

Pattern Density Effects on the Chemical Mechanical Planarization of an Interlevel Polymer Dielectric

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Abstract—Chemical Mechanical Planarization is quickly becoming a standard in microelectronic processing. CMP can decrease the depth of focus constraints in photolithography, resolve topography issues for multilevel interconnects, improve metal step coverage, and be used as an alternative etch process. The recent break-through in the copper damascene process has invoked a large number of studies focused on the planarization of oxides and metals. The research has proven beneficial for other applications where oxides are used as an interlevel dielectric material. It has also shown the need for further studies in the polishing of other dielectric materials. The purpose of this experiment was to study the effects that pattern density had on both the polish rate of the polymer and changes the pattern density made to the improvement of planarization. Interactions, if any, between the pattern density and the other factors were also to be studied.

1. BACKGROUND

Polymers are involved in the IC process in many ways including as an interlevel dielectric material. Because of this, modeling the chemical mechanical planarization of polymers can prove to be very useful. Numerous factors and resulting effects are involved in the CMP process. Listed below are some of the known factors.

- ❖ Applied downward pressure
- ❖ Rotating speed of the table and wafer carrier
- ❖ Time of polishing
- ❖ Polishing tool used
- ❖ Type of slurry
- ❖ Density of slurry
- ❖ Type of wafer carrier
- ❖ Pattern variation on the wafer
- ❖ Wafer size

Because of the large number of variables it would not be realistic to model all of the effects in one study.

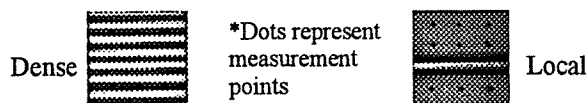
2. PROCEDURE

The first process in designing the experiment was to decide upon the factors and responses. They are shown in the following table. The experimental design was then laid out in the statistical software RS/1©.

Variables	Settings
Applied Downward Pressure	1 to 6 psi
Table Speed	100 to 150 rpm
Polishing Time	30 to 300 seconds
Pattern Density	Dense, Local, Global *
Responses	Equation
Polish Rate	Δ thickness / polish time (um/min)
Planarization Improvement	Δ variance(normalized) (%)

* Definitions of pattern density will be given in the procedure

RS/1© generated an experimental worksheet defining the variable settings for each run. Twenty-five wafers were coated with a photosensitive polyimide, patterned, and cured. The wafers were then measured on a TENCOR® P-2 Long Scan Profiler for initial thickness and uniformity. There were three different areas measured on each wafer, one for each pattern density setting. Dense patterning was defined as 43% raised topography. Local patterning was similarly defined as 86% raised topography. Global patterning was defined as an overview look at the entire 4" wafer. Below are photos of both localized areas (dense and local).



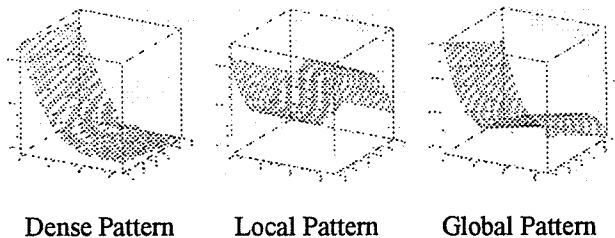
Each localized area was observed in a 300 X 300-micron window. After the pre-polish measurements were obtained the wafers were polished using the Strasbaugh 6DS-SP-polishing tool, following the polishing parameters set in the RS/1© worksheet. After polishing the wafers were cleaned utilizing a megasonic cleaning unit and a rinsing/dryer. The wafers were again measured on the

TENCOR® for thickness and planarization. An EXCEL spreadsheet was used to calculate the responses. The results were entered into RS/1® and insignificant terms were removed from the model design. The program revealed the table speed as statistically insignificant. Because of this the table speed was set at a constant value of 125 rpm for the graphical analysis. Three graphs, one for each pattern density, were made for the individual responses.

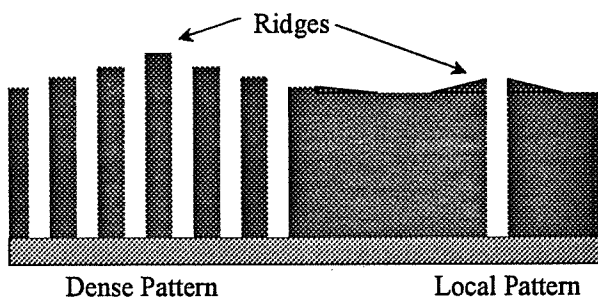
3. ANALYSIS

For the analysis of the results 3-D plots were obtained. In each graph the X-axis represents the polish time, the Y-axis represents the downward pressure and the Z-axis is the observed response. Again it should be noted that the table speed was set at a constant of 125rpm.

