Project Comparison

Internal Development:

- Capital Investment: $ 1.5 M
- Several Engrs + Staff: $ 1.0 M/Yr
- Time to Develop: 18-24 mo.
- Multiple learning cycles

Outsourced Development:

- Capital Investment: $ 0
- One Sr. Engineer: $150K/Yr
- Time to Develop: 6-9 mo.
- Leverage existing processes, staff, experience, and consulting

Time to Implement: