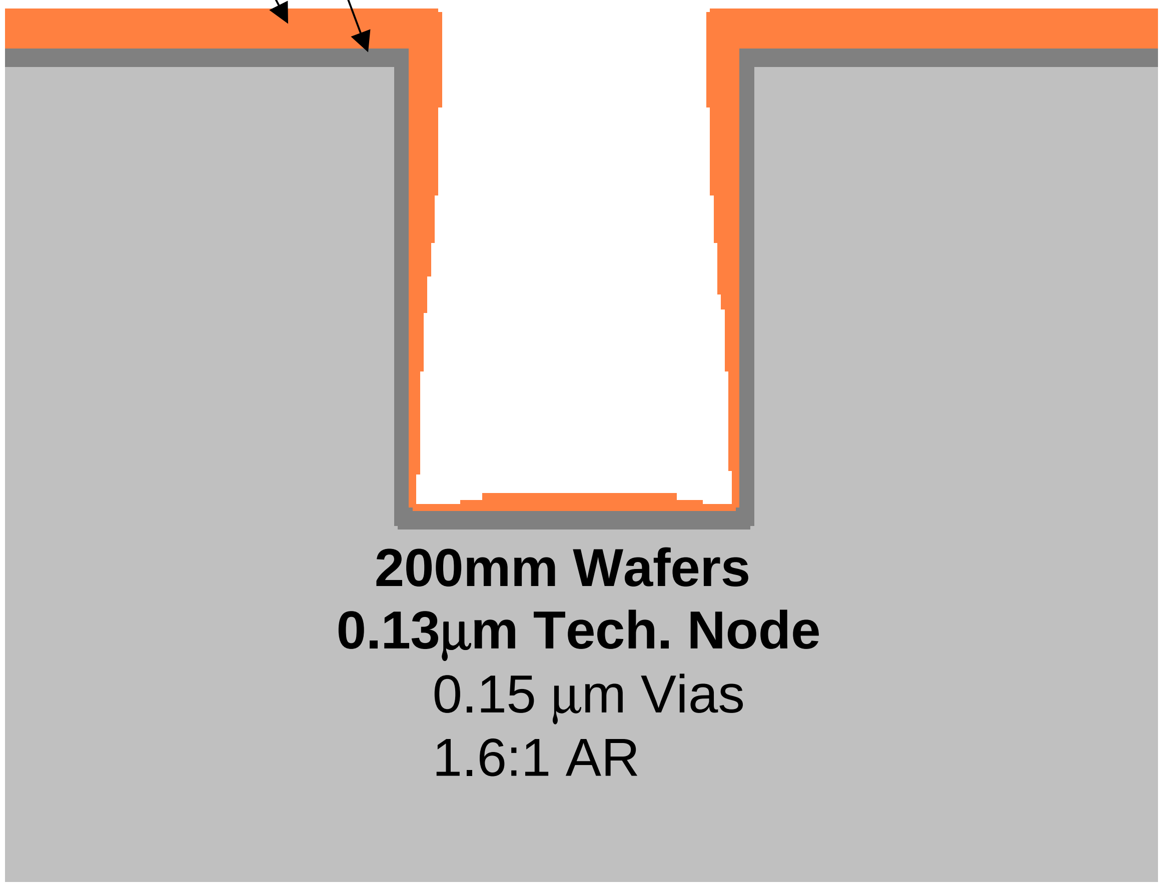
Cu Plating Today and Tomorrow: Managing the Terminal Effect

John Klocke

High Volume Production: Today



Ionized PVD Seed and Barrier

≈ 250Å Barrier Layers

≈ 1000Å Seed Layers

ECD Films

≈ 1.0 µm Thick

Flat Profile

200mm Wafers

0.13µm Tech. Node

0.15 µm Vias

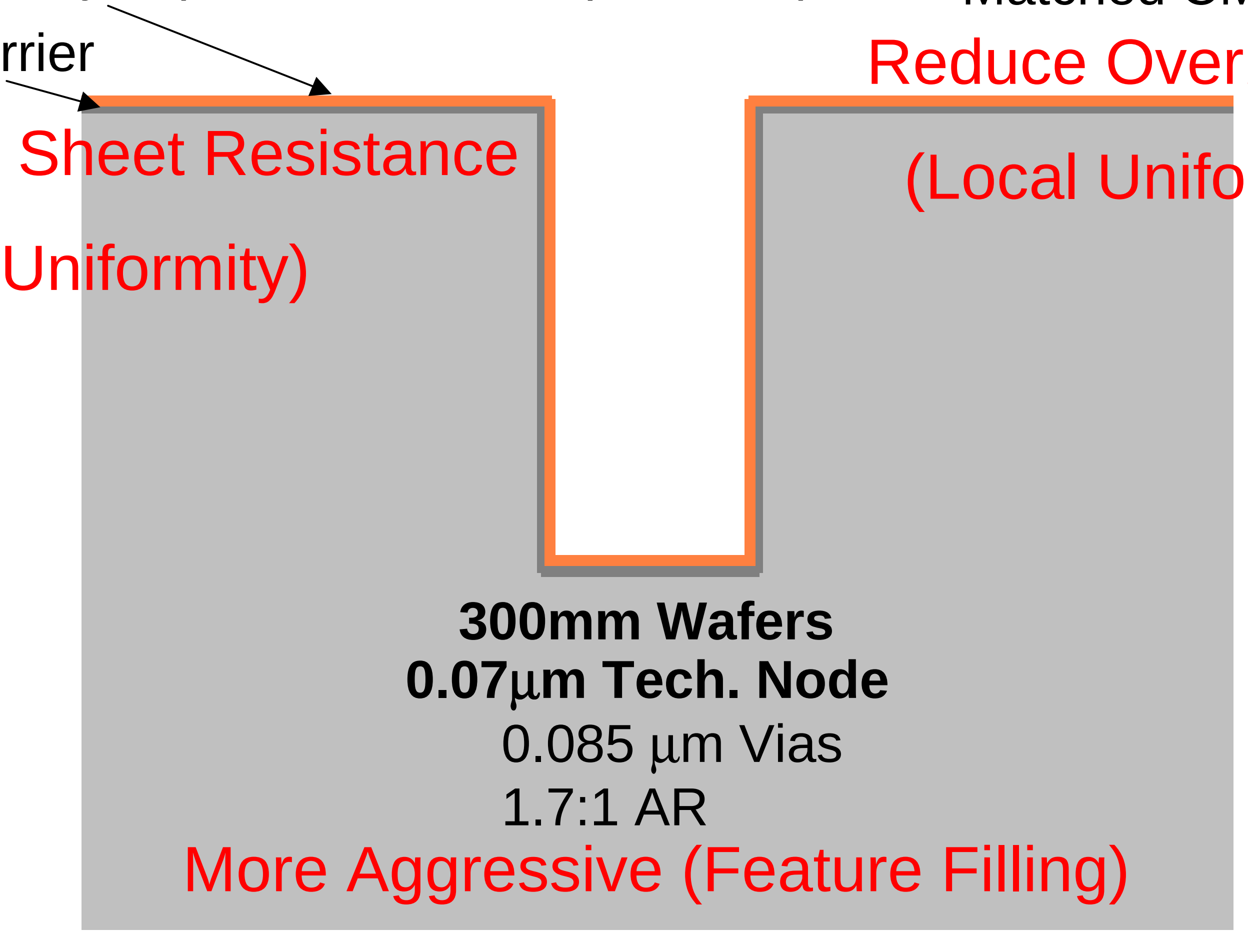
1.6:1 AR

High Volume Production: Tomorrow

ECD Films

≤ 0.5 µm Thick

Matched CMP Profile



200Å Seed Layer (Direct Barrier Deposition?)

50Å ALD Barrier

Reduce Overburden

Over 5x Sheet Resistance

(Local Uniformity)

(Global Uniformity)

300mm Wafers

0.07µm Tech. Node

0.085 µm Vias

1.7:1 AR

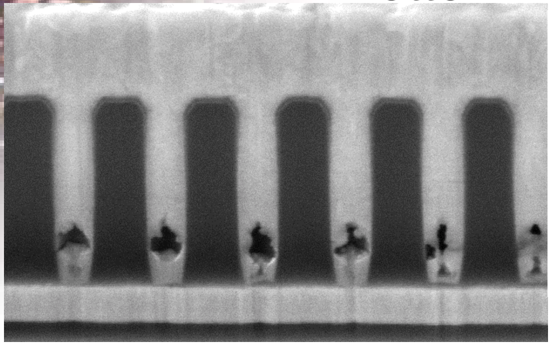
More Aggressive (Feature Filling)

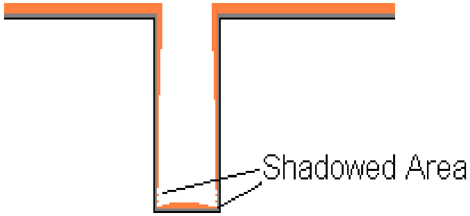
ECD Copper for Interconnects

- Feature Filling /Film Properties
  - Seed and Barrier Layers
  - Plating Chemistry
  - Plating Recipe
- Local Uniformity
- Global Uniformity

