Post Cleaning Chemical of Tungsten Chemical Mechanical Planarization for Memory Devices

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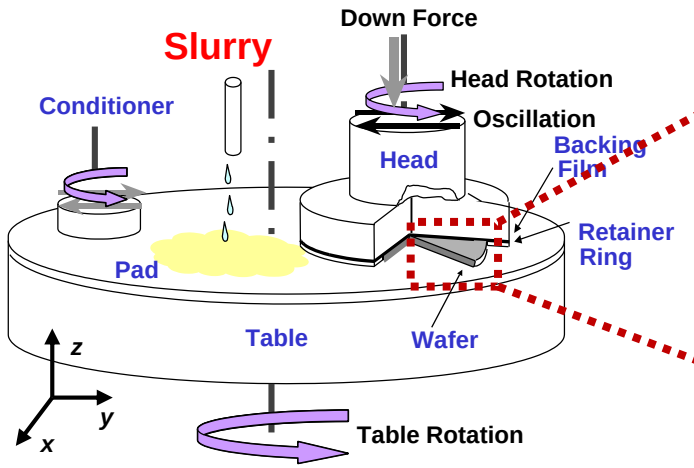
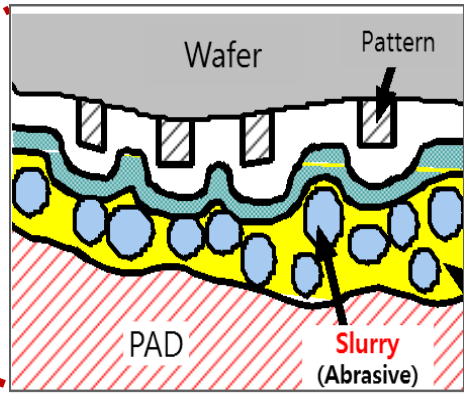
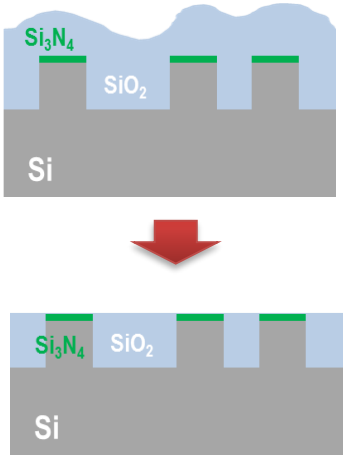
Cleaning/CMP Technology

1. *CMP Process and Cleaning challenges*
2. *Problem Statement*
3. *Results of Cleaning Chemical Evaluation*
4. *Summary*

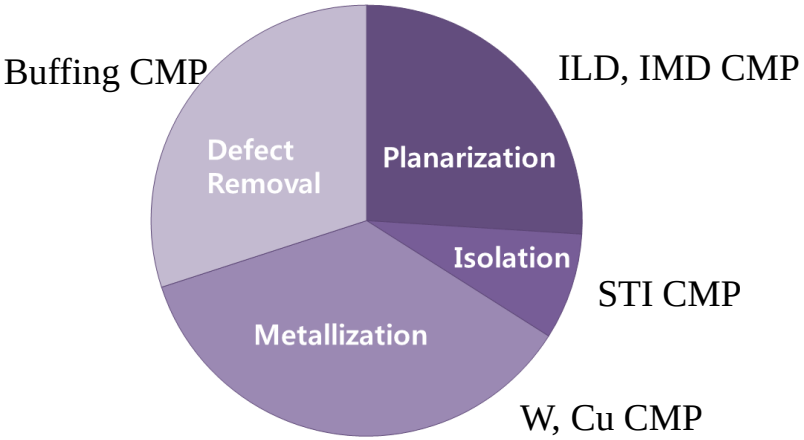
Chemical Mechanical Polishing (CMP)



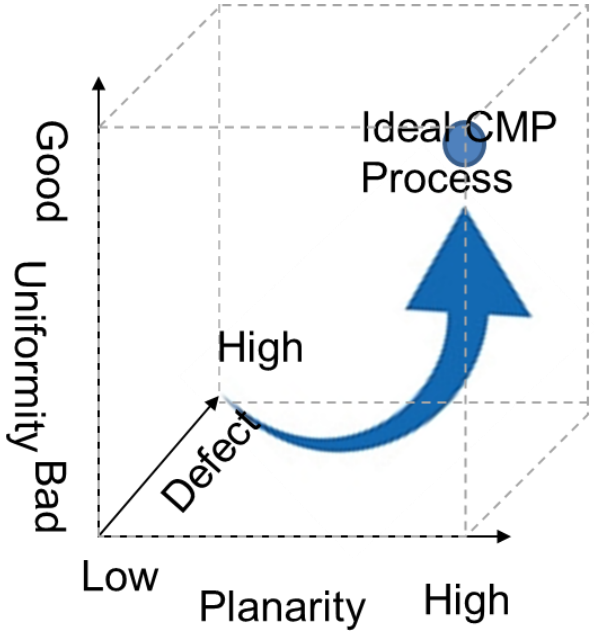


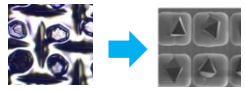
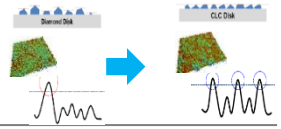
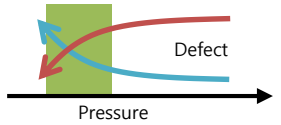
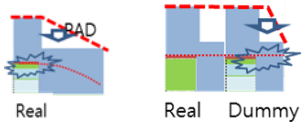


- CMP was first introduced to semiconductor process to planarize ILD.
- With improvements in equipment and consumables, CMP is used in STI CMP for isolation, W, Cu CMP for metallization and Buffing CMP for particle removal.
- The number of W CMP steps is increasing with the introduction of VNAND.



DEFECT control



Slurry	**Abrasive Size, Shape**	**Uniform, Round**	
Disk	**Diamond Height, Arrangement**	**Even protrusion, Regular**	
Pad	**Contact, Hardness**	**Uniform, Soft**	
Process /Consumables	**Head Pressure, Brush gap, Brush**	**Low Brushless**	
Environment	**Foreign Particle, Pattern**	**Edge Engineering**	
Chemical	**Cleaning Time**	**-**	-

- CMP process has been developed through equipment, functional slurries and pad, disk.
- Scratch reduction has been mainly made through pad, slurry changes.
- Particles are reduced through changes in brush and process conditions.
- Post CMP Cleaning Chemicals(SC1,NH4OH, and HF) have been used since CMP process was introduced.

