Title
Evaluation of the Effect of Pad Thickness and Stiffness on Pressure Non-Uniformity at Die-Scale in ILD CMP

Authors
Choi, Jihong
Dornfeld, David A

Publication Date
2004-05-31

EVALUATION OF THE EFFECT OF PAD THICKNESS AND STIFFNESS ON PRESSURE NON-UNIFORMITY AT DIE-SCALE IN ILD CMP

Jihong Choi
Sponsored by NSF and FLCC

ABSTRACT

In this study, 2^4 full factorial design of experiment was applied to a FEM model, which gives pattern dependant contact pressure distribution, to build a qualitative model of pad effects on within die non-uniformity (WIDNU) in CMP. Analysis of variance showed that every single effects and two-way interaction effects of hard layer stiffness and soft layer stiffness are significant compared to the round-off error from mesh change. Various regression models were built and residual analyses were done for each of them. Best model with best normality of residuals includes only the effect of hard layer stiffness, soft layer stiffness and hard layer thickness. Based on this model, basic qualitative design rule for a stacked CMP pad to minimize WIDNU were suggested.

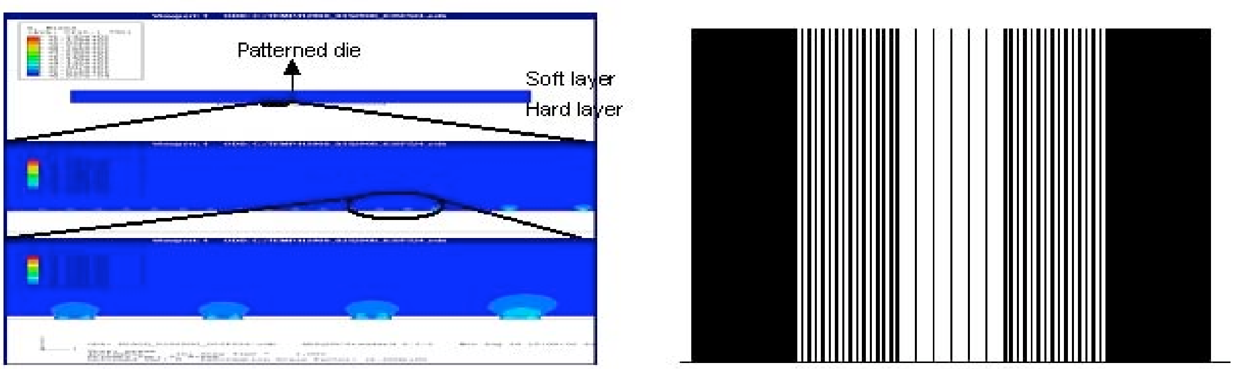
INTRODUCTION

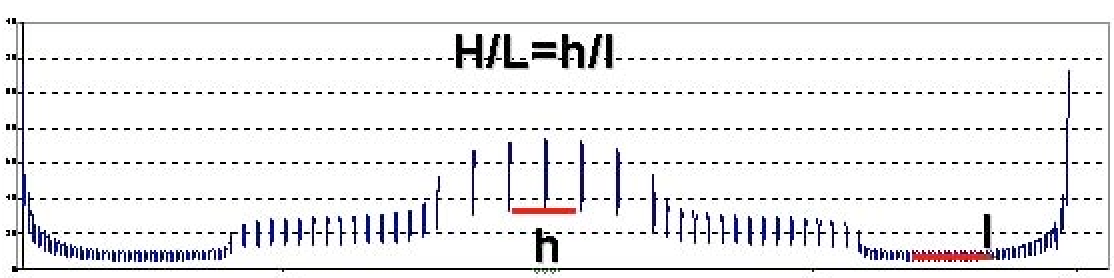
Post-CMP planarity is known to be dependent upon slurry, polishing velocity, down pressure and pad properties (Runnels, 1994). Also, the pattern density in CMP of the patterned wafer is a crucial factor. Local pattern density mainly determines local polishing performance because local down pressure is dependent upon local pattern density. Contact mechanics-based model (Chekina et al., 1998) makes it possible to calculate local pressure on a pattern. However, this model is computationally too expensive. Stein et al. developed a semi-empirical pattern density dependent CMP model (Ouma et al., 2002), which has the accuracy of a few hundred angstroms. These models enable the prediction of post CMP surface profile based on the initial topography. Many other studies have been done on the relation between pad properties and the CMP performance (Yang, 2000; Lai et al., 2002; Grillaert et al., 1998). However, the pad thickness effect cannot be evaluated with these models because a half space was assumed in these models. In this study, a finite element model, which shows good correlation with pattern density based oxide CMP model, was used to study the effect of pad thickness and stiffness on the pattern dependent pressure non-uniformity on a test pattern. To provide a basic design rule of a stacked CMP pad, the FEM model consists of two layers; a hard layer and a soft layer. For the feasibility of the FEM model, the total number of elements in the model should not be too big. A test pattern was designed to meet this goal. A 2^4 full factorial design of experiment tests were conducted to study the effect of stiffness and thickness of a hard layer and a soft layer. Replication of the same tests with a modified mesh was done to statistically evaluate the significance of each factor's effect compared to the round off error of the model.