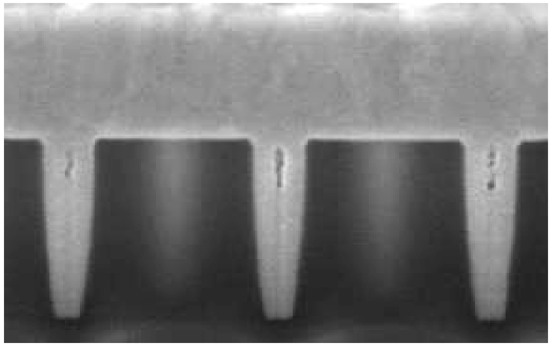
Seed and Barrier Layers

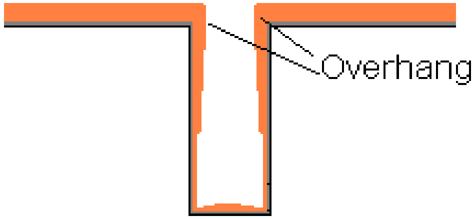
Bottom Voids



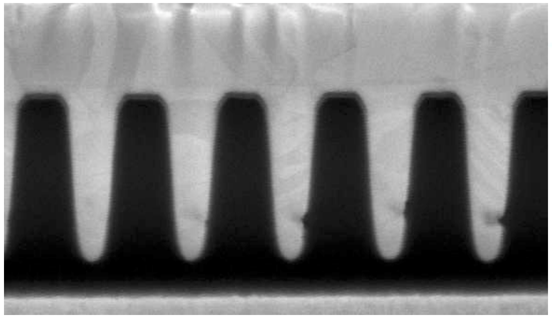


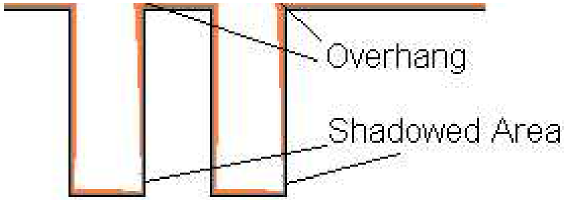
Seam Voids





Side Voids

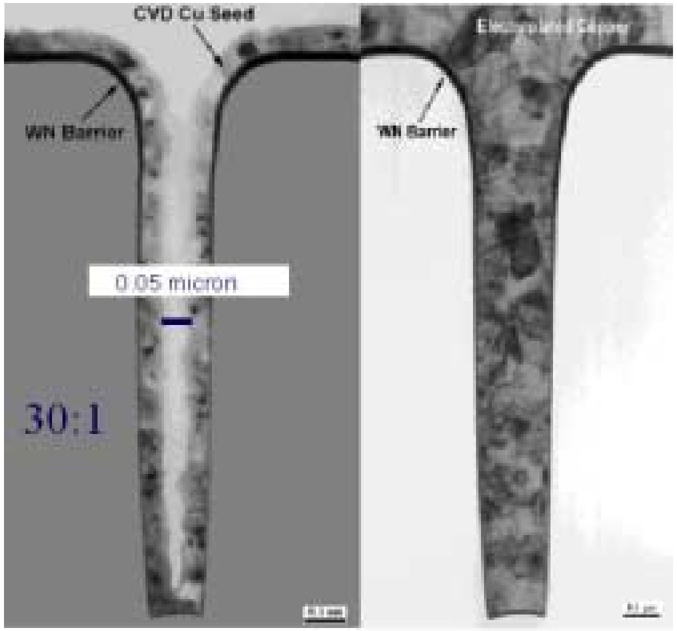




Edge of the wafer

Assuming proper current density and chemical conditions:

Good Seed = Good Fill

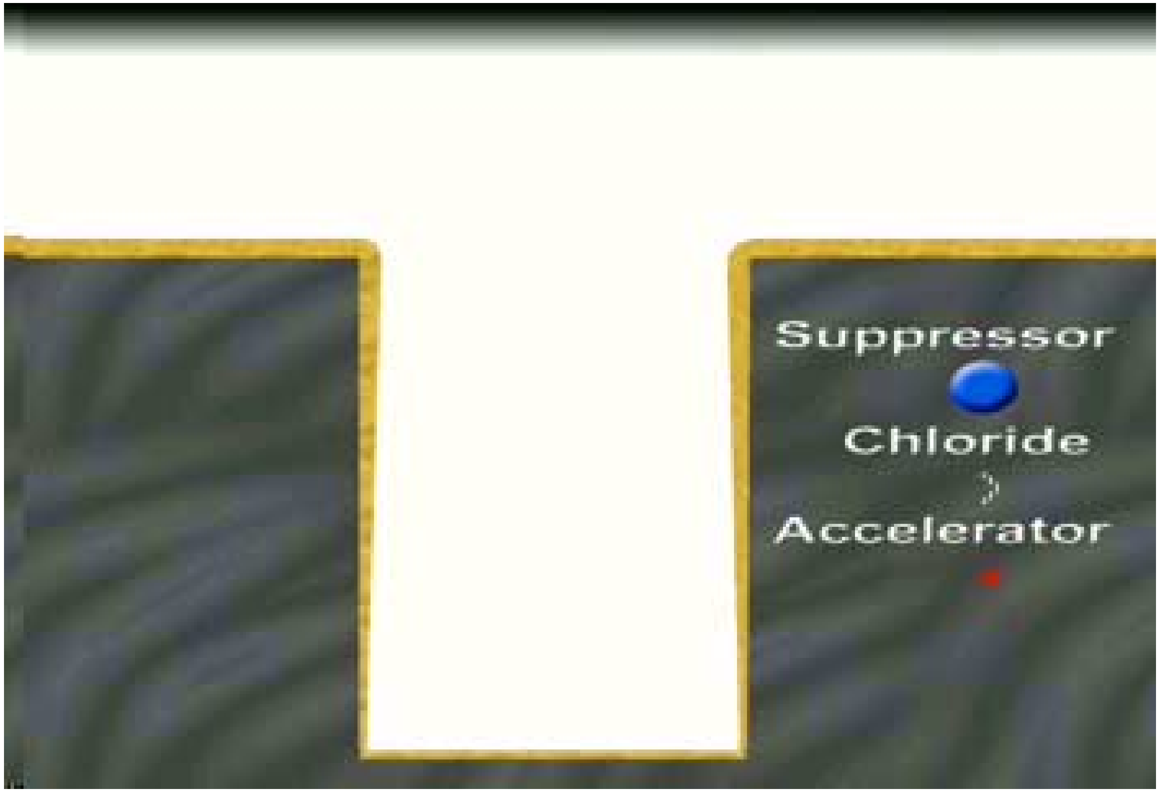


CVD Barrier and Seed layers
by Genus,
feature filled by customer
on Semitool ECD' System

Chemistry: Composition

- Organic
  - Suppressor
  - Accelerator
  - Leveler (Optional)
- Inorganic
  - Copper Sulfate
  - Sulfuric Acid
  - HCl

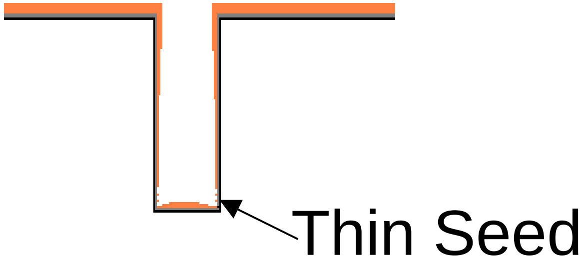
Chemistry: Fill Mechanism



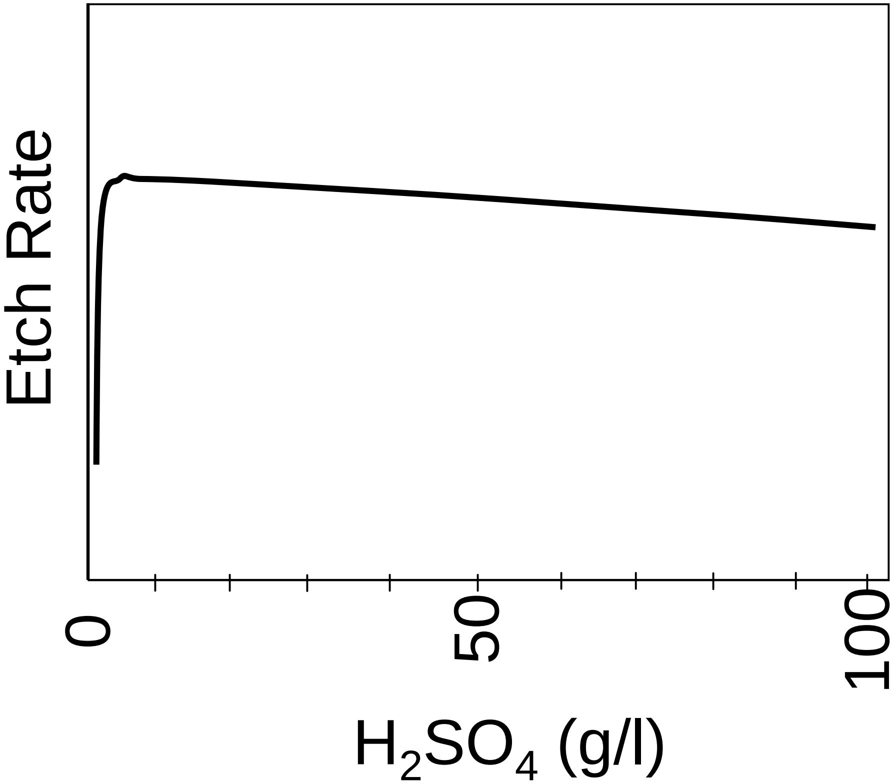
Two Component

Recipe: Cathodic Protection

	Std. Potential
$Cu^{2+} + 2e^- \rightarrow Cu$	+ 0.34
$Cu^{2+} + e^- \rightarrow Cu^+$	+ 0.16