Post CMP cleaning Challenges

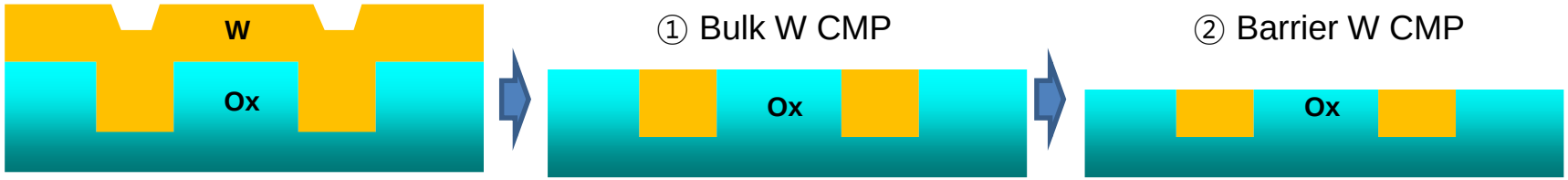
- Abrasive particle
  - Ceria Slurry Cleaning
- Smaller abrasive size
  - Smaller Particles are More Difficult to Remove
  - Difficult to measure
- Non-visual defect
  - Defects can be confirmed by Fab-out yield.
- Limited cleaning chemical
  - SC1, NH_4OH, HF
- Effect of brush lifetime
- Dependency on tool
- Design rule

Results of Cleaning Chemical Evaluation

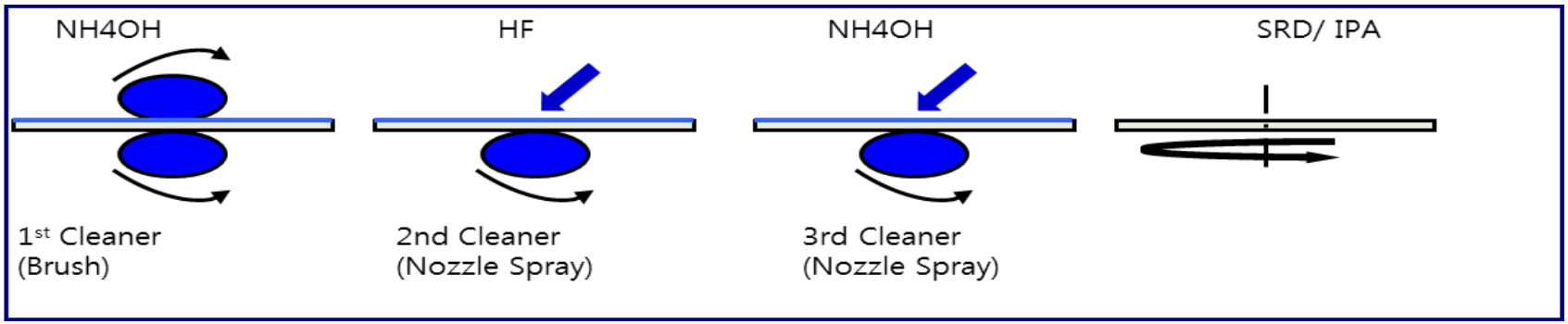
1. **Problem Statement**
2. **Contamination Source**
3. **Evaluation of Ammonia, HF**
4. **Evaluation of Formulated Cleaning Chemical**
   - **Defect on blanket wafer**
   - **Properties of Formulated Chemical**
   - **Results of Tungsten Surface Analysis**
   - **Results of Application to Pattern Wafer**

Typical Tungsten CMP Process

Ⅰ. Polishing

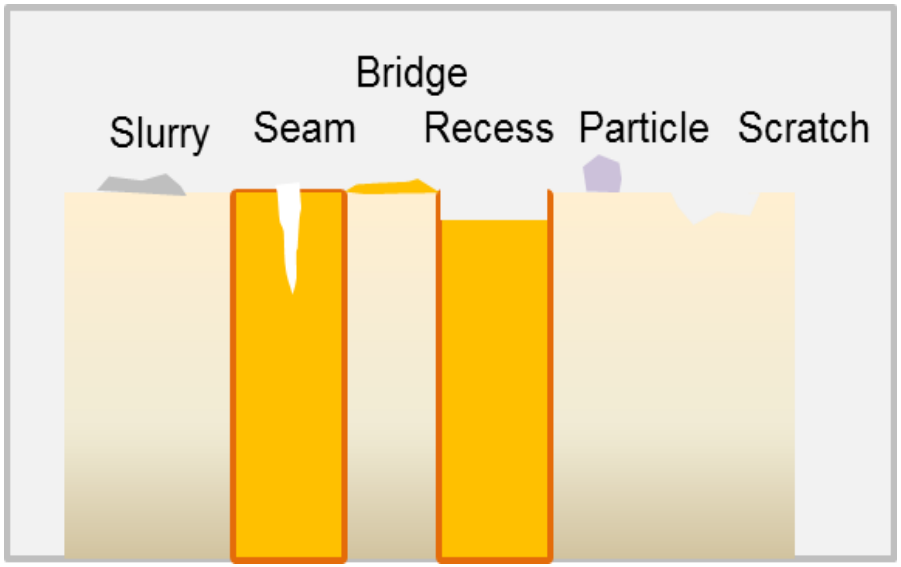


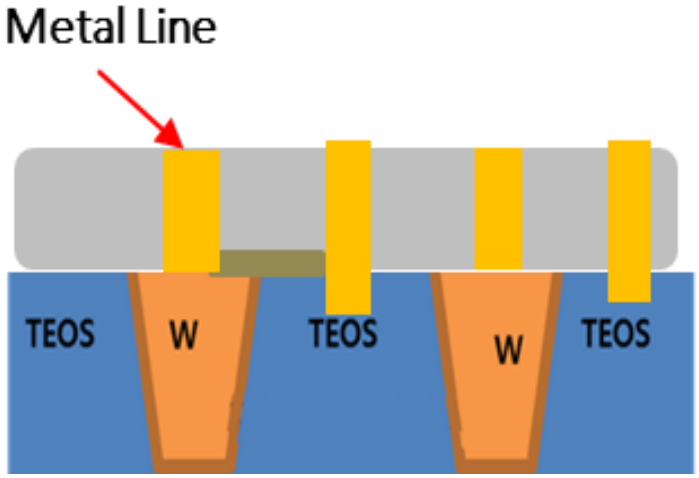
Ⅱ. Cleaning



- Tungsten CMP process consists of two process, a main polishing process and a post-CMP cleaning process.
- In the post-CMP cleaning step, all of the wafers were treated with wet chemicals to remove the remaining chemicals and abrasives on the wafer.

