Pattern Dependent Modeling of Electroplated Copper Profiles

Tae Park, Tamba Tugbawa, Duane Boning

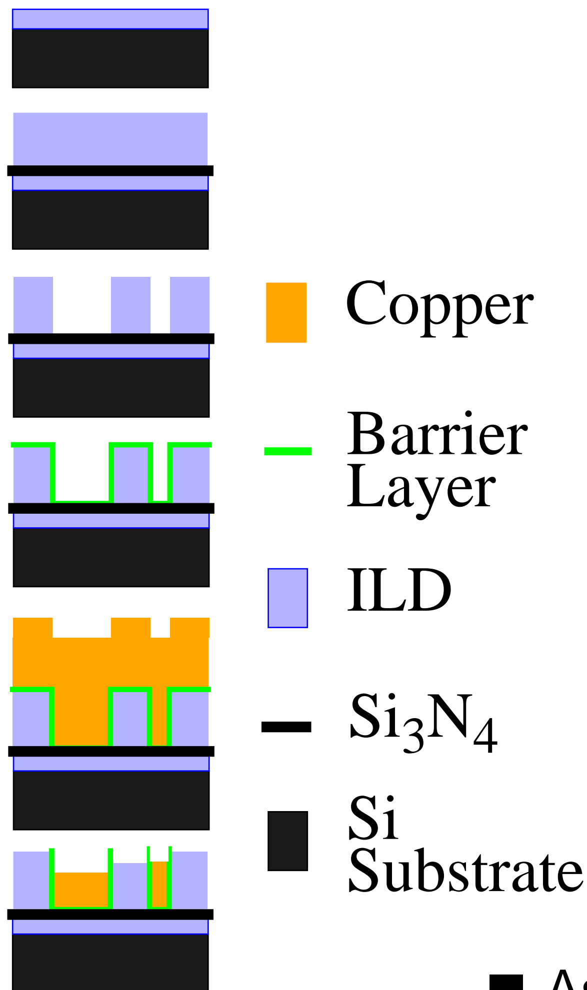
Massachusetts Institute of Technology

http://www-mtl.mit.edu/Metrology

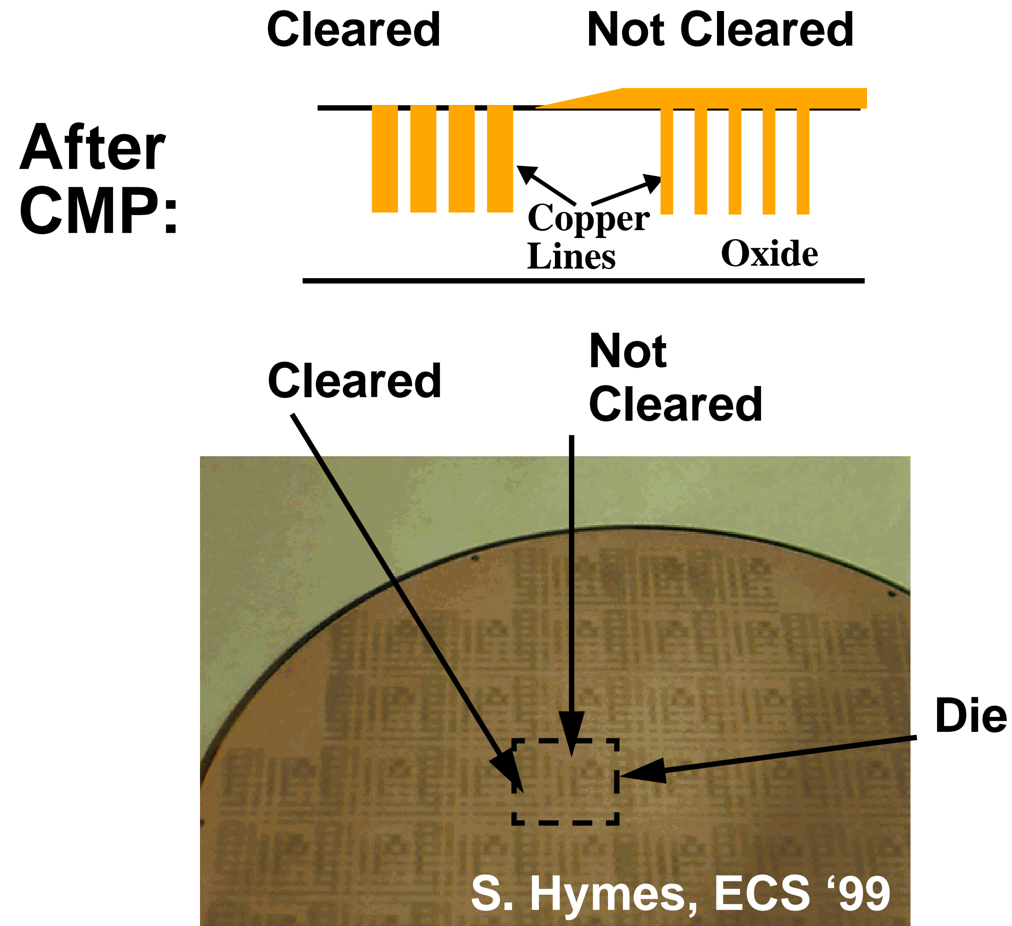
IITC, June 4-6, 2001

Copper Electroplating: Process and Problem

Single Damascene Process



Plating Impact on CMP

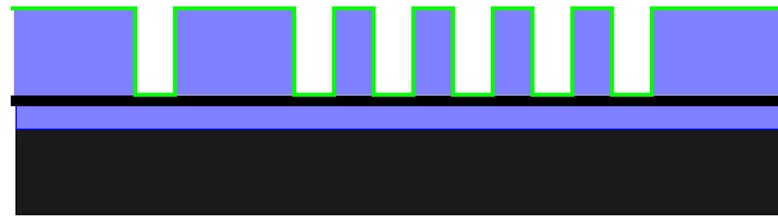


- As-plated non-uniformity directly influences CMP

Copper Electroplating Non-Uniformities

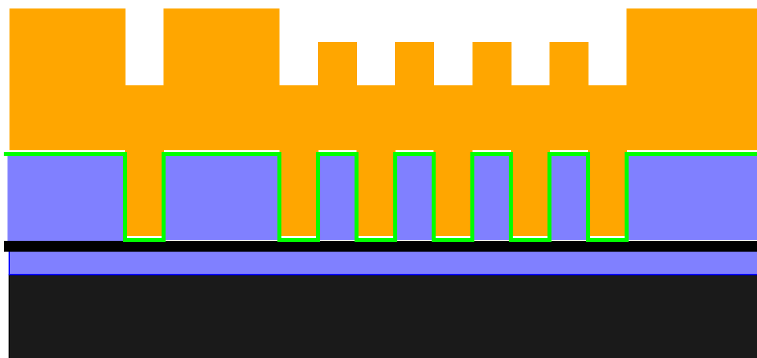