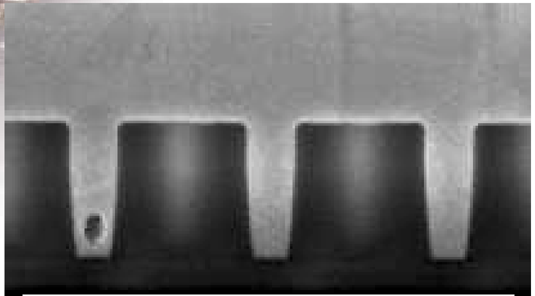


Copper Etch Rate In Plating Bath



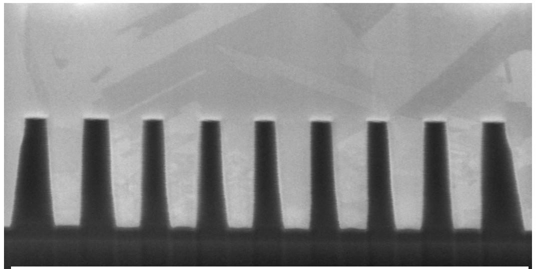
Recipe: Current Density

Current Density



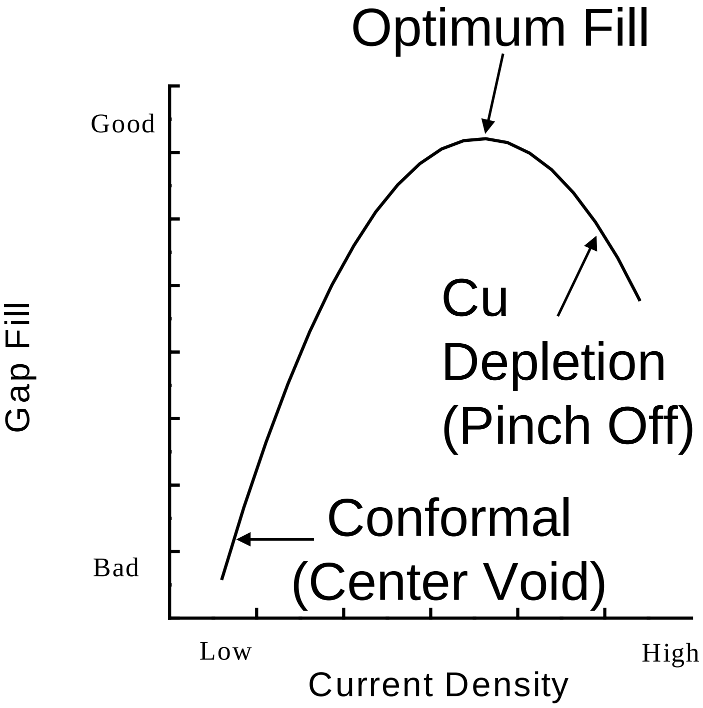
0.35micron, 4.3:1 AR Vias

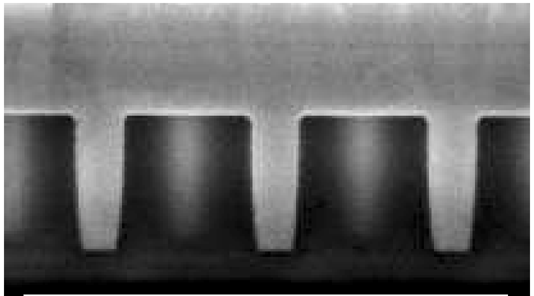
Too Low Current



0.18micron, 5.1:1 AR Trench

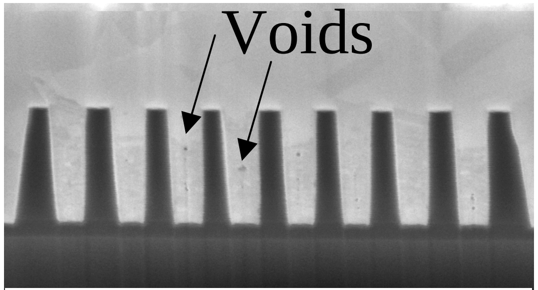
Optimum Current





0.35micron, 4.3:1 AR Vias

Optimum Current



0.18micron, 5.1:1 AR Trench

Too High Current

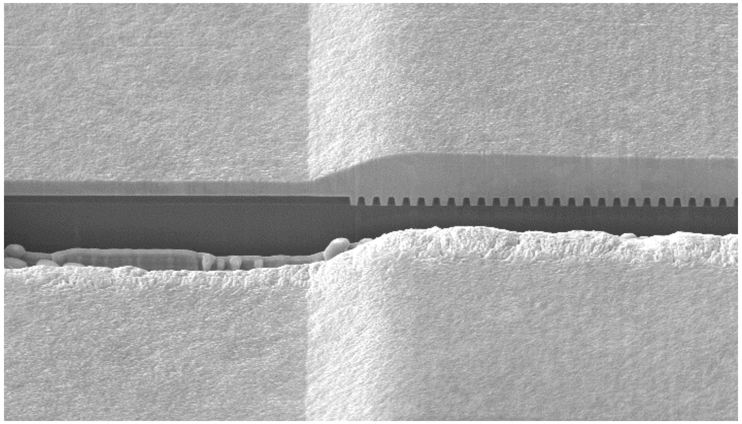
ECD Copper for Interconnects

- Feature Filling /Film Properties
- Local Uniformity
  - Chemistry Effects
  - Recipe Effects
- Global Uniformity

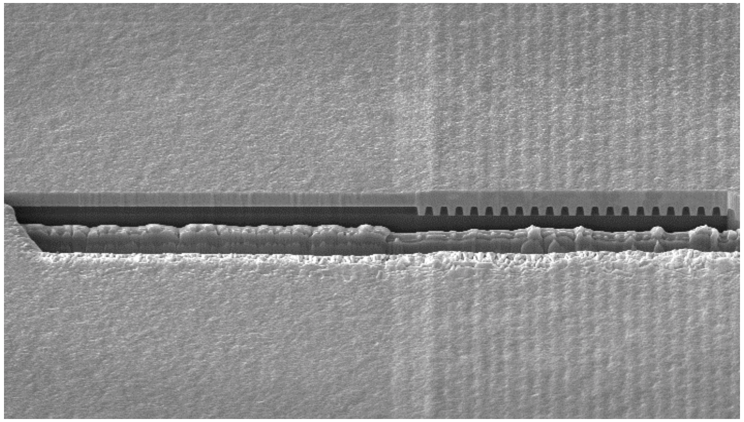
Feature Scale Uniformity

- Recipe
  - Simple Chemistry
  - Proven Process Integration
- Chemistry (Leveler)
  - Three Components
  - Simplified CMP

Two Component: DC



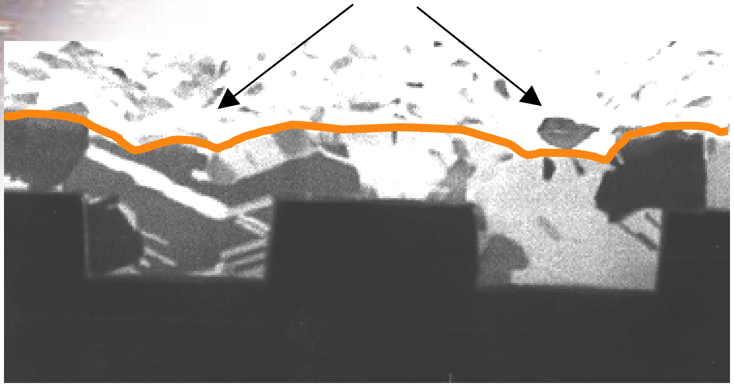
Two Component: Optimized



SEMITOOL®

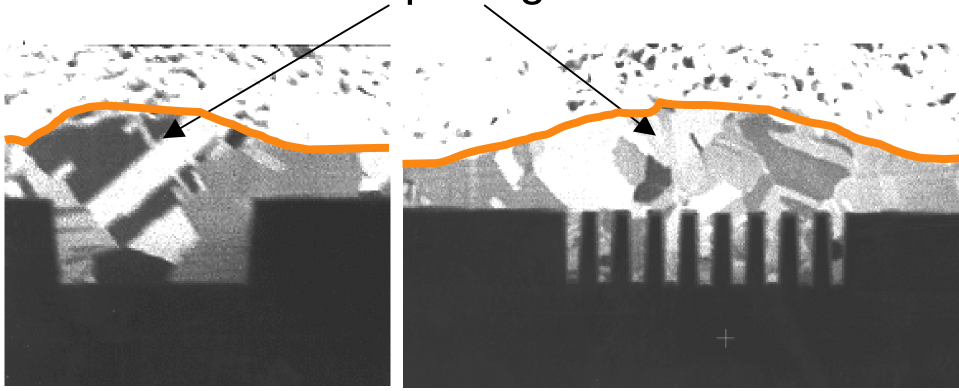
Three Component Bump Minimization

Recession



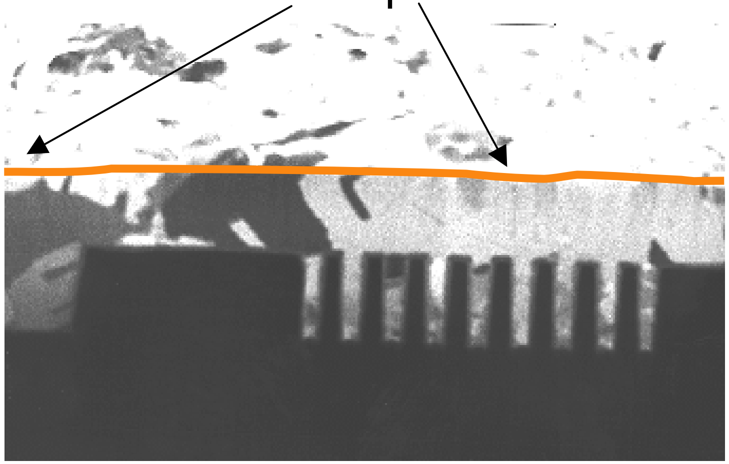
Over Suppression

Overplating



Insufficient Leveler

Planar Deposition



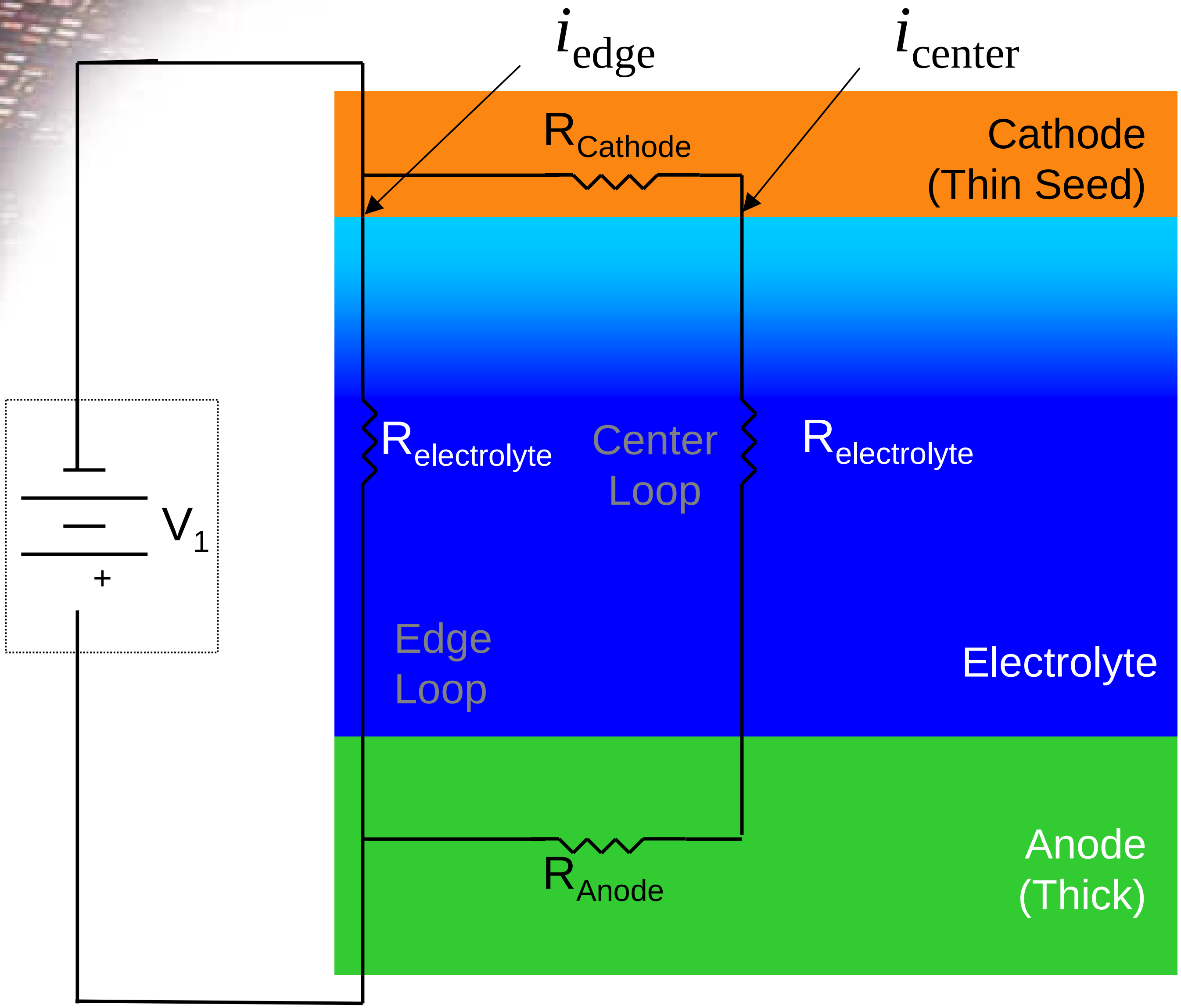
Optimized Organic Conditions

DC Process

ECD Copper for Interconnects

- Feature Filling /Film Properties
- Local Uniformity
- Global Uniformity
  - Definition: Terminal Effect
  - Transient Nonuniformity
  - Compensating for Terminal Effect

First Approximation: Terminal Effect



1) Disregard fluid flow.