Defects Induced W CMP Process



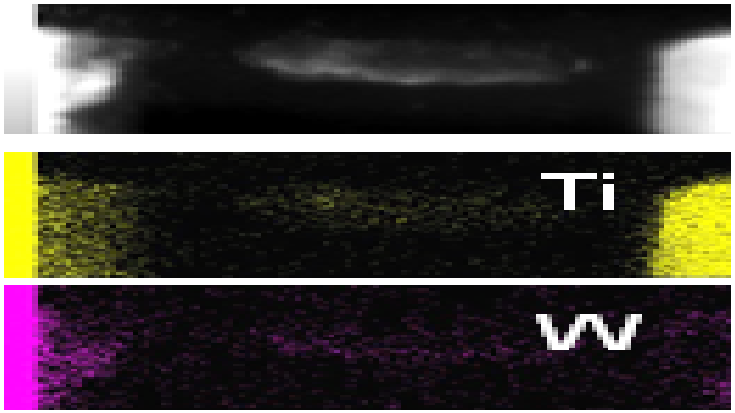


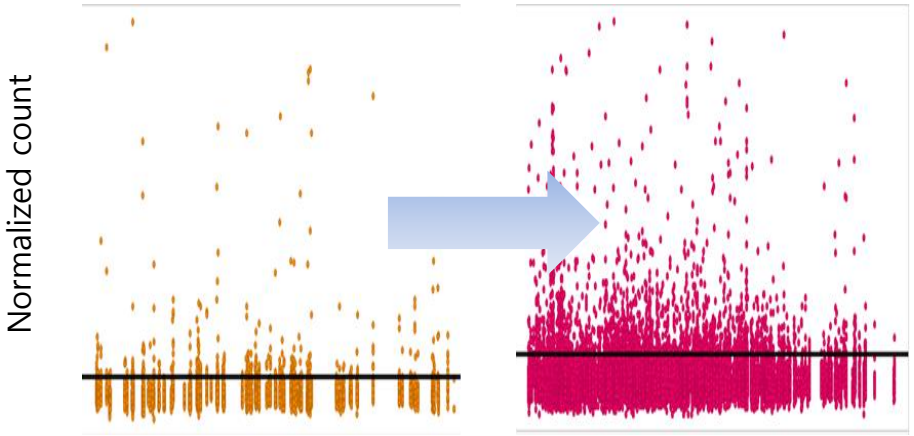
Metal Line Bridge

- Defects to be removed from W CMP process include slurry residues, organic particles, scratches and bridge.
- Bridge : Materials on the surface after W CMP causes the subsequent Metal line connection
- Conducting materials can result in the product yield loss.

Problem Statement

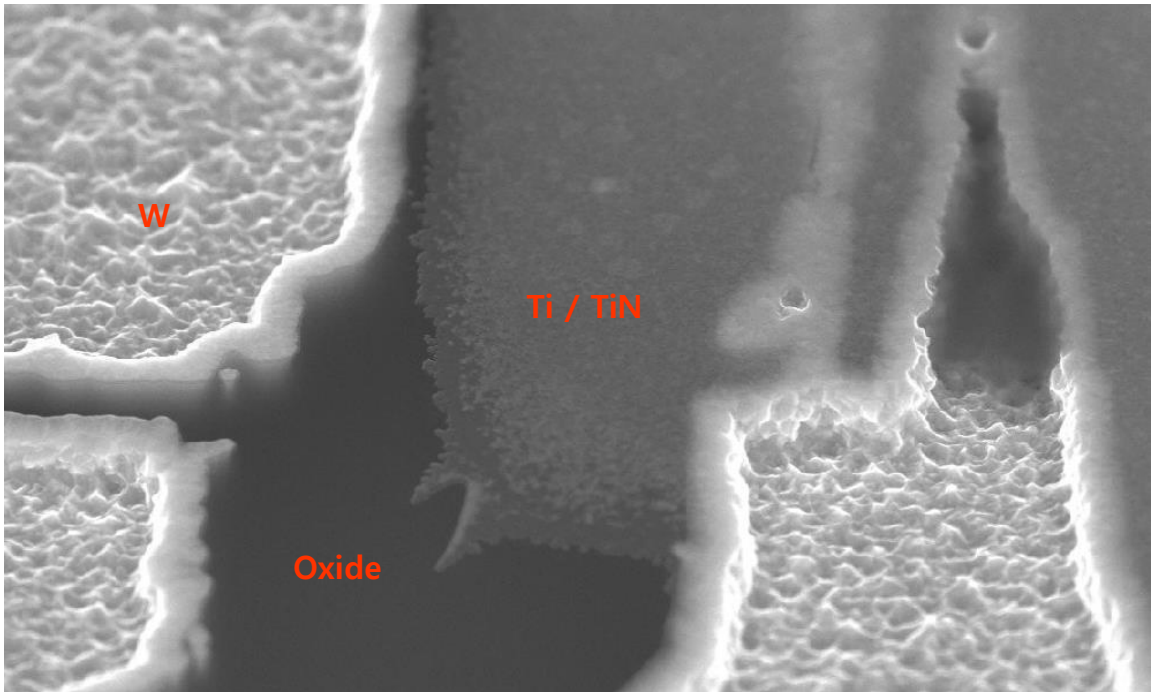
- Bridge Fail on W CMP





- The conductive material that induces the bridge is Ti, W.
- As device design rules decrease , failure counts increase.
- Residues that contribute to this issue are undetectable and do not correlate to total defects on the wafer.

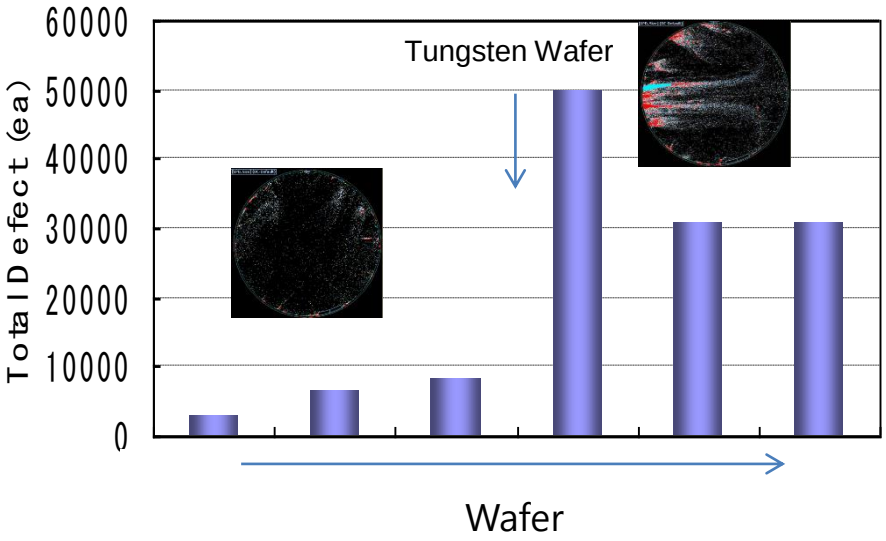
Cross Contamination Source

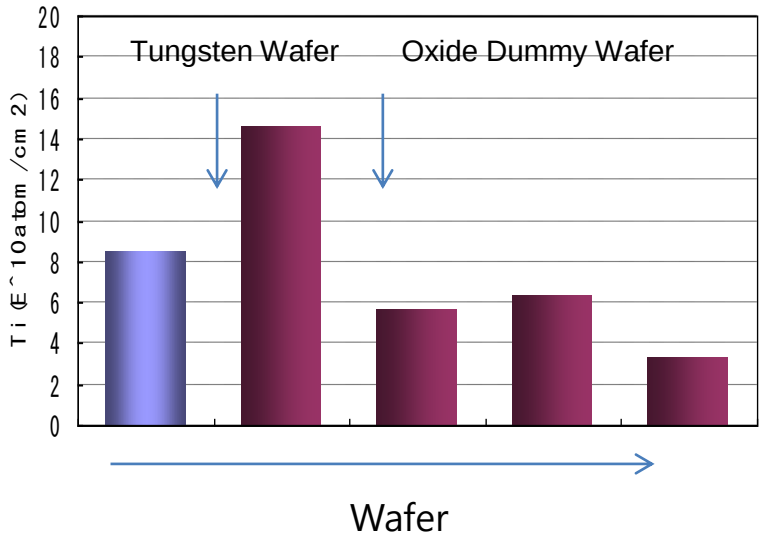


V_SEM Image

- The wafer surface has multiple films such as W, Ti, TiN, Oxide.
- These can cause brush contamination.