The results for Polish Rate can be seen below:

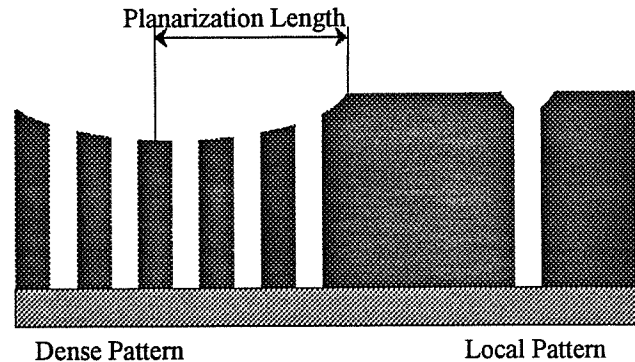


For each pattern density there is a linear relationship between the downward applied pressure and the polishing rate. This is an expected result, as the pressure is increased the polishing rate increases slightly. What is more interesting is the effect that the polishing time has between the three pattern densities. In the dense pattern there is a negative exponential relationship. This is most likely due to the initial polishing of ridges formed during the curing of the polyimide.



The local pattern graph also displays this initial high rate of polish. Again the ridges can explain this because they are formed in both the dense and local areas. As

defined the local area has less patterning and therefore has less ridges formed during the curing process. In the local pattern results there is a secondary increase in the polish

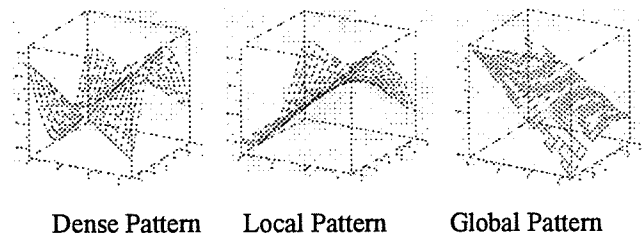


rate. This may be due to dishing effects in the densely patterned areas. When the densely patterned areas have dished an amount greater than the planarization length of

the table pad the local areas essentially become the high spots on the wafer and begin polishing at this increased

rate. This oscillation between the polishing of dense areas and local areas can explain the sinusoidal pattern seen in the graph. The global pattern appears to be simply a combination of the two localized areas.

The results for Planarization Improvement are:



As with the polishing rate graphs there is still a linear relationship with the response throughout each pattern density, although in this case the contributing factor is the polishing time not the downward pressure. The downward pressure has a parabolic effect on the planarization improvement. The dense and local patterns again present the sinusoidal patterns seen in the polishing rate graphs. This suggests that the rate in which the polymer is polishing plays a role in the planarity of the area. The global view does not appear to simply be a combination of the two localized areas as before. The graph shows that with increased polishing time the improvement in planarization decreases.

4. CONCLUSIONS

The graphical analysis shows that the downward pressure applied has a positive linear effect on the polish rate. An increase in polish time shows an oscillation in the polishing rate most likely due to ridge polishing and dishing effects between the localized areas. The global view of polish rate is an "averaged" rate of the two local areas.

The improvement in planarization also appears to be connected to the ridging and dishing effects. The alternation in the graphs is clearly visible throughout both the dense and local pattern. The global view suggests that improvements in planarity decrease with increased polish time and that the downward pressure plays only a same role in the planarity.

The possible correlation between the polish rate and the improvement of planarization suggests there may be an interaction amongst the two responses. Because of this a second experiment should be performed with an expanded design space – namely increased polish time. This will allow for further insight into the oscillations seen throughout each graph.

5. APPENDIX

Some constants in the experiment:

<i>Polyimide</i>	Probimide 7520 – from Olin Microelectronic Materials
<i>Slurry</i>	882G Al oxide – from Ferro Corp.
<i>Polishing Tool</i>	Strasbaugh 6DS-SP
<i>Table Pad</i>	Rodel IC1000P
<i>Wafer Carrier</i>	4" carrier, 36 holes, no holes plugged
<i>Spindle Speed</i>	100 rpm
<i>Slurry Flow Rate</i>	300 ml/min
<i>Back Pressure applied to Wafer</i>	-5 psi

6. REFERENCES

- [1] J. Steigerwald, S. Murarka, and R. Gutmann, "Chemical Mechanical Planarization of Microelectronic Materials", John Wiley & Sons, NY, 1997.
- [2] D. Ouma, B. Stine, R. Divecha, D. Boning, J. Chung, G. Shinn, I. Ali, and J. Clark, "Wafer- Scale Modeling of Pattern effect in oxide chemical mechanical polishing", Proceedings of the SPIE – The International Society for Optical Engineering, 1997.

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