Modeling of Pattern Dependencies in Abrasive-Free Copper CMP Processes

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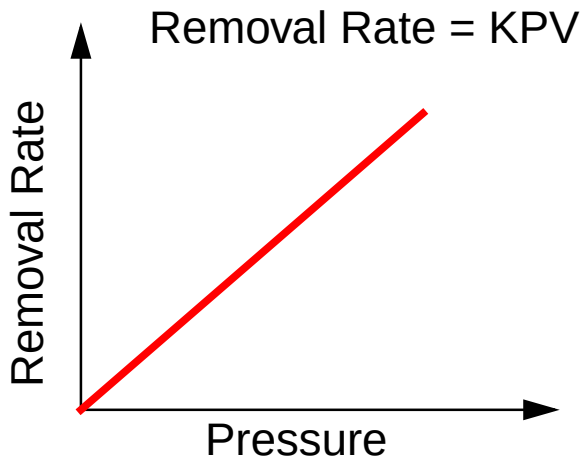
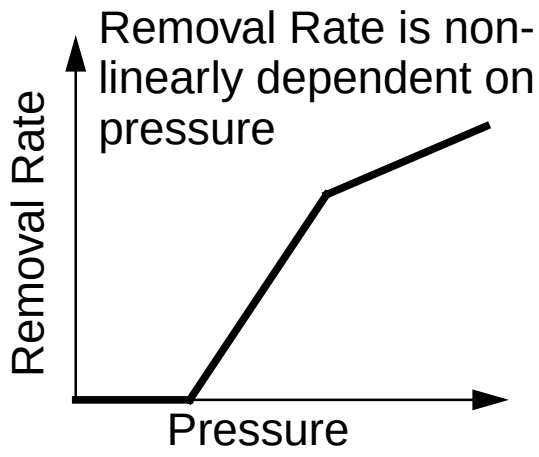
Motivation



- Prestonian Behavior: removal rate is linearly proportional to pressure
- Conventional copper CMP processes obey this rule



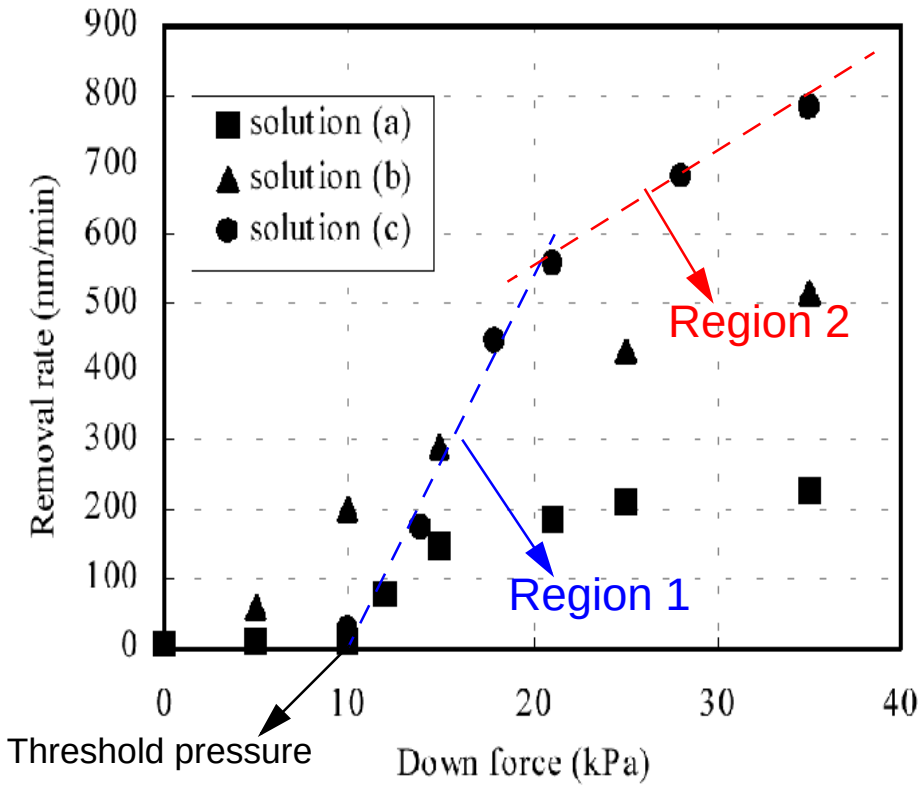
- Non-Prestonian Behavior: Removal rate is nonlinearly dependent on pressure
- Abrasive-Free copper CMP processes fall in this category

GOAL: Generalize the Density-Step-Height Model to handle both Prestonian and non-Prestonian copper CMP processes.

Outline

- Motivation: Generalize Density-Step-Height Model to Non-Prestonian CMP
- Abrasive-Free Polishing (AFP) Behavior
- Review of Density-Step-Height Model for Conventional Prestonian Processes
- Extension of Density-Step-Height Model to Non-Prestonian Processes
- Experimental Data
- Model Fits versus Experimental Data
- Summary

Abrasive-Free Polishing Behavior



- Abrasive-Free polishing uses chemical slurry without abrasive particles
- Benefits:
  - substantially improved dishing and erosion perfomance
  - reduced solid content in effluent
  - reduced scratching during CMP
- Challenge: may be difficult to clear copper in certain regions on the die
- Solution (c) gives:
  - Nonzero threshold pressure
  - Approximately linear pressure dependence in region 1
  - Approximately linear pressure dependence in region 2