Evaluation of Brush contamination

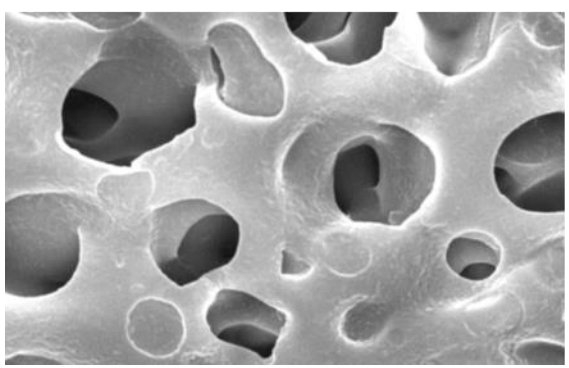


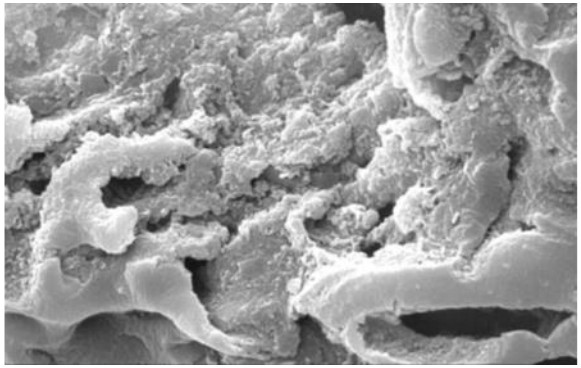


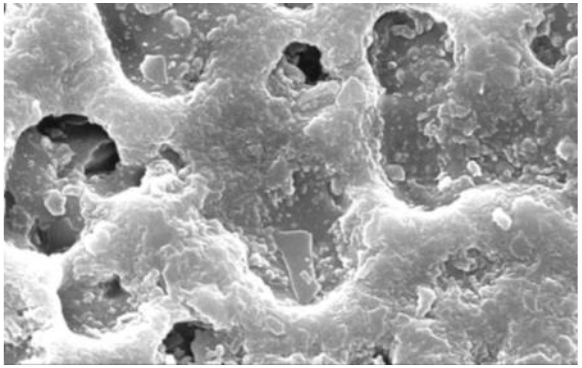
- Defects do not increase significantly during oxide film wafer polishing.
- Defect and metal contamination increase after polishing tungsten wafer.

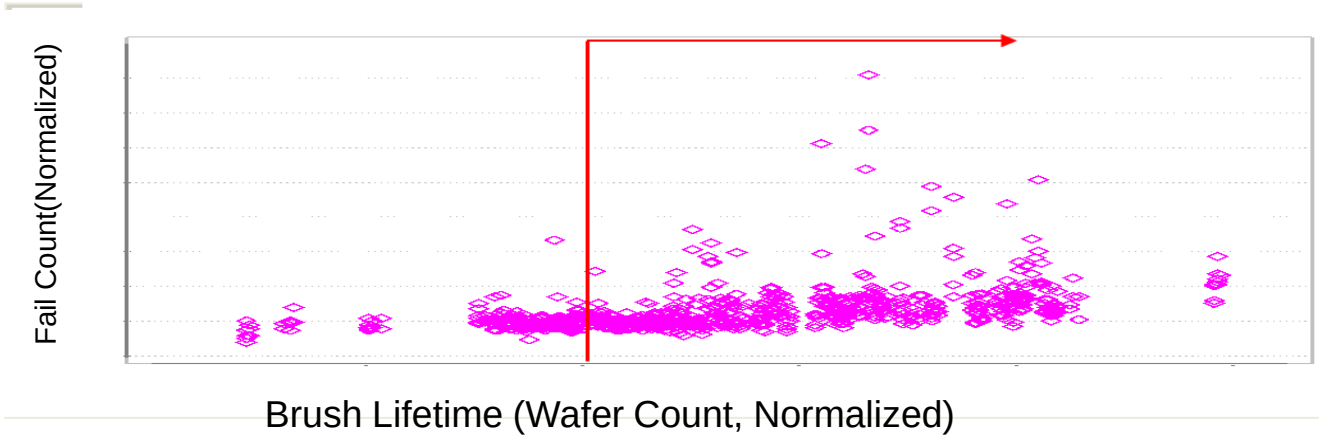
Brush Cleaning can contaminate wafers.
→ Bridge fail Increase according to Wafer Polishing.

Evaluation of Brush contamination





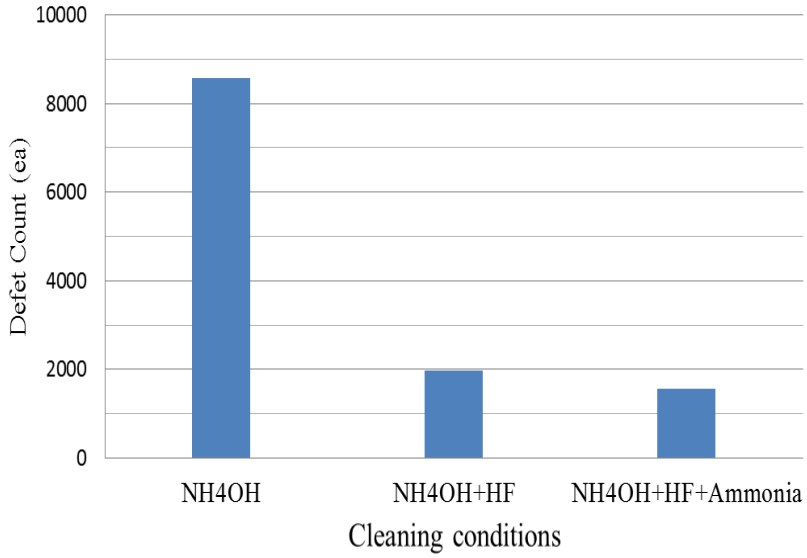




- Brush contamination is associated with an increase of defect and affects an increase in the number of failures due to invisible defects.
- As a result, the defects or failures were controlled by limiting brush usage time.

