

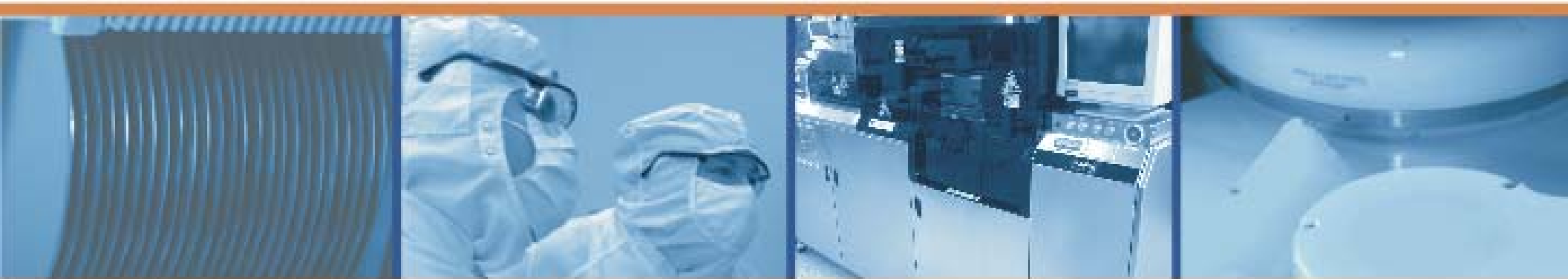
# Process Characterization of CMP Consumables

By

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- **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**

- **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

- **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 (polish and conditioning)
    - » 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

<b>Typical Project Status</b>	<b>Early screening trials New pad or slurry formulations New materials or device integration schemes</b>
<b>Typical Metrics</b>	<b>Removal rate Visual indication of surface quality</b>
<b>Testing Inputs and Constraints</b>	<b>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</b>
<b>Goal</b>	<b>Sufficient data to determine most likely candidates to continue with targeted 1<sup>st</sup> round optimization</b>

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

<b>Typical Project Status</b>	<b>All formulations frozen (even if temporarily) Process stability implied and remaining to be proven</b>
<b>Typical Metrics</b>	<b>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</b>
<b>Testing Inputs and Constraints</b>	<b>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</b>
<b>Goal</b>	<b>Consistent process performance on all metrics across a reasonable marathon run</b>