Isolated Line

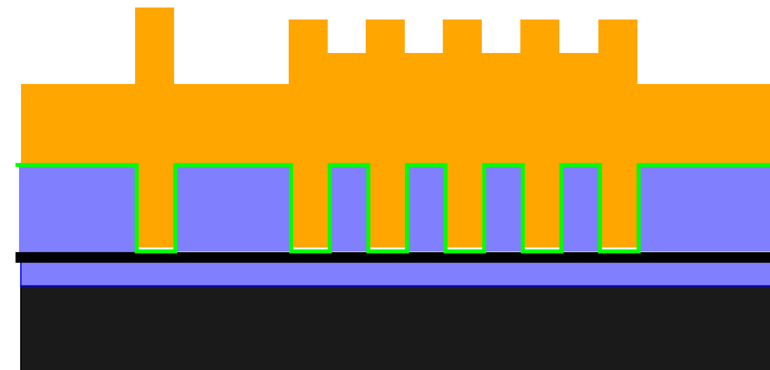
Array Region



Conventional Fill

Super Fill (Bottom-Up Fill)





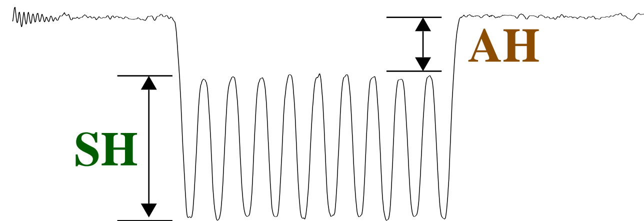
- Isolated line and array region are recessed
- Isolated line sticks up and array region is bulged

Outline

- Introduction
  - Copper Damascene Process and Electroplated Profiles
- Overall Approach and Application
- Experiment
  - Test Structure
  - Experimental Setting
- Data Analysis
  - General Trends
  - Model Framework
  - Model Fit: Conventional Fill and Super Fill
- Conclusion