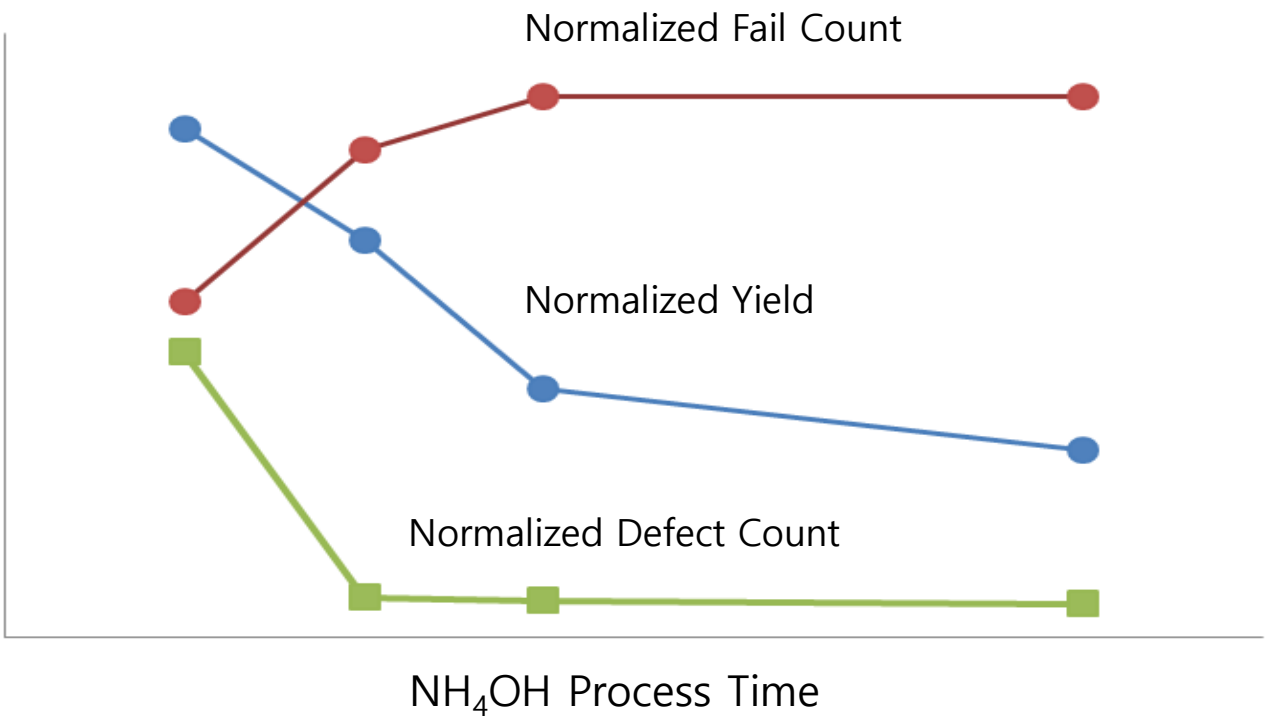
Effect of Cleaning Chemicals

	Brush	Spray1	Spray2	SRD
1	NH_4OH	X	X	o
2	NH_4OH	HF	X	o
3	NH_4OH	HF	NH_4OH	o



- HF Cleaning is most effective in removing particles
- Is it possible to increase HF cleaning time?
  → W protrusion, pattern damage, etc
- Is it possible to increase NH_4OH cleaning time?

Effect of NH_4OH on Devices



- As the NH_4OH cleaning time increases, visible or detectable defects are reduced.
- The number of failures count due to invisible defect is increased regardless of defect reduction.

Target W CMP Cleaning

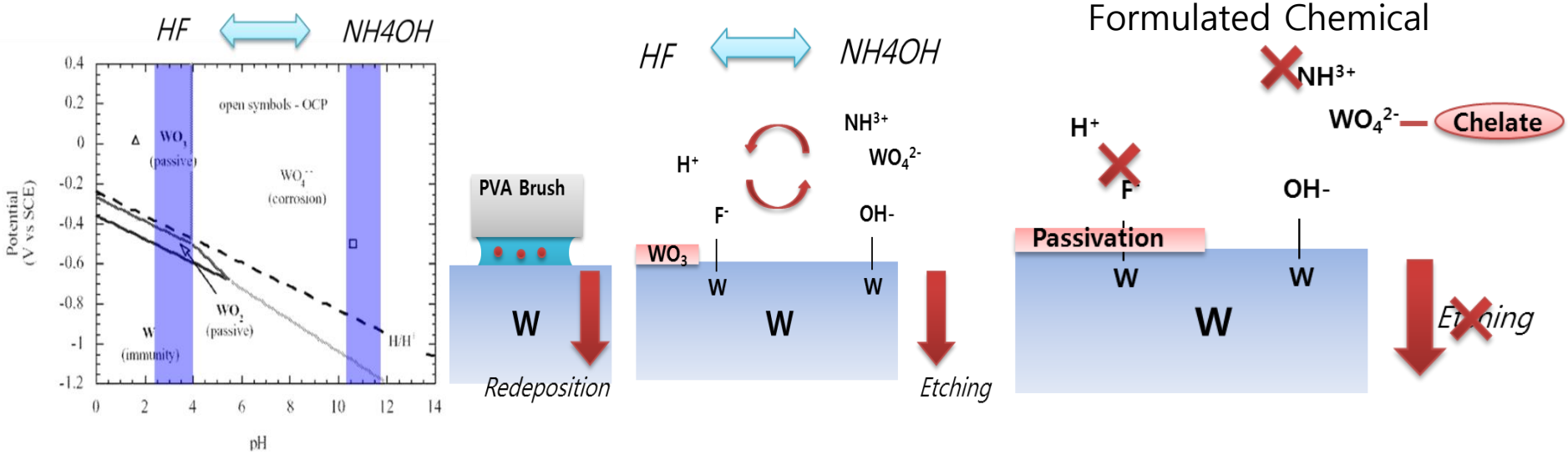
- NH4OH
  1) remove particle.
  2) Low W compatibility.
- HF
  1) Improve clean performance.
  2) Cause the loss of TiN barrier.
  3) Make negative impact on the device performance.
  4) Damage the tungsten plug and the underlying layer.

- Brush :
  1) Become loaded with slurry particles.
  2) The efficiency was reduced gradually.

	NH4OH	HF	Target Formulated Chemical
Tungsten	X	O	O
TiN	O	X	O
Clean Efficiency	△	O	O
Brush Lifetime Dependency	O	O	?

