Development of an Advanced Node High Selectivity Tungsten Slurry

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Agenda

- Tungsten Background / Overview
- Tungsten Polish Mechanism
- Performance Targets
- Key Slurry Component Selection
- Polishing Performance Results
- Summary

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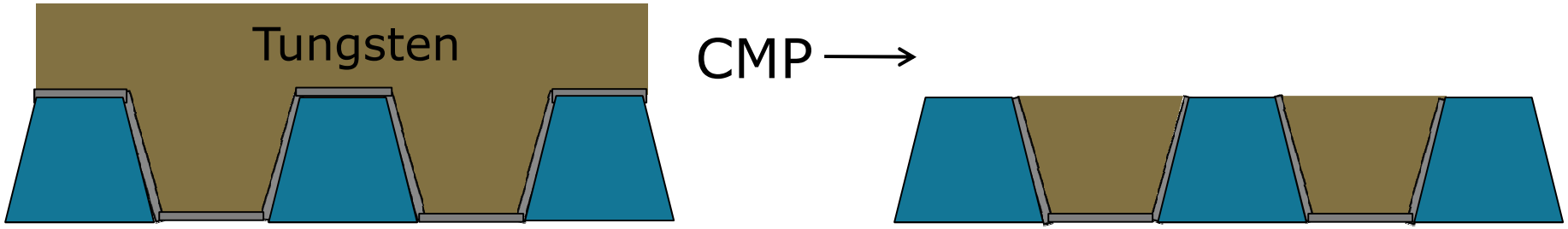
Tungsten CMP Overview

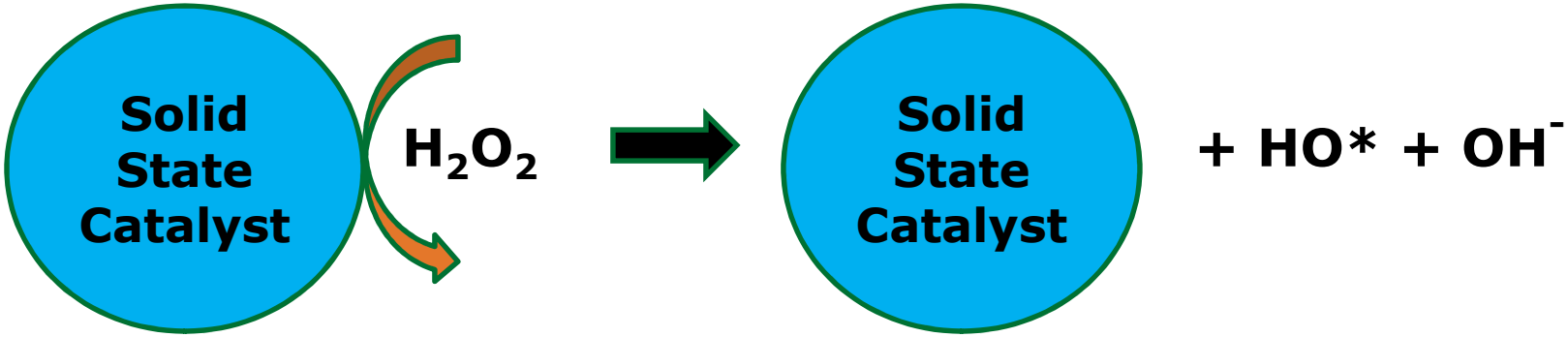
- **Tungsten History:**
  - **CMP replaced RIE for Tungsten plug overburden removal**



- **Other Applications Followed:**
  - **Local Interconnect Lines**
  - **High K Metal Gate (HKMG)**

H_2O_2 Based Tungsten Slurry Mechanism

- **H_2O_2 (hydrogen peroxide) is used as an oxidant and has a standard redox potential of 1.68eV.**



- **Addition of a metal oxide solid state (heterogeneous) catalyst decomposes H_2O_2 into hydroxyl radicals and anions.**
- **Hydroxyl radicals (*OH) have a much stronger oxidizing potential than H_2O_2.**
  - **1.68 vs > 2.60eV**