FINITE ELEMENT MODEL

Figure 1 shows the finite element model and the test pattern, which consists of five sections of different pattern densities, varies from 6% to 50%. Every line has the same width of 25um. Pattern was assumed to be made of silicon that has much bigger stiffness than the pad material. Element size of the bottom surface of the pad was 5um and each line was divided into 5 elements to match the node locations with the pad node locations for better result. Height of each line was set to be 10 um, which is much larger than in real situation, to ensure that the contact between deformed pad and bottom surface is not occur. Every degree of freedom along the bottom and side of the pad were fixed and force was given on the rigid surface beneath the pattern lines. Force was adjusted to give the overall pressure of 7psi. Pad material was assumed to be linear elastic.

Contact pressures at 3 center nodes on top surface of each line were averaged to represent the contact pressure on each line. This contact pressure distribution showed good correlation with the distribution of local material removal rates obtained from pattern density based oxide CMP model (Ouma et al., 2002). The output of the model, H/L, is the ratio of the highest contact pressure and the lowest contact pressure in the test pattern. High H/L means high pressure non-uniformity and low H/L means low pressure non-uniformity in a die, which induce non-uniform local material removal rates in a die. Hence, H/L represents within die non-uniformity (WIDNU) of post-CMP surface. Figure 2 shows one of the contact pressure distributions on the test pattern and H/L.





DESIGN OF EXPERIMENT

2^4 Full factorial DOE with factors of Eh, Es, Th and Ts (stiffness of hard layer, stiffness of soft layer, thickness of hard layer and thickness of soft layer) was conducted. Each level value for stiffness was chosen around the reported value from Baker, 1996. Thickness value was chosen around the measured value of a stacked CMP pad (IC1400). Because FEM simulation has unavoidable round off error, which is uncontrollable and mesh-dependent, replication of the simulation with different mesh generates different result. The difference of the two results can be considered as the noise effect in the replication of experimental test. To evaluate the significance of each factor's effect compared to the round off error of the model, same tests were conducted with different mesh. Hence, this test can be considered as a 2^4 full factorial test with one n=2 replications. Figure 3 show two different meshes used for the same test and Table 1 shows test matrix with obtained H/L values. Total number of elements is around 100,000 in both meshes and computation time for each run was about 90 minutes in a Pentium 4 PC (1.8GHz, 512MB memory). General-purpose commercial FEM package, ABAQUS/CAE 6.3 was used to build and run this model. Different pad models with different thickness were pre-made and simulations were done with each of those models changing stiffness.