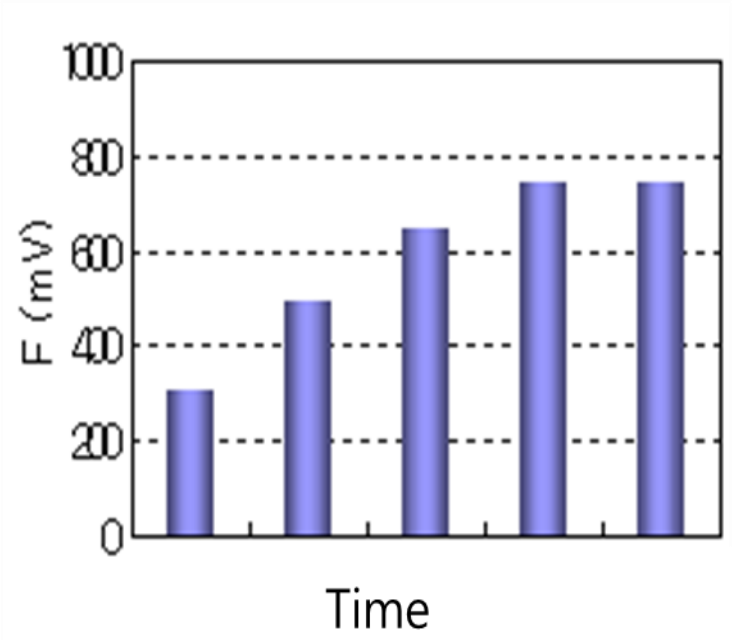
Therefore, the use of a formulated chemistry is quite critical in Tungsten Post CMP clean process.

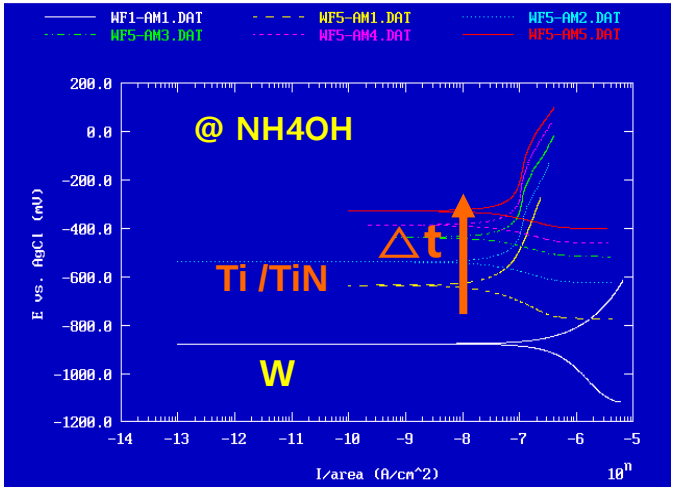
Target Defect Removal



- Surfactant : Prevention of re-adsorption of particle
- Chelating Agent : Metal decontamination
  → Metallic contamination removed from the surface is stabilized in the solution by chelating agents
- pH: Acid (W etch prevention)
  → Re-adsorption side effect is overcome with surfactant
- Additive
  → Silica particle removal and organic residue removal

Corrosion Potential of W/Ti Cleaning Chemical NH_4OH

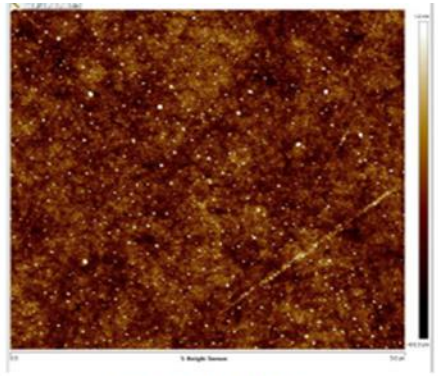




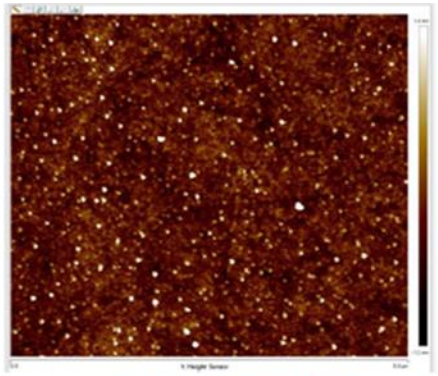
Evaluation of potential change according to ammonia cleaning time

1. The potential shifts to positive depending on the NH4OH exposure time.
2. The barrier metal increases the possibility of being reduced or precipitated.

