6.780 Term Project

Copper Electrochemical Deposition Topography Regression

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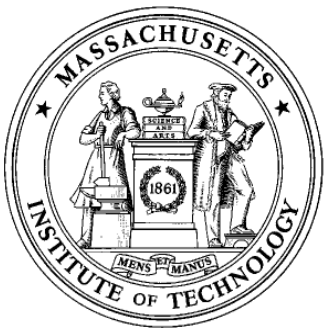

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Presentation Overview

- Introdcution
  - Copper technology
  - Electroplating
- Review of previous electroplating model
- Proposed model
  - Characterization Mask and Measurements
  - Re-examine model parameters
  - Investigate the significance of model parameters
  - Integreated model
- Conclusion

Introduction

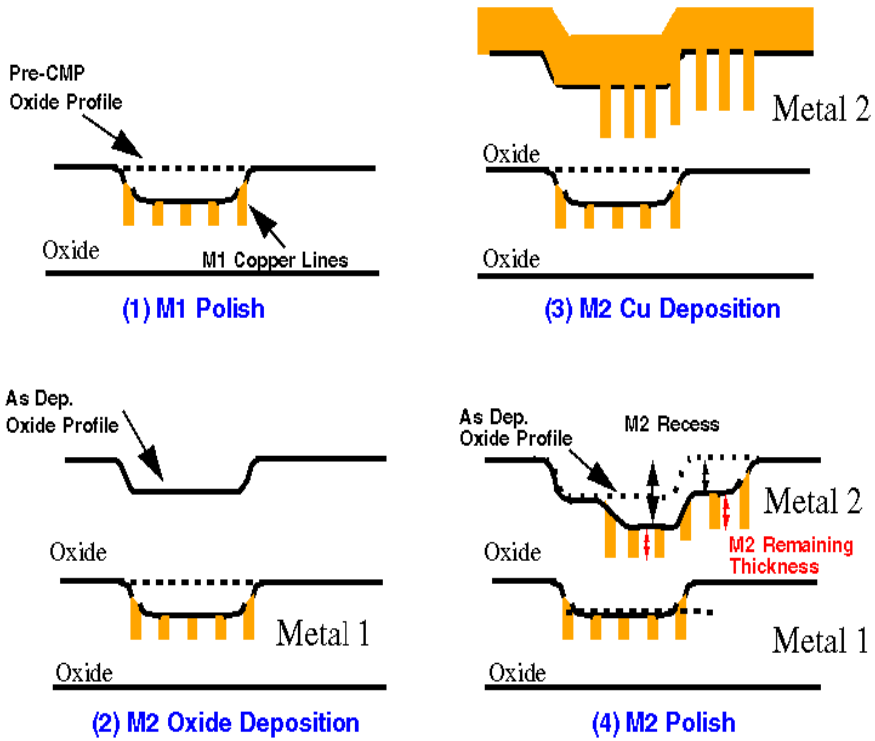
Multilevel Copper Metallization:

- Critical Interconnect Technology
- Dual Damascene:

  Chemical-Mechanical Polishing
  Electrochemical Deposition
- Advantages:

  Local and Global Planarization
  Superfilling Ability
  Lower Cost
- Problems:

  Dishing & Erosion in Copper CMP
  Pattern Dependence of ECP
  Multilevel Interconnect Structure
- Modeling of Multilevel Metallization



Multilevel Process Sequence

T. Park, "Characterization and Modeling of Pattern dependencies in Copper Interconnects for Integrated Circuits," Ph.D. Thesis, MIT, May 2002

Literature Review – ECD models

Copper Electroplating:

- Superfilling
- Organic Additives:
  - – Accelerators
  - – Suppressors w/ Chloride Ions
  - – Levelers
- Models:

Diffusion-Adsorption Mechanism

Andricacos; West; Cao etc.