Outline

- Motivation
- Abrasive-Free Polishing (AFP) Behavior
- ✔ **Review of Density-Step-Height Model for Conventional Prestonian Processes**
  - ❑ Intrinsic Copper CMP Stages
  - ❑ Removal Rate Diagrams: Removal Rate versus Step Height (or Dishing)
- Extension of Density-Step-Height Model to Non-Prestonian Processes
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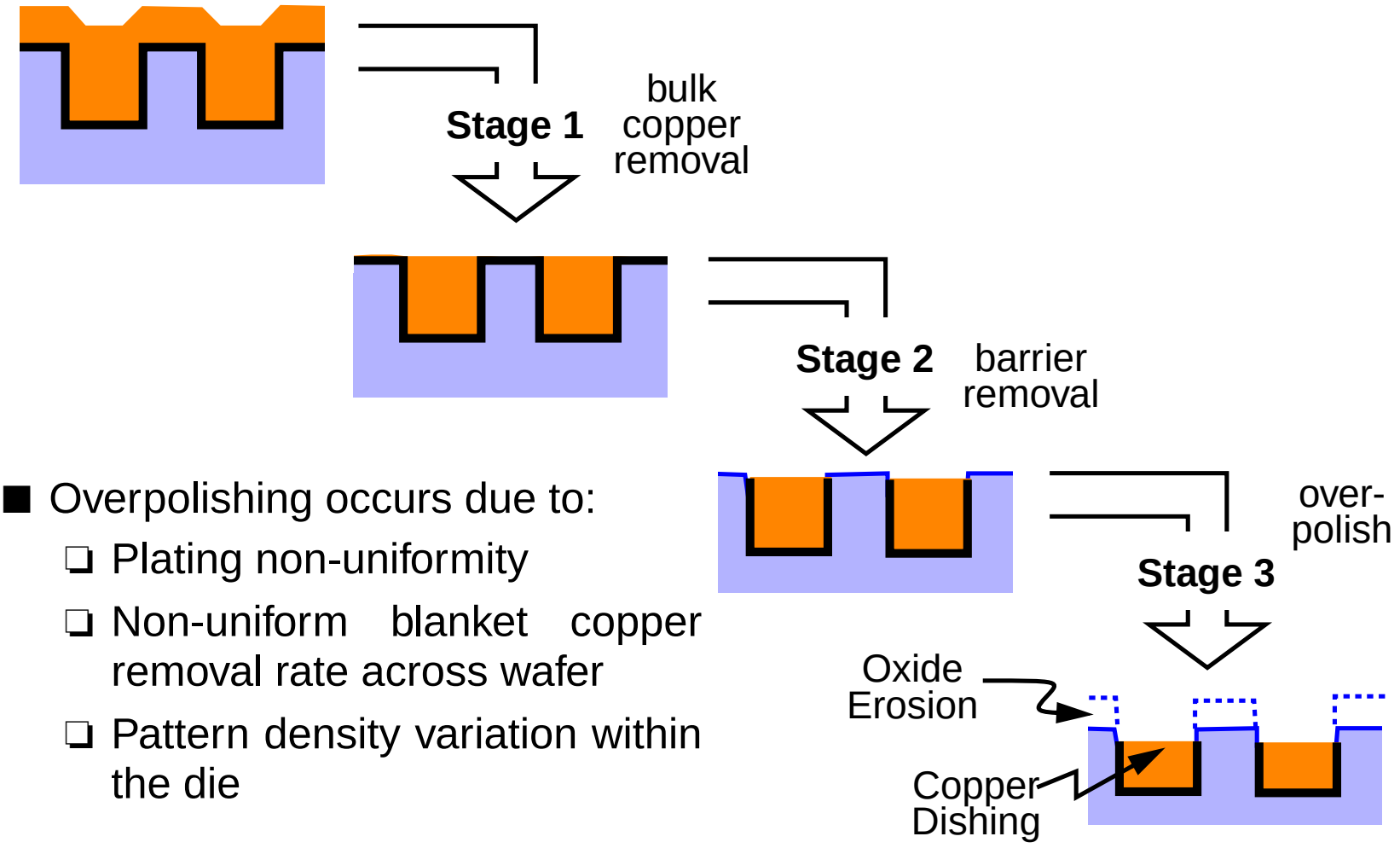
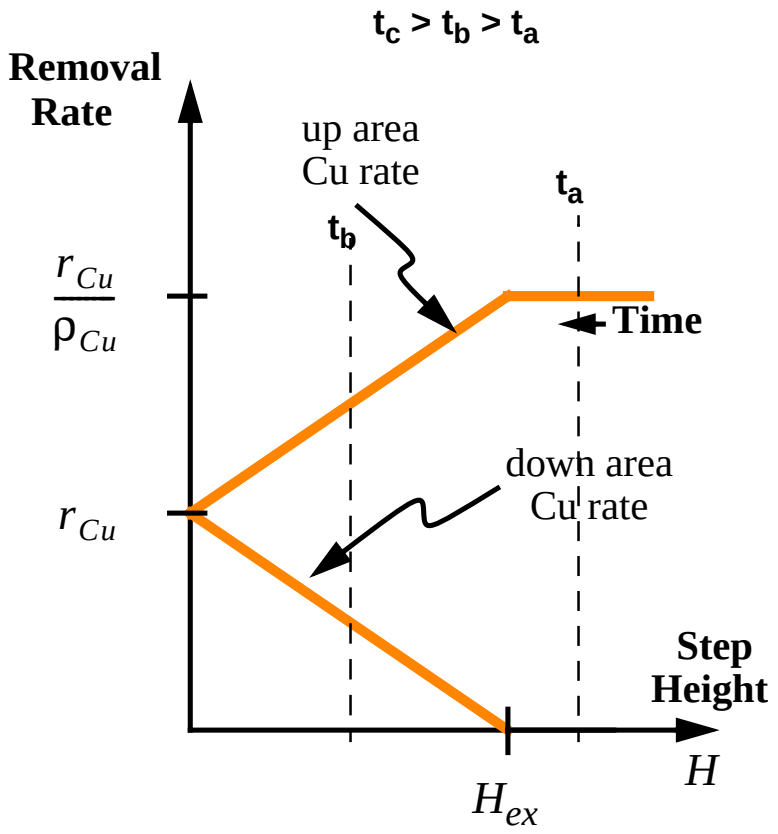
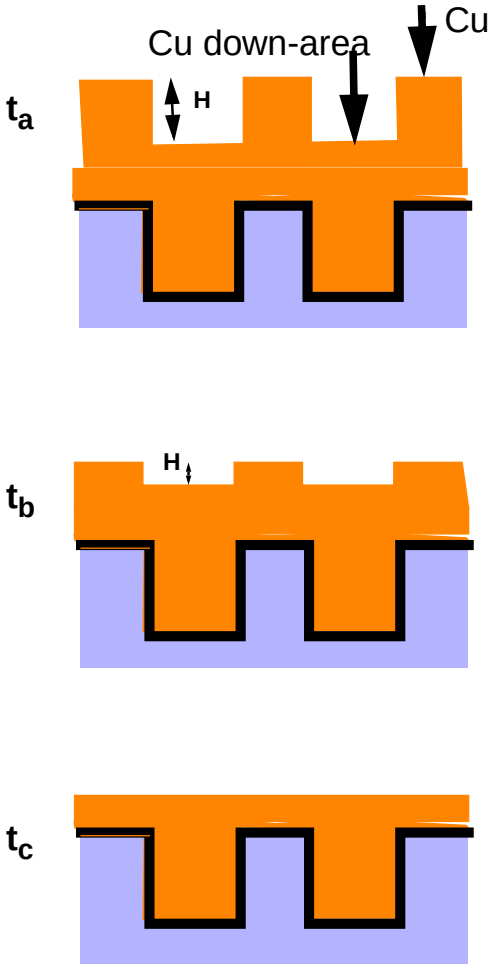
The Three Intrinsic Stages in Cu CMP



- Overpolishing occurs due to:
  - Plating non-uniformity
  - Non-uniform blanket copper removal rate across wafer
  - Pattern density variation within the die