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

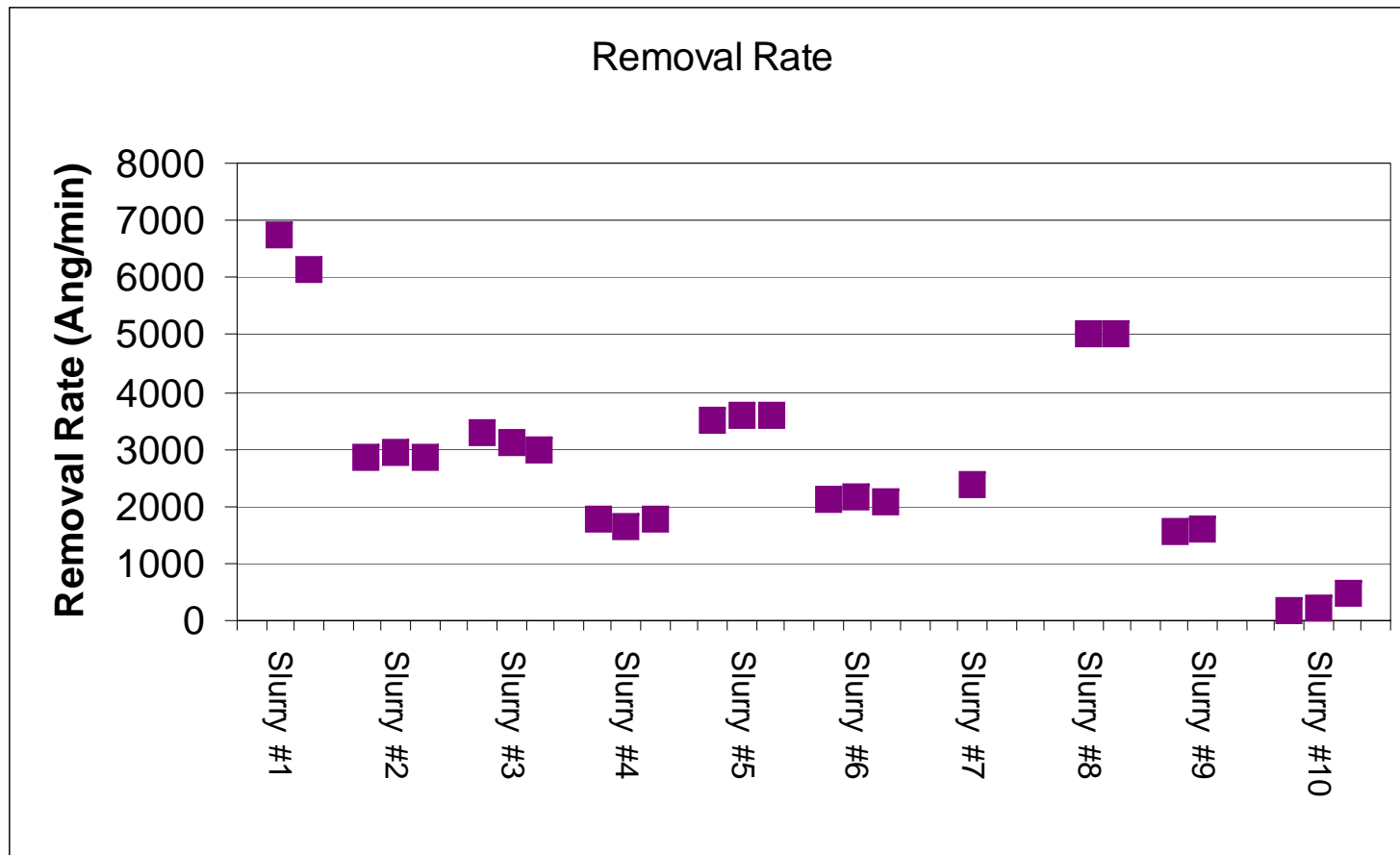


- A few examples will help illustrate the groupings of characterization levels just described
- Note that all examples represent live data taken on various materials polished at TFS
- Deliberate mix of internal and external data
- No customer identity is or will be provided
- Examples are for reference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