2) Assume a uniform boundary layer and interfacial resistance.

3) Assume bath conductivity much lower than bulk conductivity of Copper (Equipotential Anode).

4) Fixed Reactor Geometry

Consider two arbitrary surface elements in the system. One at the center and one at the edge.

Ohm's Law

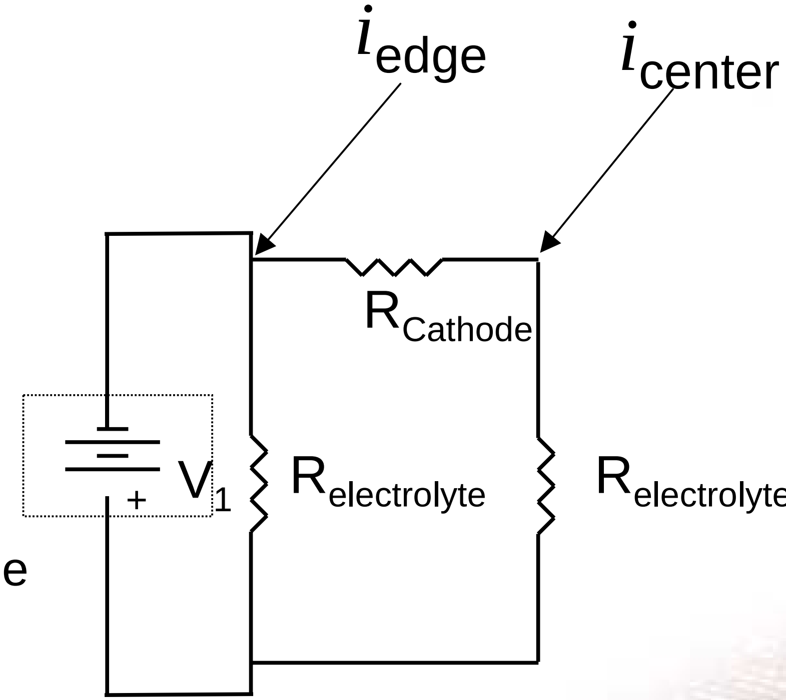
The full treatment...

$$i_{\text{edge}} = V_1/R_{\text{electrolyte}}$$

$$i_{\text{center}} = \frac{V_1}{(R_{\text{cathode}} + R_{\text{electrolyte}})}$$

Reduces to:

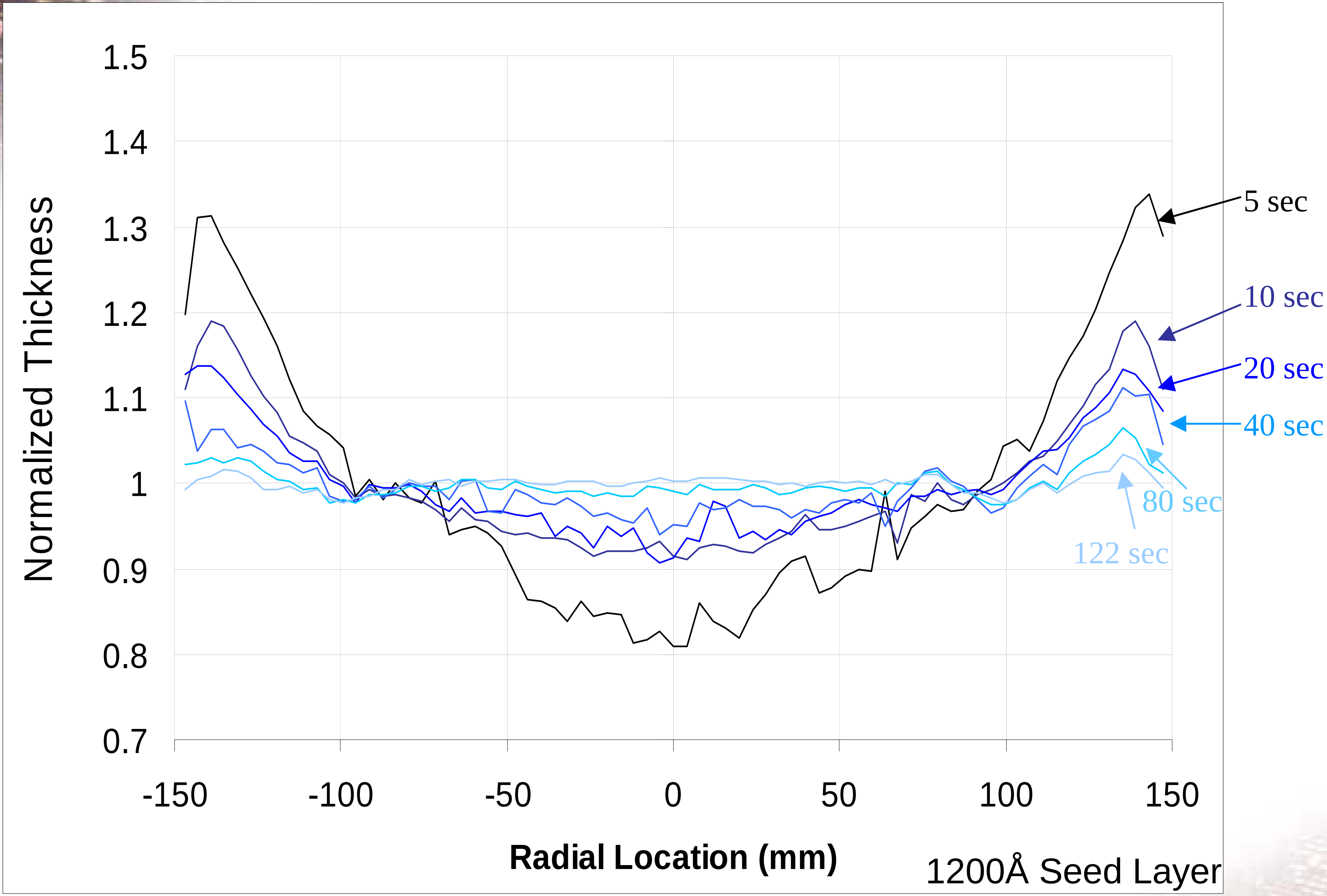
$$i_{\text{center}} = i_{\text{edge}} \frac{R_{\text{electrolyte}}}{(R_{\text{cathode}} + R_{\text{electrolyte}})}$$