Density-Step-Height Model: Bulk Cu Removal

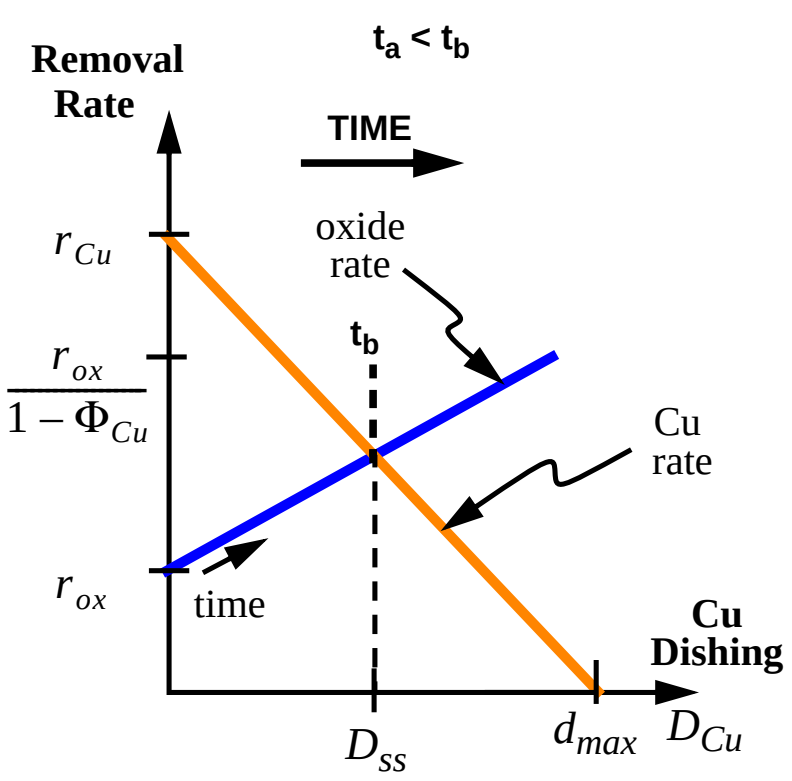


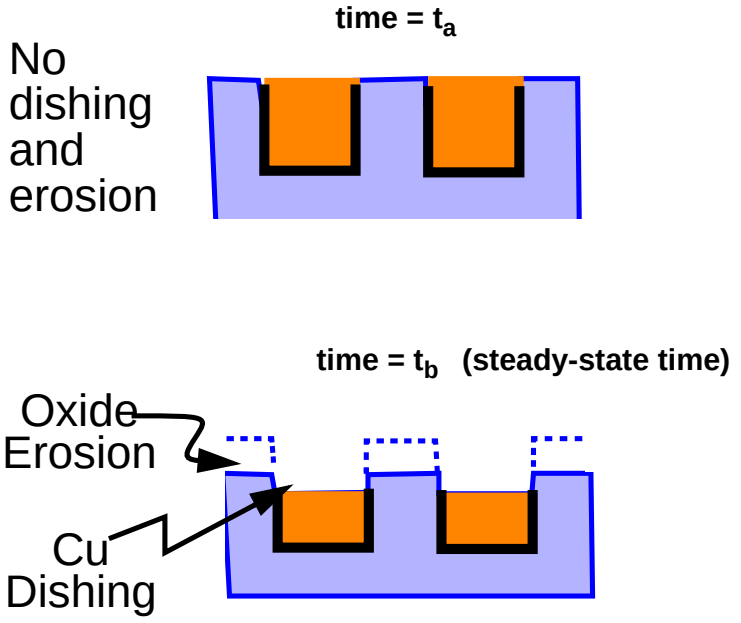


- Up-area contact only
- Up and down area contact
- Planar surface: step height is equal to zero

- **H_{ex}**: local step-height above which no material is removed in the “down area
- ρ_{Cu} is Cu pattern density (not necessarily layout density)

Density-Step-Height Model (cont).: Overpolish





- d_{max} is maximum Cu dishing.
- D_{Cu} is Cu dishing.
- Φ_{Cu} is pattern density in overpolish.

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- ✔ **Extension of Density-Step-Height Model to Non-Prestonian Processes**
  - ❑ Removal Rate versus Pressure dependence
  - ❑ Pressure versus Step-Height (or Dishing)
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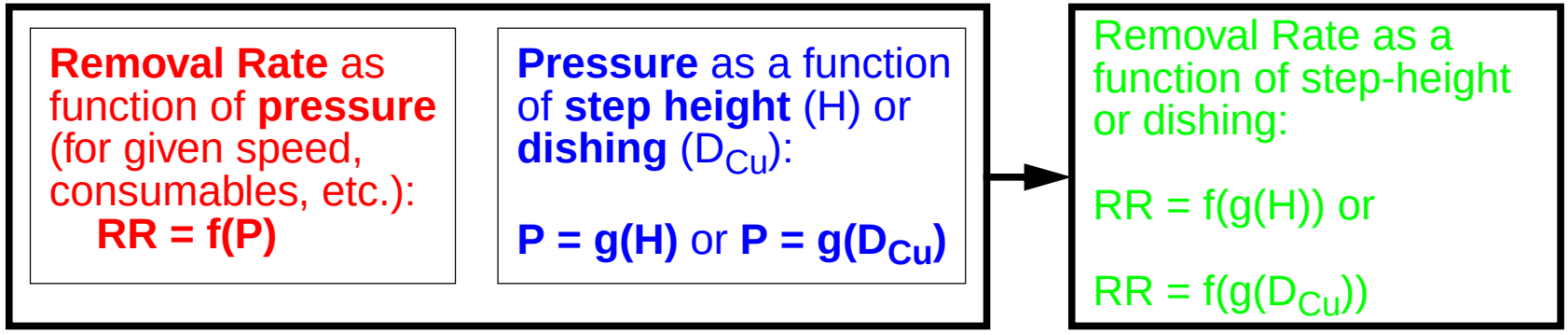
Extension of Density-Step-Height Model

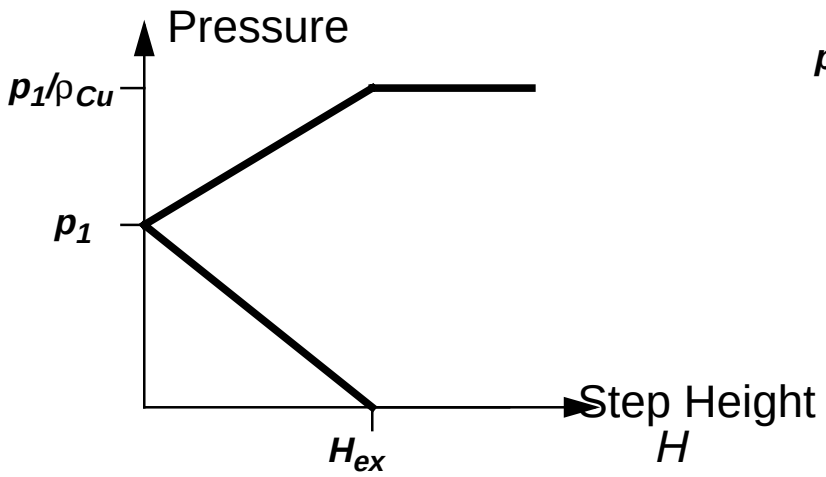
- Previously: Removal Rate versus Step-Height (or dishing) derived from experimental data
- New Proposal: Splitting Removal Rate Diagrams



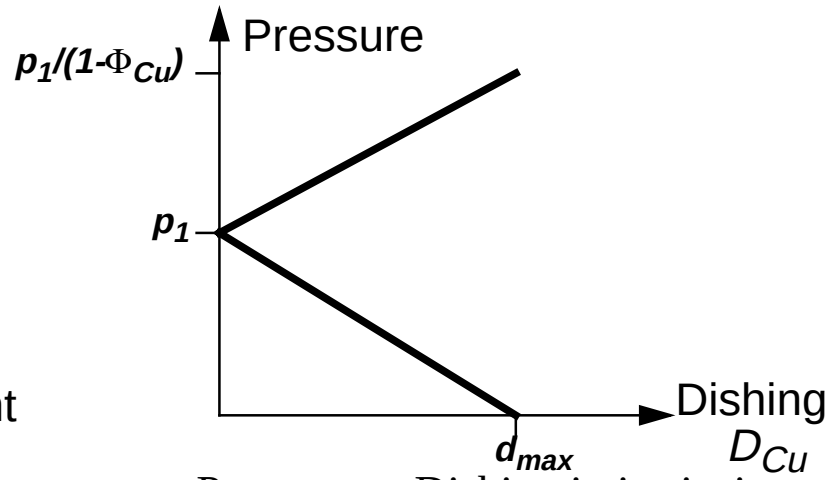
- Two relationships needed:
  - Removal rate versus pressure relationship (linear or non-linear)
  - **Pressure** versus step-height (or dishing) relationship