## Slurry formulation trials on IPEC polisher

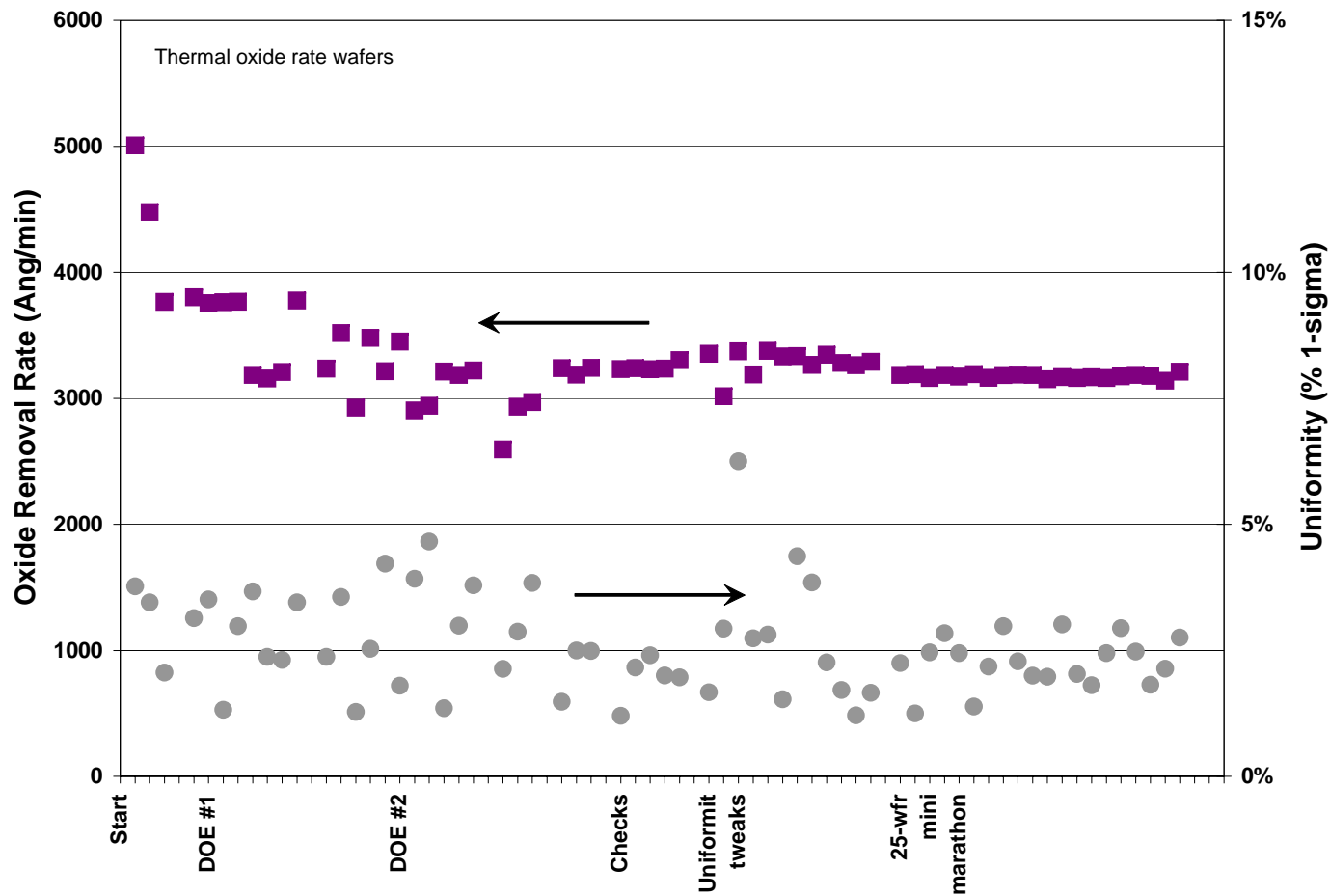
<b>CMP Data Summary Table</b>				
<b>Slurry #</b>	<b>Copper CMP Results</b>			
	<b>Rate</b>	<b>Unif.</b>	<b>Ra (Ang)</b>	<b>Comments</b>
1	6440	7.75%	30	
2	2880	7.85%	10	
3	3132	9.26%	11	
4	1725	10.59%	6	Excellent Ra, low rate
5	3556	5.06%	8	
6	2130	7.98%	74	
7	2385	4.94%	14	
8	4995	5.60%	459	Excessive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