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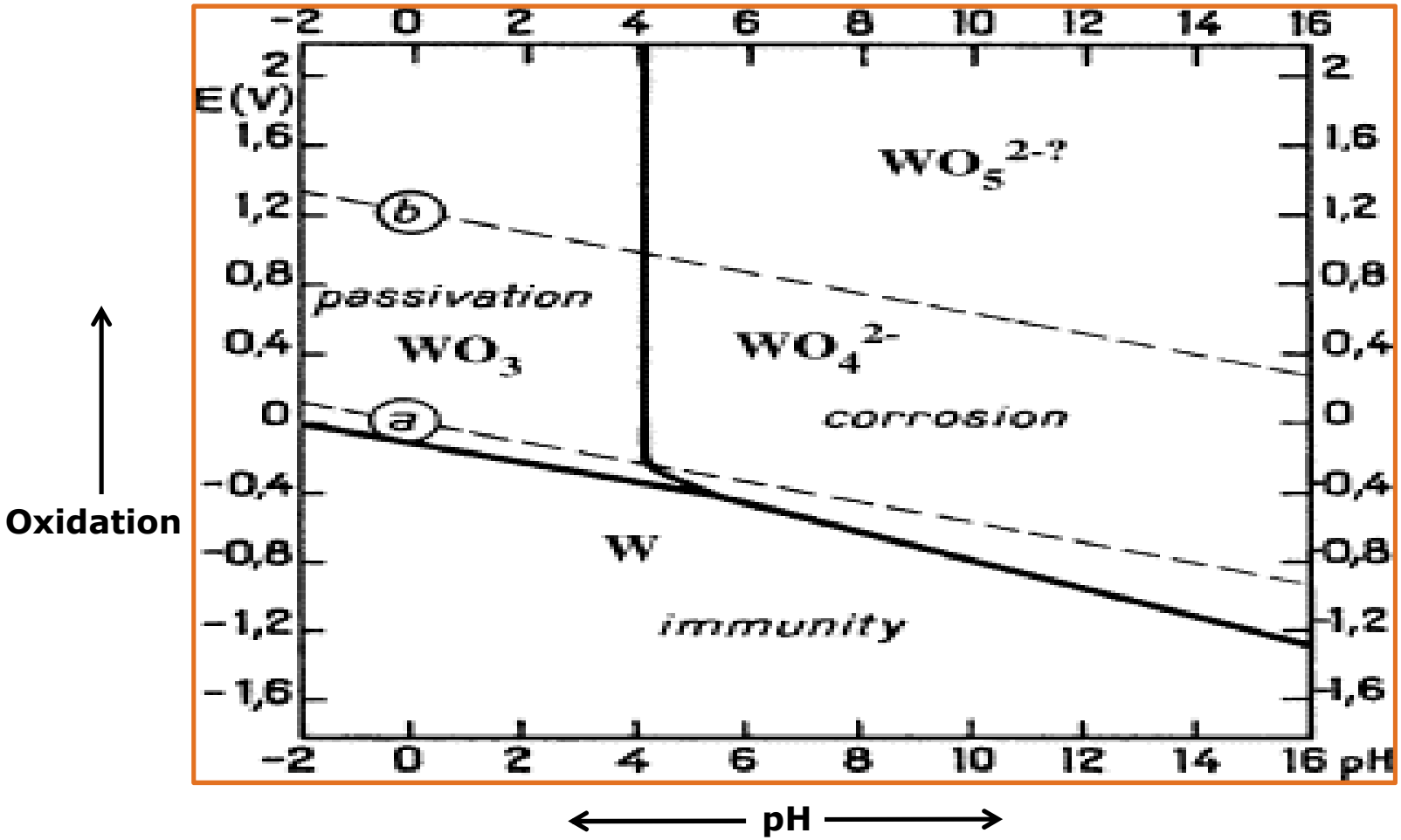
H_2O_2 Based Tungsten Slurry Mechanism

- **Hydroxyl radicals rapidly form a WO_3 and WO_4^{2-} mixture on the metallic W surface.**
- **WO_4^{2-} exists as H_2WO_4 at acidic pH.**
- **H_2WO_4 and WO_3 films are removed from the surface under applied mechanical force during polishing.**

Tungsten Slurry Mechanism

eV-pH Equilibrium Diagram for Tungsten in Water



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Tungsten High Selectivity Slurry Performance Targets

- **High Removal Rate (>4000Å/min.)**
- **Low WIW NU (< 3% 1s)**
- **High or Tunable Selectivity (>100:1) ***
- **Low Defectivity**
- **Low Oxide Loss and Array Erosion ***
- **Long Shelf Life (> 1 yr)**
- **Low Cost of Ownership**

***High Selectivity is required to minimize overall dielectric loss and array erosion (topography)**

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Key Base Slurry Components

Key Component	Purpose	Result
Oxidizer (H_2O_2)	Oxidize Metallic W into WO_3 and WO_4^{2-}	Create/Support W Removal Rate
Catalyst	Create Super Oxidizing Hydroxyl Radicals (*OH)	Support/Increase W Removal Rate
Abrasive	Mechanical Removal of WO_3	Increase W Removal Rate
Corrosion Inhibitor	Protect W Metal	Low Static Etch Rate (SER) Eliminated/Minimized W Corrosion
pH Adjustor	Adjust pH of Formulation	Modulation of Film Selectivity

- **Tungsten CMP mechanism has unique slurry formulation requirements**
  - **Unique catalytic oxidation process**

Experimental Setup

- **AMAT Mirra 200mm Polisher (Titan head)**
- **Dow IC1000 Pad**
- **Diamond Disc Pad Conditioning**
- **3 psi Downforce**
- **120 rpm Platen Speed**

