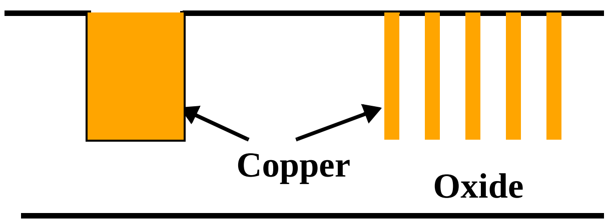
Framework for Modeling of Pattern Dependencies in Multi-Step Cu CMP Processes

SEMICON West 2000
July 11 th, 2000.

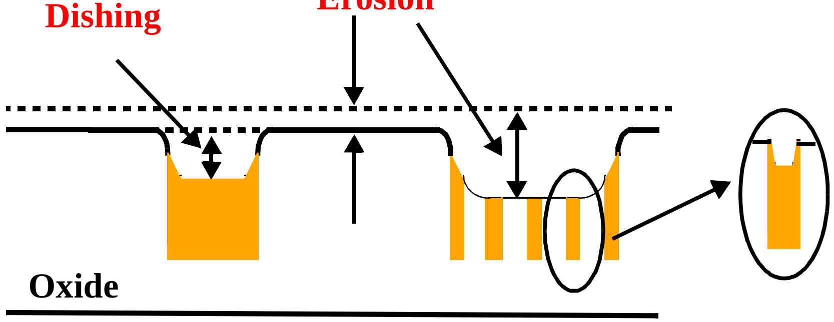
Tamba Tugbawa, Tae Park, Duane Boning

Massachusetts Institute of Technology
Electrical Engineering and Computer Science
Microsystems Technology Laboratories, Rm 39-567.

Motivation:Pattern Dependent Problems in Cu CMP



Ideal Case



Realistic Case

Cu Dishing and Oxide Erosion lead to:

- Higher line resistance.
- Surface Non-Uniformity
- Possible shorting of adjacent lines on higher metal levels.

GOALS:

- Identify the key layout dependencies of dishing and erosion.
- Predict the amount of dishing and erosion for any layout, for a given polish process.
- Design around dishing and erosion.
- Minimize dishing and erosion.