Pressure vs. Step Height Relation

- Pressure versus step-height (or dishing) relationship



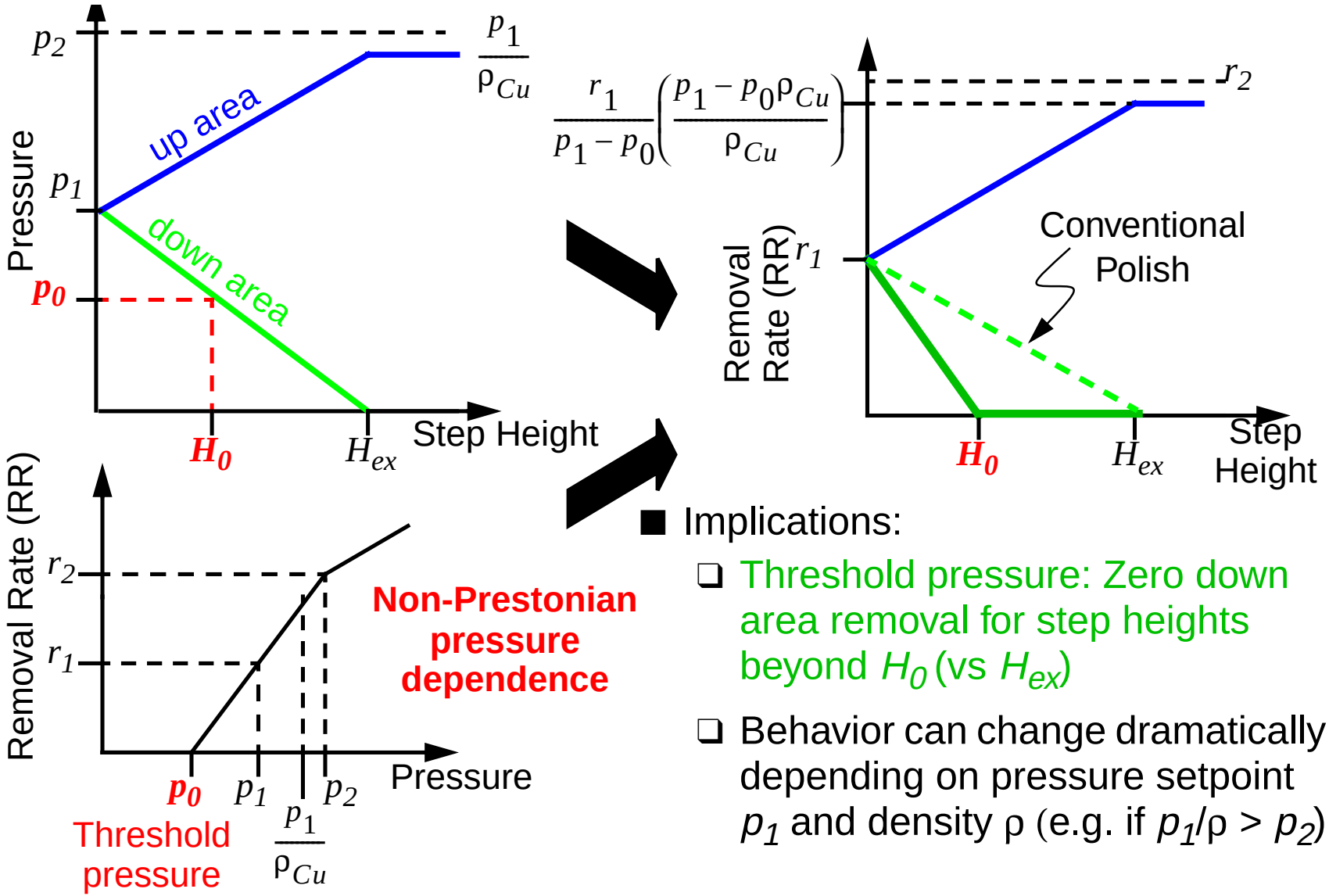
Pressure vs Step Height in intrinsic stage 1



Pressure vs Dishing in intrinsic stage 3

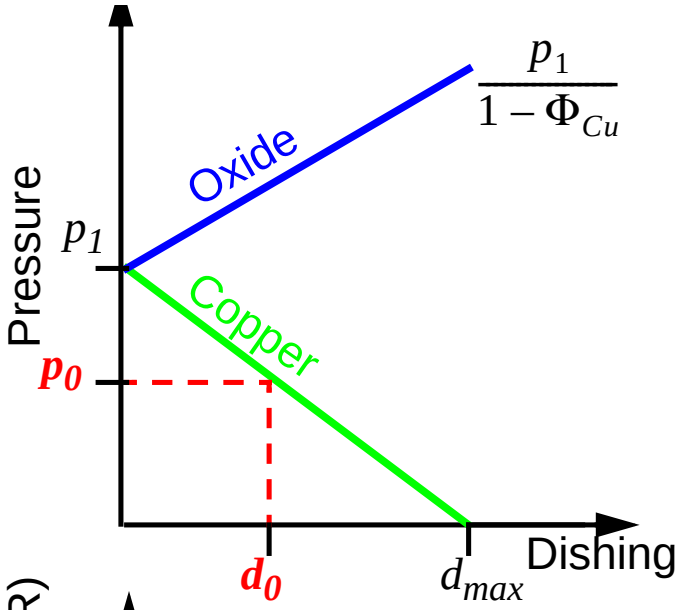
- ρ_{Cu} is copper pattern density in stage 1
- H_{ex} is critical step height. It is pattern dependent
- Φ_{Cu} is copper pattern density in stage 3
- p_1 is polish pressure (downforce)
- d_{max} is maximum dishing. It is pattern dependent.

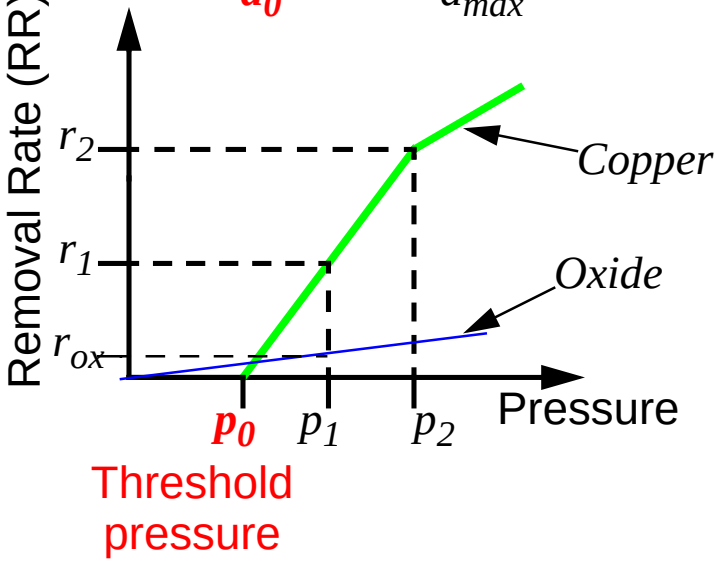
Density-Step-Height Model for AFP:Bulk Cu Clearing