$R_{\text{electrolyte}}$: Inverse to Bath Conductivity

R_{cathode} : Proportional seed thickness and wafer size

Conventional Process: Thickness Profiles

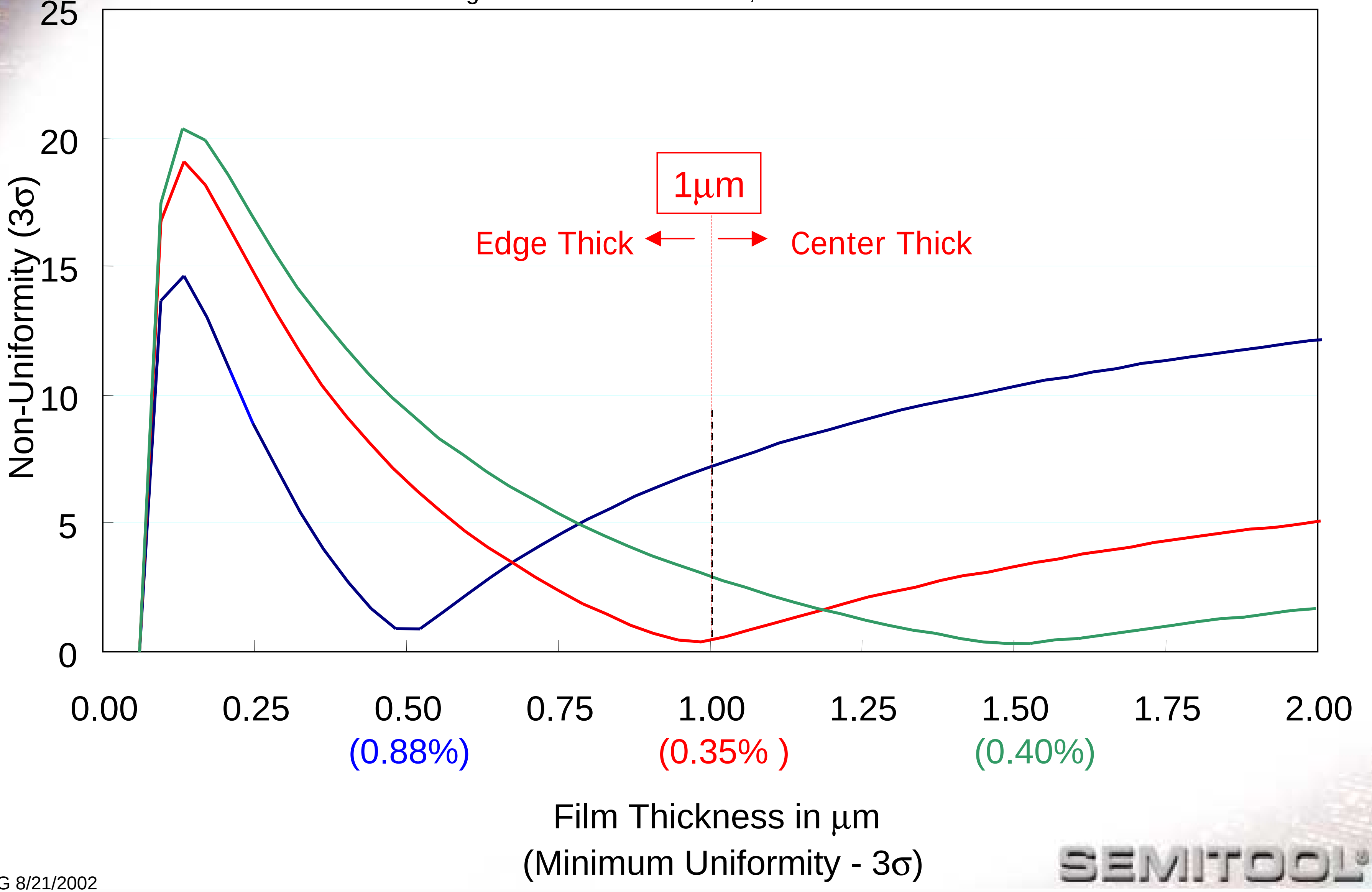


SEMITOOL®

Hardware Controlled Uniformity

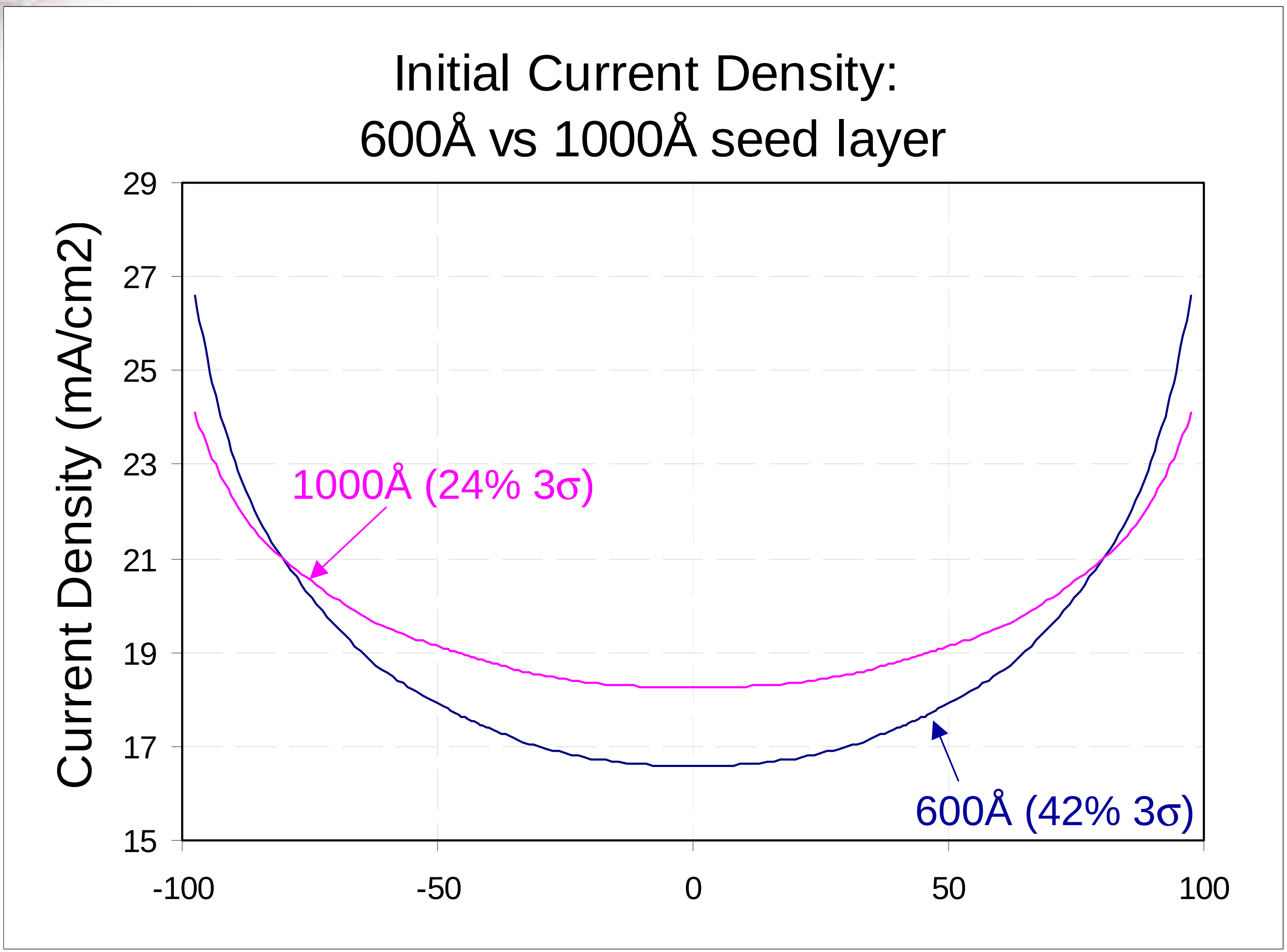
Uniformity Trajectory for Various Conventional Reactors