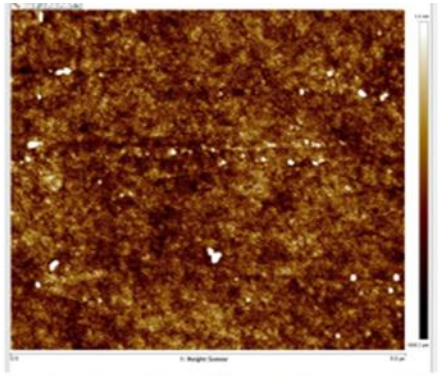
Particle Removal



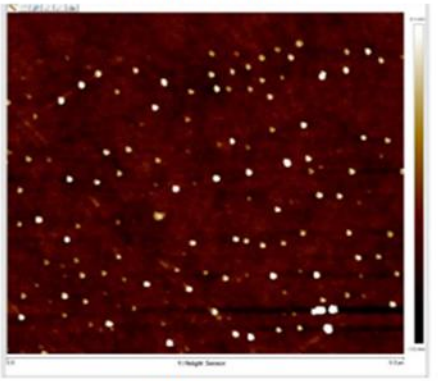
Ammonia Clean



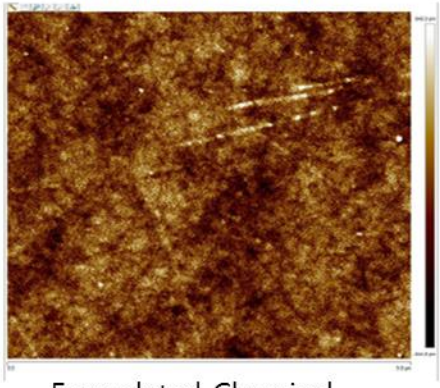
Ammonia + dHF Clean



Ammonia + dHF Clean+ Ammonia



DIW Clean

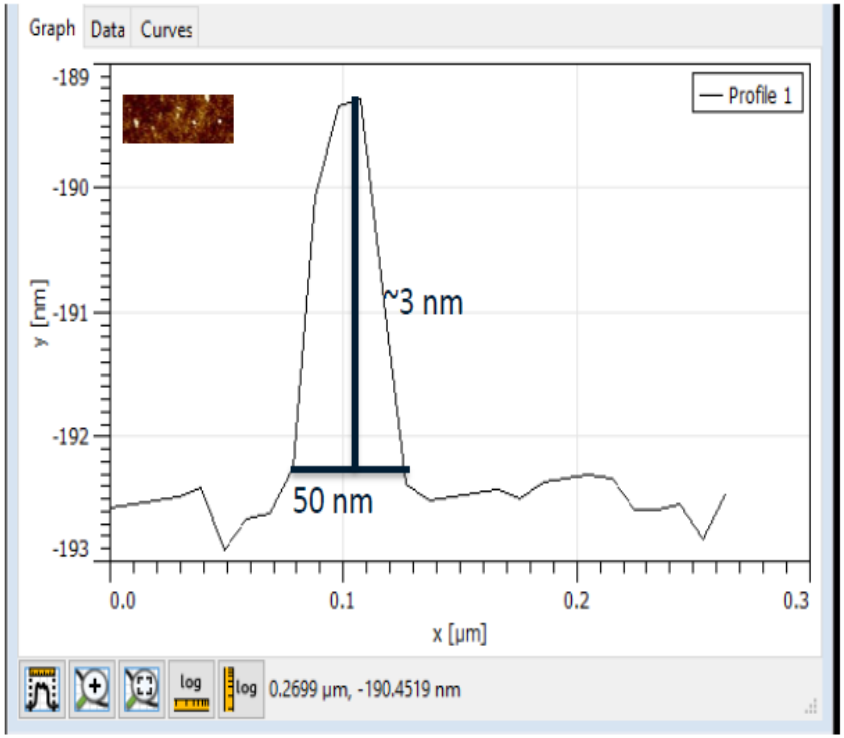


Formulated Chemical

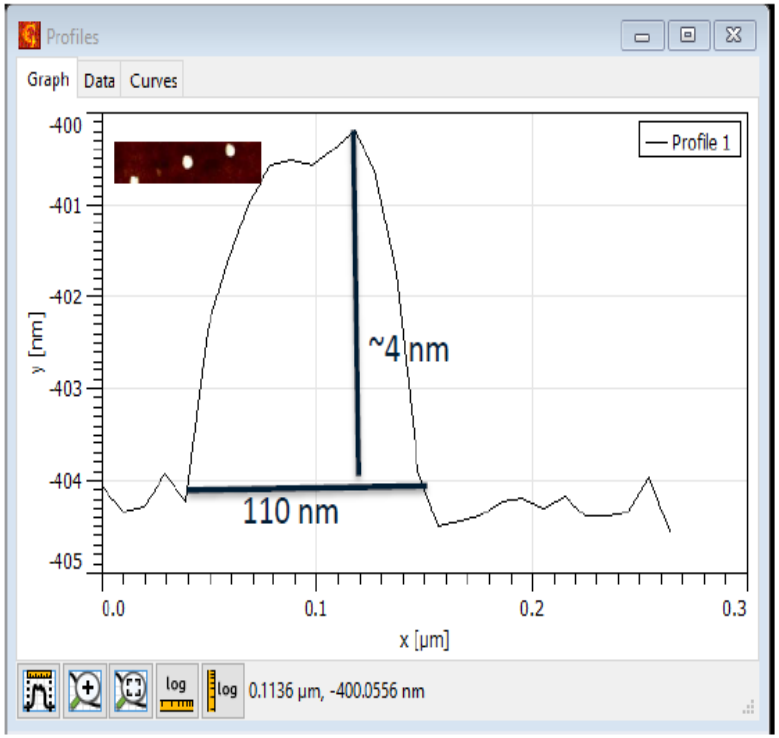
Image courtesy of VERSUM

- Formulated chemicals show the smallest number of defects.
- There is no correlation between the reduction of the defect and the yield.
- After selecting the best formulation for particle removal on blanket wafers, pattern wafers were cleaned with new chemical.

Particle Removal



Typical defect after NH_4OH/HF

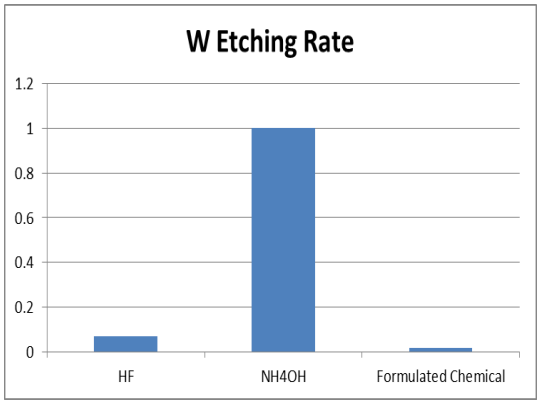


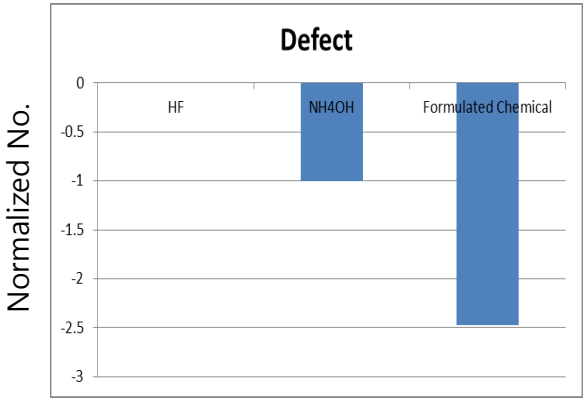
Typical defect after DIW Clean

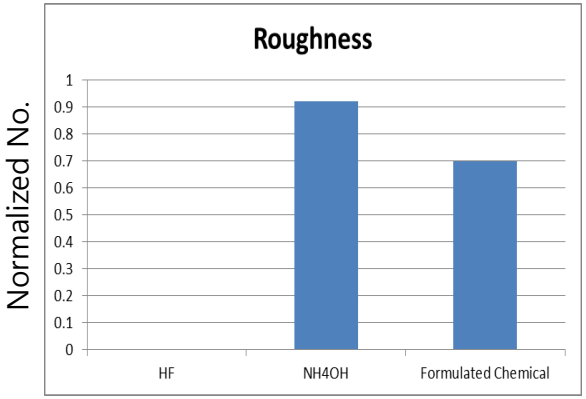
Image courtesy of VERSUM

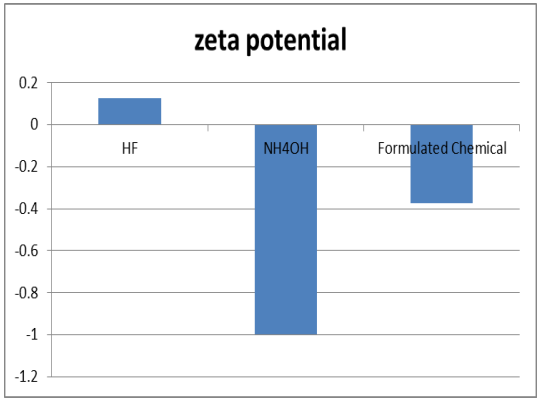
- Cleaning processes like NH_4OH/ HF appeared more successful in removing large particles however appeared insufficient for removing small particles.