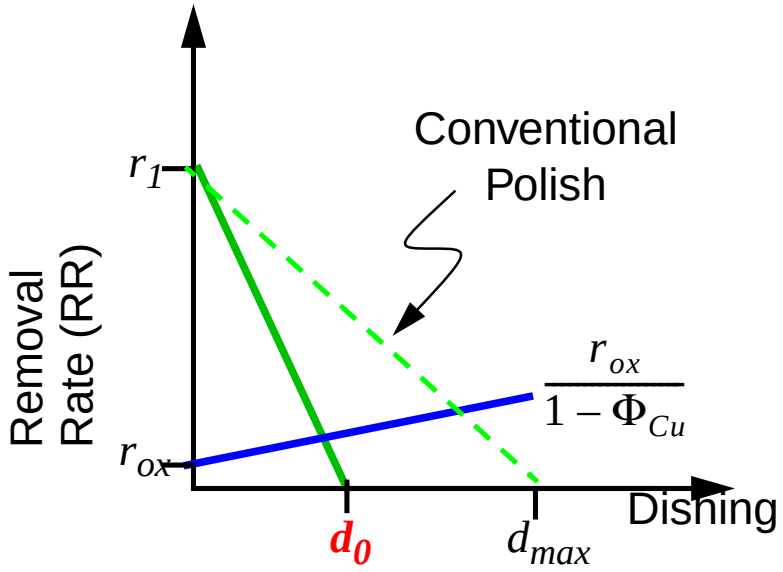


- Implications:
  - Threshold pressure: Zero down area removal for step heights beyond H_0 (vs H_{ex})
  - Behavior can change dramatically depending on pressure setpoint p_1 and density ρ (e.g. if $p_1/\rho > p_2$)

Density-Step-Height Model for AFP: Overpolishing







- Implications:
  - Threshold pressure: Effective maximum dishing is d_0 (as opposed to d_{max}).
  - Decreased steady-state dishing compared to conventional polishing case.

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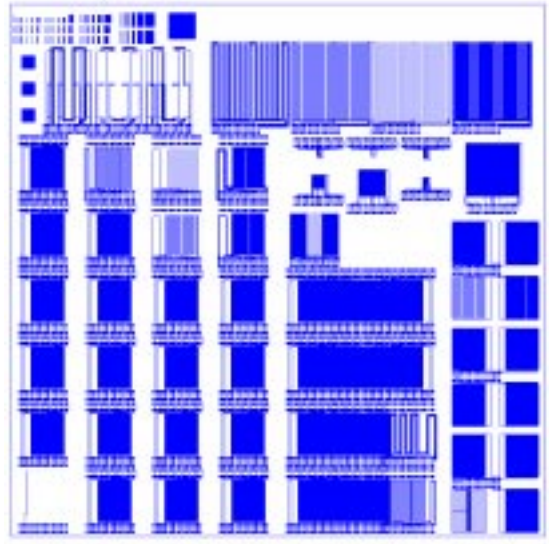
Experimental Setup

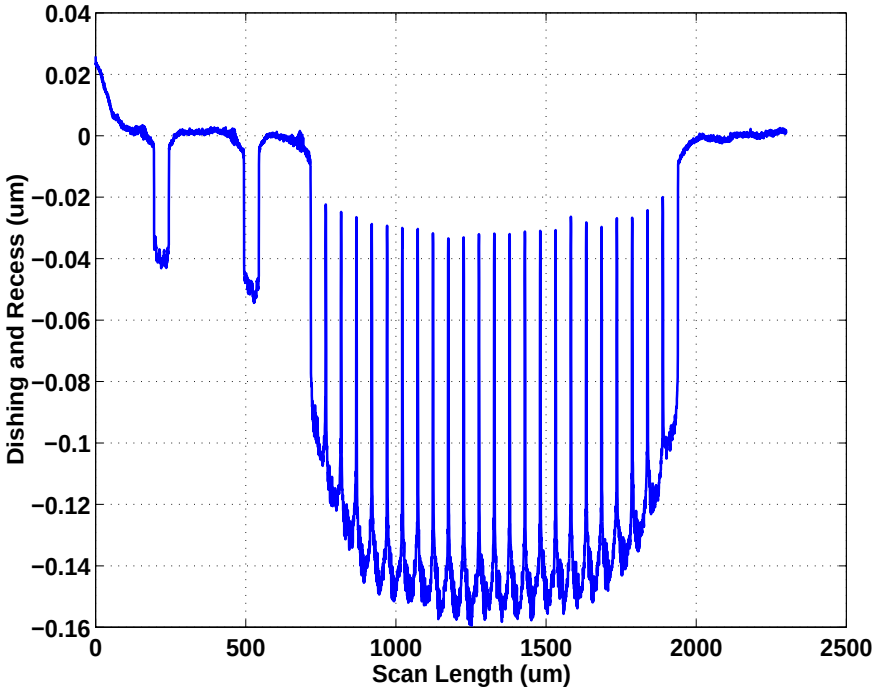
Wafer ID	Polish Time (s)	End-point time (s)	No. of polish steps
1	143	143	1
2	152	142	1
3	161	141	1
4	173	142	1
5	203	143	1
6	262	142	1



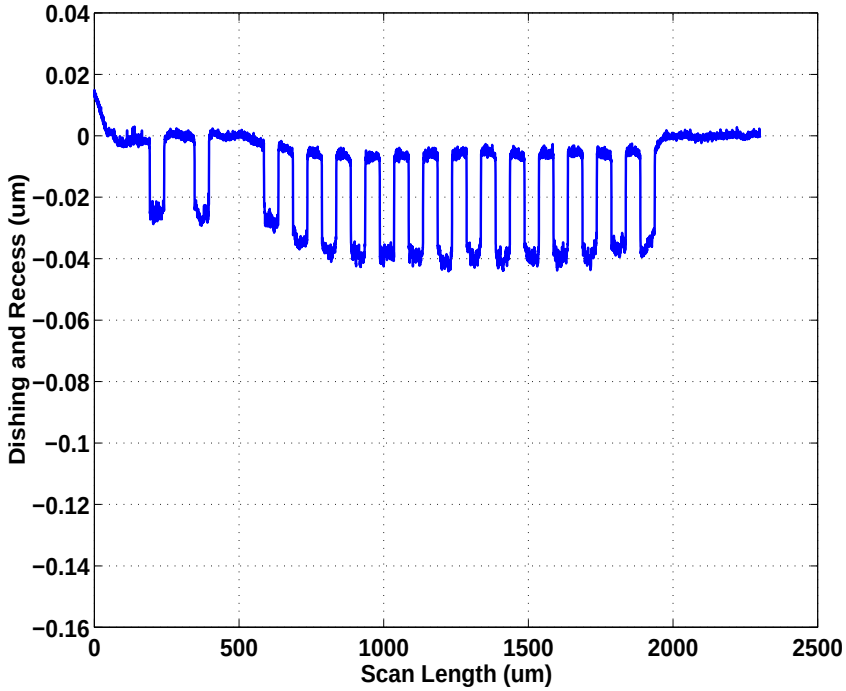
Metal level one of MIT-SEMATECH 854 mask

- Slurry: Hitachi C430-1
- Mask: Metal level one of MIT-SEMATECH 854 mask
- Threshold pressure: p_0 = 3.0 psi; Polish pressure (downforce setting on tool): p_1= 4.7 psi; Breakpoint pressure: p_2 = 6.0 psi
- Blanket copper removal rate: r_1 = 5200 Angs/min