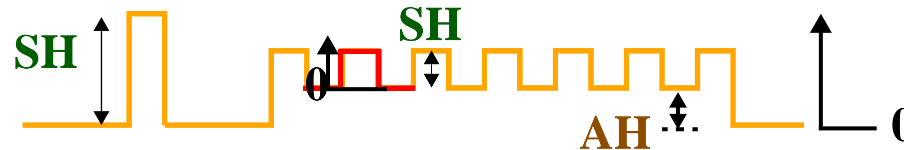
Copper Electroplated Profiles

Sample Scan:
Conventional Fill



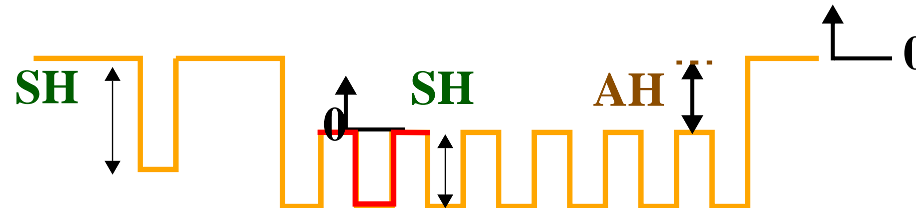
SH - Step Height
AH - Array Height

Case 2:
Super
Fill



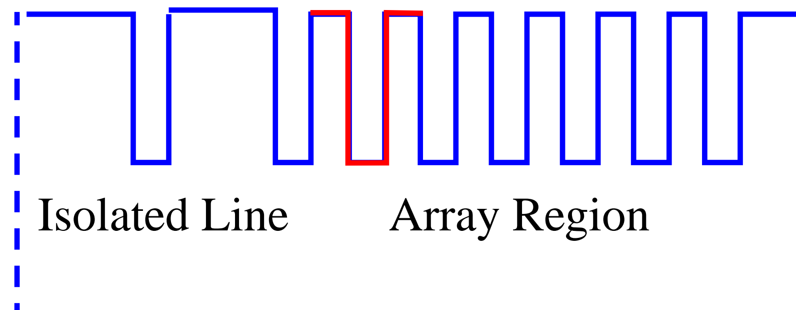
Copper Profile

Case 1:
Conventional
Fill



Copper Profile

Underlying
Oxide
Trenches



Oxide Profile

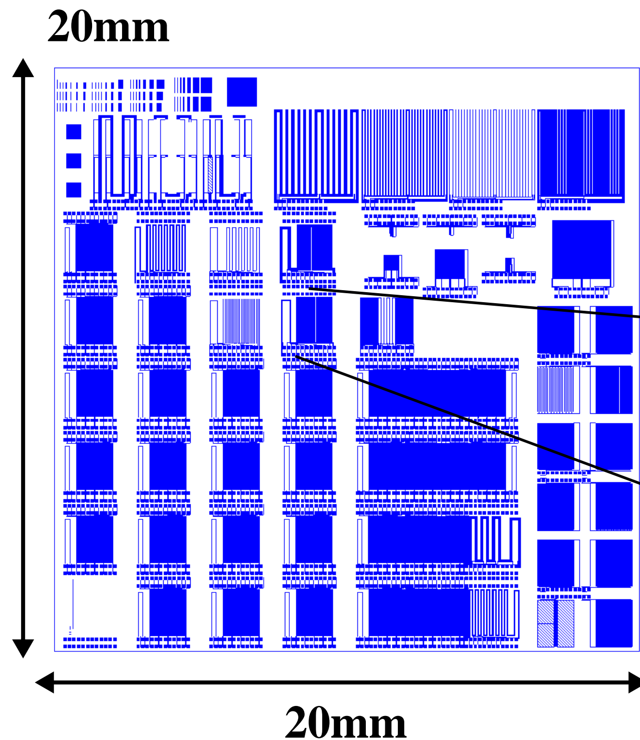
Overall Approach

- Copper Plating Model and Integration with CMP Model

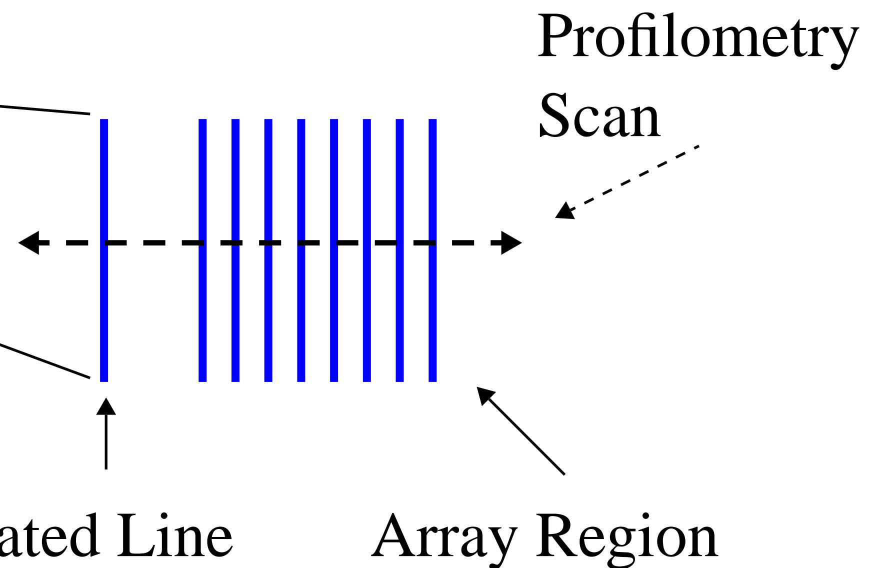
Plating Process → Test Structure → Measurements of Step Height and Array Recess/Bulge → Cu Plating Characterization & Model: Parameter Extraction and Fit → Chip-Level Simulation → Integrated Copper CMP Model

Test Structure and Measurement Location

- Originally designed to study pattern effects in copper CMP and adopted for deposition study
- Layout factors: various line width and line space combinations



Copper Test Mask
(MIT/SEMATECH 854 Mask shown)



