DIRECT MEASUREMENT OF PLANARIZATION LENGTH FOR COPPER CHEMICAL MECHANICAL PLANARIZATION POLISHING (CMP) PROCESSES USING A LARGE PATTERN TEST MASK

Paul Lefevre, Albert Gonzales, Tom Brown, Gerald Martin, International SEMATECH, Austin, TX; Tamba Tugbawa, Tae Park, Duane Boning, Microsystems Technology Laboratories, MIT, Cambridge, MA; Michael Gostein, Philips Analytical, Natick, MA; John Nguyen, Speedfam-IPEC, Phoenix, AZ.

Abstract

We have used a large pattern test mask and a specific arrangement of structures on a wafer for direct measurement of an average planarization length for copper chemical mechanical polishing (CMP) processes. We propose new minimum, maximum, and average planarization length definitions, based on up and down area measurements as a function of trench width. The average planarization length is useful for qualitatively comparing the planarization capability of copper CMP processes. We have also performed several experiments that show how the average planarization length depends on polish process settings such as down force and relative speed, as well as on consumables such as pad and slurry.

Introduction

Copper electroplating introduces severe topography on a die with a large pattern range. In the case where “bottom-up” fill plating technique is used, arrays that have sub-micron line widths and line spaces are overplated, arrays that have high layout pattern densities and fine line spaces are under-plated, and arrays that have large line widths and large line spaces are conformal. This topography introduced by the plating process needs to be planarized before the copper overburden is completely cleared, if we are to avoid severely overpolishing certain structures on the die. Severe overpolishing leads to excessive dishing, erosion, and nonuniformity. The planarization length succintly summarizes the planarization capability of a given CMP process. In copper CMP, the planarization length tells us the extent to which a CMP process can planarize the electroplated topography during the overburden copper clearing stage. The larger the planarization length, the better the planarization capability of the process in question, and the more uniform will be the polishing across different densities within the die.

Hymes et al. used wafer scale patterns to determine the planarization length for copper CMP processes [1]. However, they did not detail exactly how the planarization length could be directly obtained from the wafer scale patterns. In this work, we have designed a new wafer-scale mask, and used a specific wafer layout scheme to directly measure the average planarization length of a given copper CMP process. The wafer layout scheme takes into account the nonuniform nature of CMP processes. We also present experimental results that show the effect of polish process settings and consumables on the average planarization length.

Large Pattern Test Mask

The new wafer-scale test mask is referred to as the SEMATECH/MIT 862 mask. It contains square trenches of widths 1 µm to 8 mm, and arrays with lines and spaces in the range 1 µm to 100 µm. Figure 1 shows the mask, which is available for public use. In addition to the squares on the mask, squares of widths ranging from 10 mm to 25 mm are directly exposed on the wafers without the use of a mask. The wafer layout scheme is shown in figure 2. All the large squares are at the same distance from the wafer center in order to avoid within wafer nonuniformity (WIWNU) bias. The mask is repeated five times on the wafer in order to get the interaction between wafer level uniformity and planarization.

Measuring the Average Planarization Length

As illustrated in figure 3, when we plot the difference between the amounts removed in the up-area (field region) and the down-area (trenches), versus the trench width (or feature size) on a logarithmic scale, we get a curve that is at first constant with trench width until a critical trench width at which it starts to decrease linearly with trench width. We define the critical trench width at which the curve starts to decrease as the *minimum planarization length*. This is the same as the maximum trench width at which the planarization efficiency is 100%, i.e. it is the trench width above which we begin to remove material in the down area. If we extrapolate the linearly decreasing portion of the curve mentioned earlier, we reach zero on the vertical axis (when the difference in the amount removed in the up area minus that removed in the down area is zero). The trench width (or feature size) corresponding to this point is what we define as the *maximum planarization length*. It is the minimum trench width at which the planarization efficiency is 0%, i.e. it is the minimum trench width at which the same amount is removed in the down and up areas. The average planarization length is defined as the geometric mean of the minimum planarization length and the maximum planarization length as shown in equation 1, where PL is the planarization length.

$$Average(PL) = \sqrt{Minimum(PL) \times Maximum(PL)} \qquad \text{[Eq. 1]}$$

To illustrate how the average planarization length can be directly measured from experiments, we performed the following experiments with six wafers having the SEMATECH/MIT 862 mask patterns, and the specific wafer layout scheme shown in figure 2. The wafers went through the following pre-CMP process sequence:

1. Deposition of 5000 Angstroms of TEOS
2. Deposition of 500 Angstroms of Nitride
3. Deposition of 5000 Angstroms of Oxide
4. Etching of 5000 Angstroms trenches in the Oxide
5. Deposition of 250 Angstroms of Tantalum
6. Deposition of 1000 Angstroms of copper seed layer
7. Electroplating of 10000 Angstroms of copper

The six wafers were polished to target bulk removal of 10%, 25%, 50%, 50%, 75%, and 90% respectively of the measured as-plated step-heights, with a down-force of 4 psi, and table and carrier speeds of 75 rpm. A stacked pad and a commercially available slurry were used as the consumables. The thicknesses of the remaining copper in the trenches and outside the trenches were measured using a Philips Impulse 300 tool. Figure 3 shows a plot of the amount removed in the up-area minus the amount removed in the trenches (the down-area) versus trench width (or feature size) on a logarithmic scale. From the figure, we see that at trench widths up to 1.25 mm, the amount removed in the up-area minus that removed in the down area is constant. 1.25 mm is therefore the minimum planarization length. Above 1.25 mm, the difference between the amounts removed in the up and down areas decreases linearly with trench width.

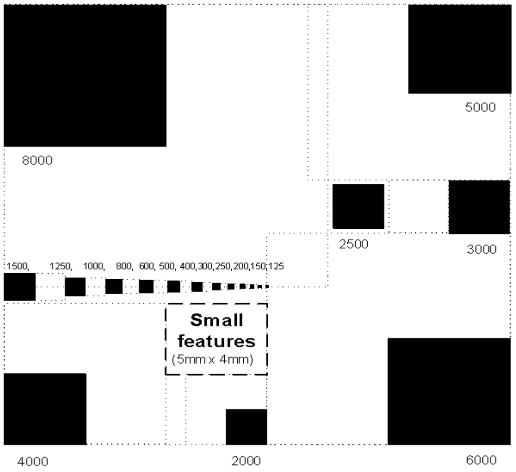


Fig 1: SEMATECH/MIT 862 mask

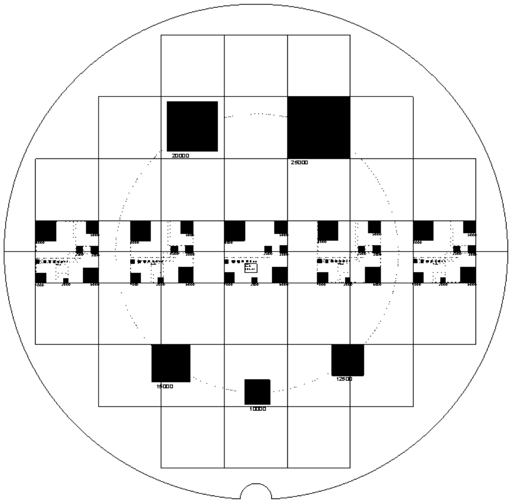
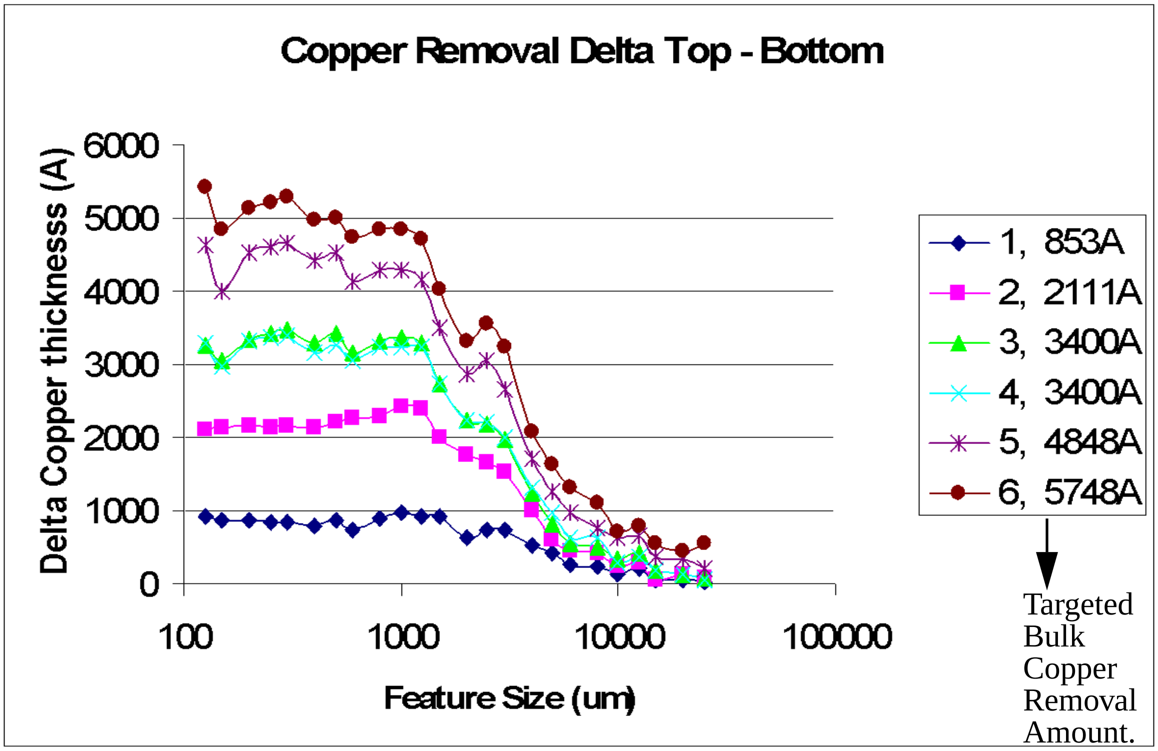