- **Base Slurry: Medium-High Selectivity**

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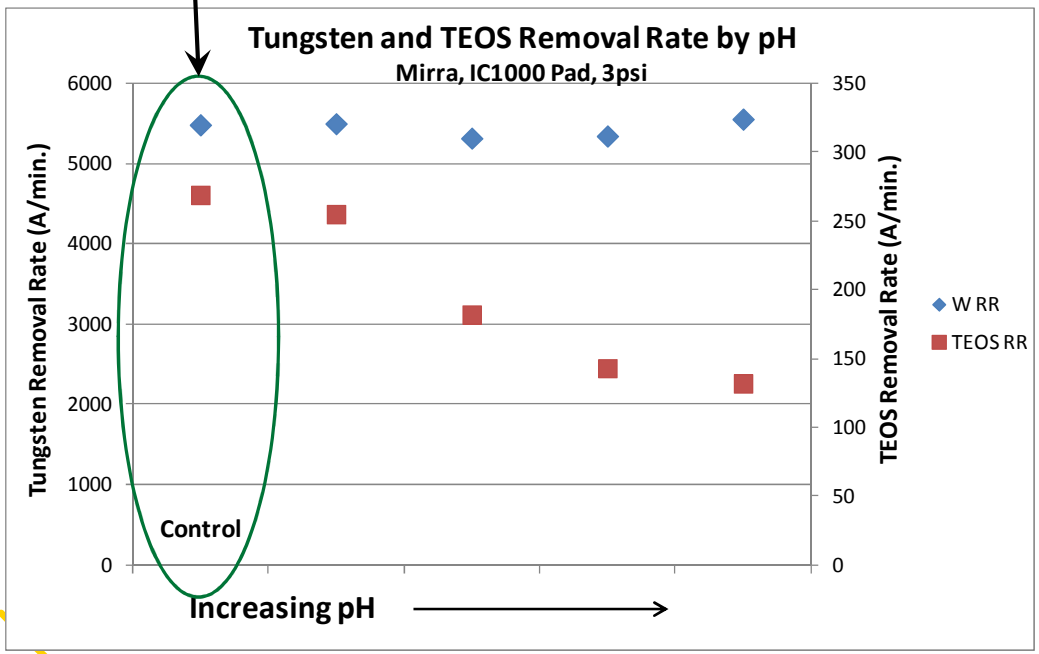
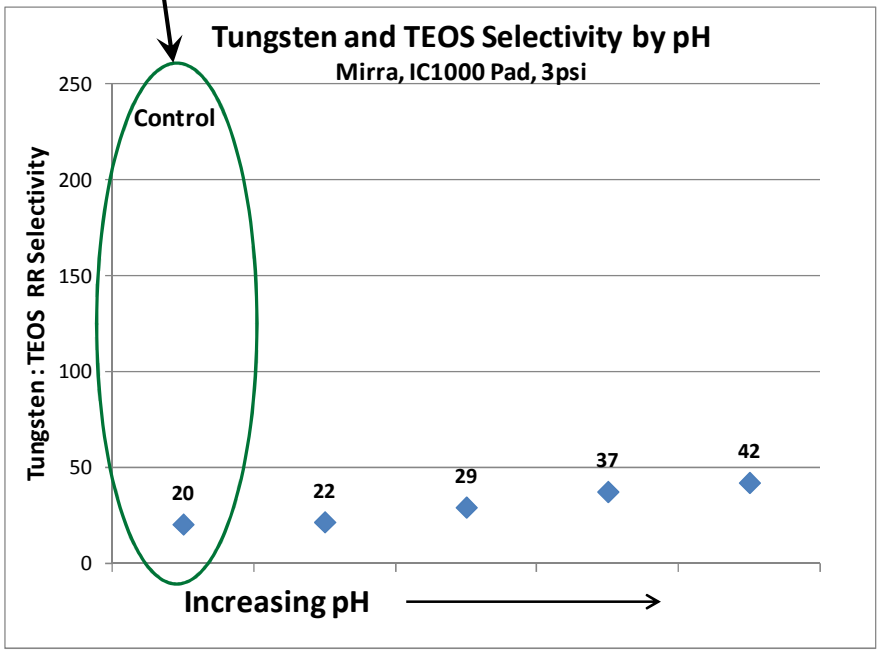
Key Slurry Components
pH Adjustor

- **Base Tungsten Formulation: Medium-High Tungsten : TEOS Selectivity**
  - **W Removal Rate: > 5000 Å/min.**
  - **TEOS Removal Rate: 250 Å/min.**
  - **W : TEOS Selectivity: ~20:1**

