Improvement of Non-Uniformity (NU) in Chemical-Mechanical Polishing (CMP) from the Viewpoint of Consumable Effects Based on a Developed Material Removal Model

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ABSTRACT--- Controlling/designing the consumable parameters is a possible way to optimize the non-uniformity in CMP, and may be a better choice than the conventional method of adding dummy structures with the decrease of the feature size in ICs and higher requirements on the circuit performance. In this report, the motivation for improving NU by adjusting consumable parameters are discussed. Details on this report can be found in J. Luo and D. A. Dornfeld, "Improvement of NU in CMP from the viewpoint of consumable effects based on a developed material removal model," ESRC reports, UC Berkeley, 2000.

I. MOTIVATION

The non-uniformity (NU) in chemical-mechanical polishing (CMP) process is an issue associated with the non-uniform material removal rate over the wafer surface due to the uneven distribution of pressure times velocity over the surface. Basically, two kinds of non-uniformities exist in the CMP process, one is on the wafer scale, or namely the with-in wafer non-uniformity (WIWNU), the other on the die scale, or namely the with-in die non-uniformity (WIDNU) and pattern density effect. The WIWNU is related to the elastic deformation of the polishing pad and the velocity distribution over the wafer-pad interface. The WIDNU is related to the pressure difference over the different density area. Due to the non-uniform material removal rate over different locations at the wafer surface, the even-thickness surface before polishing will become non-planrized. The degree of non-planarity (NP) is defined as the height difference over the surface after polishing and determined by the non-uniformity of material removal rate and the polishing time/the average height to be polished. The non-uniformity (NU) of material removal rate can be expressed as follows once the maximum, minimum, and average material removal rate is known:

$$NU= \frac{MRR_{\max} - MRR_{\min}}{MRR_{avg}} \times 100\ \% \qquad (1)$$

Apparently, the NU is a parameter without unit. As to be shown later, the $MRR_{\max}$ in Eq. 1 is the material removal rate on the location with the maximum pressure times velocity over the wafer surface, the $MRR_{\min}$ is the material removal rate on the location with the minimum pressure times velocity over the wafer surface, and the MRR_{avg} is the average material removal rate. For WIDNU or pattern density effect, the $MRR_{\max}$ is the material removal rate on the low density area where the pressure is larger, $MRR_{\min}$ is the material removal rate on the high density area where the pressure is smaller and MRR_{avg} is the mean material removal rate over the whole die area. The non-planarity after the polishing can be written as:

$$NP= H_{\max}-H_{\min}= (MRR_{\max}-MRR_{\min})\times T= (MRR_{\max}-MRR_{\min})\times H/MRR_{avg}= NU\times H, \qquad (2)$$

where $H_{\max}$ is the height of the highest point on the wafer/die, $H_{\min}$ is the height of the lowest point on the wafer/die, T the polishing time and H the average height to be removed. Since H is a constant specified before polishing, the non-uniformity (NU) of material removal rate is linearly related to the final non-planarization (NP).

Experimental *MRR* data shows that the *MRR* satisfies the Preston's equation

$$MRR= K_p P_0 V + MRR_0 \qquad (3)$$

when the P_0V is large enough, where *MRR* is the material removal rate, P_0 the down pressure, V the relative velocity of wafer, K_p and MRR_0 two constant values independent of P_0V representing the effect of consumable parameters. A linear relationship exists between the P_0V and the *MRR* according to Eq. 3. For different consumable combinations/recipes, the values of K_p and MRR_0 may be different. Fig. 1 shows the three possible pressure times velocity dependences of material removal rate for three different consumable combinations, with different values of K_p and MRR_o.