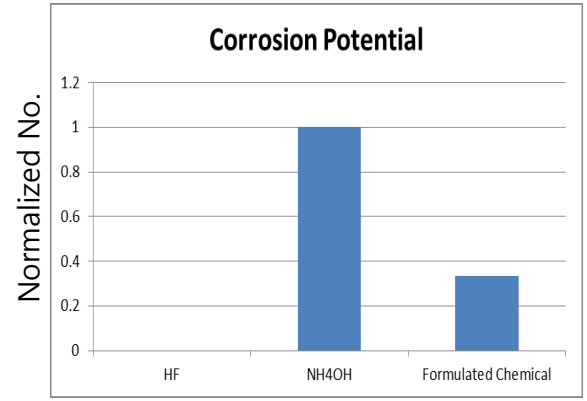
Properties of Formulated Chemical











Tungsten surface analysis result

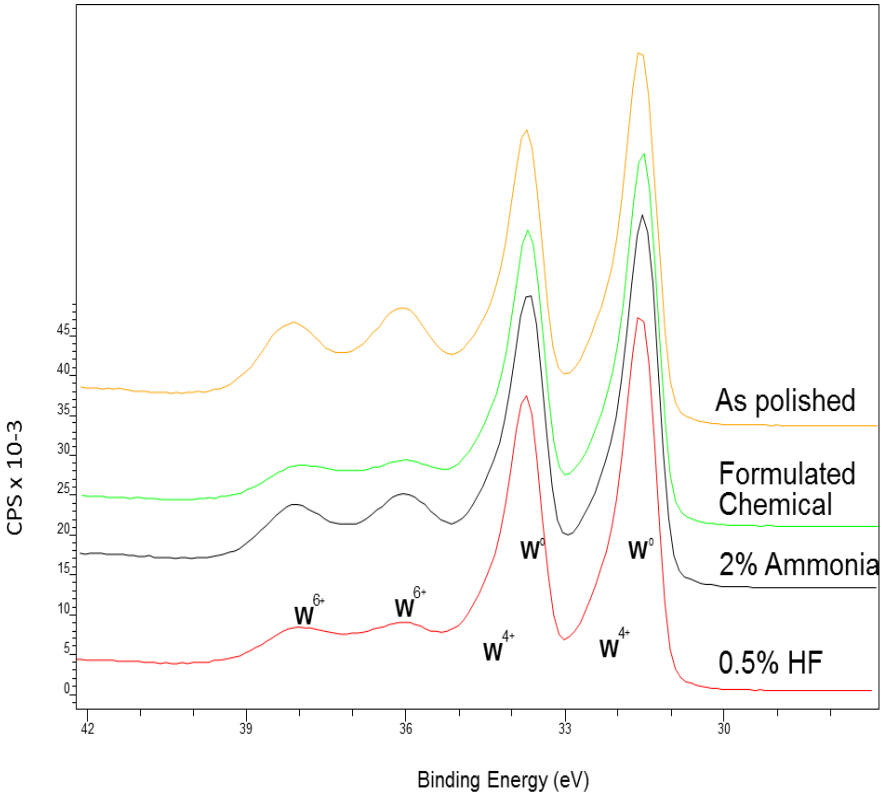


Image courtesy of VERSUM

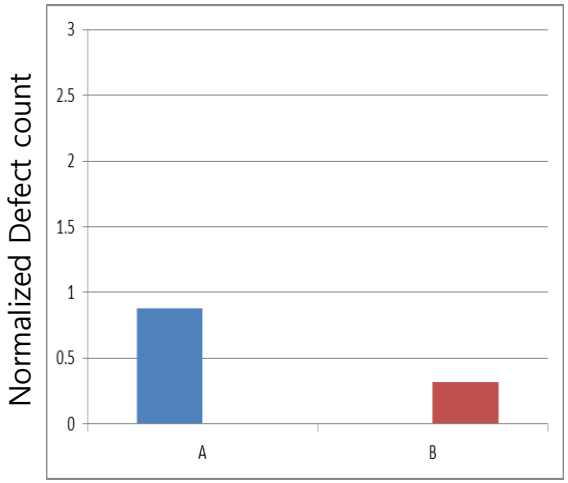
$$W^{+} + 3H_2O \rightarrow WO_3 + 6H^{+} + 6e^{-}$$

$$WO_3 + H_2O \rightarrow WO_4^{2-} + 2H^{+}$$

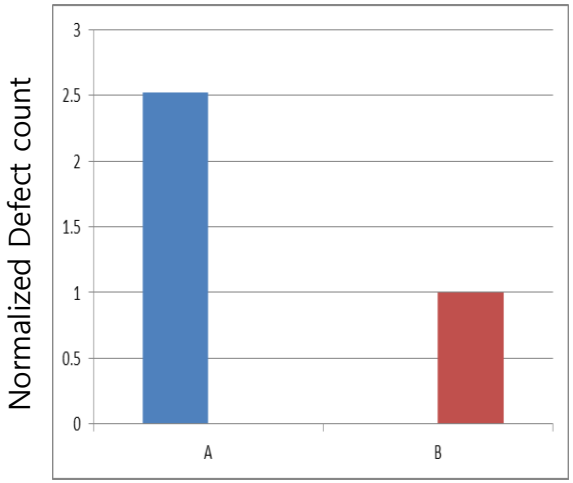
- Formulated chemistries are able to increase stable metallic species on the surface.
- Ammonia treated sample has higher oxidation of the surfaces, likely a result of tungsten dissolving to form WO_4^{2-} and re-depositing back.
- Re-deposition may be a concern for electrical leakage.

Evaluation Results on Pattern Wafer

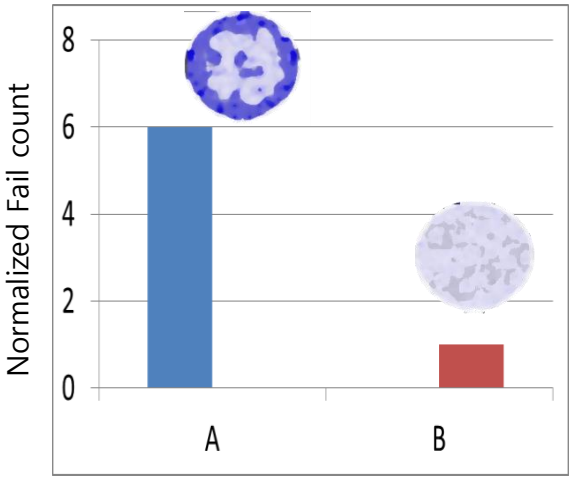
	Brush	Spray1	Spray2
A	NH_4OH	HF	NH_4OH
B	Chemical	Chemical	Chemical



Defect after CMP



Defect after Film Dep. Followed by CMP



- Defects decreased under the B condition.
- It has been confirmed that it has decreased even after subsequent film deposition to see smaller defects.
- Formulated Chemical is effective for particle removal and bridge failure reduction.

Summary

1. The CMP process has been mainly improved with tool, slurry, and pad for planarity, uniformity and defect.

2. As the device design rule decreases, bridge failure must be improved.

3. Improvements with existing chemicals (NH_4OH, HF) are limited.

4. In the memory devices, post CMP cleaning chemicals have been applied to the Cu processes, but there is also a need for new chemicals for W CMP.

5. It has been confirmed that the bridge generation by environment, chemicals can be reduced and the process margins can be increased using formulated chemicals.