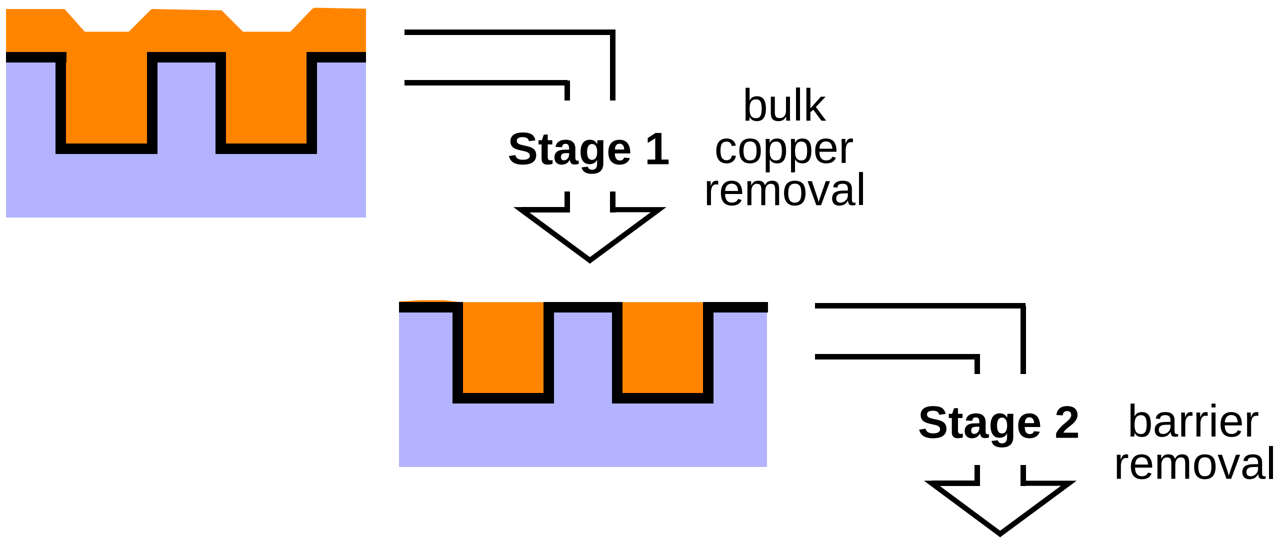
Outline

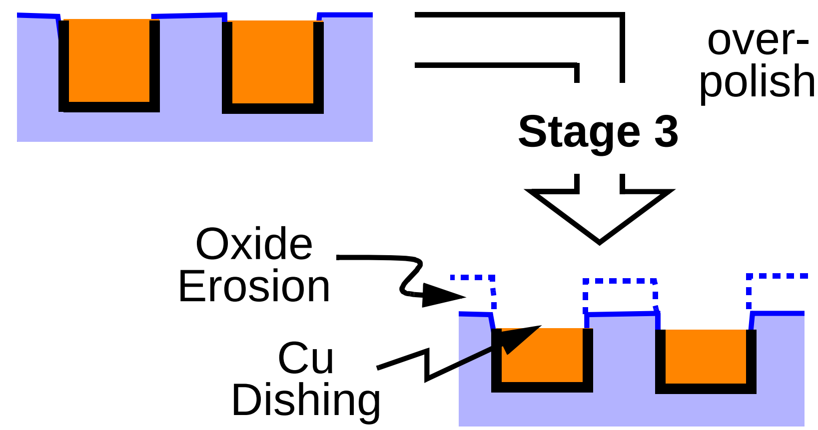
- Model Formulation
  - ❏ Modeling Approach
  - ❏ The Three Intrinsic Stages in Cu CMP
  - ❏ Model Parameters
- Model Calibration
  - ❏ Calibration Mask Set
  - ❏ Calibration Methodology
- A Typical Cu CMP Process
- Summary

Modeling Approach

- Identify the **intrinsic stages** in Cu CMP.
- Construct **Removal-Rate Diagrams (RR-diagrams)** for each **intrinsic** stage.
- Formulate the **model equations** from the **RR-diagrams**.
- Develop a methodology for **calibrating** the model i.e. **extracting** model parameters (unknowns) for a given process.