Eh(Mpa)	Es(Mpa)	Th(mm)	Ts(mm)	h/l	
174	30	1	1	6.329872	6.328903
174	30	1	1.6	6.774769	6.7643
174	30	1.6	1	5.962938	5.788283
174	30	1.6	1.6	6.271255	6.016656
174	70	1	1	5.48383	5.661342
174	70	1	1.6	5.684502	5.858407
174	70	1.6	1	5.27297	5.447174
174	70	1.6	1.6	5.381071	5.34857
406	30	1	1	7.943655	8.207835
406	30	1	1.6	9.120535	9.635371
406	30	1.6	1	6.670885	6.946132
406	30	1.6	1.6	7.787766	7.128359
406	70	1	1	6.61927	6.379577
406	70	1	1.6	6.824732	6.804492
406	70	1.6	1	5.803045	6.025001
406	70	1.6	1.6	6.300478	6.288556

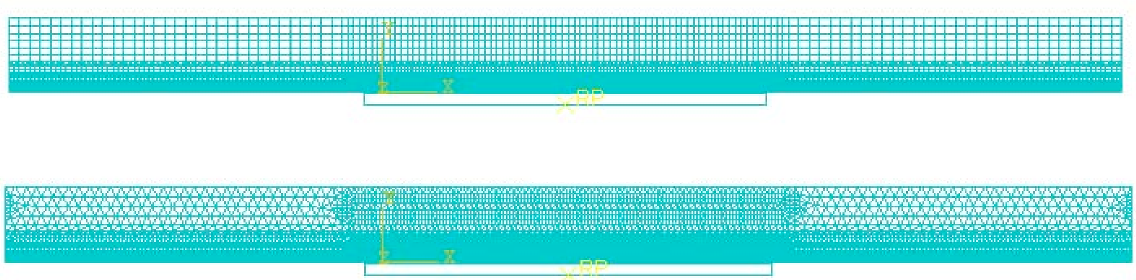
RESULTS AND DISCUSSION

Figure 4 shows the normal probability plot of the effects. From this plot, effect of soft layer stiffness (Es), effect of hard layer stiffness (Eh), and effect of hard layer thickness (Th) were decided to be significant among the all-15 effects. Regression model with these three effects is given as:

$$H/L = 6.526892 \times 0.628464 \times Eh - 0.577953 \times Es - 0.374445 \times Th \quad (1)$$

Residual analysis of this model has been done. Figure 5 shows the plot of residuals and normal probability plot of residuals. Clearly, residuals a and b are out of normality. These points are corresponding to the result of test #10, which gave unusually large H/L. Beside these two points regression model (1) gives normally distributed residuals.

To build a better model, which gives better normality of residuals, more effects have been

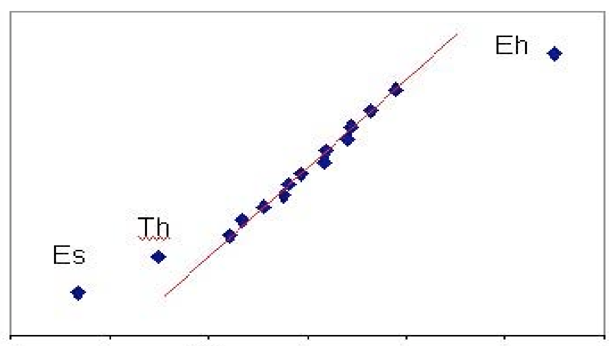


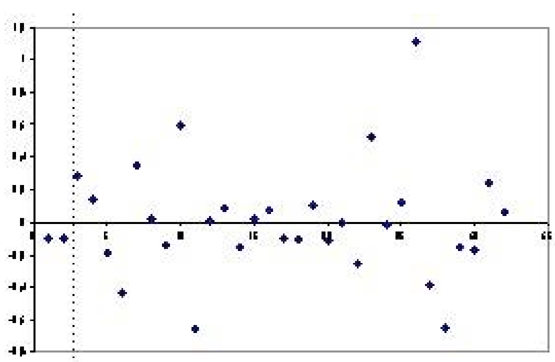
Source of Variance	Sum of Squares	Degrees of Freedom	Mean Square	F0	P-value
Eh	12.63894425	1	12.63894425	354.3771	2.42891E-12
Es	10.68895196	1	10.68895196	299.7022	8.74685E-12
Th	4.486700576	1	4.486700576	125.8004	5.4402E-09
Ts	1.583802768	1	1.583802768	44.40746	5.44269E-06
EhEs	1.238847052	1	1.238847052	34.73542	2.26618E-05
EhTh	0.841180973	1	0.841180973	23.58546	0.000175
EhTs	0.3764239	1	0.3764239	10.55436	0.005034259
EsTh	0.807618193	1	0.807618193	22.64441	0.00021363
EsTs	0.387619911	1	0.387619911	10.86828	0.004550754
ThTs	0.113590428	1	0.113590428	3.184906	0.093292448
EhEsTh	0.328626603	1	0.328626603	9.214198	0.007873952
EhEsTs	0.070538567	1	0.070538567	1.977796	0.178747445
EhThTs	0.006128698	1	0.006128698	0.17184	0.68398666
EsThTs	0.06048946	1	0.06048946	1.696034	0.211243177
EhEsThTs	0.068501402	1	0.068501402	1.920677	0.184795939
ERROR	0.570643862	16	0.035665241		
Total	34.2686086	31			