Removal Rates



Selectivity



- **Increasing pH decreased TEOS RR and increased W : TEOS Selectivity**

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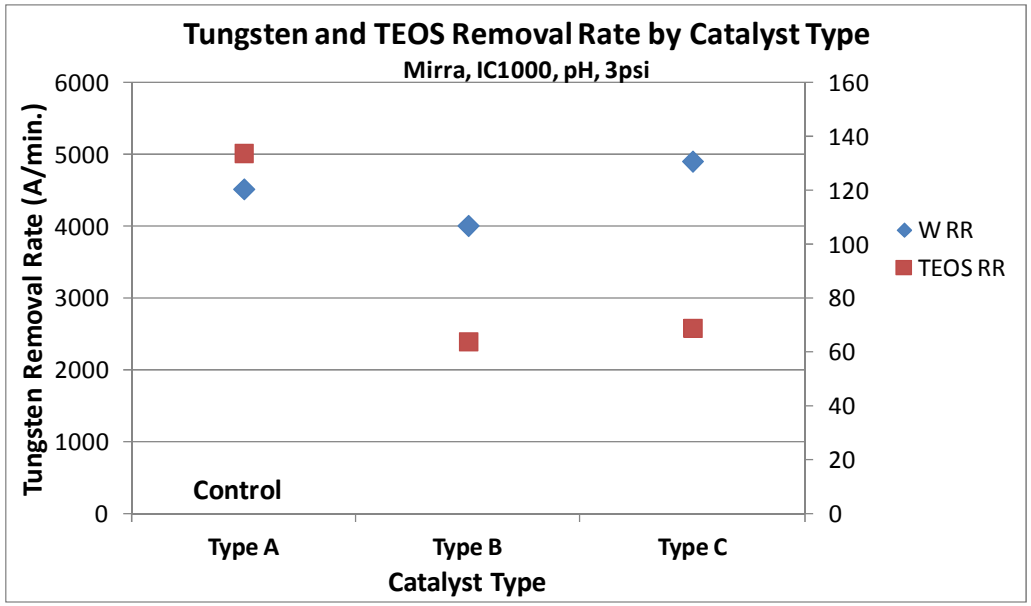
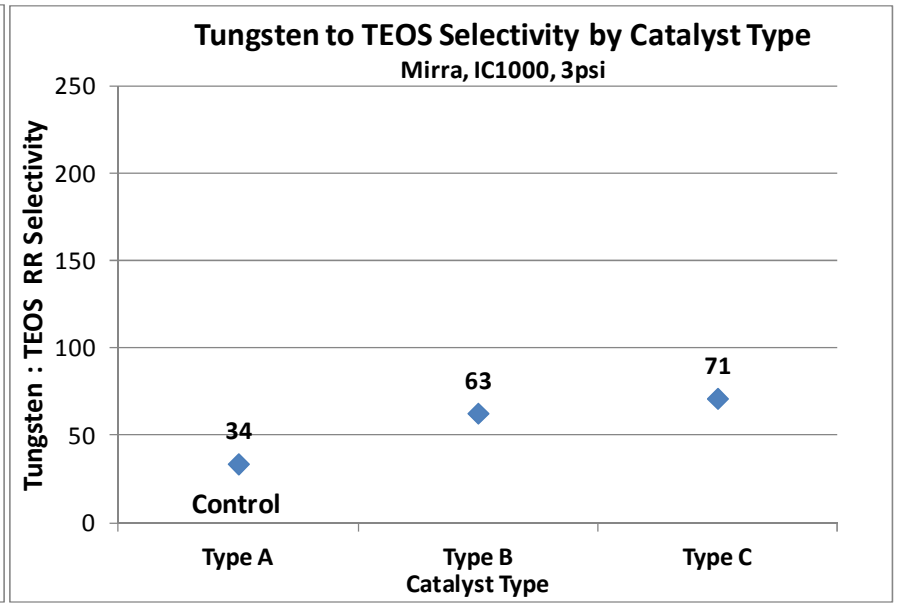
Key Slurry Components
Solid State Catalyst Selection