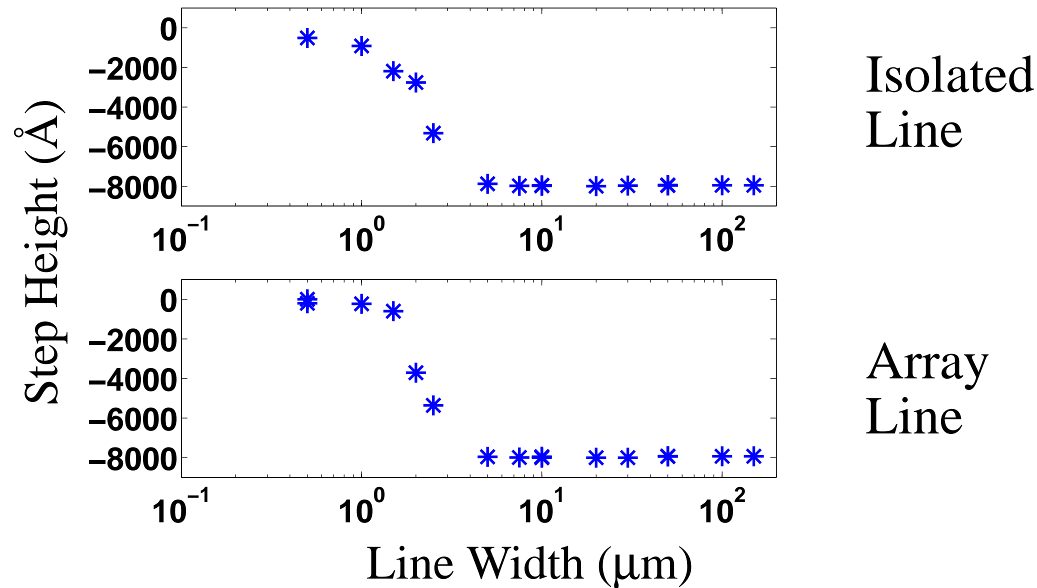
Experimental Setting

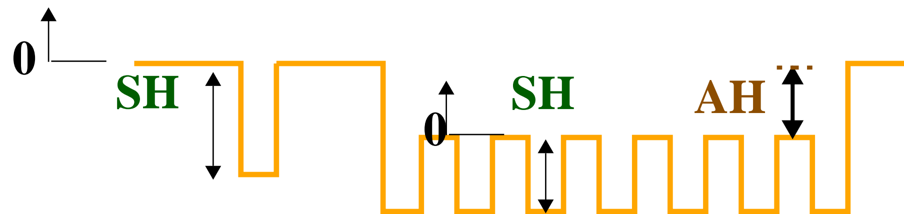
- Four Different Platings: Two Conventional Fills and Two Superfills
- Three Different Masks: MIT/SEMATCH 954 and 854, and SKW6-2

Copper Electroplated Wafer Types

Wafer Type	Plating Tool	Recipe
A: SKW6-2	Semitool	Conventional Fill
B: MIT/SEMATECH 954	Semitool	Conventional Fill
C: MIT/SEMATECH 854	Novellus	Super Fill 1
D: MIT/SEMATECH 854	Novellus	Super Fill 2

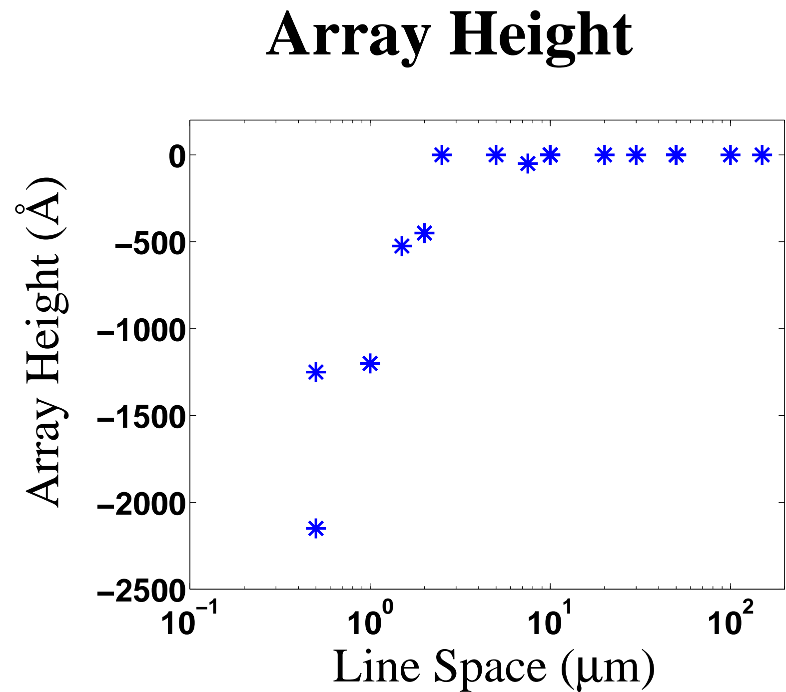
Conventional Fill: Step Height Trends

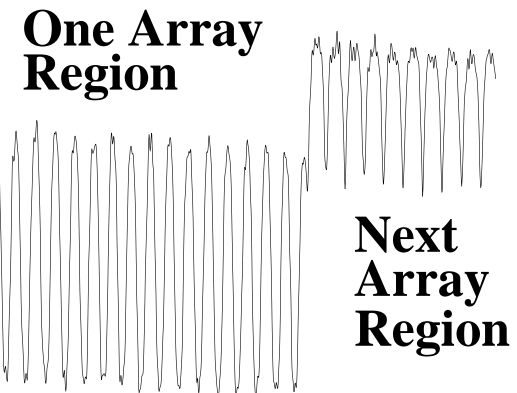


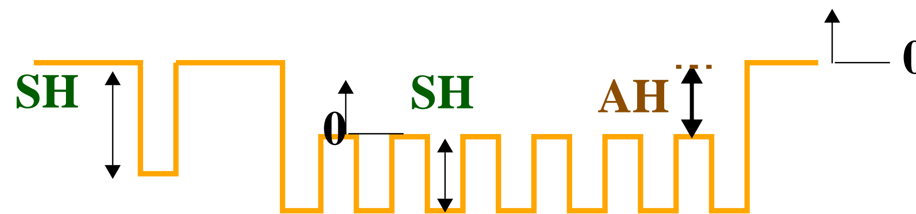


- Step height captured by line width: near zero for small line width and approaches the initial oxide trench depth of 8000Å as line width increases.