Experimental Data



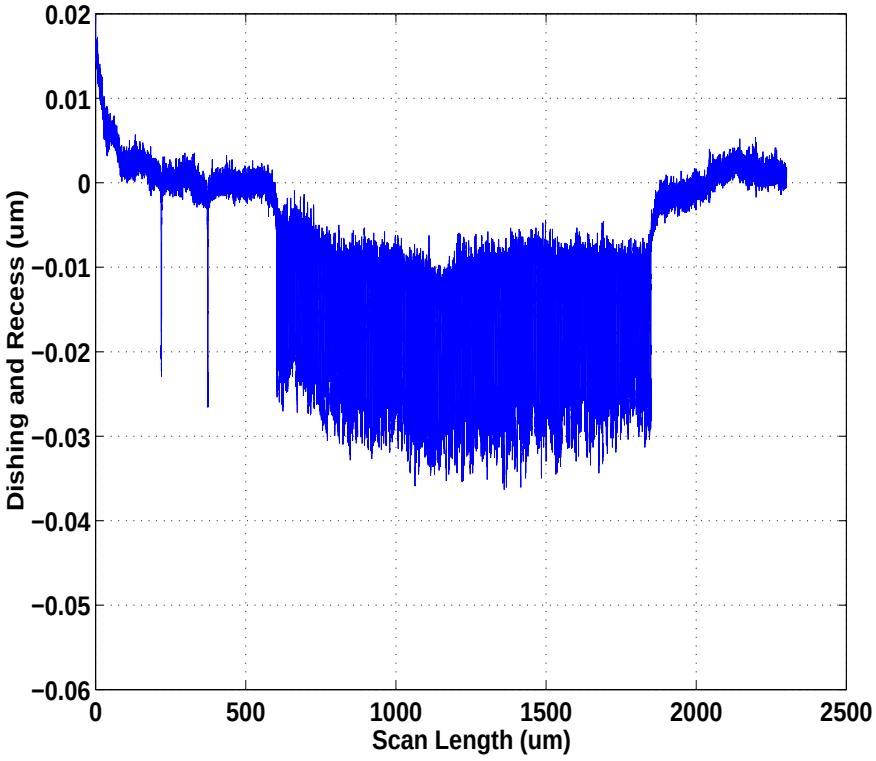
50 μm line width & 1 μm line space array structure



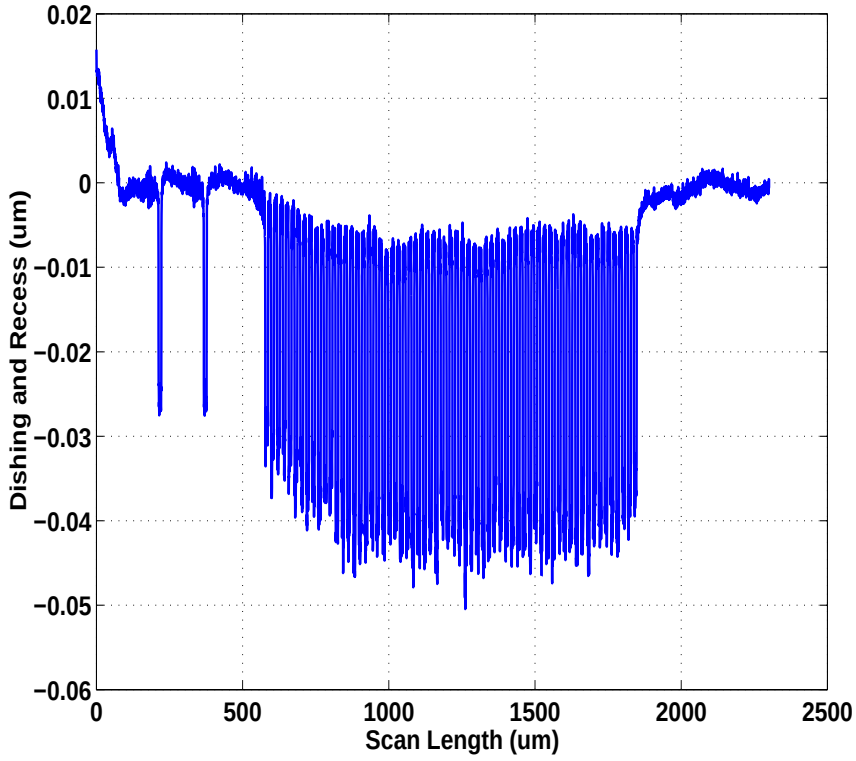
50 μm line width & 50 μm line space array structure

- Dishing depends mainly on **copper pattern density** and line width:
  - The higher the copper pattern density, the higher the dishing.
  - Isolated lines dish less than array lines, of same line width.
- Erosion depends mainly on **copper pattern density**:
  - The higher the copper pattern density, the higher the erosion.

Experimental Data (cont.)



1 μm linewidth, 1 μm linespace structure



10 μm linewidth, 10 μm linespace structure

- Dishing depends mainly on copper pattern density and **line width**.
  - The larger the line width, the higher the dishing.

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Model Calibration

$$d_{max} = Aw^{\alpha}\left(\frac{1}{1-\Phi_{Cu}}\right)^{\beta} \quad [1]$$

$$d_0 = d_{max}\left(\frac{p_1 - p_0}{p_1}\right) \quad [2]$$

w: line width in microns

Φ_{Cu}: copper pattern density in overpolish stage

d_{max}: maximum dishing in angstroms

d_0: Effective maximum dishing due to nonzero threshold pressure.

p_0: Threshold pressure

p_1: Polish pressure (downforce setting on tool).

