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

**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

**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
## 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)  
<table>
<thead>
<tr>
<th></th>
<th>Process stability implied and remaining to be proven</th>
</tr>
</thead>
</table>
| 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

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<th>Comments</th>
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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

Light point defects vs. Polish time

LPD's (raw number)

Polish time (minutes)

pre/post 679/184
pre/post 184/105
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

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All values represent surface area densities in 1E10 atoms per square cm
Process Sensitivity Example: Slurry Comparison

Baseline oxide process

![Graph showing oxide removal rate and uniformity comparison between Slurry A and Slurry B.](image-url)
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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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:**

![Diagram showing time comparison between internal and outsourced development projects.](Image)