Removal Rates



Selectivity

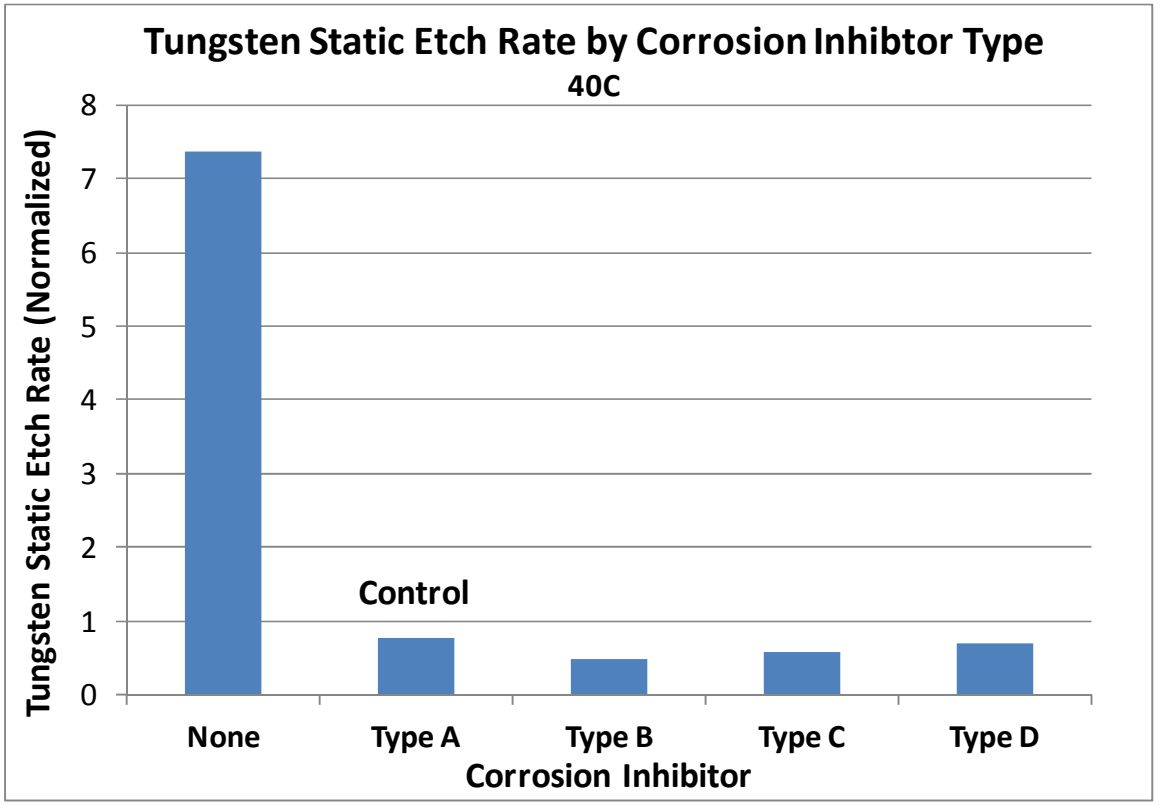


- **Type C Solid Catalyst provides:**
  - **Highest W RR**
  - **Lowest TEOS RR**
  - **Highest W:TEOS Selectivity (>70:1 in Base Formula)**
  - **Also provides WIW NU benefit (later slide)**

Key Slurry Components

Corrosion Inhibitor Selection

Static Etch Rate (SER)



- **High Static Etch Rate (SER) has been correlated to tungsten corrosion.**
- **Some Corrosion Inhibitors can reduce SER, but often also decrease tungsten Removal Rate.**

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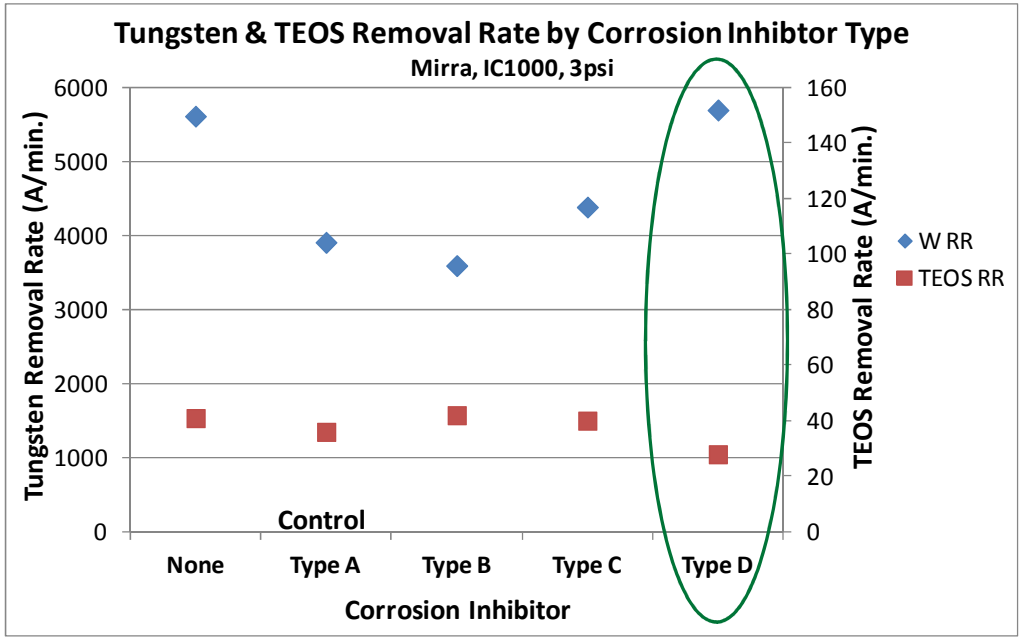
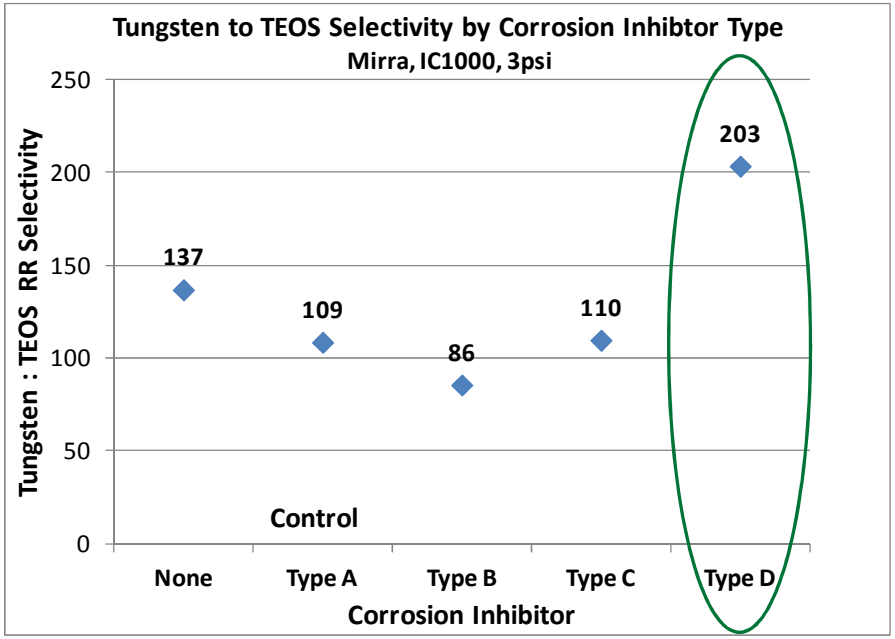
Key Slurry Components