r_1: Blanket copper removal rate

r_{ox}: Blanket oxide removal rate

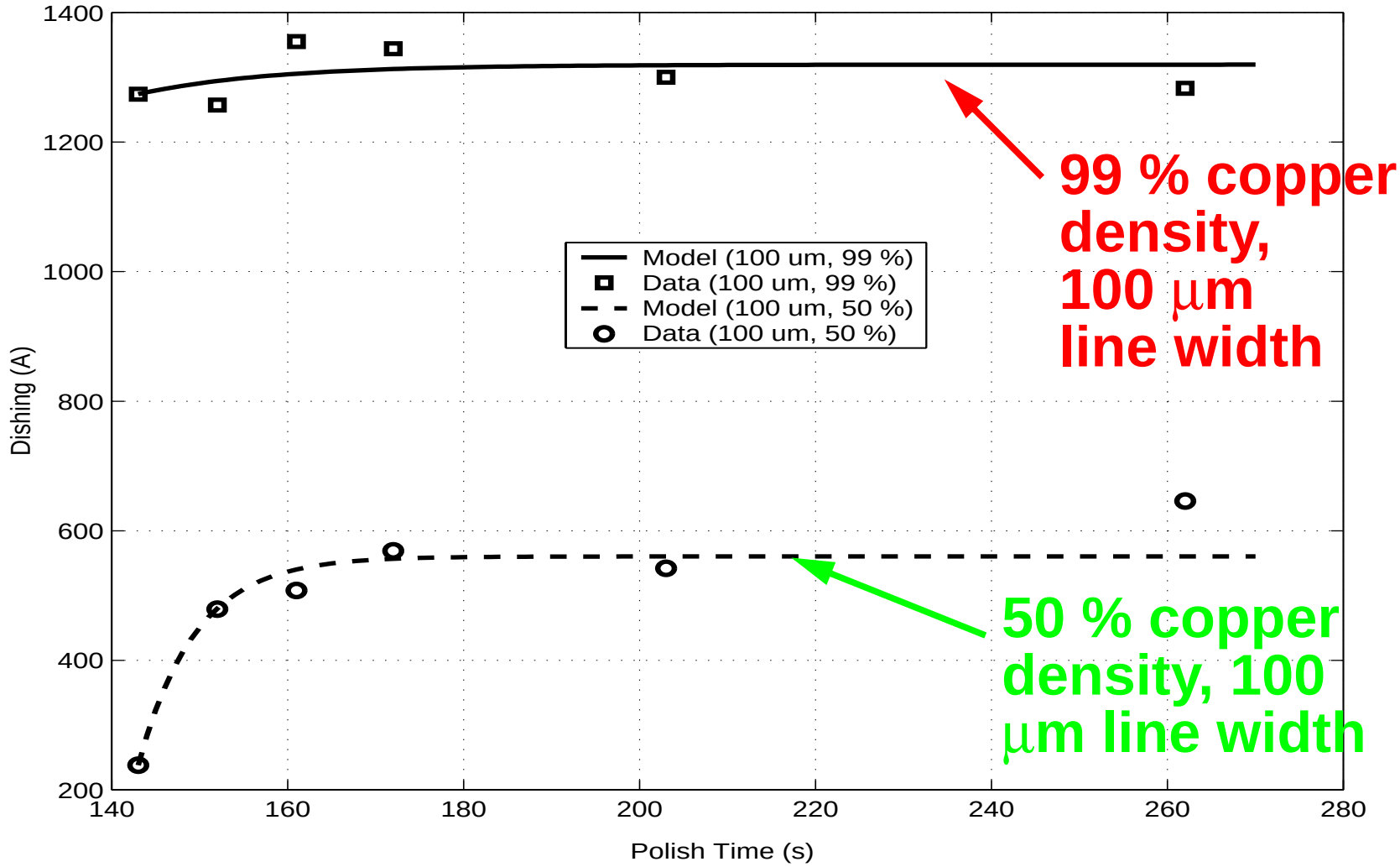
L_3: Density length scale in stage 3

A,α,β: dmax fitting parameters

Parameter Symbol	Value
p_0	3.0 psi*
p_1	4.7 psi*
r_1	5200 A/min*
r_{ox}	13.6 A/min
L_3	500 μm
A	579.6
α	0.179
β	0.241

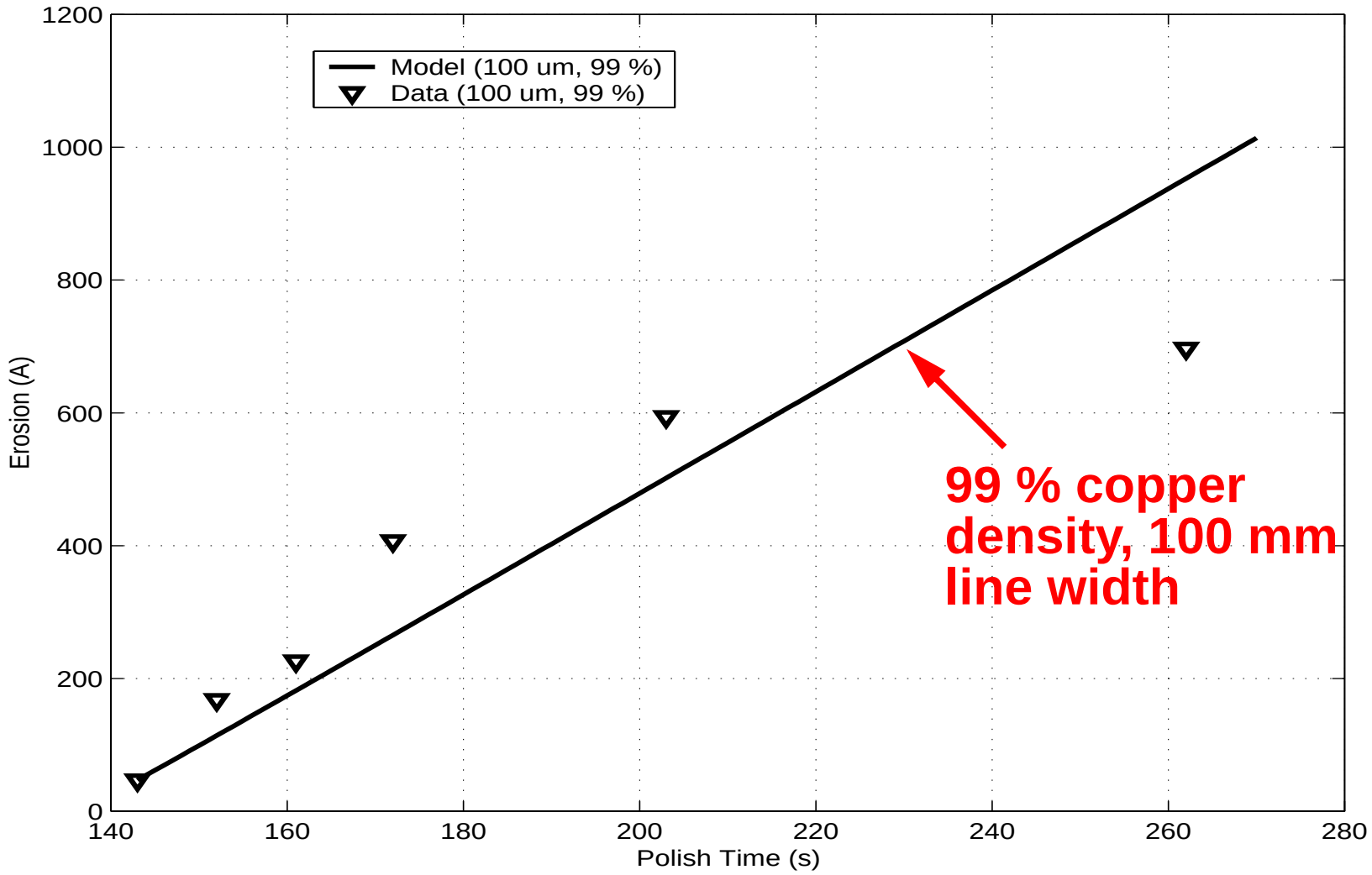
* means value is known from process

Model Fit vs Experimental Data (1)