Single-component to Multi-component

Leveler Absent

West “Accelerator-Accumulation Model”

Moffat “Curvature Enhanced Accelerator Coverage Model”

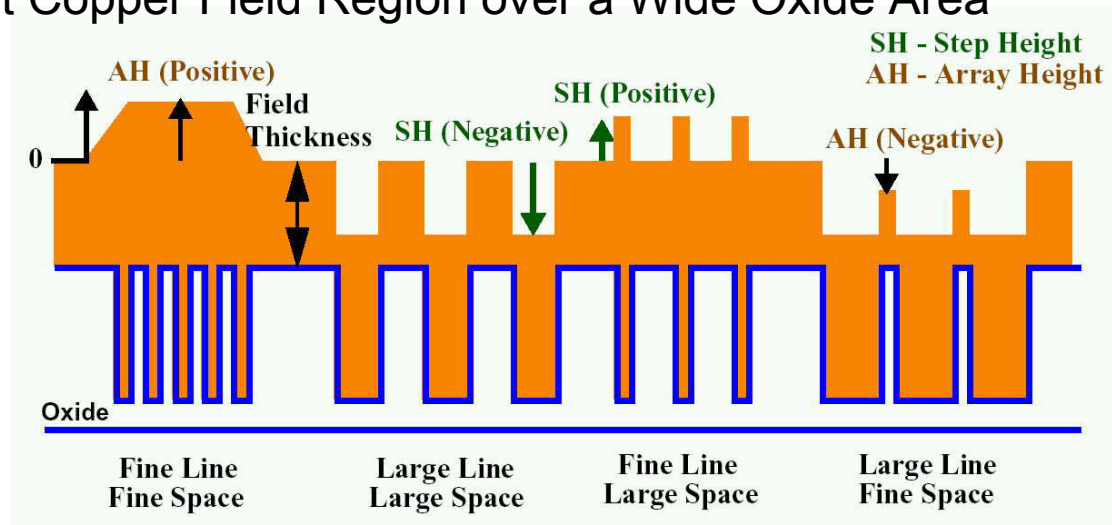
Evolution of hole filling with different deposition conditions

R. Rosenberg, D. C. Edelstein, C.-K. Hu, and K. P. Rodbell, Annu. Rev. Mater. Res., Vol. 30, pp. 229-262, 2000.

Literature Review – Tae's ECD Model

Step Height: Bottom Depth of Each Line with respect to the Nearby Surface

Array Height: Top Surface Height of Copper over an Array Region with respect to the Flat Copper Field Region over a Wide Oxide Area



Topography in Superfilling Copper Electroplating

T. Park, Ph.D. Thesis, Electrical Engineering and Computer Science, MIT, May 2002.

$$SH = A*lw + B*lw^{-1} + C*lw^{2} + D*ls + E*lw*ls + Const.$$

$$AH = Ae*lw + Be*lw^{-1} + Ce*lw^{-2} + De*ls + Ee*lw*ls + Conste.$$

Characterization Mask

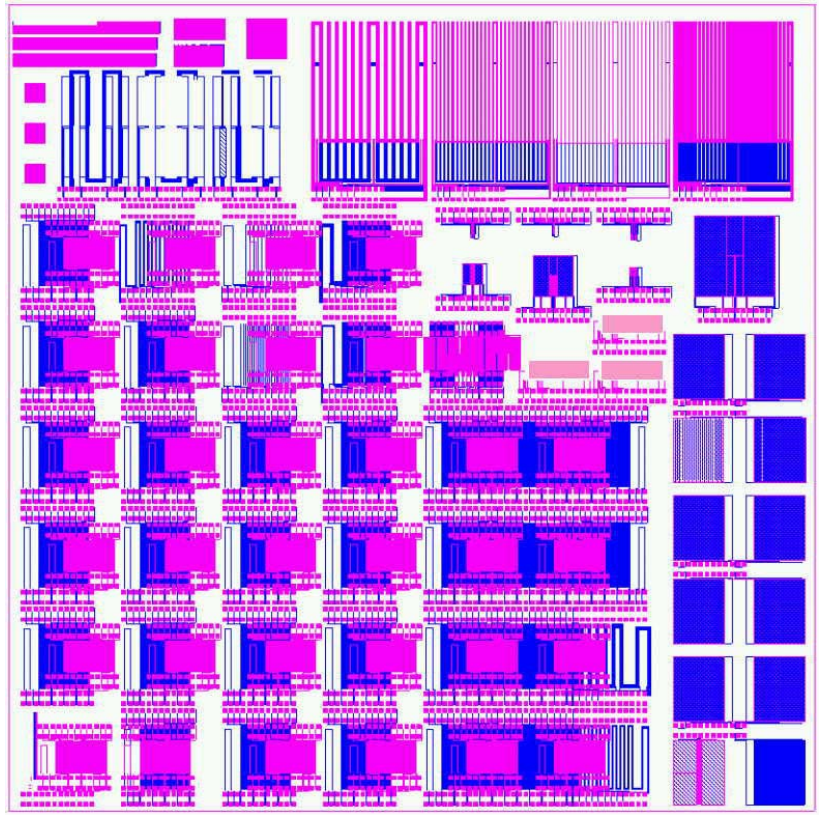
Integrated Chip-Scale ECD/CMP Model :