Corrosion Inhibitor Selection

Removal Rates



Selectivity



- **Corrosion Inhibitor Types A, B, & C reduce tungsten RR & Selectivity.**
- **Corrosion Inhibitor Type D:**
  - **Does not reduce tungsten RR**
  - **Reduces TEOS RR**
  - **Increases W to TEOS Selectivity**
  - **Suppresses SER (previous slide)**

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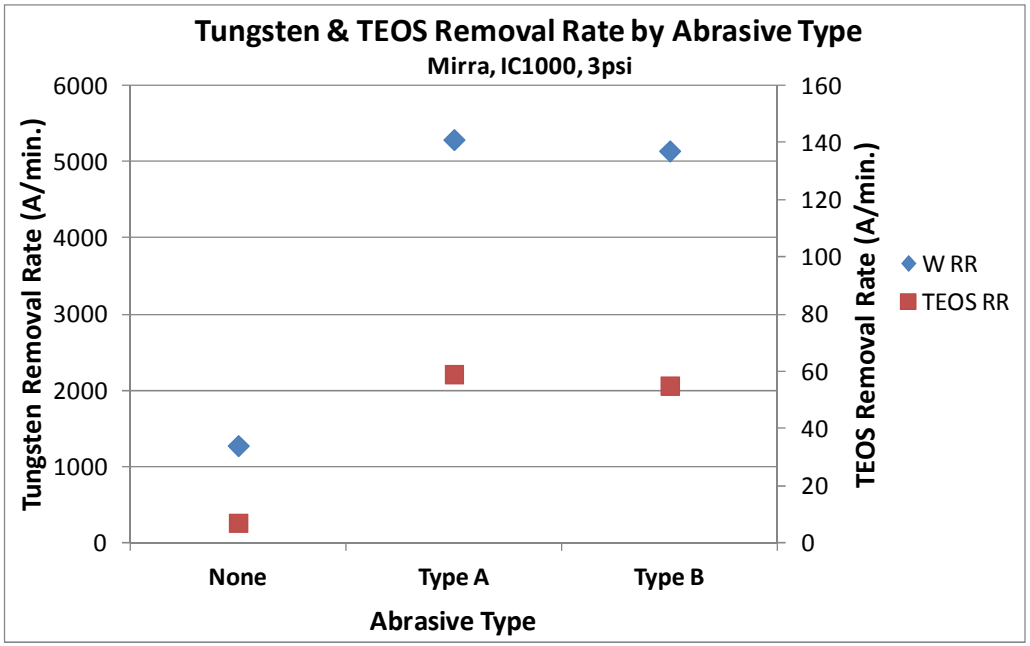
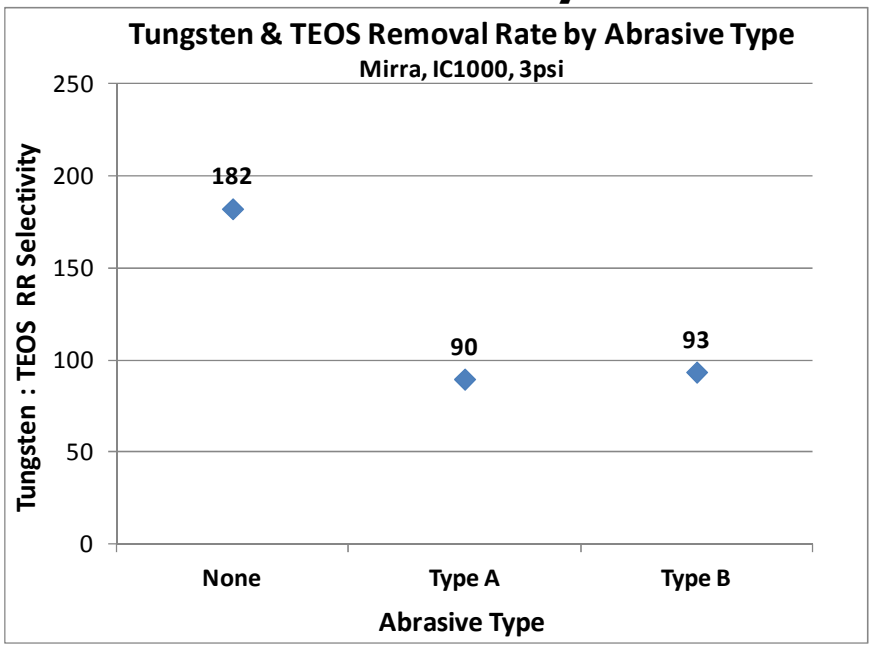
Key Slurry Components