# Screening: High rate Cu slurries

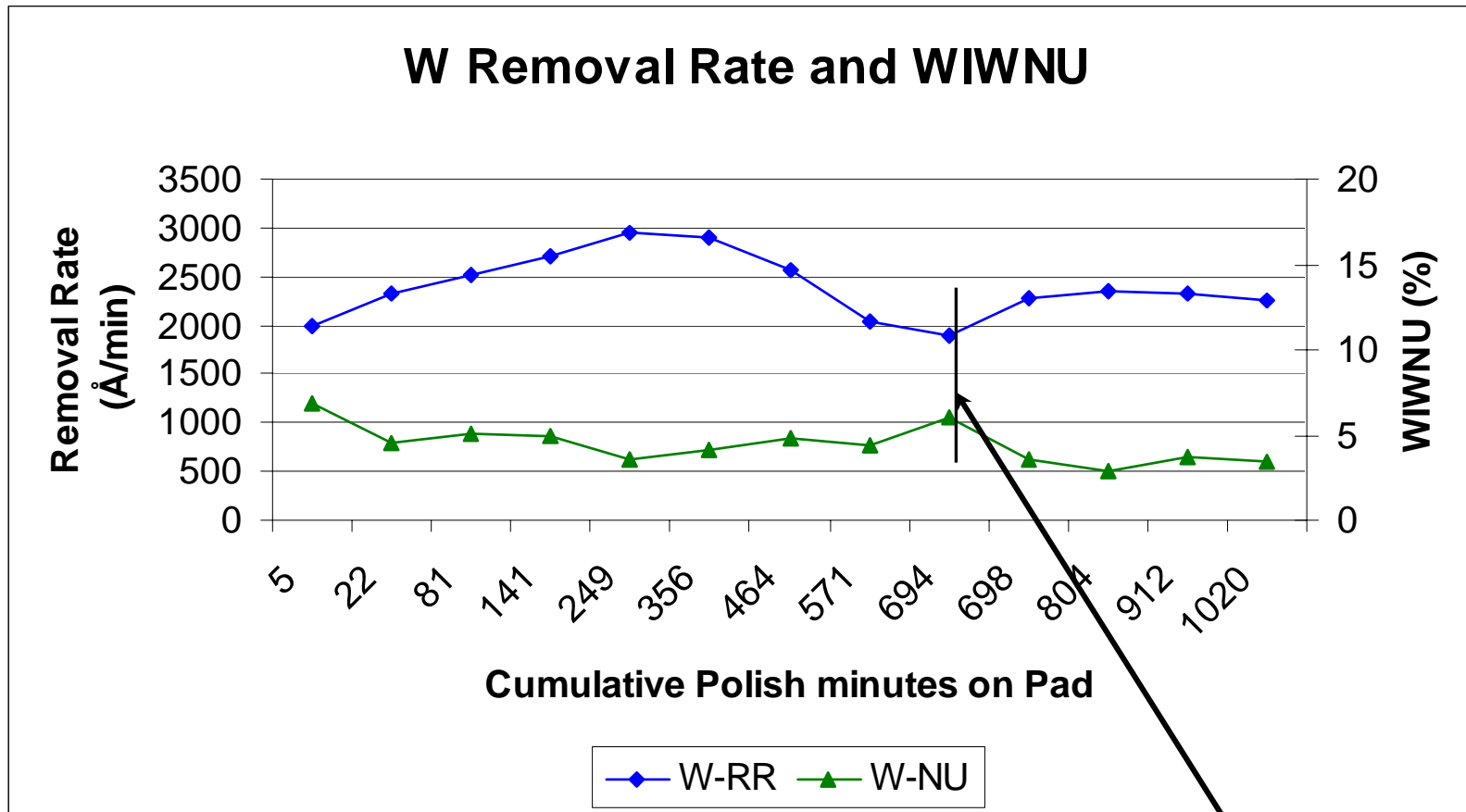


If goal is >4kA/min rate, most of these can be eliminated