Note: Changes made are with shields, thieves and/or diffusers



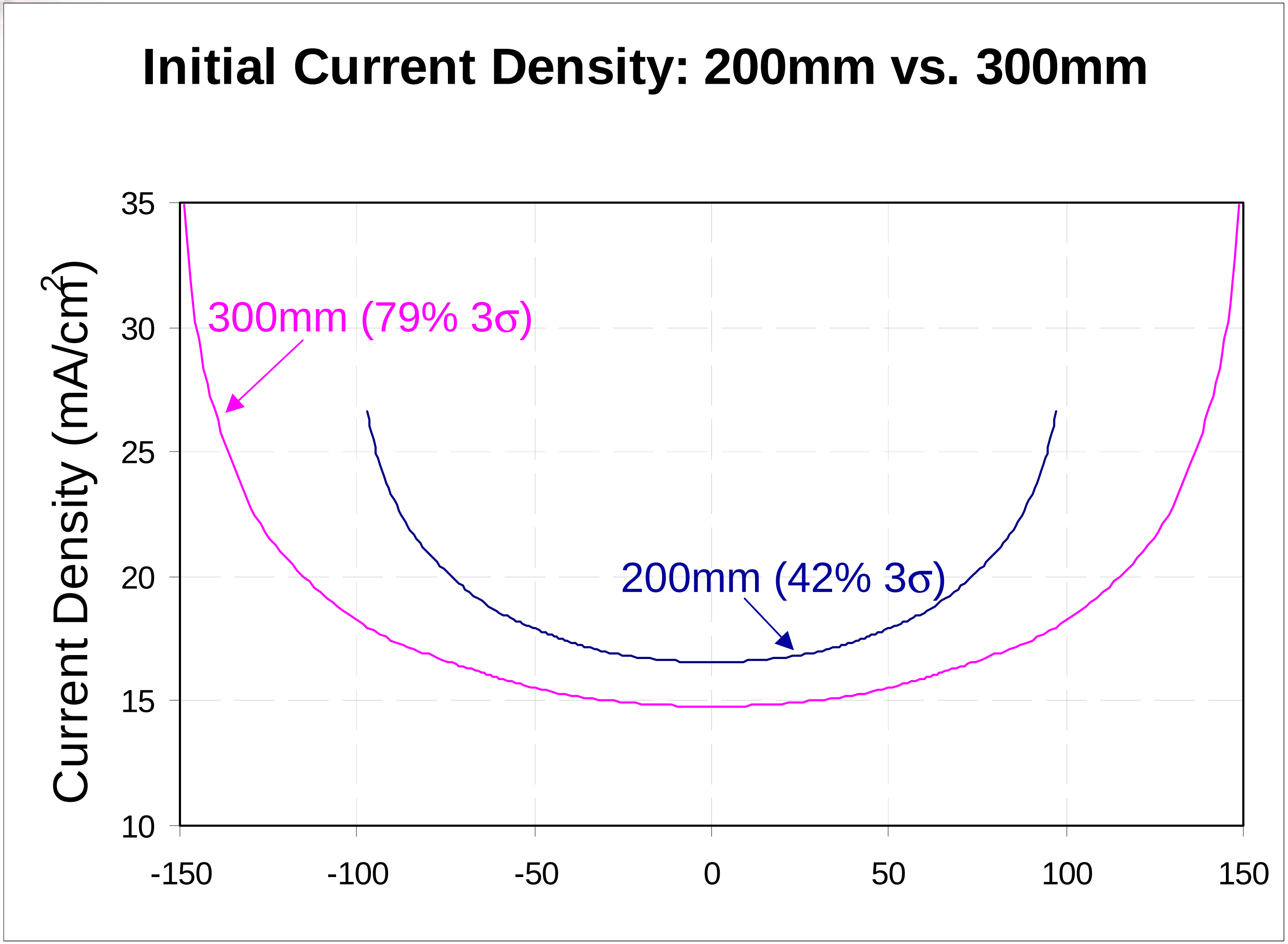
SEMITOOL®

Seed Layer Thickness



Optimized at 1.0µm Thickness
200mm Wafer

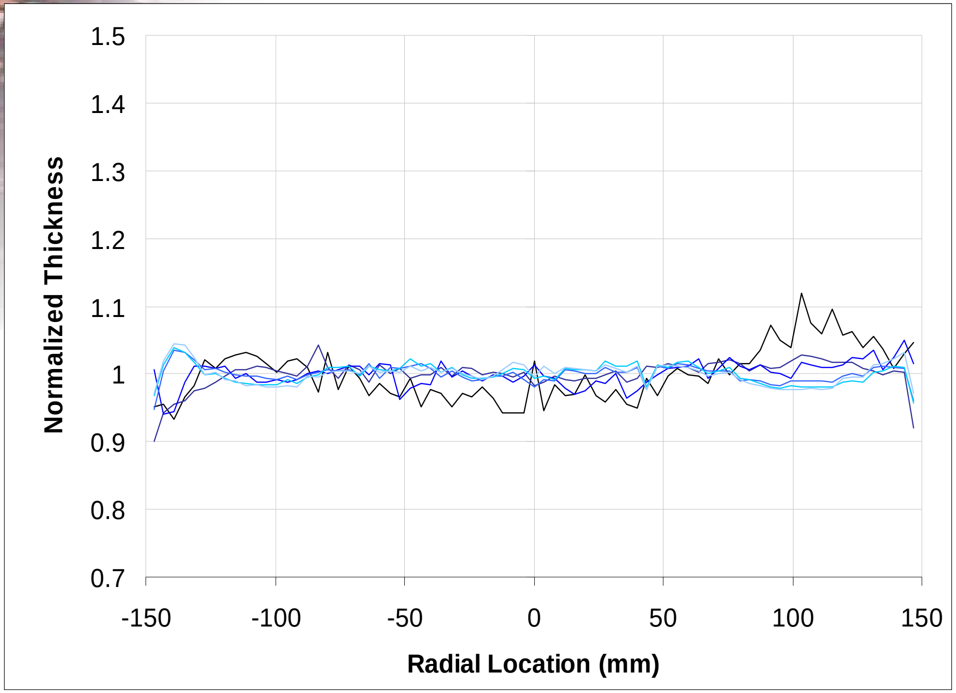
Wafer Size



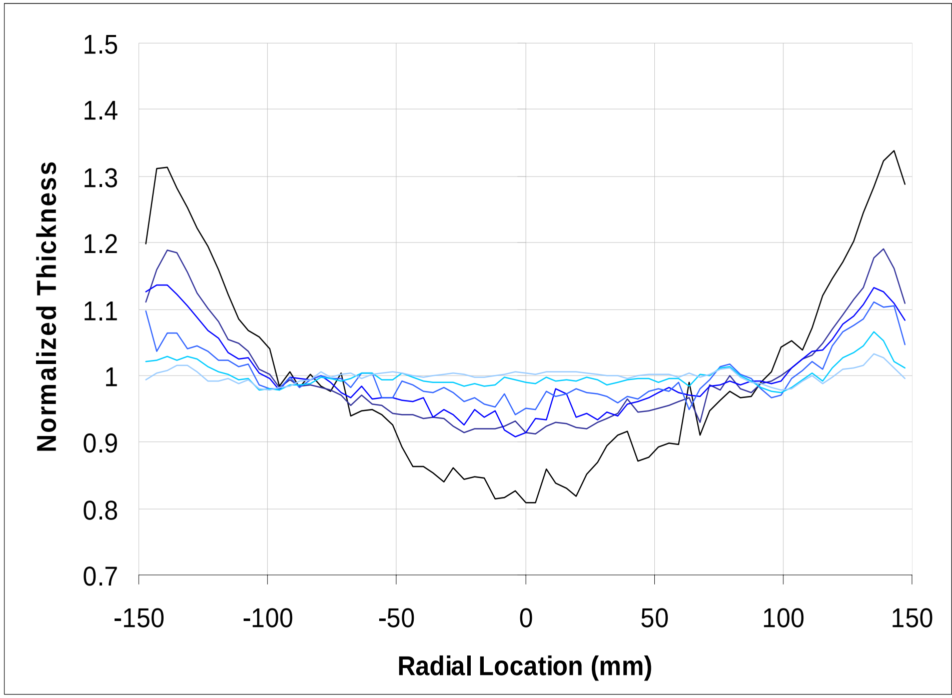
Optimized at 1.0μm Thickness

600Å Seed Layer

Dynamically Controlled Current Distribution