Primary Abrasive Selection

Removal Rates



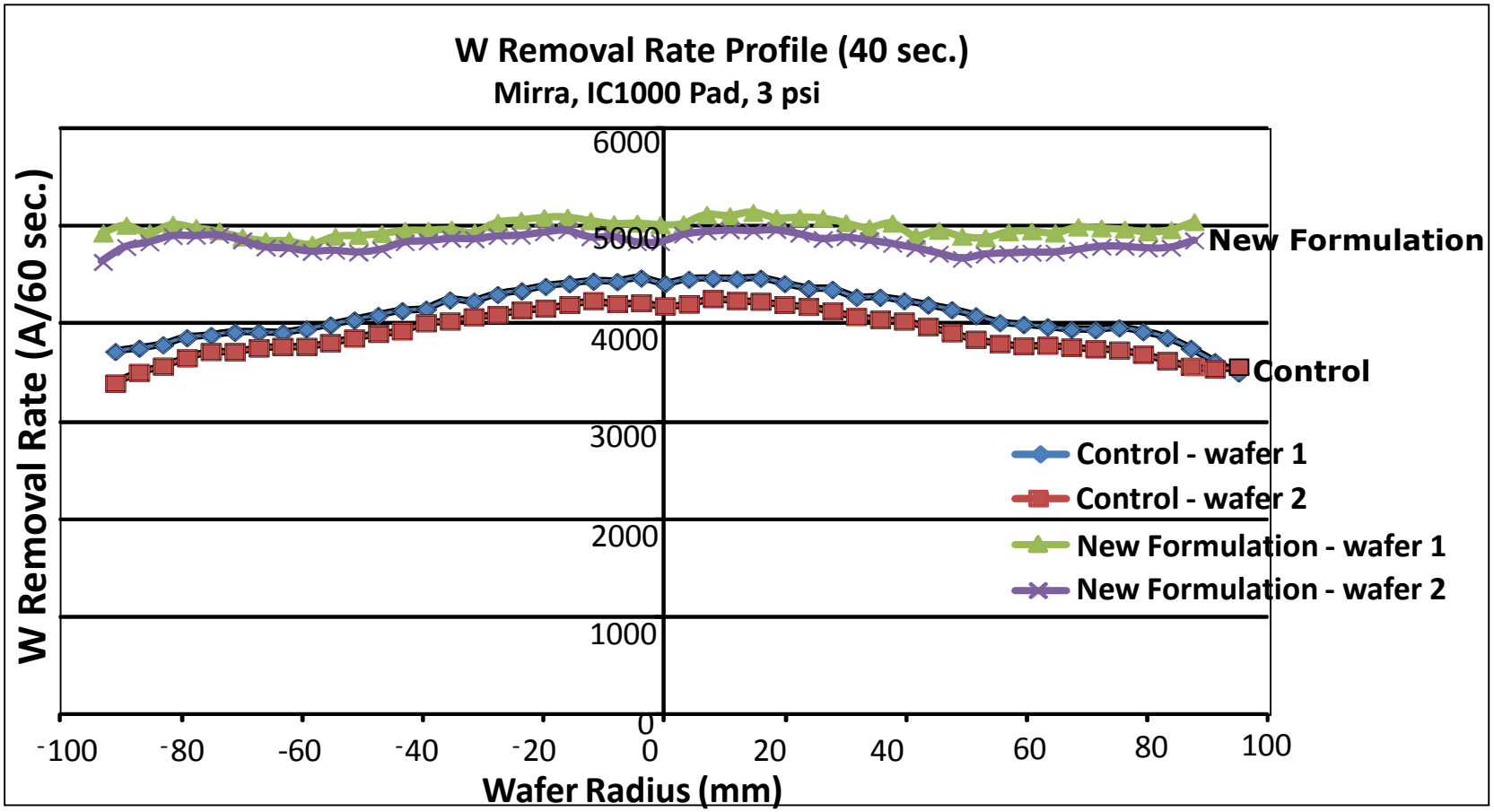
Selectivity



- **Presence of primary Abrasive, in addition to Solid Catalyst, is critical for providing tungsten removal rate.**
- **Abrasive Type A or Type B show similar performance**

Tungsten Removal Rate Profiles

60 sec. Polish Time



- **New Formulation shows improve performance vs Control**
  - **Higher W Removal Rate**
  - **Improved WIW NU**
  - **Higher W : TEOS Selectivity (previous slides)**