# Process Optimization Example: (Thermal Ox)

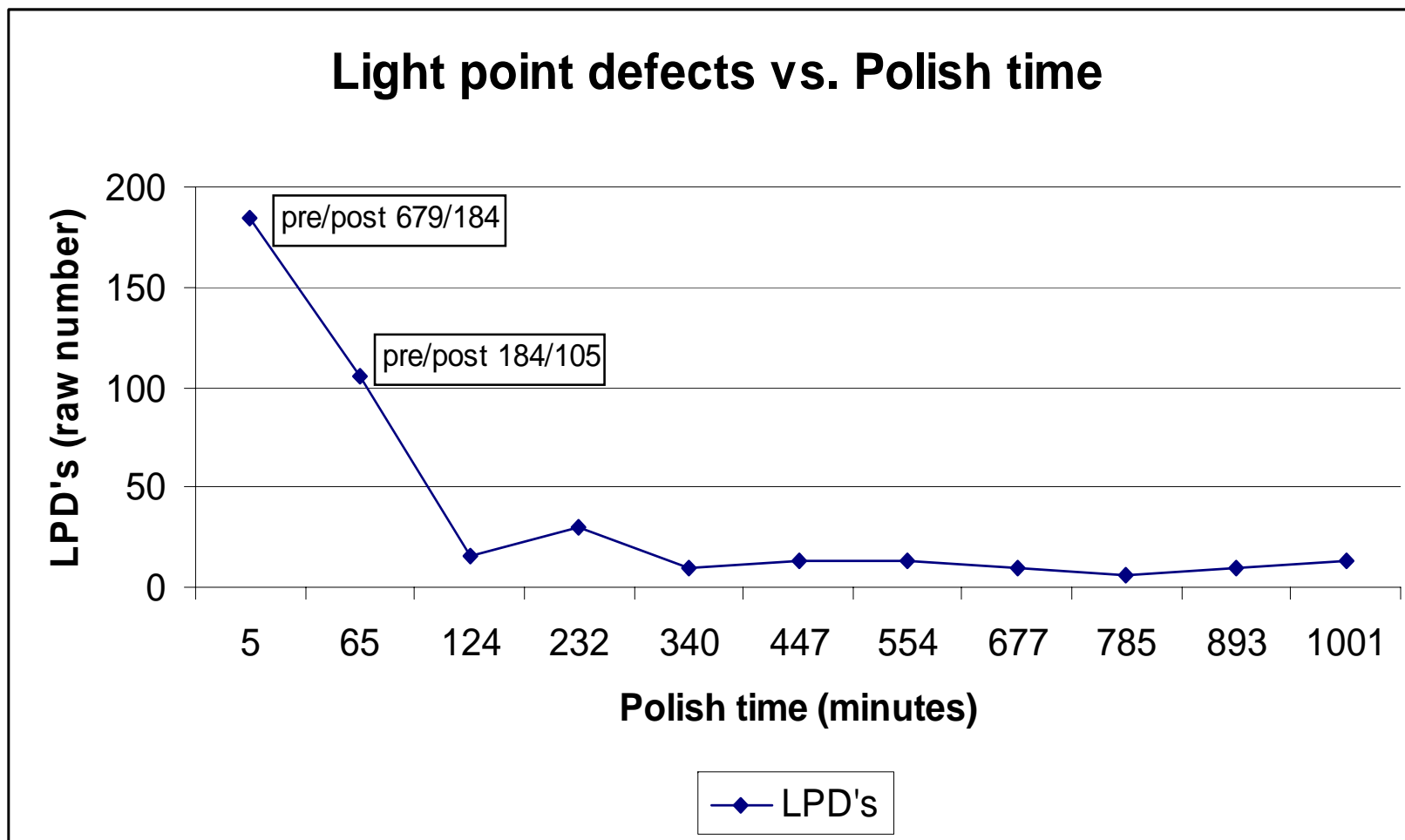


Optimized process now ready for full marathon, if desired