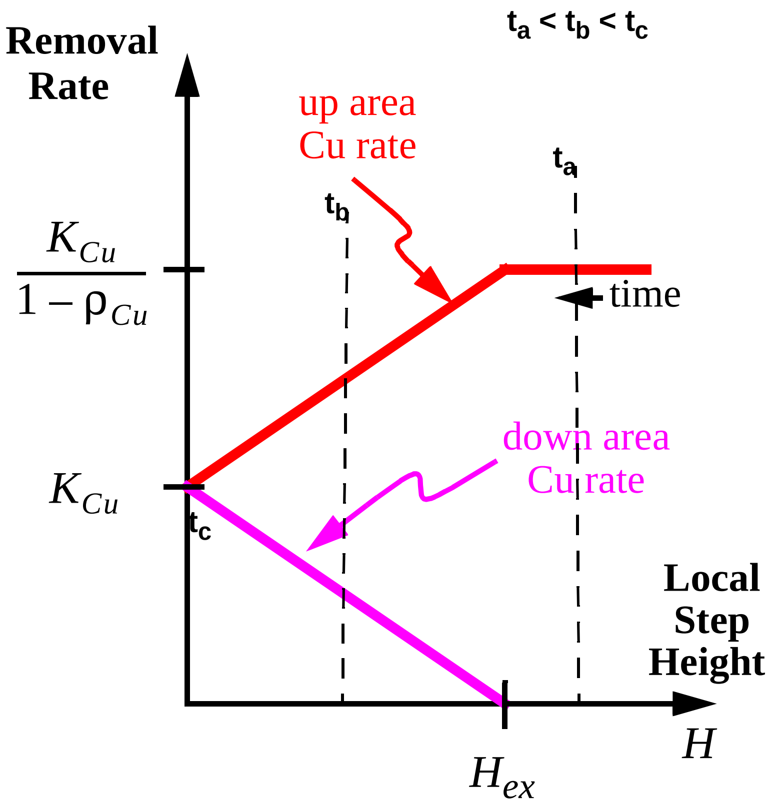
The Three Intrinsic Stages in Cu CMP

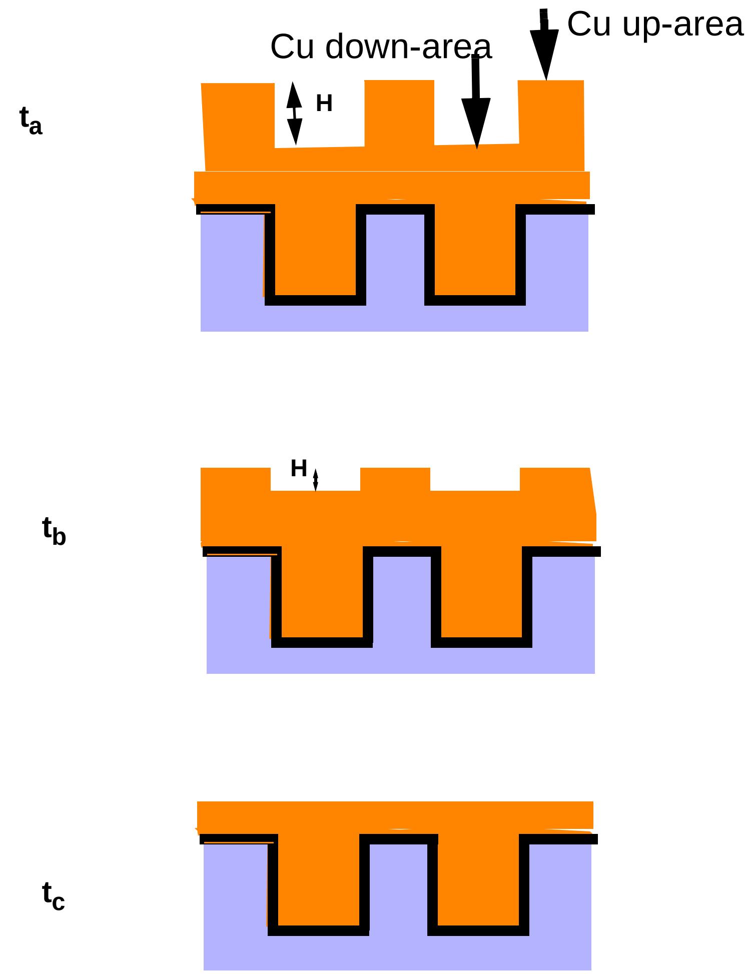




- Overpolish occurs due to:
  - Recess caused by electroplating.
  - Non-uniform removal rate across the wafer.
  - Non-uniform pattern within a die (pattern meaning pattern density, line width and line space).

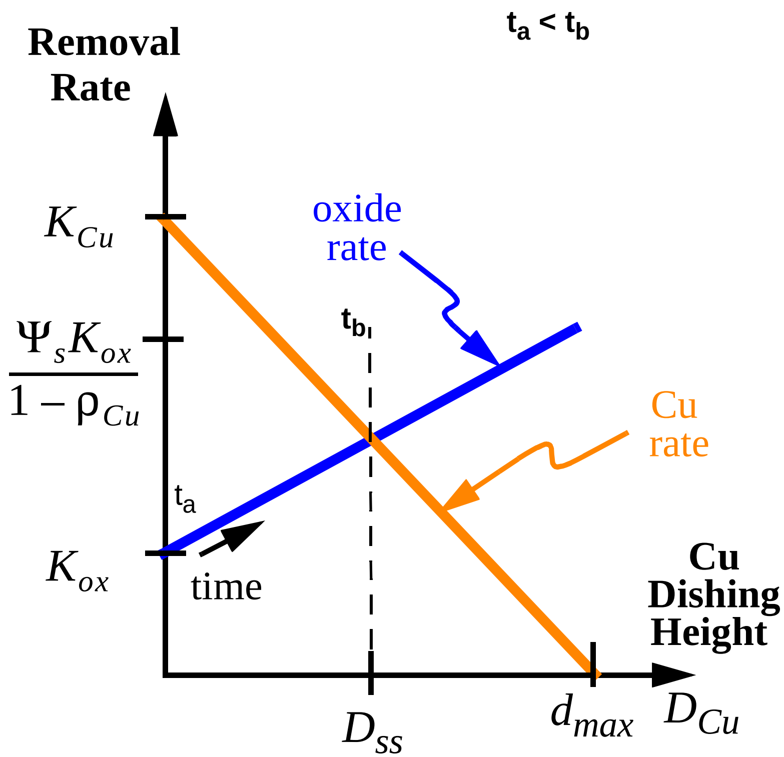
Stage 1: Removal of Overburden Cu

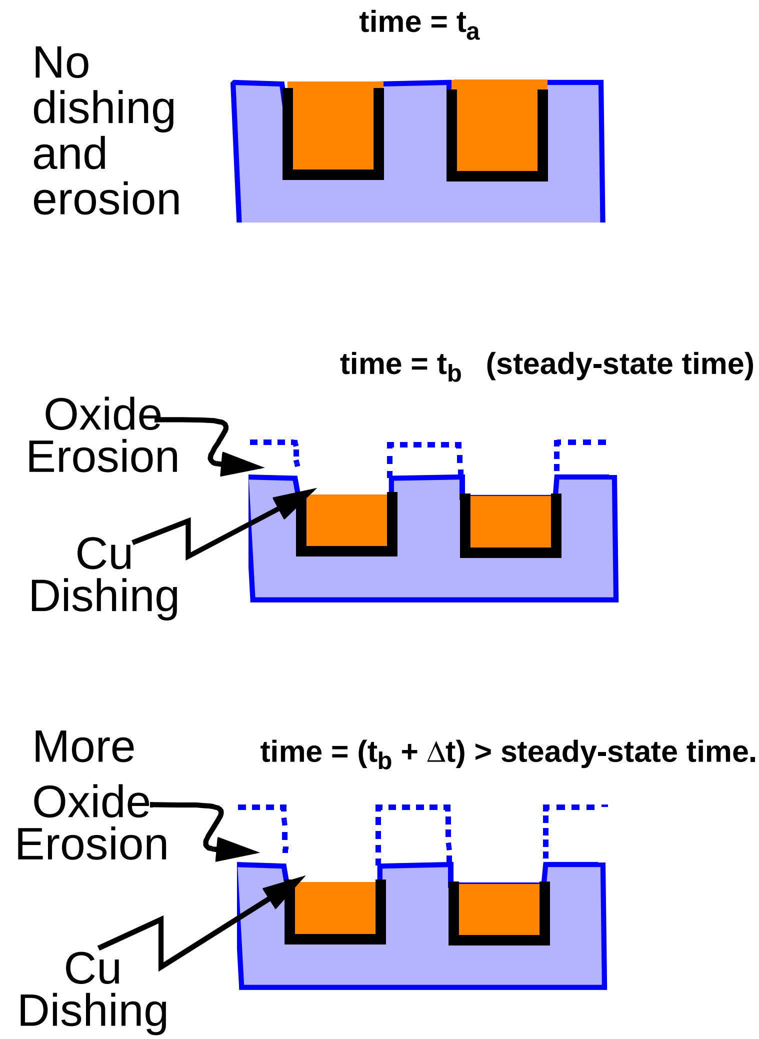




- **H_{ex}**: Local step height above which the pad does not contact the down area.