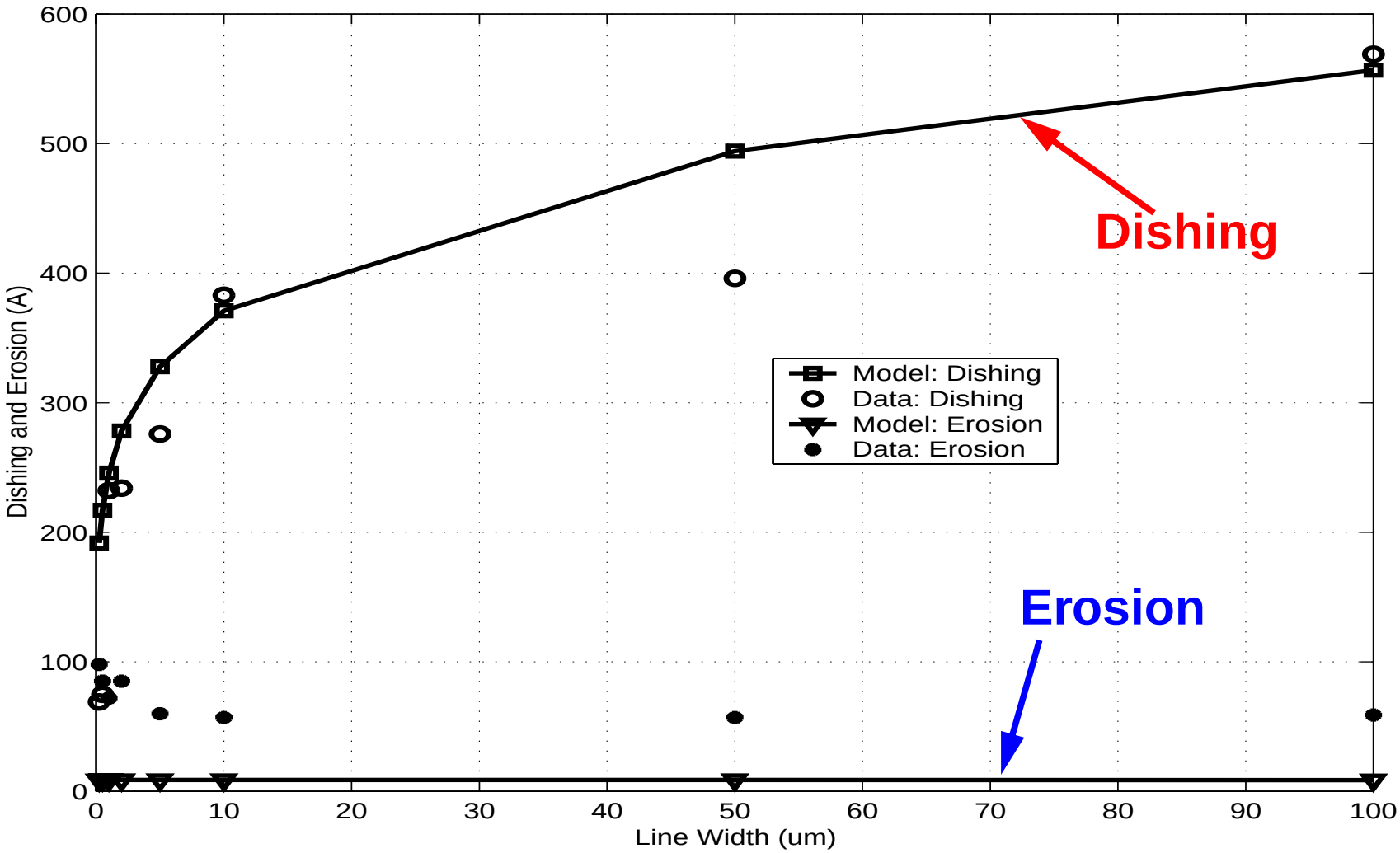
Dishing vs Polish Time

Model Fit vs Experimental Data (2)



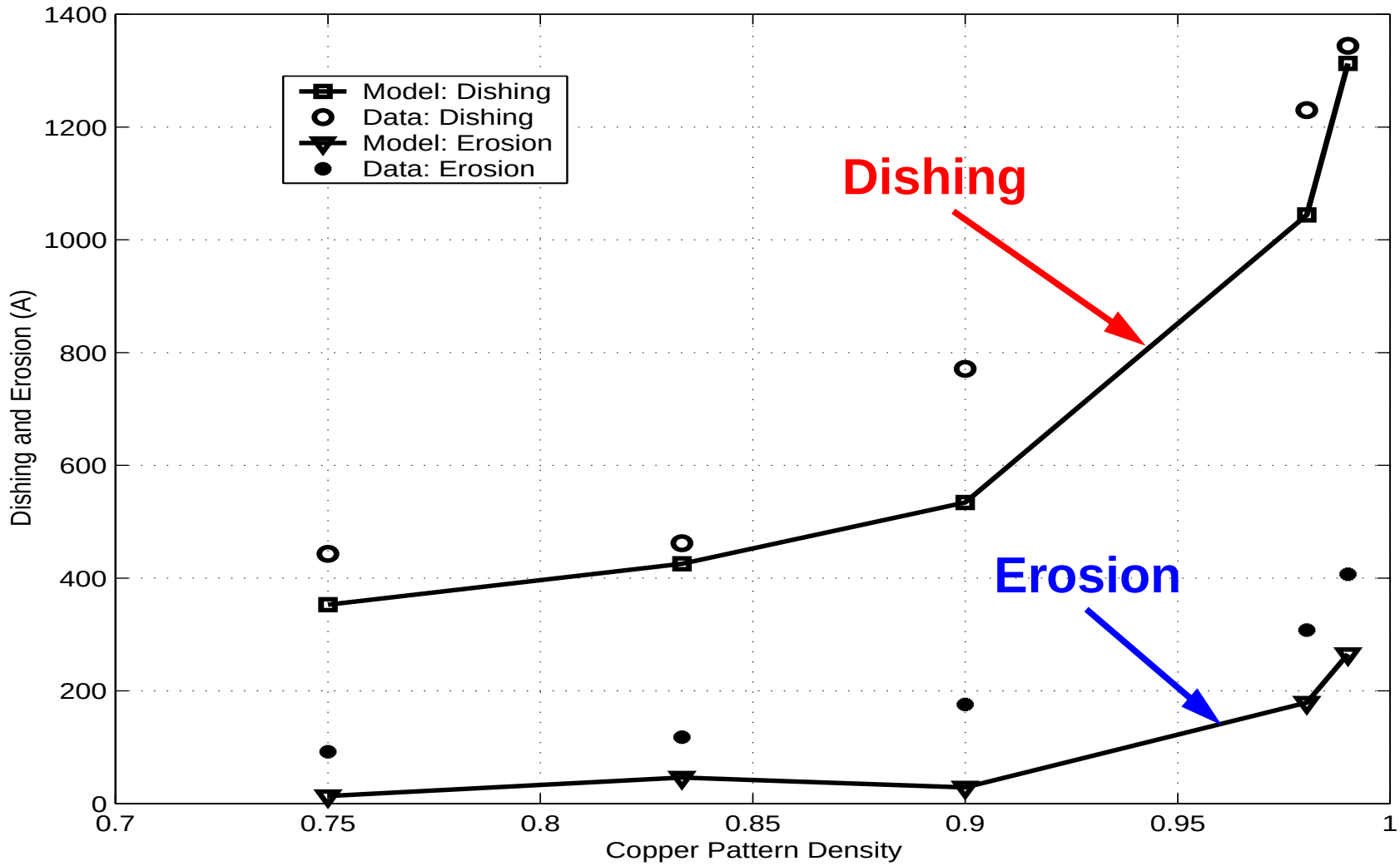
Erosion vs Polish Time

Model Fit vs Experimental Data (3)



Dishing and Erosion vs line width for 50 % density

Model Fit vs Experimental Data (4)



Dishing and Erosion vs density for fixed line space

Summary

- We propose an extension to the density-step-height model to properly model non-prestonian copper CMP processes.
- The model splits removal rate diagrams into two:
  - Removal rate versus pressure for given speed, consumables, etc.
  - Pressure versus step height (or dishing)
- The model accurately captures the trends in dishing and erosion during Abrasive-Free Copper Polishing.