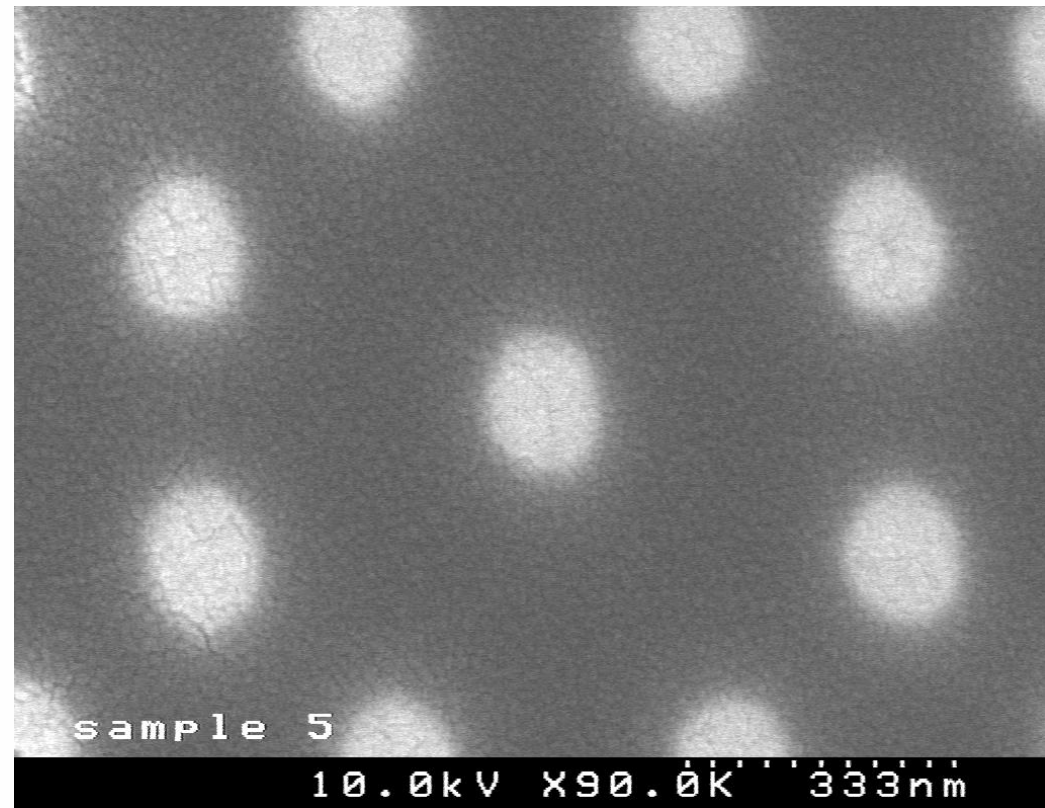


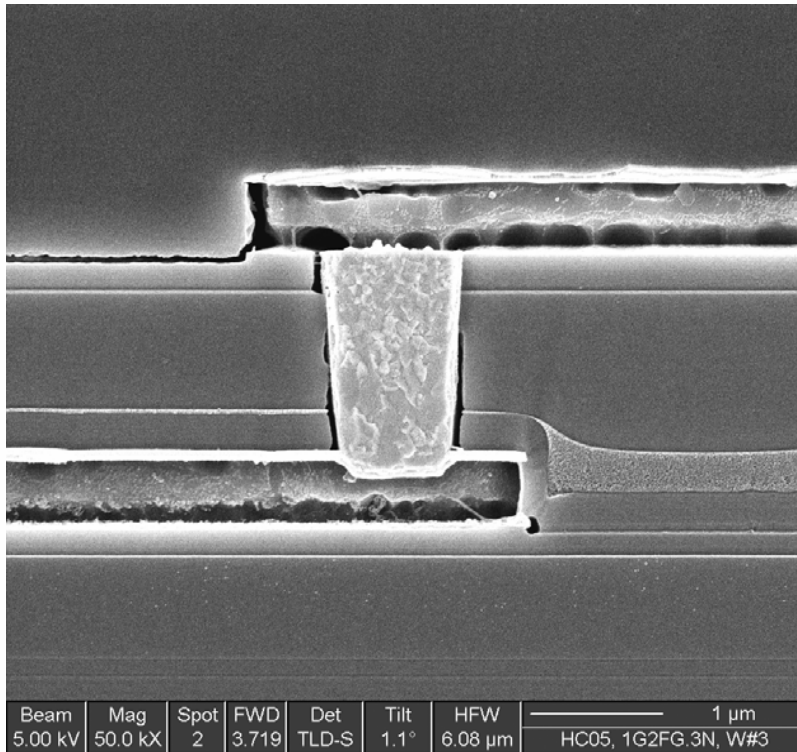
Expt paused to develop brush conditioning then continued with improved process stability