Stage 3: Overpolish

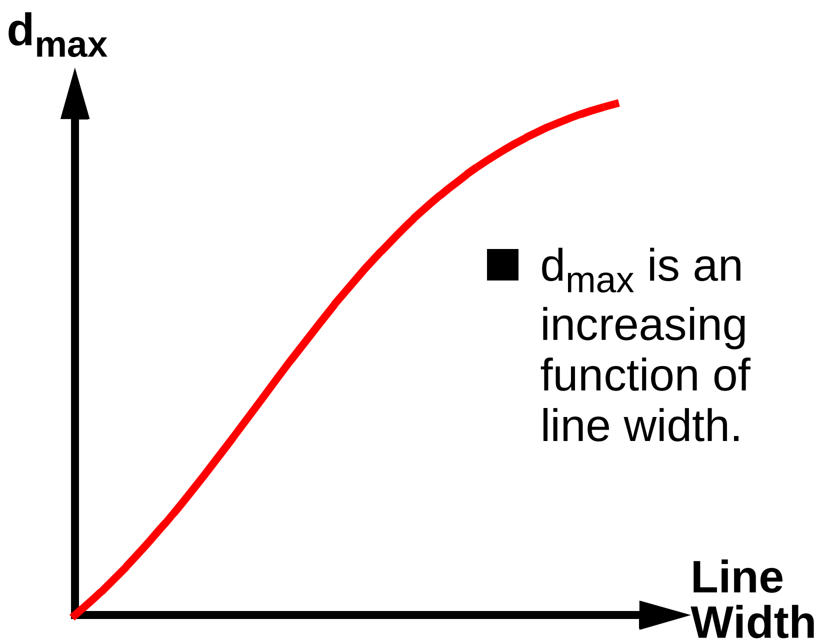




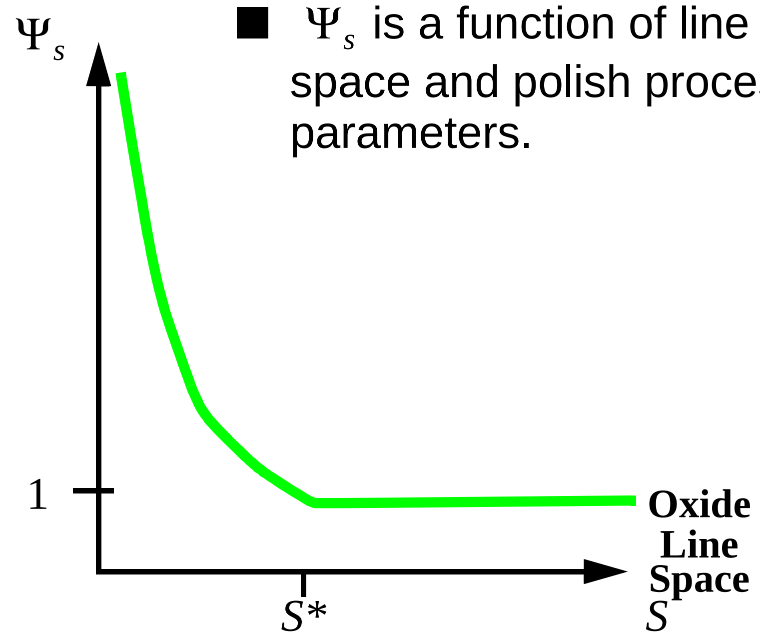
- **D_{ss} is steady-state Cu dishing.**
- **d_{max} is maximum Cu dishing.**
- **Ψ_s is the edge rounding factor.**

Model Parameters

- The model parameters are:
  - K_{ox}, K_{Cu}, K_b : **These are blanket removal rates.**
  - d_{max}, H_{ex} , Ψ_s : **These are the pattern dependent parameters.**
  - Planarization Length: **It depends on the polish process parameters.**



- d_{max} is an increasing function of line width.



- Ψ_s is a function of line space and polish process parameters.