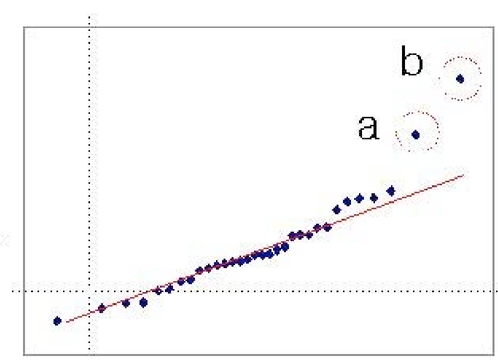
included in the regression model. Table 2 shows analysis of variance of effects. Eh, Es, Th, Ts and EhEs have p-value of less than 10^{-4}. These effects were chosen to be included in a new regression model. Modified regression model is given as,

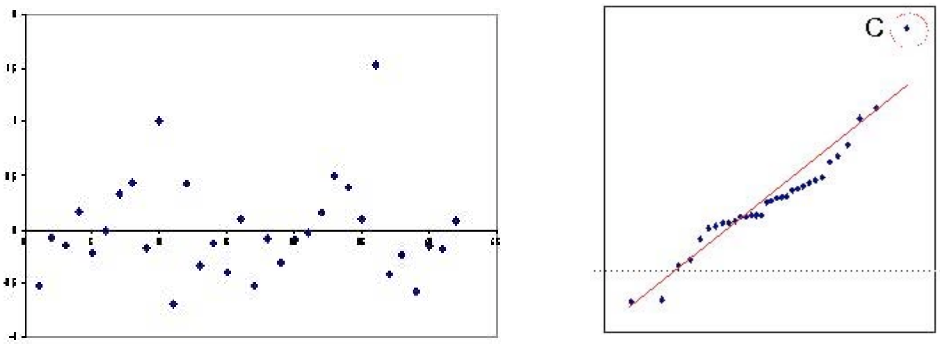
$$H/L = 6.526892 + 0.628464\times Eh - 0.577953\times Es - 0.374445\times Th + 0.222472\times Ts - 0.196759\times Eh\times Es \quad (2)$$

Ts and EhEs, which are not captured in the









normal probability plot of effects, have been included in the regression model. Even though the regression model was modified, residual plot shown in figure 6 still gives a bad normality of residuals. Residual c, which is corresponding to b in Figure 5, is still far out of normality. Moreover, fluctuation over the normality line is observed in this case. More regression models that include more two-way interactions or three-way interactions were tested and normality of the residuals of each of these models were plotted to find a best model with best normality of residuals. Amongst those models, two given models (1) and (2) were the best.

Response surfaces were plotted using regression model (1). Because only three significant parameters, Eh, Es and Th, were used, response surfaces were plotted in Eh-Es space, Eh-Th space and Es-Th space.