- Developed by Park and Tugbawa
- Extension to the Multilevel Metallization

Addition of a Interlevel Dielectric Deposition Model

Other Extensions to Accommodate a Pre-existing Surface Topography Created by previous CMP

- MIT/SEMATECH 854 Multilevel Test Mask:
  - Feature Sizes 0.18 μm to 100 μm
  - Layout Densities 1% to 99%
  - Physical and Electrical Measurement



Metal 1: Blue (Dark); Metal 2: Magenta (Light)

Multilevel Test Mask Layout

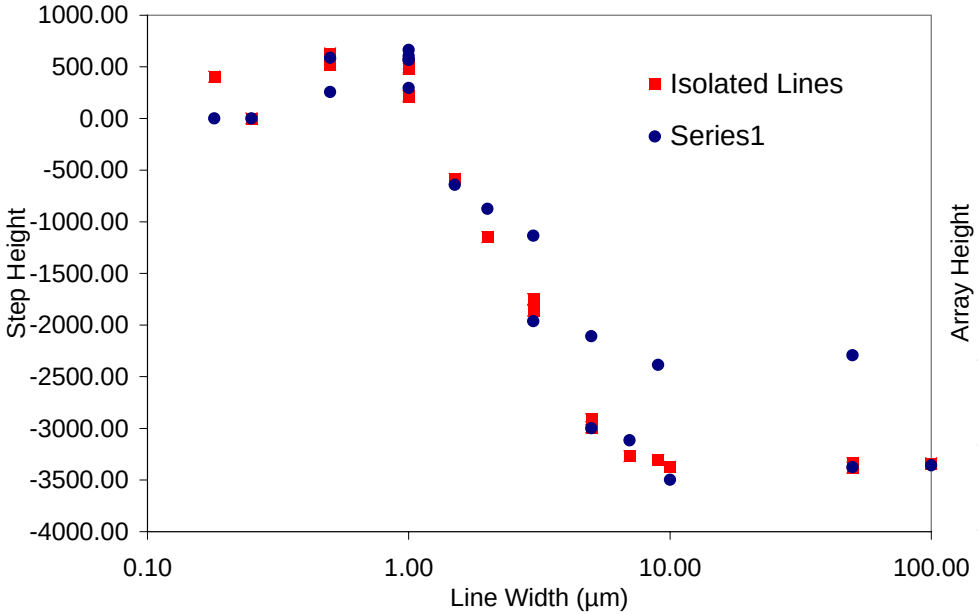
ECD Experiments

- Several Electroplated Wafers with different target copper thickness

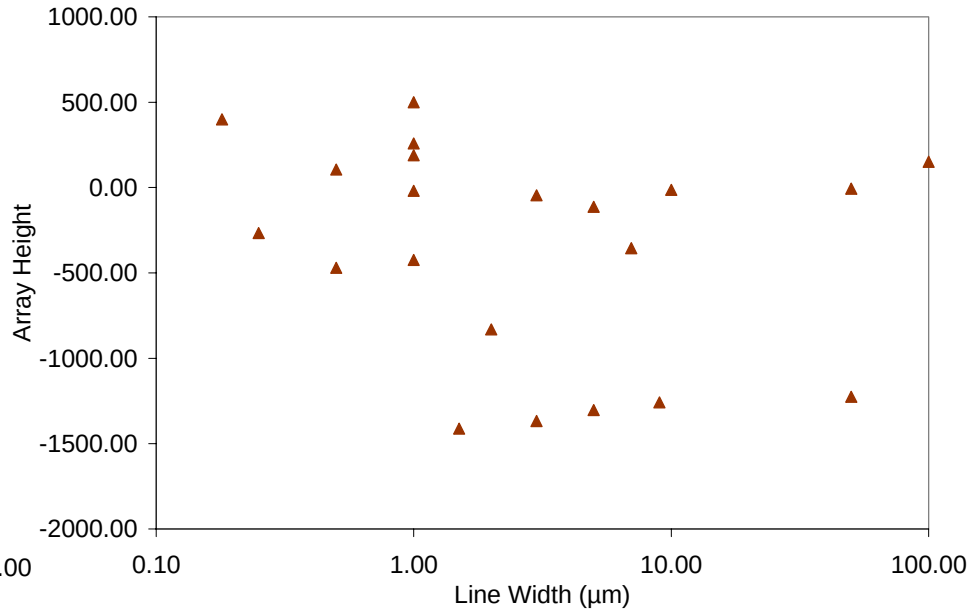
# of Split	# of Wafers	Target Copper Thickness (μm)	Measured Copper Thickness (μm)
1	2	~0.4	0.27
2	2	~0.7	0.86
3	2	~0.9	1.04
4	2	~1.15	1.17
5	2	~1.5	1.46

- Each split has 21 measurement sites

Experiment Data for Split 1



Step height vs. Line width



Array height vs. Line width

Fit with Tae's Model- Array Height

AH		0.4	0.7	0.9	1.15	1.5
R_square		0.685	0.796	0.881	0.861	0.908
R_square_adj		0.642	0.768	0.865	0.841	0.896
Lack of fit		5.081	20.801	24.873	12.658	12.105
Const	Est.	-435.685	-1283.287	-1579.862	-1626.250	-1455.446
	t	-3.130	-5.680	-7.820	-6.880	-7.710
	Prob>|t|	0.0035	<.0001	<.0001	<.0001	<.0001
Lw	Est.	-10.027	-8.099	-29.371	-32.084	-78.773
	t	-0.510	-0.250	-1.030	-0.960	-2.950
	Prob>|t|	0.6140	0.8014	0.3110	0.3435	0.0056
Lw^-1	Est.	-88.919	479.959	659.297	772.792	660.584
	t	-0.770	2.550	3.920	3.930	4.200