Model Parameters

$$d_{max} = f(\theta_p, l_w, l_s) \qquad \text{(Eq. 1)}$$

OR

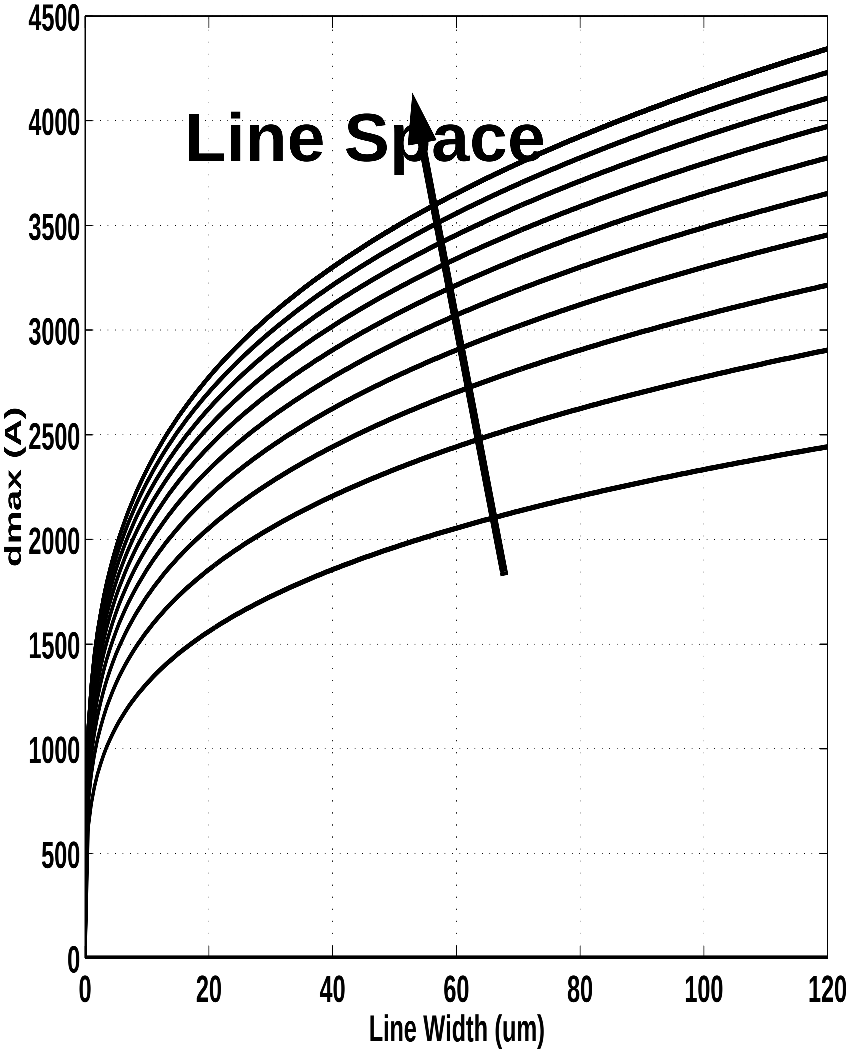
$$d_{max} = g(\theta_p, l_w, \rho_{Cu}) \qquad \text{(Eq. 2)}$$