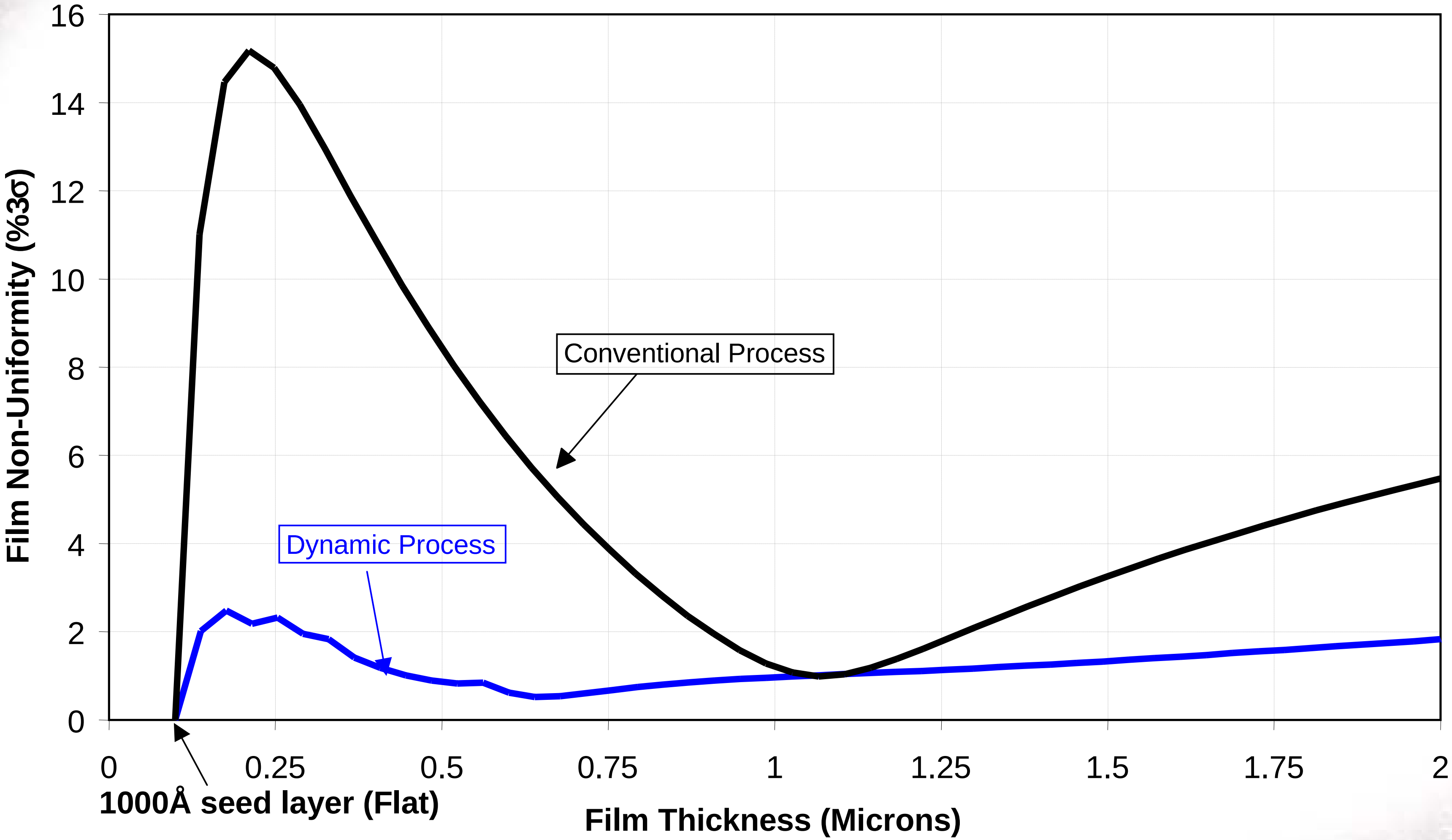
Dynamically Controlled Process



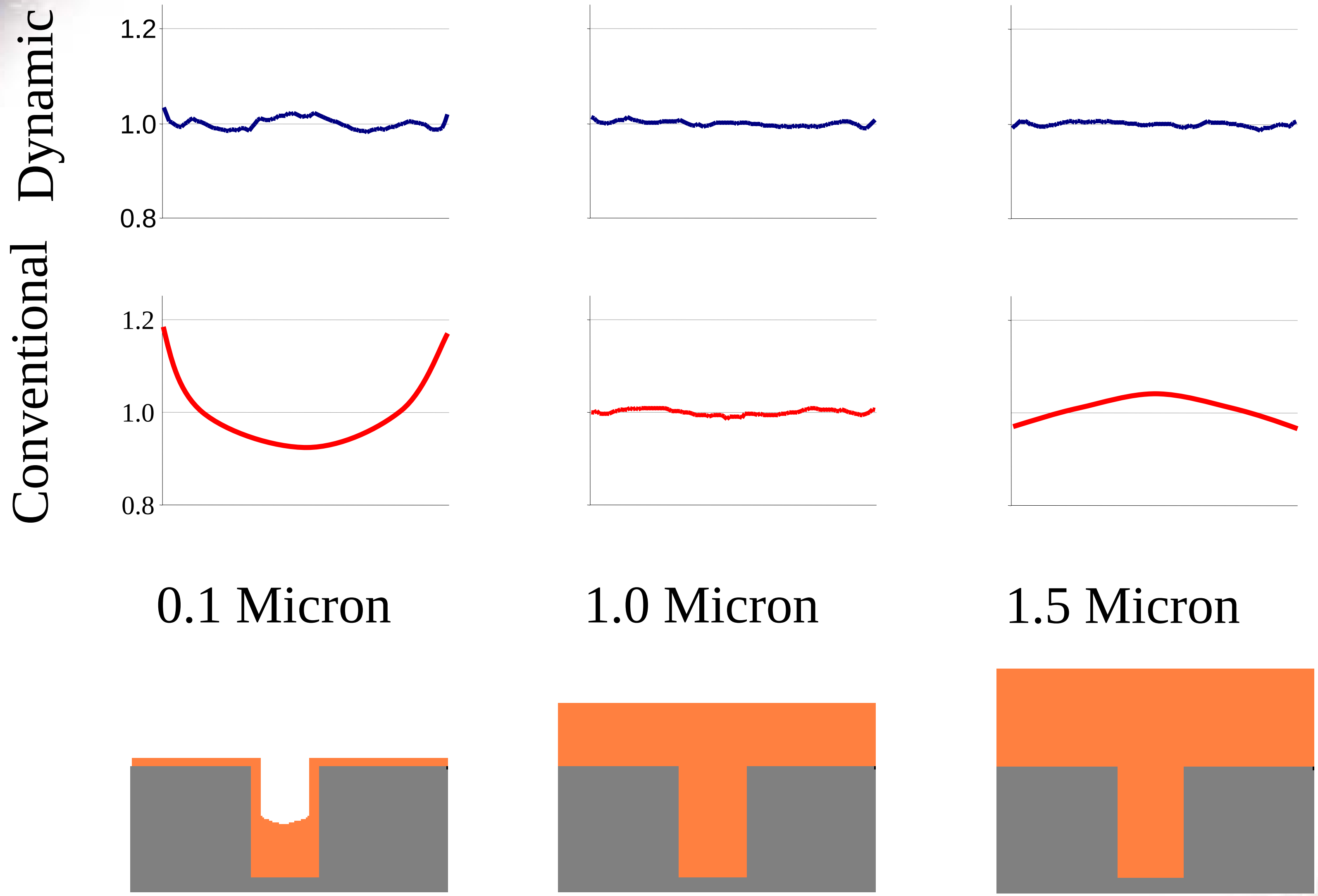
Conventional Process

1200Å Seed Layer

Modeling Data



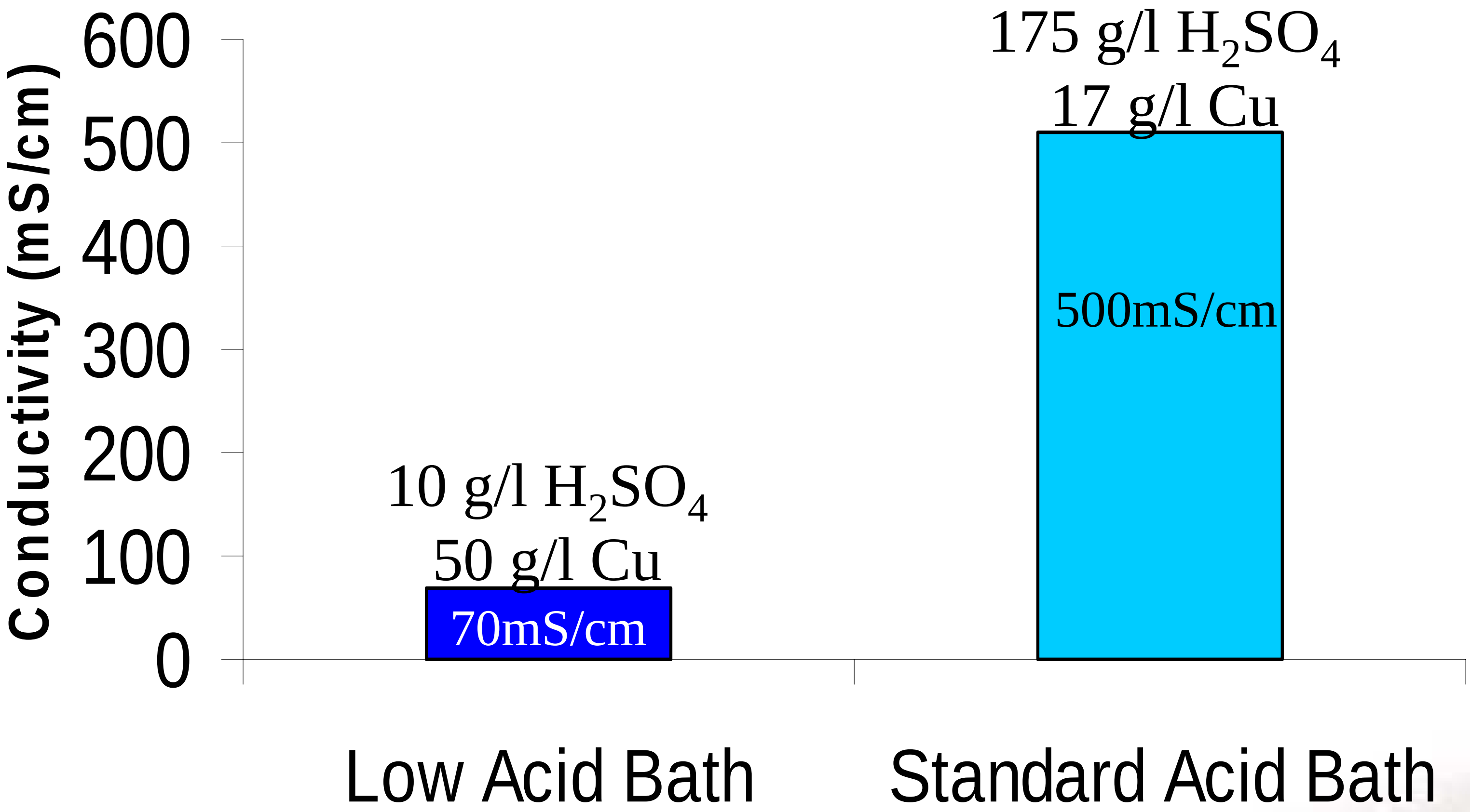
Plated Film Growth



Bath Conductivity

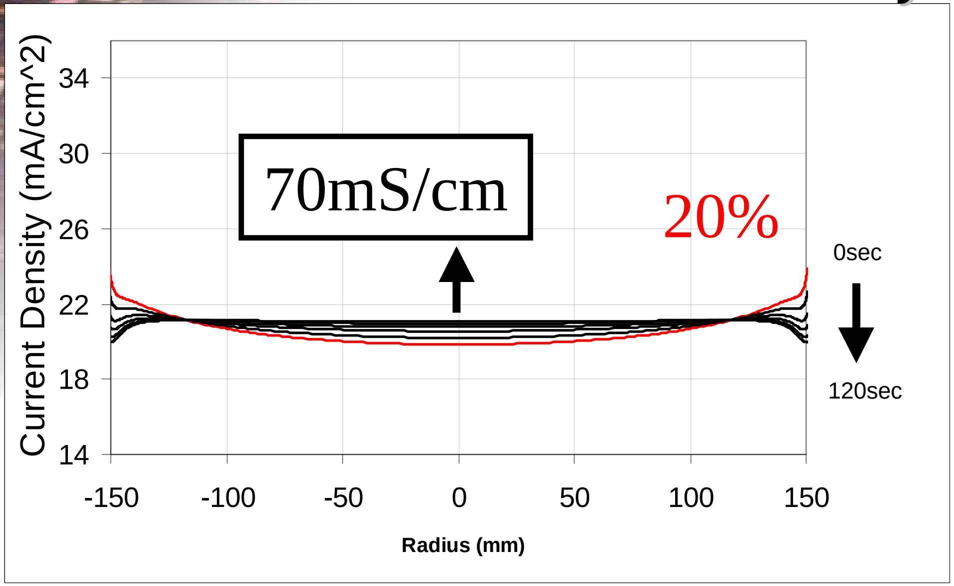
$$i_{center} = i_{edge} \frac{R_{electrolyte}}{(R_{cathode} + R_{electrolyte})}$$