	Prob>|t|	0.4486	0.0152	0.0004	0.0004	0.0002
Lw^-2	Est.	23.907	-37.132	-57.459	-76.130	-63.347
	t	1.250	-1.200	-2.080	-2.350	-2.450
	Prob>|t|	0.2182	0.2380	0.0450	0.0242	0.0193
Ls	Est.	82.087	154.354	170.082	174.375	154.276
	t	5.920	6.870	8.460	7.420	8.210
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001
*Lw*Ls*	Est.	-1.656	-1.325	0.188	1.430	4.401
	t	-0.780	-0.390	0.060	0.400	1.530
	Prob>|t|	0.4389	0.7017	0.9515	0.6926	0.1335

Fit Tae's Model- Step Height

SH		0.4	0.7	0.9	1.15	1.5
R_square		0.965	0.973	0.968	0.970	0.949
R_square_adj		0.963	0.971	0.965	0.968	0.945
Lack of fit		32.295	10.738	10.661	7.687	18.437
Const	Est.	599.664	1602.657	1179.359	1510.908	746.353
	t	4.620	11.870	9.660	11.210	5.420
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001
Lw	Est.	-1140.785	-1235.590	-798.109	-965.676	-501.056
	t	-22.480	-23.430	-16.740	-18.340	-9.320
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001
Lw^-1	Est.	-52.793	-268.138	-228.850	-268.953	-163.640
	t	-1.630	-7.980	-7.540	-8.020	-4.780
	Prob>|t|	0.1064	<.0001	<.0001	<.0001	<.0001
Lw^-2	Est.	83.758	88.120	55.024	65.808	32.216
	t	19.020	19.260	13.300	14.400	6.910
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001
Ls	Est.	-5.629	25.789	29.894	14.622	43.711
	t	-0.560	2.470	3.160	1.400	4.100
	Prob>|t|	0.5773	0.0158	0.0022	0.1651	<.0001
*Lw*Ls*	Est.	-6.568	-16.269	-18.927	-18.662	-20.698
	t	-3.170	-7.550	-9.710	-8.670	-9.420
	Prob>|t|	0.0022	<.0001	<.0001	<.0001	<.0001