$$H_{ex} = u(\beta_p, l_w, l_s) \qquad \text{(Eq. 3)}$$

OR

$$H_{ex} = v(\beta_p, l_w, \rho_{Cu}) \qquad \text{(Eq. 4)}$$

$$\Psi_s = w(\alpha_p, l_s) \qquad \text{(Eq. 5)}$$

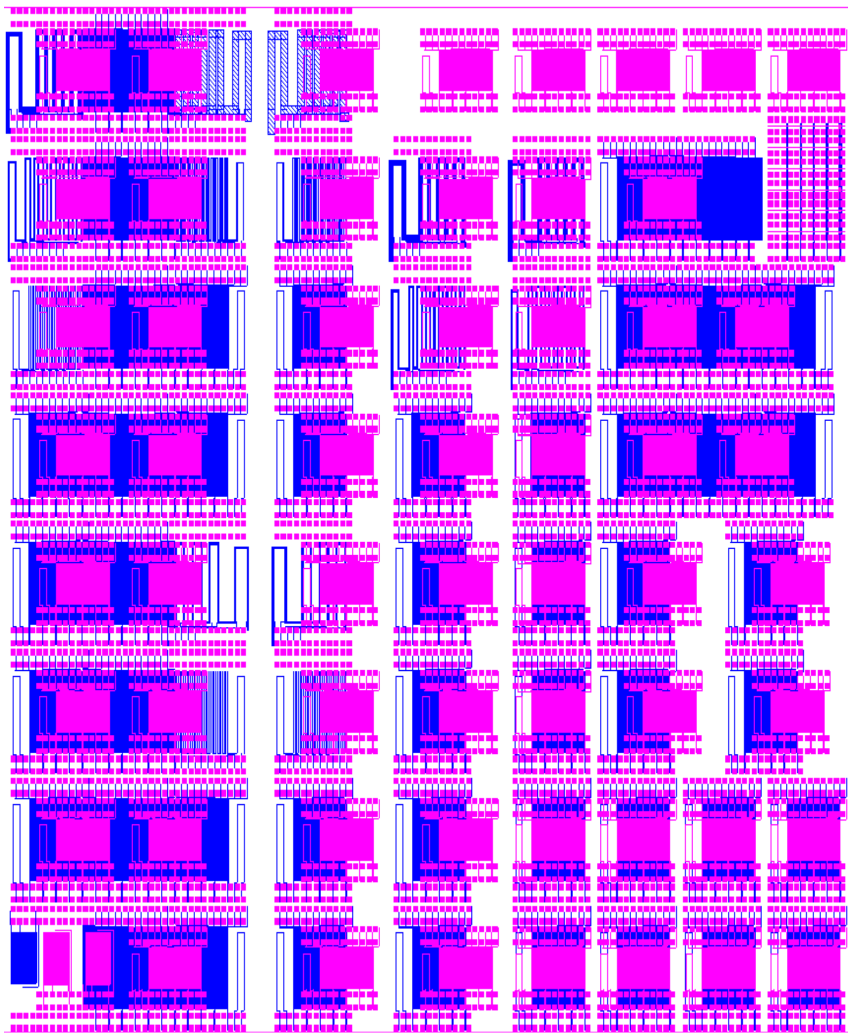


Outline

Part 1

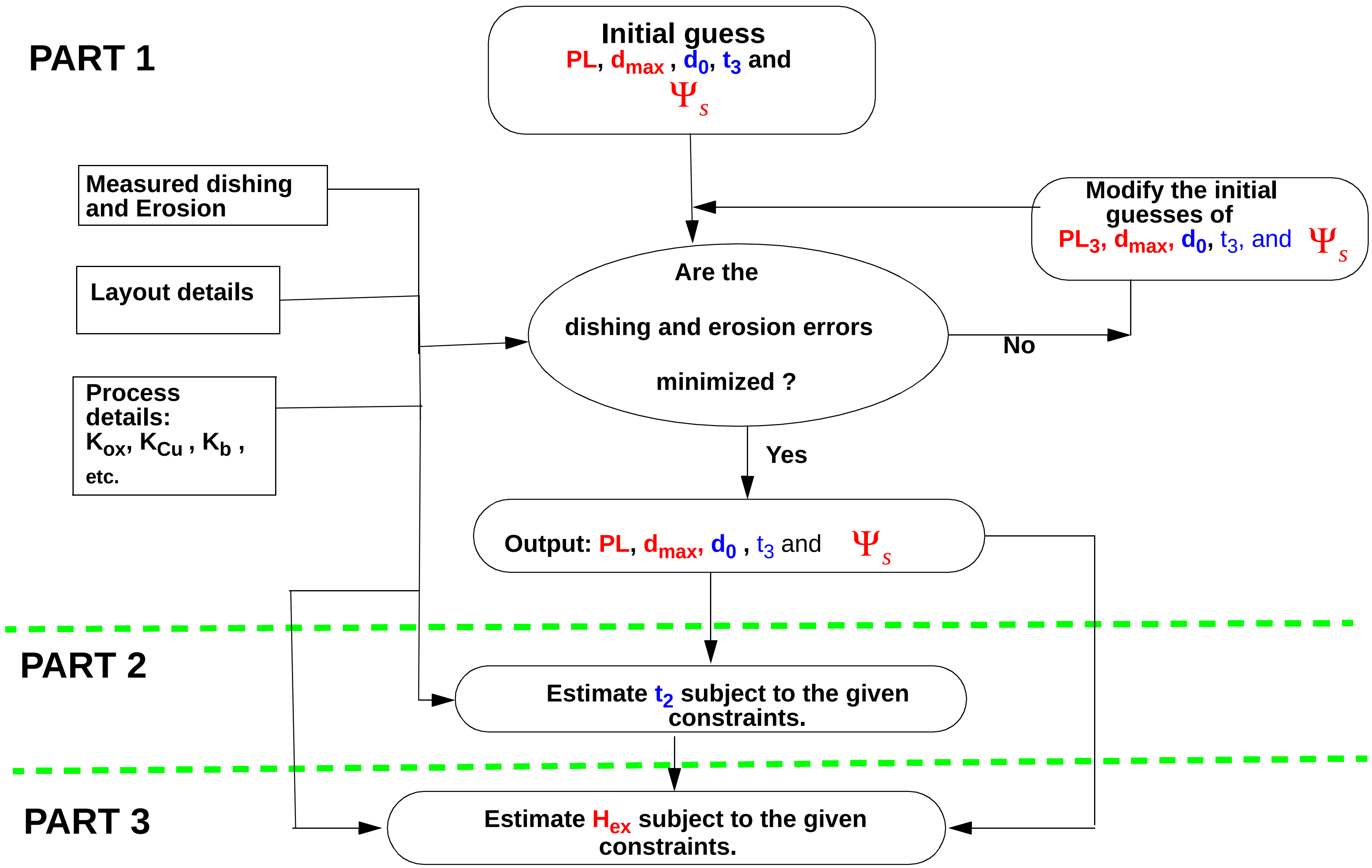
- Formulation of Mathematical Model
  - ❑ Modeling Approach
  - ❑ The Three Intrinsic Stages in Cu CMP
  - ❑ Model Parameters
- ✔ **Model Calibration**
  - ❑ Calibration Mask Set.
  - ❑ Calibration Methodology.
- A Typical Cu CMP Process
- Summary

Calibration Mask Set



- Wide range of pitch and density structures on M1.
- Electrical (resistance) test structures.
- Multi-level effects of M1 on M2.