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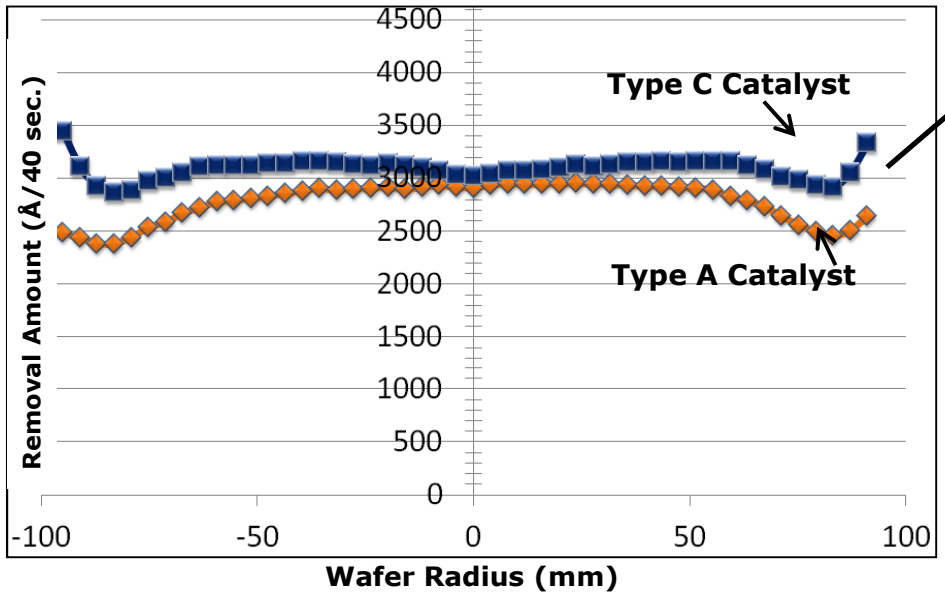
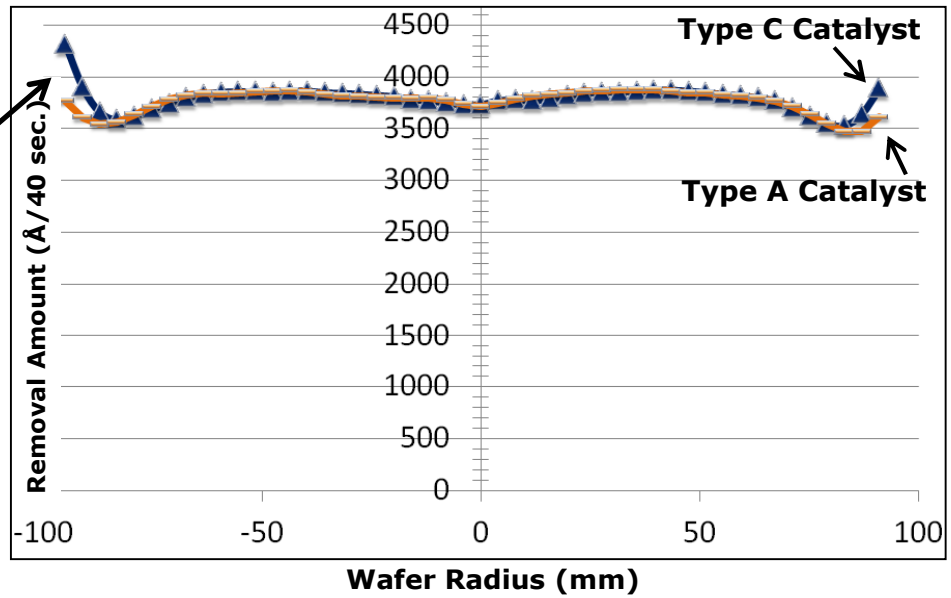
Tungsten Removal Profiles (40 sec.)

Corrosion Inhibitor Type B vs Type D
Catalyst Type A vs Type C

Type B Corrosion Inhibitor



Type D Corrosion Inhibitor



- **Corrosion Inhibitor Type D increases tungsten removal rate and improves RR non-uniformity (lower center to edge delta)**
- **Catalyst Type C increases tungsten removal rate at the edge**
  - **Allows process tuning for the achievement of a potentially desirable fast edge removal rate**

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Summary

- **Tungsten was the First Metal Based CMP Process Implemented by the Semiconductor Industry.**
- **CMP of Tungsten Films is a Unique Mechanism Requiring a Specialized CMP Slurry Formulation.**
- **High Selectivity of W to SiO2 is Required to Minimize Dielectric Loss and Topography.**
- **Selection of Key Slurry Formulation Components is Critical for Achieving:**
  - **High Tungsten and Tunable Dielectric Removal Rates**
  - **Desired Tungsten Removal Rate Profile (WIW NU)**
  - **High or Tunable Selectivity**
  - **Low Corrosion (Defects)**