Conventional Fill: Array Height Trends

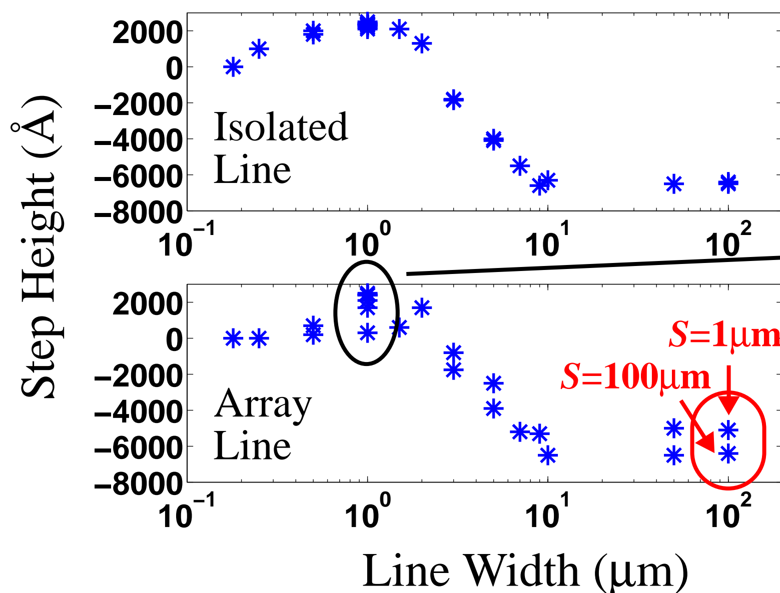


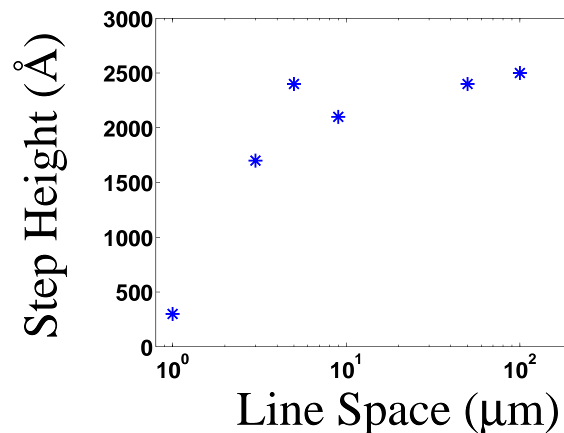


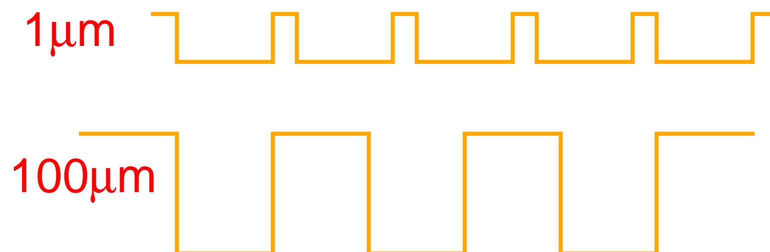


- Array height captured by line space: negative for small features and zero for large line spaces.

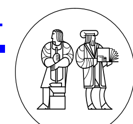
Superfill: Step Height Trends



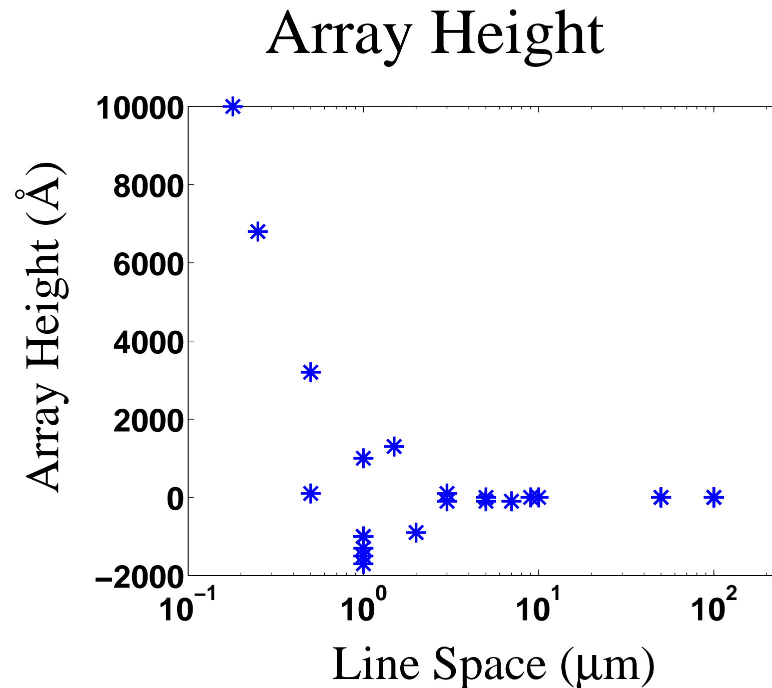


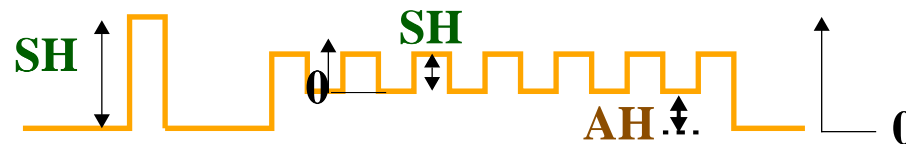


- Step height captured by line width: positive for small line width with a peak of 2500Å at 1µm line width, and approaches the initial oxide trench depth of 6000Å as line width increases



Superfill: Array Height Trends





- Array height: positive for small features, then decreases and becomes negative as line space becomes larger, and zero for large line spaces