We Want More Physical Insights

A Simple Geometrical Model :

- Based on CEAC Model
- Straight Vertical and Horizontal Lines
- Local Growth Rate
- Horizontal and Vertical Displacement

A Schematic of the Approximate Geometry for a Simple Model

D. Josell, D. Wheeler, W. H. Huber, J. E. Bonevich, and T. P. Moffat, J.E.S. , Vol. 148, No. 12, pp. 767-773, 2001.

Re-examine Model Parameters

Josell suggests growth rate

~ curvature

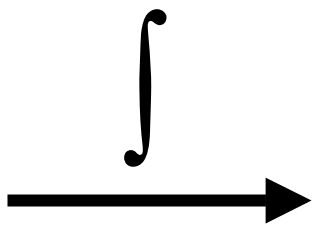
- In trench

  growth rate ~ lw^{-3}, lw^{-2}, lw^{-1}, *const*, *lw*

- Raised area

  growth rate ~ ls^{-2}, ls^{-1}, *const*

- Density *(lw/(lw+ls))*



Model parameters
lw^{-2}
lw^{-1}
log(lw)
lw
lw^{2}
ls^{-1}
log(ls)
ls
den

Step Height Regression

SH		0.4	0.7	0.9	1.15	1.5
R_square		0.973081	0.95349	0.928218	0.940541	0.890403
R_square_adj		0.971718	0.951135	0.924584	0.93753	0.884853
Lack of fit		23.0819	19.5529	25.4797	16.7879	40.4799
Const	Est.	-88.11664	1944.5453	1577.0976	1903.0837	1181.3182
	t	72.00722	11.7	9.29	10.76	6.27
	Prob>|t|	0.2247	<.0001	<.0001	<.0001	<.0001
Lw	Est.	372.45984	-1305.478	-879.4136	-1045.843	-589.9706
	t	29.64162	-19.24	-12.68	-14.49	-7.67
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001
Lw^2	Est.		82.531919	48.523615	59.398313	25.106428
	t		13.98	8.05	9.46	3.75
	Prob>|t|		<.0001	<.0001	<.0001	0.0003
Lw^{-1}	Est.	-978.6177	-281.5053	-244.4001	-284.2856	-180.6464
	t	62.0174	-6.42	-5.46	-6.1	-3.64
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	0.0005
Ls	Est.		-28.36327	-33.10376	-47.49509	-25.18388
	t		-2.86	-3.26	-4.49	-2.24
	Prob>|t|		0.0055	0.0016	<.0001	0.0281
~~log(Lw)~~	Est.	-6843.032				
	t	308.7443				
	Prob>|t|	<.0001				
~~den~~	Est.	371.97591				
	t	92.70221				
	Prob>|t|	0.0001				

Array Height Regression

AH		0.4	0.7	0.9	1.15	1.5
R_square		0.892074	0.937413	0.949214	0.92293	0.970162
R_square_adj		0.880407	0.930647	0.943724	0.914598	0.966936
Lack of fit		0.5386	4.7878	8.9538	5.7626	2.5536
Const	Est.	-717.6067	117.668	-1230.939	-1171.685	-885.7573
	t	-13.47	1.26	-15.17	-10.87	-9.47
	Prob>|t|	<.0001	0.2147	<.0001	<.0001	<.0001
Lw	Est.		247.51906	132.6121	159.38763	-331.0837
	t		4.85	5.37	4.86	-8.45
	Prob>|t|		<.0001	<.0001	<.0001	<.0001
~~Lw^2~~	Est.					24.909473
	t					7.31
	Prob>|t|					<.0001
Lw^{-1}	Est.	64.596456	277.80282			426.91038
	t	2.06	9.16			14.36
	Prob>|t|	0.0465	<.0001			<.0001
~~Lw^{-2}~~	Est.		-11.94738			
	t		-2.83			
	Prob>|t|		0.0074			
~~Ls~~	Est.	-94.33653				
	t	-4.54				
	Prob>|t|	<.0001				
Ls^{-1}	Est.	265.83364		262.16547	224.52839	
	t	4.08		4.78	3.08	
	Prob>|t|	0.0002		<.0001	0.0039	
log(Lw)	Est.			-1908.121	-2190.742	
	t			-9.53	-8.24	
	Prob>|t|			<.0001	<.0001	
log(Ls)	Est.	1693.2938		1673.2166	1709.0233	1376.1209
	t	7.46		16.22	12.47	25.58
	Prob>|t|	<.0001		<.0001	<.0001	<.0001
~~den~~	Est.		-2754.783			
	t		-20.83			
	Prob>|t|		<.0001			