Fig 2: Wafer layout scheme

Figure 4 shows the curves in figure 3 with linear lines superimposed to easily obtain the maximum and minimum planarization lengths, which are 10 mm and 1.25 mm in this case. The corresponding average planarization length is 3.54 mm.

Dependence of the Average Planarization Length on Consumables and Polish Process Settings.

It is well documented that the planarization length in dielectric CMP depends on the consumables, as well as on the polish process settings such as the down force and the table speed [2,3]. To see how the average planarization length depends on process settings and consumables in copper CMP, we polished several wafers with the processes described in tables 1 and 2. Each of the wafers had the SEMATECH/MIT 862 mask patterns, and had the special wafer layout scheme shown in figure 2. They all went through the pre-CMP process sequence discussed earlier.



Targeted Bulk Copper Removal Amount.

Fig 3: Difference in amount removed in up and down areas versus trench width (feature size)

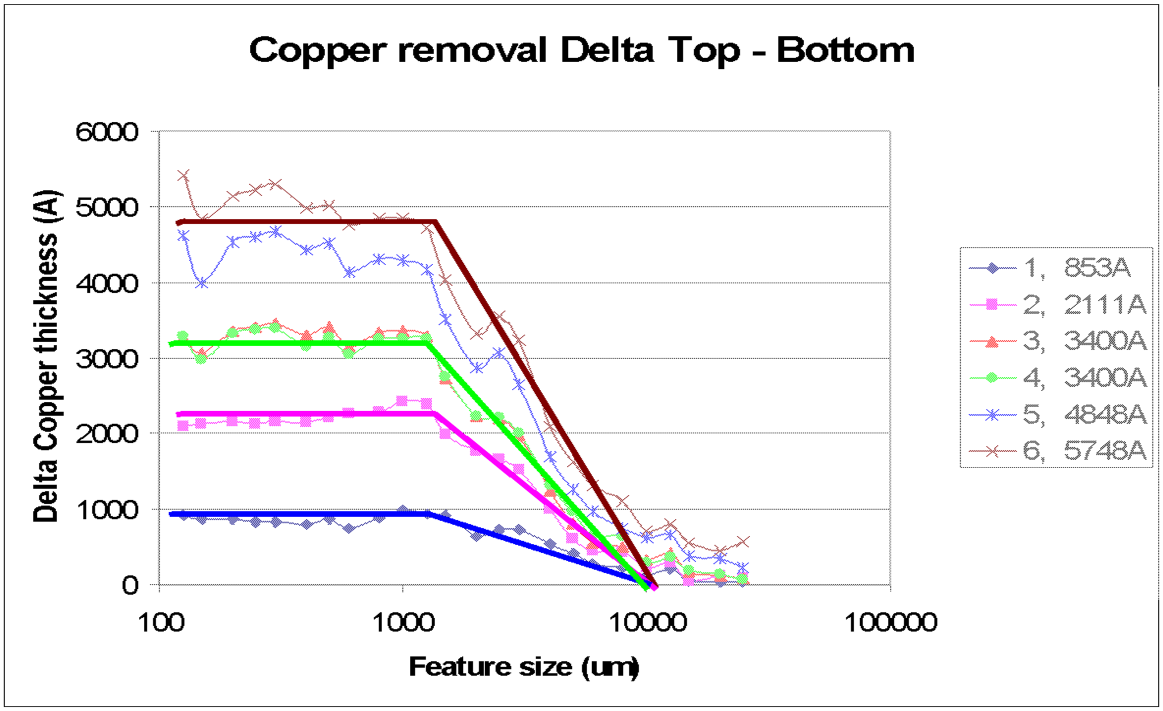


Fig 4: Measurement of maximum, minimum, and average planarization length

Table 1: Consumable Experiments (PL means planarization length)

Down Force (psi)	Carrier Speed (rpm)	Table Speed (rpm)	Slurry Type	Pad Type	Tool Type	Min. PL (µm)	Max. PL (µm)	Average PL (µm)
4	75	75	A	Stacked	Rotary	1250	9000	3354
4	75	75	A	Solo	Rotary	1250	28000	5916
4	75	75	B	Solo	Rotary	1250	39690	7044
2	100	100	C	Stacked	Rotary	2000	39690	8910
			D	Solo**	Orbital	1000	50009	7072

Table 2: Process Settings Experiments with Rotary CMP tool (PL is planarization length)

Down Force (psi)	Carrier Speed (rpm)	Table Speed (rpm)	Slurry Flow (ml/min)	Slurry Type	Pad Type	Min. PL (µm)	Max. PL (µm)	Average PL (µm)
2	65	65	125	C	Stacked	2000	20000	6325
3	100	100	200	C	Stacked	2000	12500	5000
3	100	100	50	C	Stacked	2000	12500	5000
3	30	30	200	C	Stacked	2000	8000	4000
3	30	30	50	C	Stacked	2000	8000	4000
1	100	100	200	C	Stacked	3000	39375	10869
1	100	100	50	C	Stacked	3000	39375	10869
1	30	30	200	C	Stacked	2500	39375	9922
1	30	30	50	C	Stacked	2500	39375	9922