Copper Deposition Model Framework

- Empirical polynomial fit with line width and line space interaction term
- Step Height: strong dependency on line width

$$\mathrm{SH} = a_S W + b_S S + c_S W^2 + d_S W^3 + e_S W \times S + Const_S$$

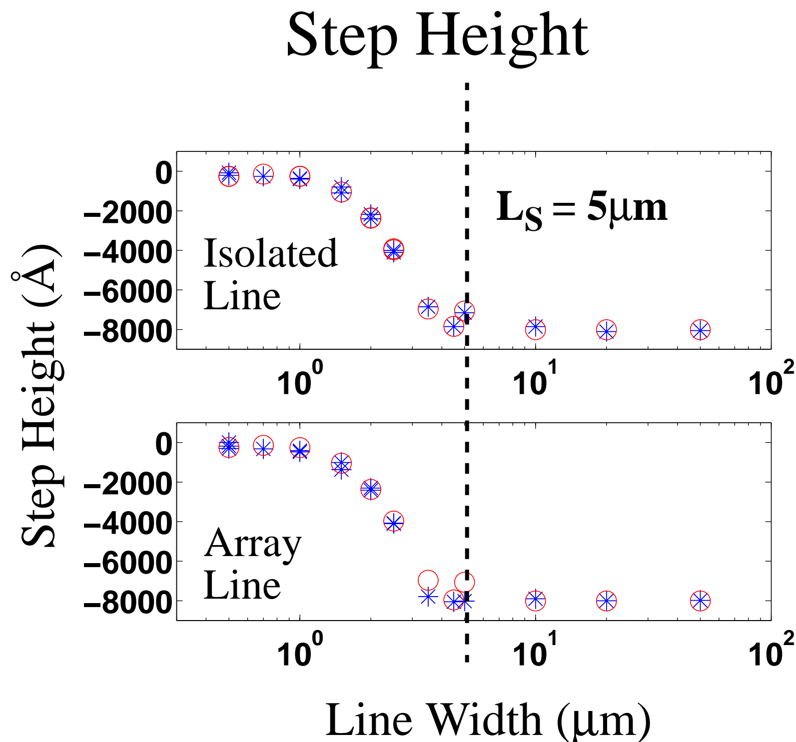
- Array Height: strong dependency on line space

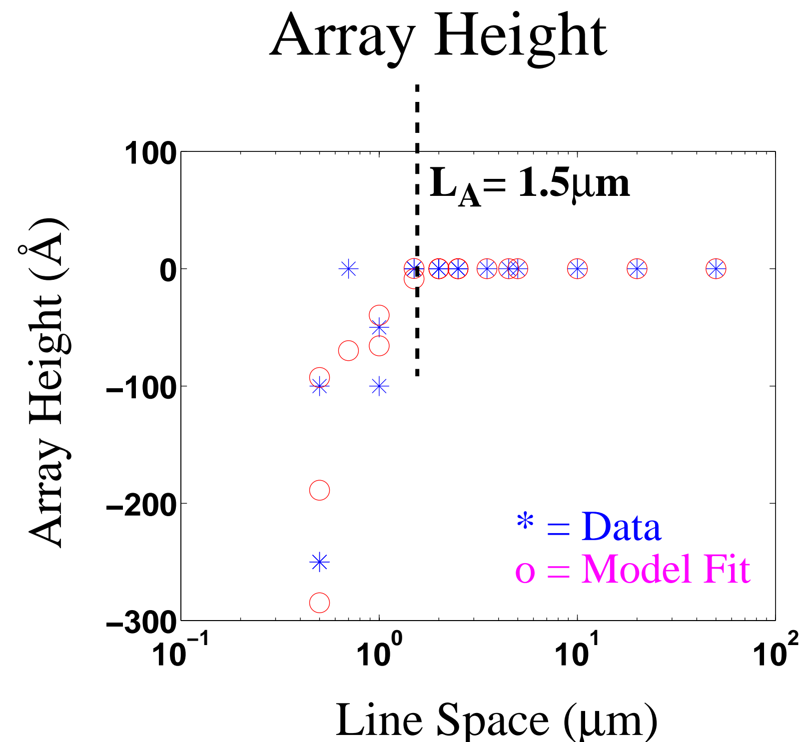
$$\mathrm{AH} = a_A W + b_A S + c_A S^2 + d_A S^3 + e_A W \times S + Const_A$$