Calibration Methodology



A Typical Cu CMP Process: 2 Step Polish Process

POLISH STEP 1

- ❑ Slurry 1
- ❑ Down Force 1
- ❑ Table Speed 1
- ❑ Pad 1

$K_{Cu(1)} > K_{b(1)} > K_{ox(1)}$

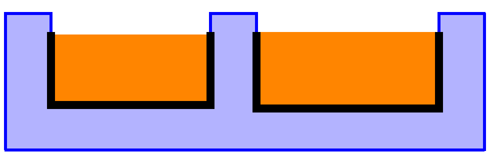
END POINT TIME

POLISH STEP 2

- ❑ Slurry 2
- ❑ Down Force 2
- ❑ Table Speed 2
- ❑ Pad 2

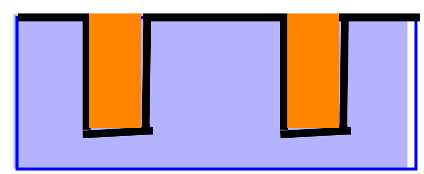
$K_{Cu(2)} < K_{b(2)} < K_{ox(2)}$

At the end point time, we might have the following extreme scenarios:



High Cu density structure:

- ❑ Overpolish Stage.
- ❑ Dishing and Erosion present.



Low Cu density structure:

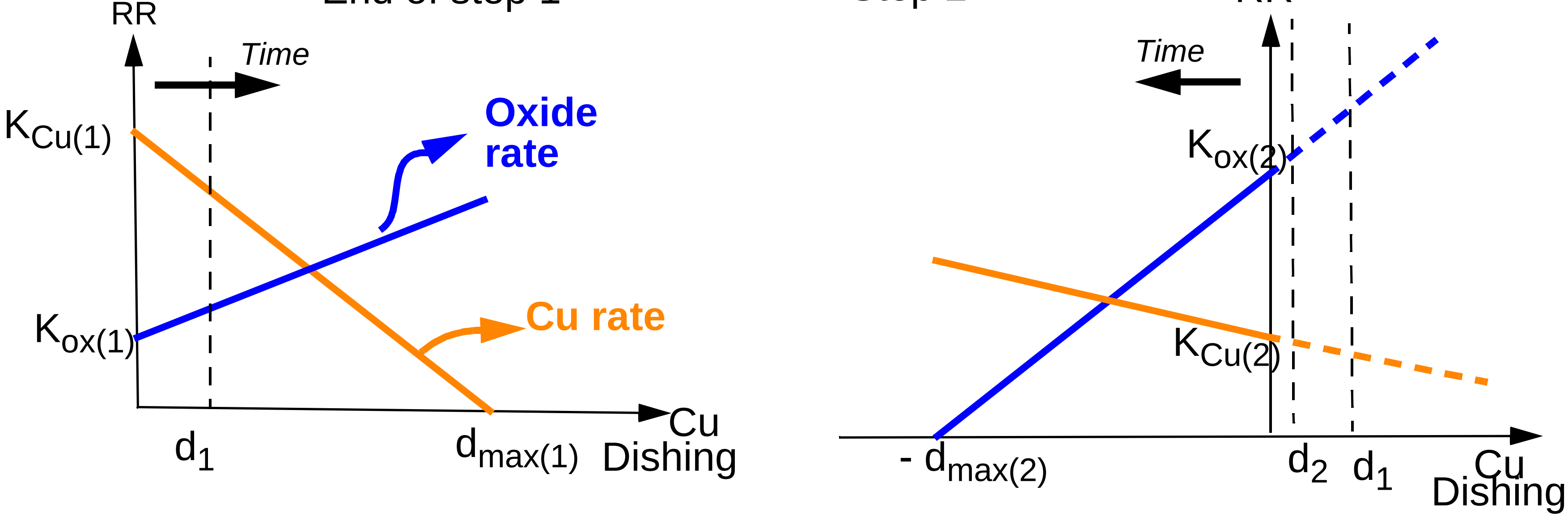
- ❑ Barrier Removal Stage.
- ❑ No dishing and erosion.

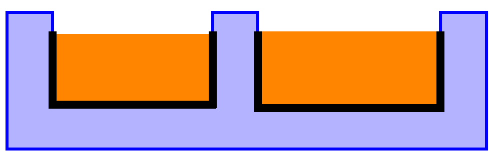
A Two Step Polish Process (cont.)

For the high Cu density structure, we have the following scenario:

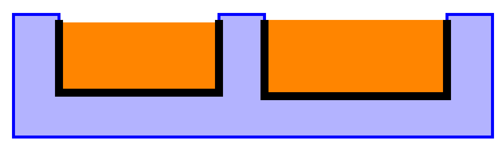
End of step 1

Step 2





- Dishing = d_1
- Erosion greater than zero.