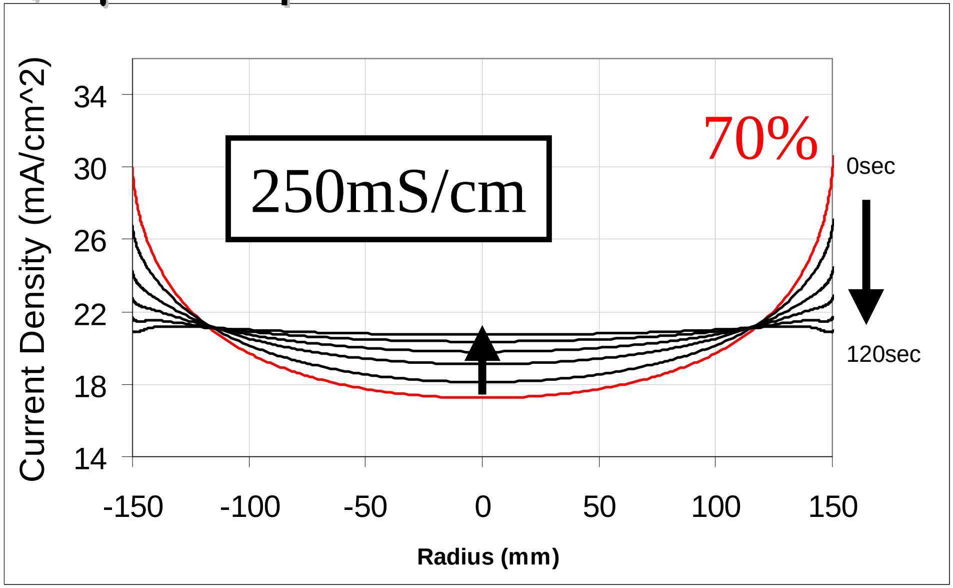
High Acid vs. Low Acid

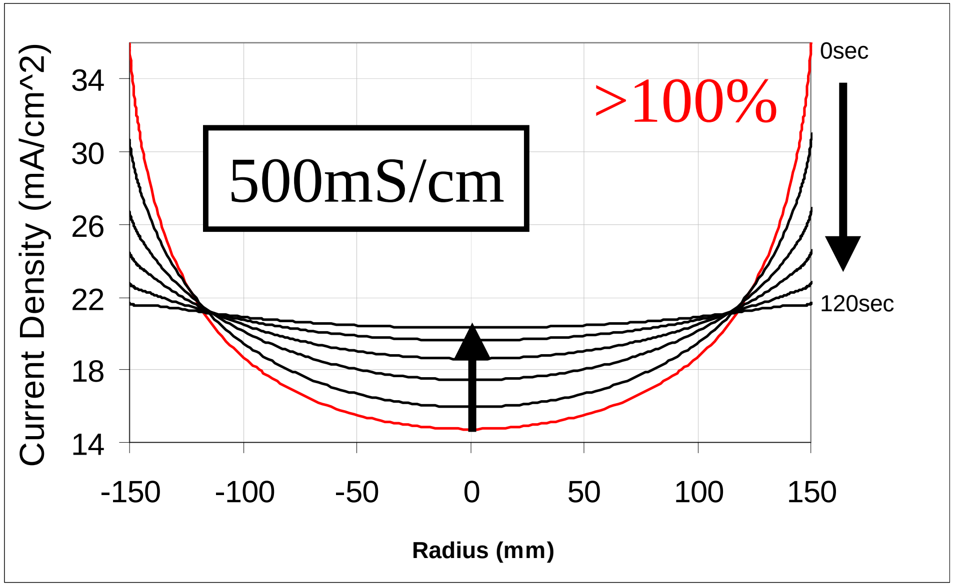


Modeling Data

1000Å seed layer, 1µm deposition

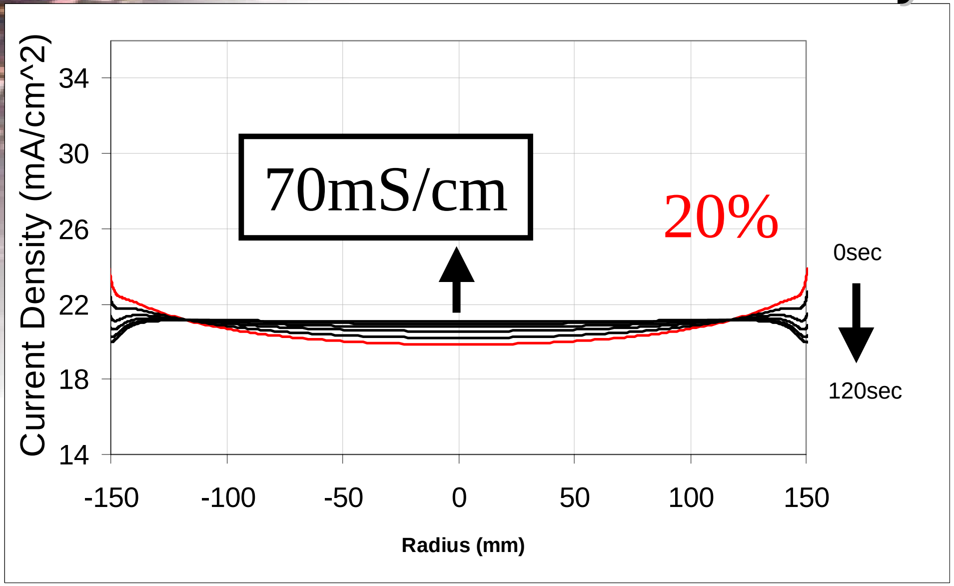


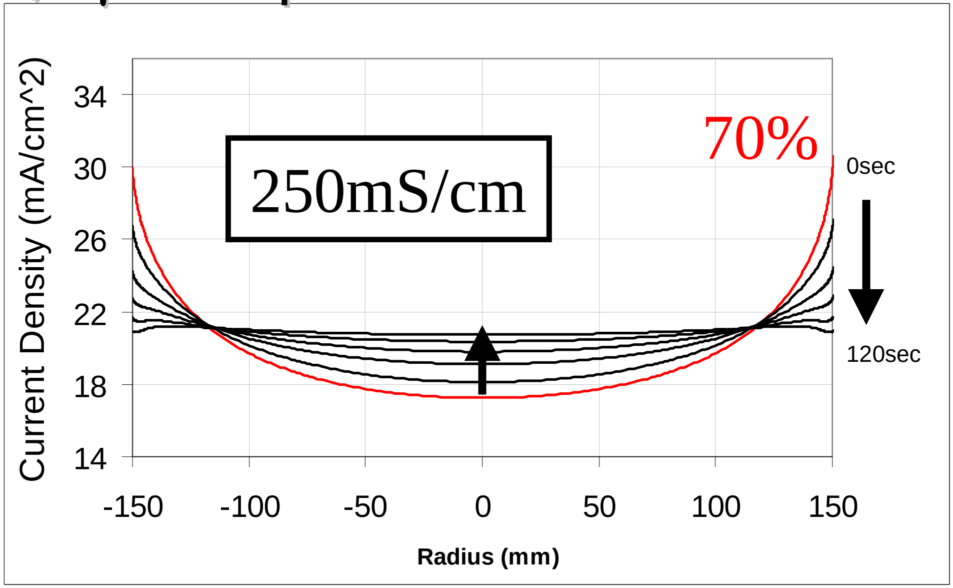


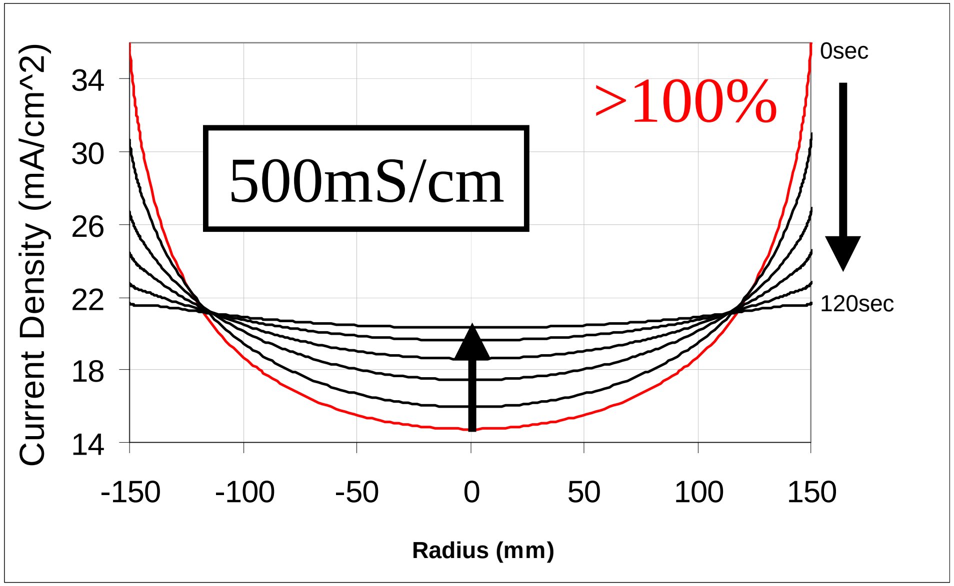


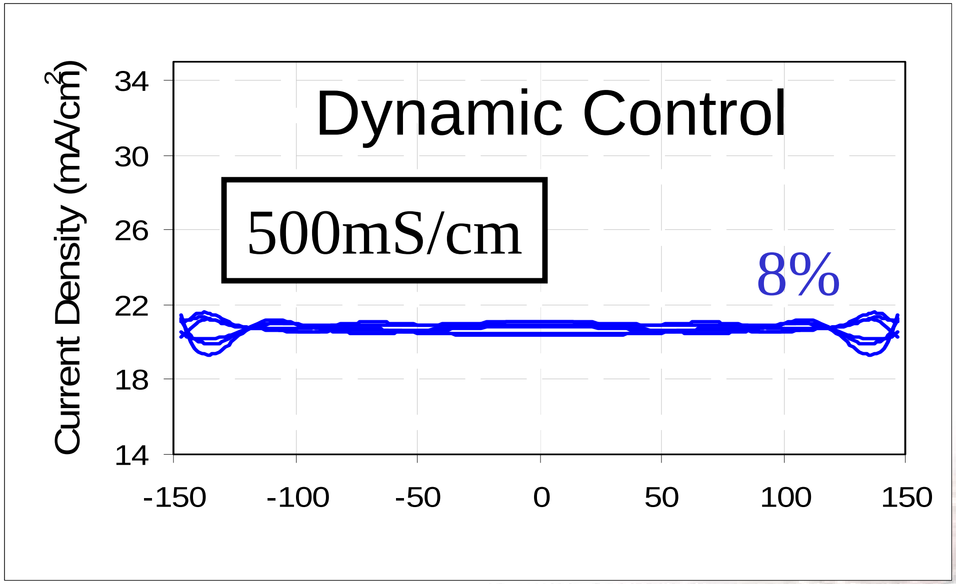
Modeling Data

1000Å seed layer, 1µm deposition

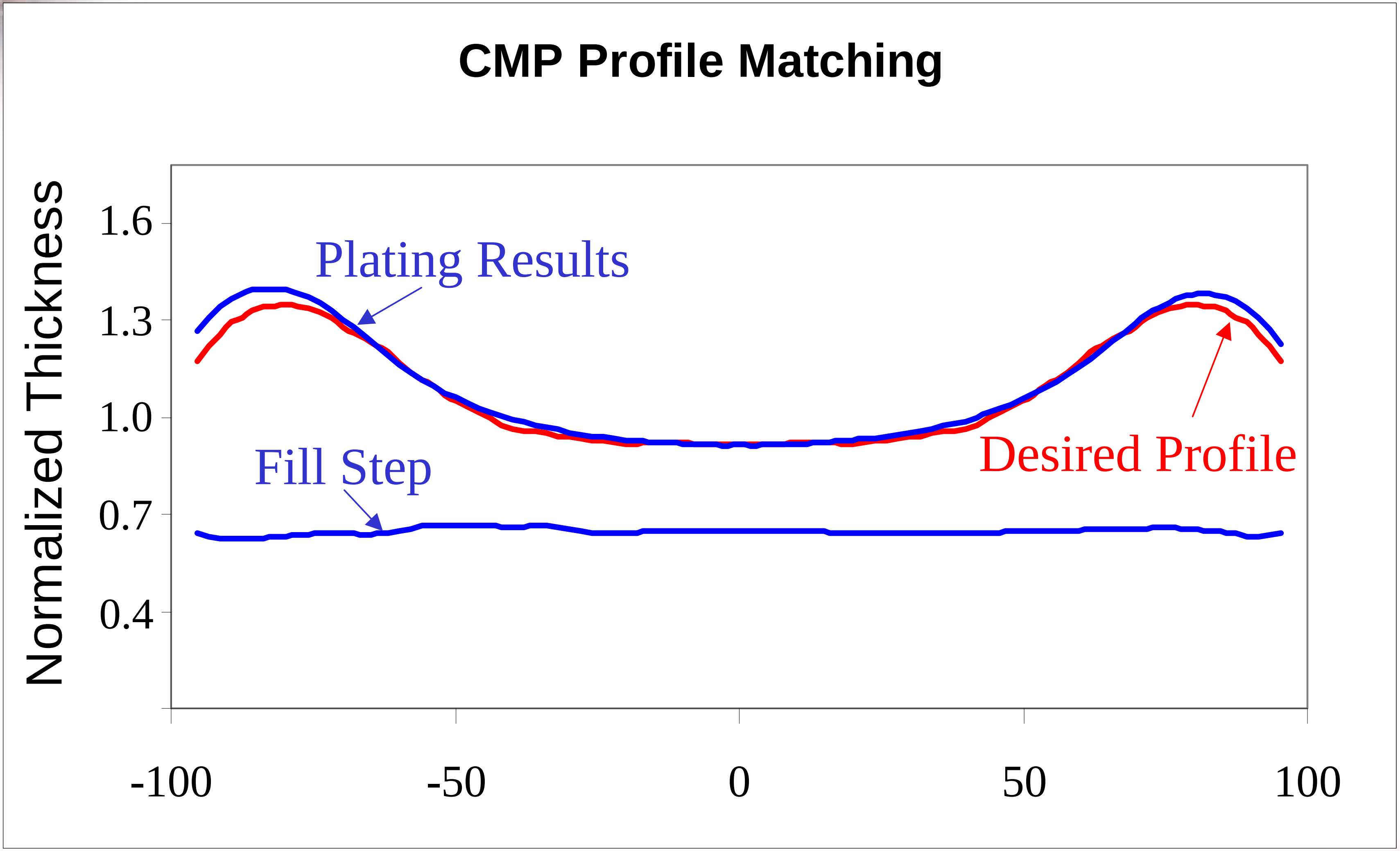








Fill Profile vs. CMP Profile



Summary

- Feature Filling/Film Properties
  - Optimized Organic and Inorganic Conditions
  - Current Density
- Local Uniformity
  - Recipe
  - 3 Component Chemistries
- Global Uniformity
  - Bath Conductivity (Seed Limited)
  - Dynamic Control Current Distribution