$$W = \text{Line Width},\ S = \text{Line Space}$$

- Model coefficient is process dependent

Case A: SKW6-2 Conventional Fill



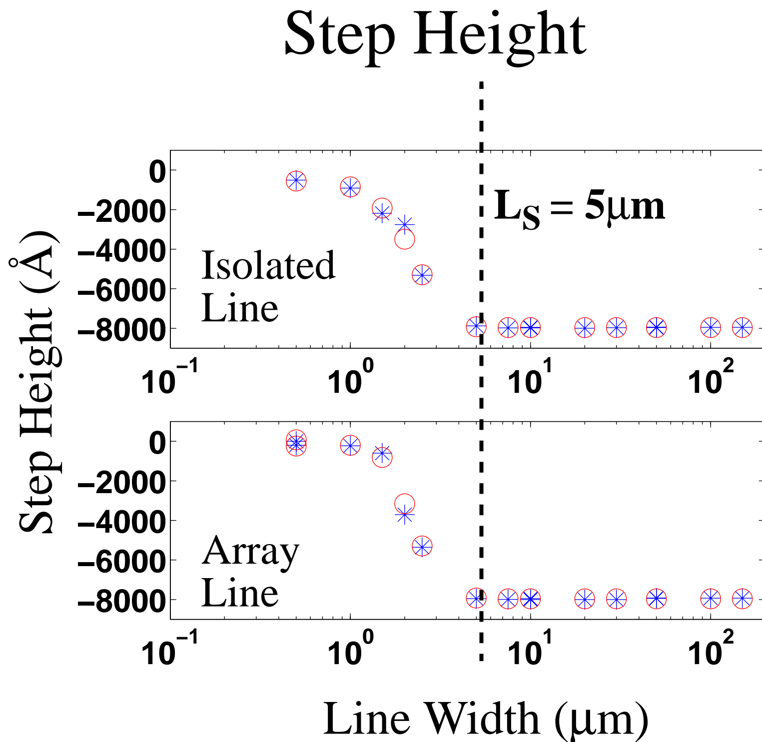


RMS Error = 234 Å
R^2 = 0.9944

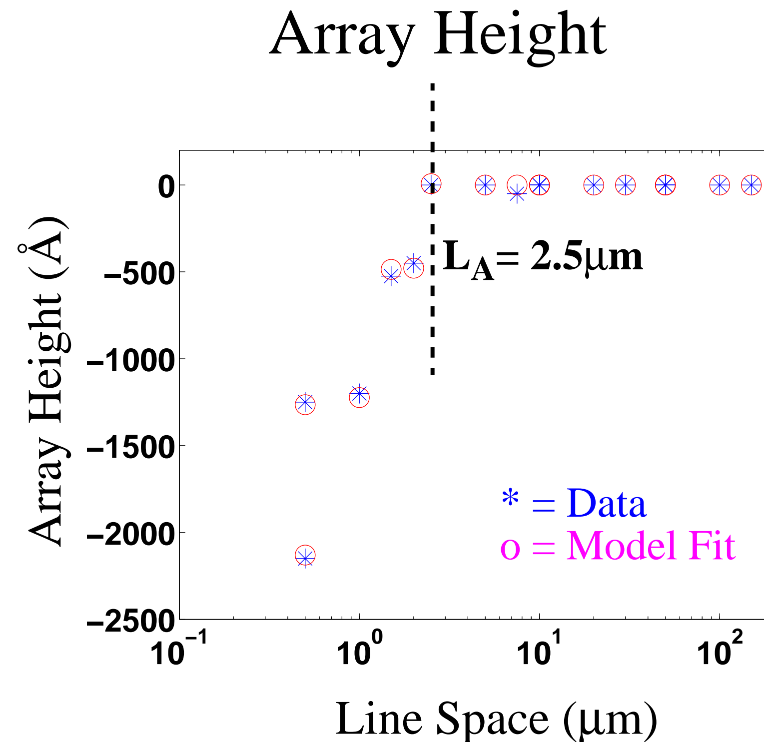
RMS Error = 30 Å
R^2 = 0.8864

- All negative heights and conformal
- Critical line width, L_S, of 5µm
- Critical line space, L_A, of 1.5µm