Integrated Step Height Model

Model parameters: lw^{-1}, lw, lw^2 ,ls

SH		0.4	0.7	0.9	1.15	1.5
R_square		0.961	0.953	0.928	0.941	0.890
R_square_adj		0.959	0.951	0.925	0.938	0.885
Lack of fit		35.174	19.553	25.480	16.788	40.480
Const	Est.	737.7	1944.5	1577.1	1903.1	1181.3
	t	5.7	11.7	9.3	10.8	6.3
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001
Lw	Est.	-1169.0	-1305.5	-879.4	-1045.8	-590.0
	t	-22.2	-19.2	-12.7	-14.5	-7.7
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001
Lw^2	Est.	81.5	82.5	48.5	59.4	25.1
	t	17.8	14.0	8.1	9.5	3.8
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	0.0003
Lw^{-1}	Est.	-58.2	-281.5	-244.4	-284.3	-180.6
	t	-1.7	-6.4	-5.5	-6.1	-3.6
	Prob>|t|	0.0916	<.0001	<.0001	<.0001	0.0005
Ls	Est.	-27.5	-28.4	-33.1	-47.5	-25.2
	t	-3.6	-2.9	-3.3	-4.5	-2.2
	Prob>|t|	0.0006	0.0055	0.0016	<.0001	0.0281

Integrated Array Height Model

Model parameters: lw^{-1}, $log(lw)$, lw, ls^{-1} ,$log(ls)$

AH		0.4	0.7	0.9	1.15	1.5
R_square		0.864	0.936	0.949	0.923	0.961
R_square_adj		0.845	0.927	0.942	0.912	0.956
Lack of fit		1.201	5.306	9.638	6.193	4.122
Const	Est.	-694.6	-1116.0	-1226.3	-1159.6	-1141.8
	t	-11.0	-12.9	-13.5	-9.6	-13.5
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001
Lw	Est.	-58.5	33.2	135.6	167.1	125.6
	t	-2.4	1.0	3.9	3.6	3.9
	Prob>|t|	0.0210	0.3269	0.0004	0.0009	0.0004
Lw^{-1}	Est.	376.3	582.8	-17.2	-44.4	64.1
	t	3.9	4.3	-0.1	-0.2	0.5
	Prob>|t|	0.0005	0.0001	0.9032	0.8137	0.6277
Ls^{-1}	Est.	-100.3	-215.9	273.5	253.6	142.4
	t	-1.3	-2.1	2.5	1.8	1.4
	Prob>|t|	0.1879	0.0432	0.0155	0.0845	0.1638
log(Lw)	Est.	789.5	-231.3	-1951.2	-2301.7	-2010.4
	t	2.8	-0.6	-4.8	-4.3	-5.3
	Prob>|t|	0.0081	0.5555	<.0001	0.0001	<.0001
log(Ls)	Est.	565.9	1031.7	1684.2	1737.2	1572.0
	t	5.9	7.8	12.2	9.5	12.3
	Prob>|t|	<.0001	<.0001	<.0001	<.0001	<.0001

Conclusion

- We re-examine the physical meaning of model parameters of previous ECD model
- Integrated model proposed uses parameters with more physical meaning: lw^{-1}, $log(lw)$, lw, lw^{2}, ls^{-1} ,$log(ls)$, ls
- The integrated model performs better in the array height prediction and comparable in the step height compared with Tae's electroplating model
- Further study on the relationship between the regression coefficients and film thickness is desired