The computed average planarization length for these processes are also shown in tables 1 and 2 . The experimental results show that the measured average planarization length depends on the slurry type, pad stiffness, polish process settings such as down force and relative speed. It does not seem to depend on the slurry flow rate. The stiffer the pad, the higher the average planarization length. Also the higher the relative speed and the lower the down force, the higher the average planarization length. Clearly, some slurries give a higher average planarization length than others.

Summary and Conclusions

We have shown how to directly measure the average planarization length for a given copper CMP process from experiments. This length gives us a sense of which process has a better planarization capability. We should be careful not to confuse this average planarization length with the planarization length in the density-step-height dielectric and copper CMP models [2,4]. The planarization lengths in these models are minimum sum of squared error planarization lengths, i.e. they are the lengths which give the minimum sum of squared errors between experimental data and the models in question. Further work needs to be done to see how the average planarization length defined in the present work relates to the density-step-height model's extracted planarization length. In addition, more study is needed to understand the impact of the initial trench depth on the average planarization length. Theoretically, the planarization length should not depend on trench depth. However our definition of the average planarization length makes it susceptible to variation with initial trench depth. Nevertheless, the average planarization length gives us a good qualitative indicator of the planarization capability of the copper CMP process in question.

References

[1] S. Hymes, K. Smekalin, T. Brown, H. Yeung, M. Joffe, M. Banet, T. Park, T. Tugbawa, D. Boning, J. Nguyen, T. West, and W. Sands, "Determination of the Planarization Distance for Copper CMP Process," *CMP Symposium, MRS Spring Meeting*, April 1999.

[2] D. Ouma, Modeling of Chemical Mechanical Polishing for Dielectric Planarization, Ph. D. Thesis, MIT, November 1998.

[3] B. Lee, T. Gan, D. Boning, J. David, B. Bonner, P. McKeever, and T. Osterheld, "Using Wafer-Scale Patterns for CMP Analysis," *CMP Symposium, MRS Spring Meeting*, April 2000.

[4] T. Tugbawa, T. Park, D. Boning, T. Pan, P. Li, S. Hymes, T. Brown, and L. Camilletti, "Modeling of Pattern Dependencies for Multi-Level Copper Chemical Mechanical Polishing Processes," *CMP Symposium, MRS Spring Meeting*, April 2001.