Case B: MIT/SEMATECH 954 Conventional Fill



RMS Error = 350 Å
R^2 = 0.9908

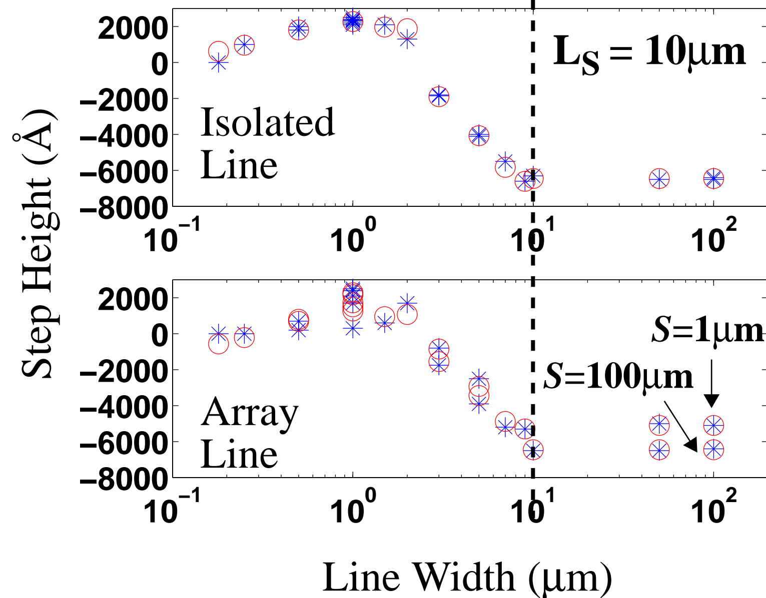


RMS Error = 60 Å
R^2 = 0.9988

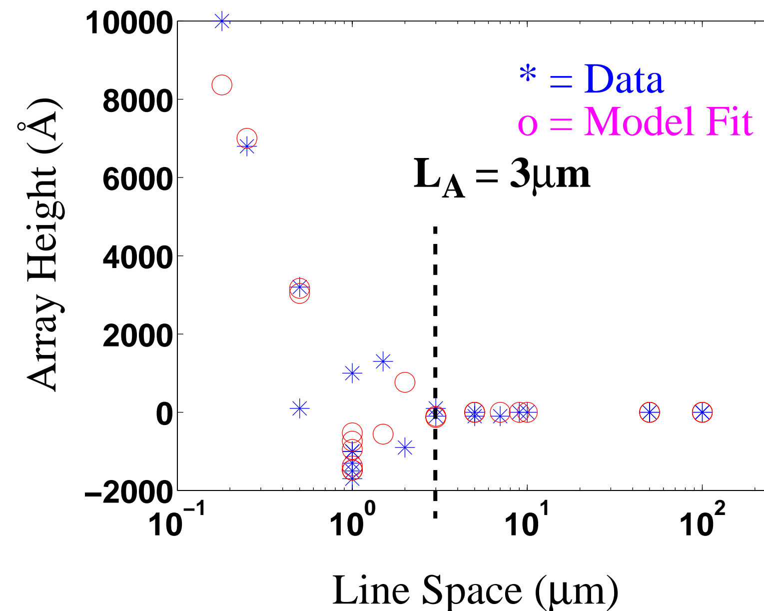
- All negative heights and conformal
- Critical line width, L_S, of 5µm
- Critical line space, L_A, of 2.5µm

Case C: MIT/SEMATECH Superfill 1

Step Height



Array Height

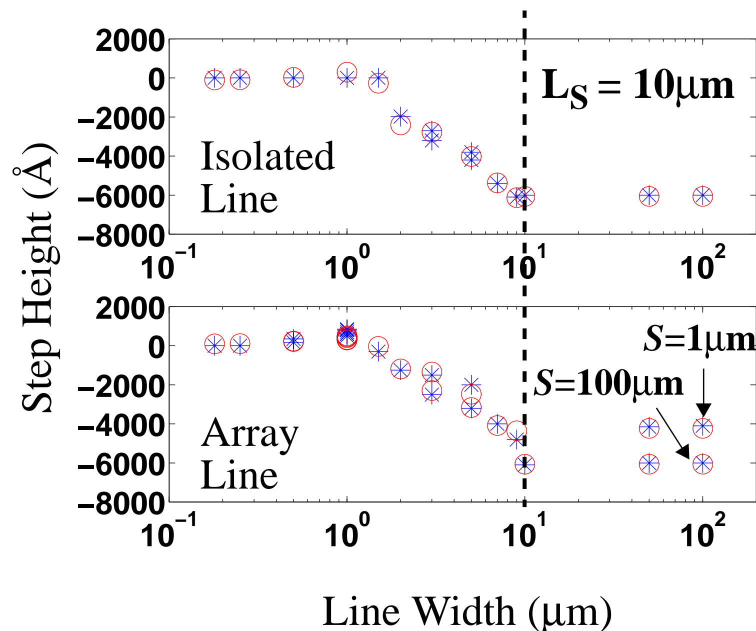


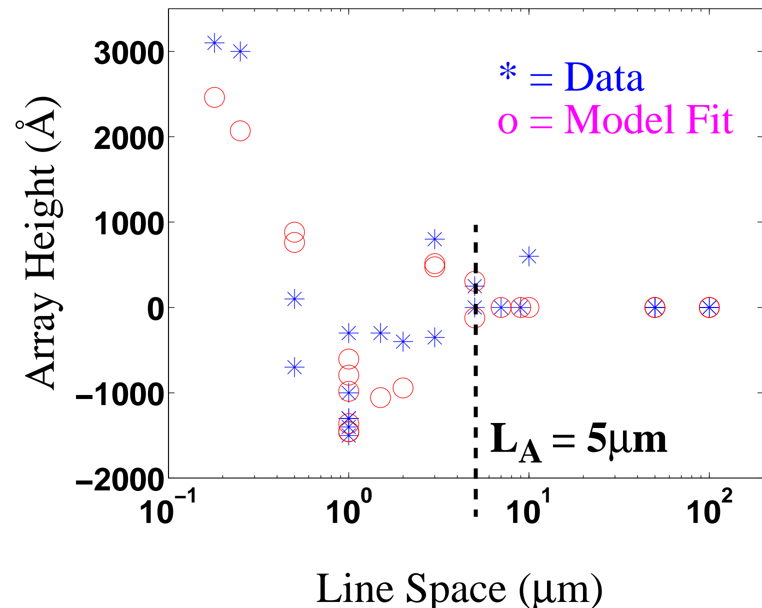
RMS Error = 371 Å
R^2 = 0.8852

RMS Error = 1645 Å
R^2 = 0.8583

- Positive and negative heights
- Superfill lines stick up: 2500Å at 1µm line width
- Critical line width, L_S, of 10µm & critical line space, L_A, of 3µm

Case D: MIT/SEMATECH Superfill 2





- Positive and negative heights
- Superfill lines stick up: less than 500Å at 1µm line width
- Critical line width, L_S, of 10µm & critical line space, L_A, of 5µm

Conclusion

- Copper Plating Dependencies
  - Plating profile follows a trend based on a pattern factor: pattern dependency
  - Positive and negative step heights and array heights: create as-plated non-uniform surface and directly influence CMP
  - Critical feature dimensions: associated with step height and array height

- Model Formulation
  - Step Height: primary dependency on line width
  - Array Height: primary dependency on line space
  - Polynomial model framework with interaction term captures the primary data trends

Future Work

- Explore alternative model form to capture superfill more effectively
- Extension to incorporate plating physics into model form
- Integrate copper plating model with copper CMP model

Acknowledgments

■ Special thanks to Sematech and SKW for providing patterned copper wafers for this study