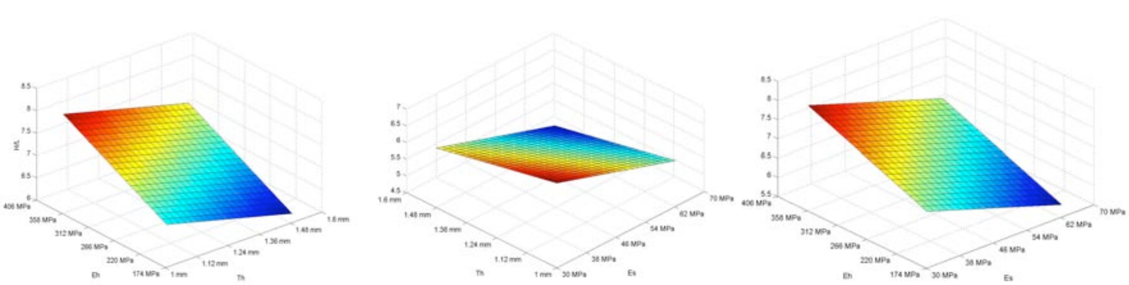
Figure 7 shows three response surfaces in these spaces with remnant parameter set to be –1. No interaction effect was included in the regression model and all response surfaces are flat surface without curvature. Response surfaces in Eh-Es, Th-Ts, Eh-Th and Es-Ts space of regression model (2), which includes the interaction effect EhEs, are given in Figure 8. Because of the interaction effect, slight curvature is observed in Eh-Es, Eh-Th and Es-Ts surfaces.

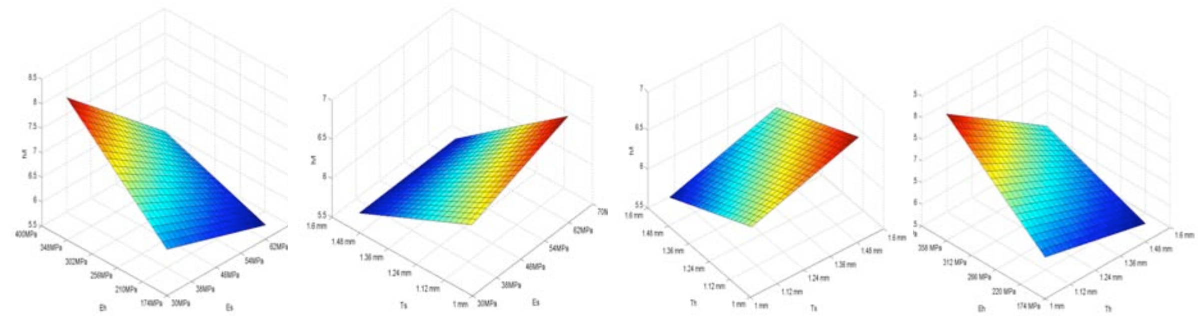
Because the original goal of this study was to 'qualitatively' investigate the effect of pad thickness and stiffness on the WIDNU, no optimization effort has been done with the model. Instead, we can qualitatively deduce following basic conclusions from models (1) and (2), which can provide basic design rule of a stacked CMP pad.

(1) The stiffer the hard layer, the bigger the WIDNU

(2) The thicker the hard layer, the smaller the WIDNU

(3) The stiffer the soft layer, the smaller the WIDNU





REFERENCES

S.R.Runnels (1994), "Feature-Scale Fluid-Based Erosion Modeling for Chemical-Mechanical Polishing", *J.Electrochem. Soc.,*vol.141, no.7, pp.1900-1904.

O.G.Chekina, L.M.Keer, and H.Liang, (1998), "Wear-contact Problems and Modeling of Chemical Mechanical Polishing", *J.Electochem Soc*., vol. 145, no.6, June, pp. 2100-2106.

D.O.Ouma, D.S.Boning, J.E.Chung, W.G.Easter, V.Saxena, S.Misra and A.Crevasse (2002), "Characterization and Modeling of Oxide Chemical Mechanical Polishing Using Planarization Length and Pattern Density Concepts", *IEEE Trans. Semiconduct. Manufact*., vol. 15, no.2, May, pp 232-244.

L.Yang (2000), "Modeling CMP for Copper Dual Damascene Interconnects", *Solid State Technology*, pp.111-121.

J.Lai, N.Saka, and J.Chun (2002), "Evolution of Copper-Oxide Damascene Structures in Chemical Mechanical Polishing", *J.Electrochem. Soc*., vol 149, no.1 ,pp. G31-G40.

J.Grillaert et al. (1998), "Modeling Step Height Reduction and Local Removal Rates Based on Pad-Substrate Interaction" *, Proc. Of CMP-MIC*, pp.79-86.

A.R.Baker (1996), "The origin of edge effect in chemical mechanical planarization", Proc. Electrochem soc.meeting. vol 96, p228.