## Blanket film low-defect TEOS wafers



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





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



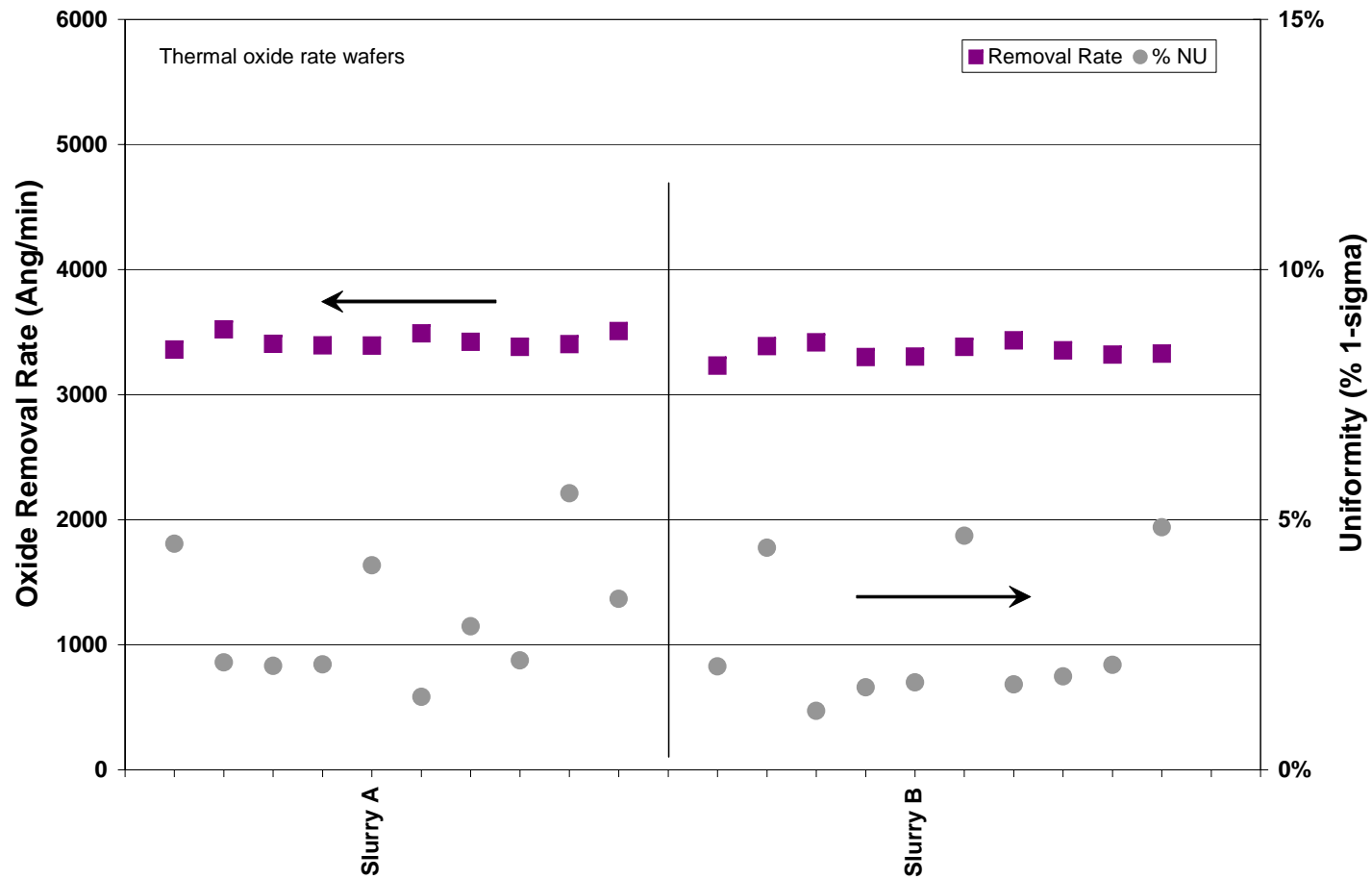
# Baseline: Residual Contamination Data

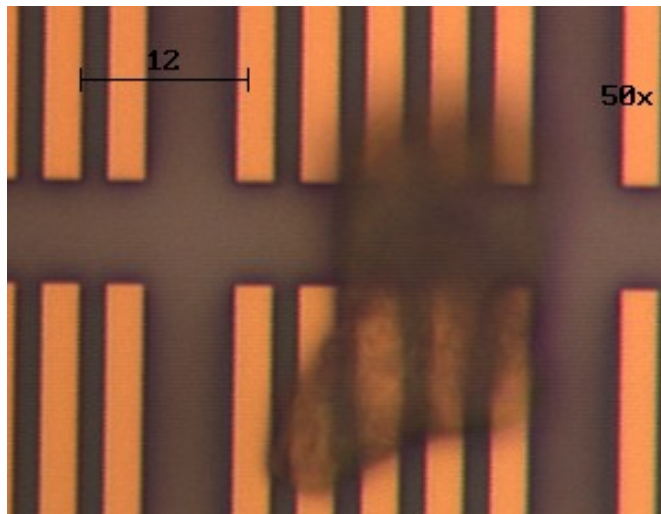
## Key Point

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

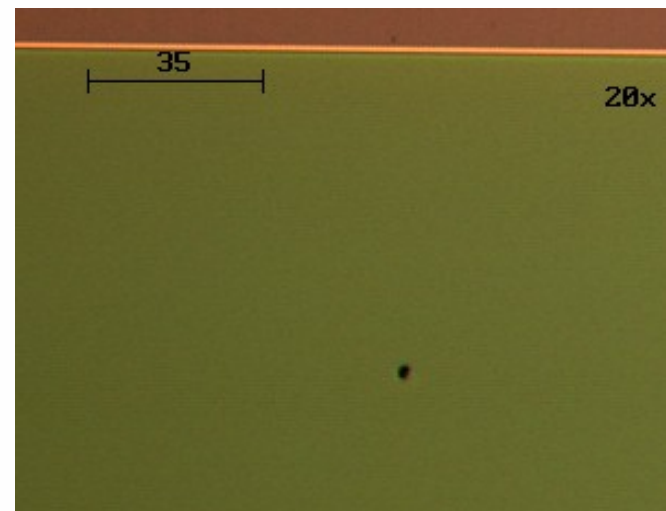
#	Element	Mainstream Fab Reference	Baseline on 472 at TFS	Baseline on 372M at TFS	Scrubber Qual	Second Scrubber Qual
All values represent surface area densities in 1E10 atoms per square cm						
1	P	108.07	96.28	76.24	80.32	84.78
2	S	478.7	368.09	389.6	383.63	384.49
3	Cl	79.84	80.98	66.78	77.42	72.85
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