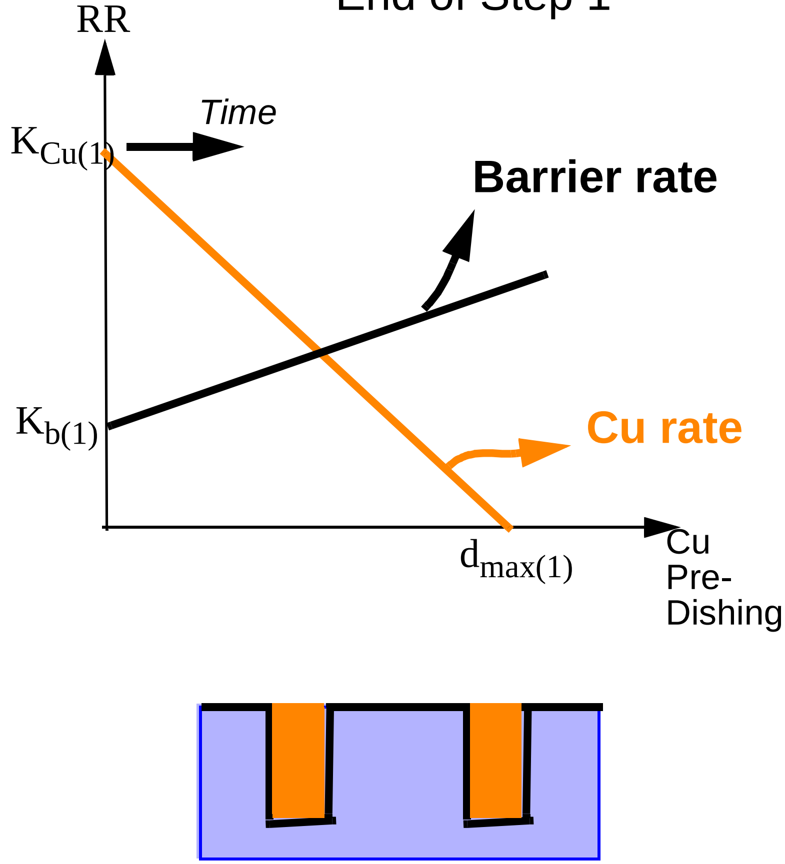


- Dishing = d_2 ($d_2 < d_1$).
- Increased Erosion.

A Two Step Polish Process (cont).

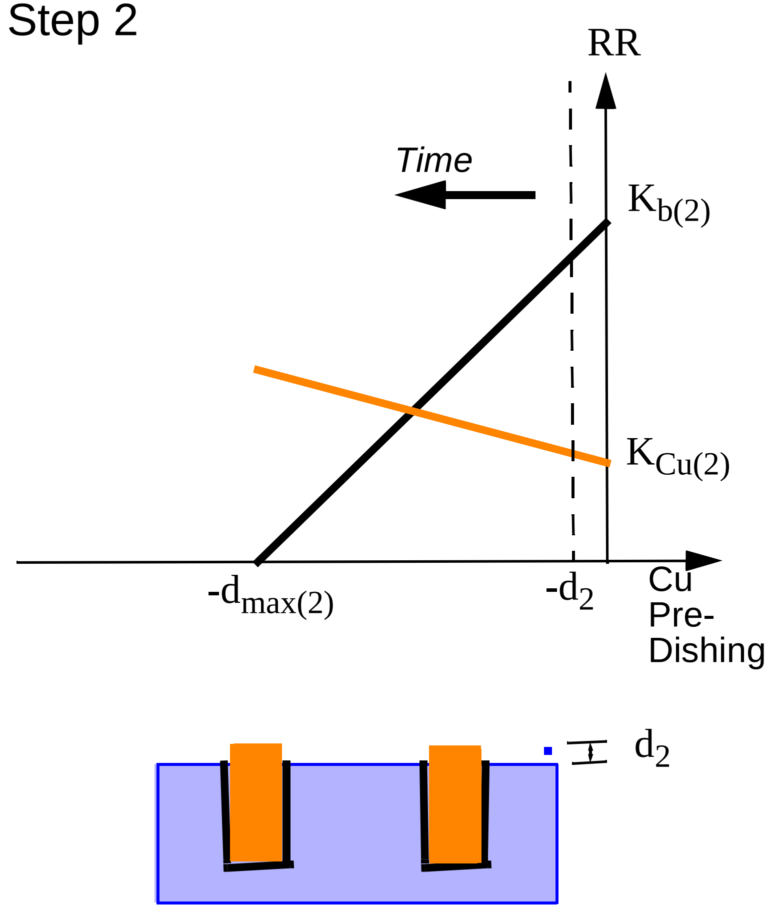
For the low Cu density structure, we have the following scenario:

End of Step 1



Zero pre-dishing; Barrier not yet cleared.

Step 2



Dishing = $-d_2$; Barrier has just being cleared.

Summary

- Model for pattern dependencies in copper CMP developed.
  - Model captures three intrinsic stages of Cu CMP processes.
  - Model exploits the dependence of removal rate on local step-height.
  - Preliminary results show that the model explains the pattern and time trends observed in experimental data.
- Model parameter extraction methodology proposed.
- Framework for extending the model to multi-step polish process proposed.
- Future work: Relating the model parameters to the polish process parameters like down force, table speed, pad elasticity, etc.
- Our ultimate goals include:
  - Prediction of oxide (or more generally dielectric) thicknesses and Cu thicknesses across an entire chip (after CMP), for a given process.
  - Designing around dishing and erosion.
  - Minimizing dishing and erosion.