## Baseline oxide process

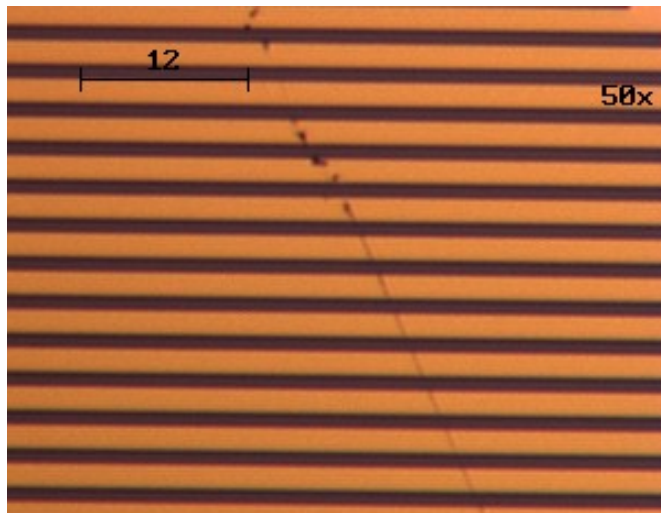




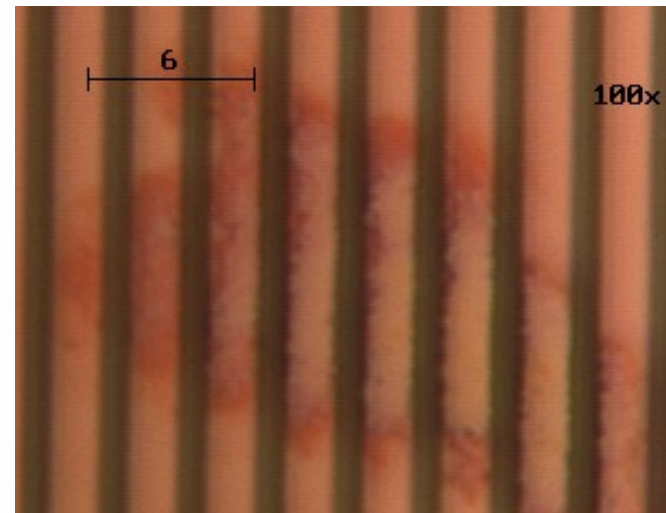
**Large particle**



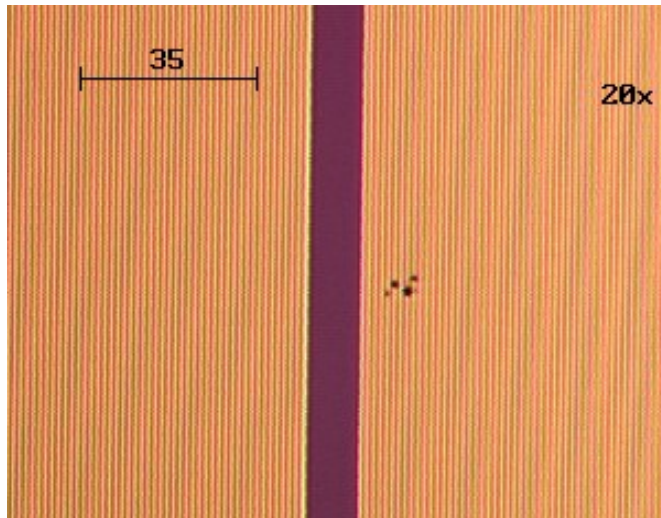
**Small particle on oxide**



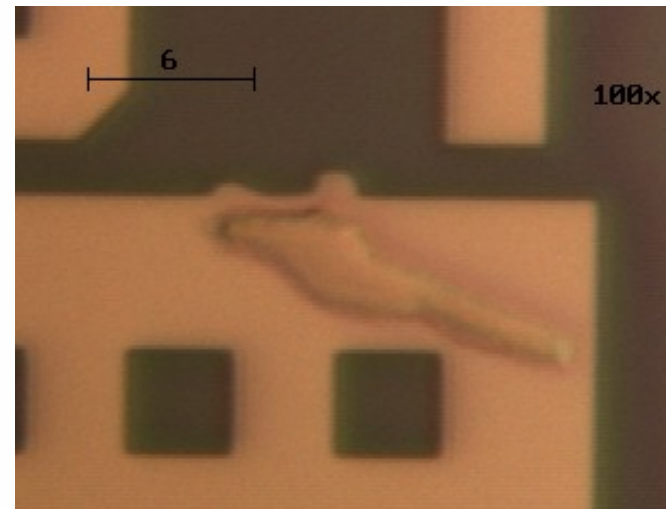
**Scratch**



**Corrosion**



**Cluster of pits**



**Prior layer defect**

- Entire staff at TFS, with specific thanks to the following individuals:
  - Jeanie Simmons
  - Donna Grannis
  - Terry Pfau
  - Paul Lenkersdorfer
  - Roy McCoy
  - Jim Dekarske
  - Tim Knippa
- Many customers who, though unnamed here, have helped us refine the CMP process characterization methods described in this presentation.

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