Substituting Eq. 3 into Eq. 1, with the consideration that *MRR* is maximum when the P_0V is maximum and *MRR* is minimum when the P_0V is minimum, we have

$$NU= \frac{K_p (P_0V)_{\max} + MRR_0 - K_p (P_0V)_{\min} - MRR_0}{K_p (P_0V)_{avg} + MRR_0} = \frac{K_p[(P_0V)_{\max} - (P_oV)_{\min}]}{MRR_{avg}}. \qquad (4)$$

To reduce NU, from Eq. 4 there are basically two methods. Method 1 is to reduce the non-uniformity of the distribution of the pressure times the velocity, or reduce the value of $(P_0V)_{\max}$-$(P_0V)_{\min}$. For WIWNU, this can be realized through the optimization of polishing head and platen design. Numerical methods including finite element method (FEM) and boundary element method (BEM), and dynamics and fluid flow analysis may be helpful for analyzing and reducing the non-uniformity of the pressure and velocity distribution on this scale. Based on a similar idea, adding dummy patterns in the low-density area may help to reduce the pressure difference and therefore the NU in the die level. This method is simple. However, eventually adding the dummy features in the die level will create circuit performance difficulties, due to extra parasitic capacitance and other factors. An alternative method to reduce the NU, according to Eq. 4, is to reduce the sensitivity of material removal rate on the distribution of pressure times velocity. This can be realized through the adjustment of the Preston's coefficient K_p and the average material removal rate MRR_{avg}. The production rate cannot be decreased. Therefore, the average material removal rate should be constant or increased after the adjustment. To satisfy the above NU and *MRR* requirements simultaneously, there are basically 4 choices. They are listed in Table 1 with symbols '↑' indicating 'increases', '↓' indicating 'decreases' and '→' indicating 'keeps constant'. This can be realized based on the understanding of the material removal mechanism. A detailed model have been developed to explain this mechanism [1-3]. The details on the improvement of NU using this model can be found in [4].

II. REFERENCES

[1] J. F. Luo and D. A. Dornfeld, 'Material removal mechanism in chemical mechanical polishing: theory and modeling,' *IEEE Transaction: Semiconductor Manufacturing*, in press, 2000.

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[4]. J. Luo and D. A. Dornfeld, "Improvement of NU in CMP from the viewpoint of consumable effects based on a developed material removal model," ESRC reports, UC Berkeley, 2000.

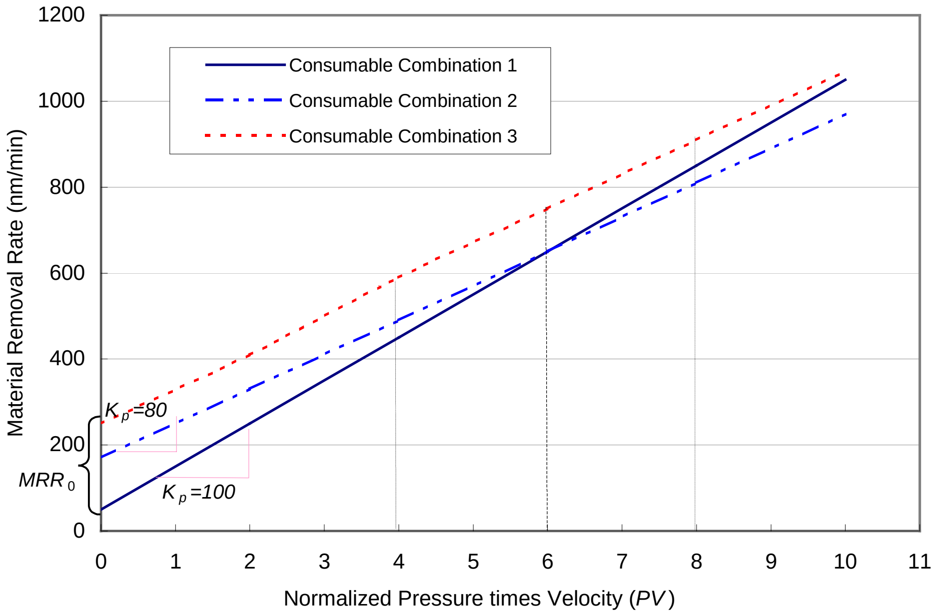

Figure 1. The material removal rate equation for different consumable combinations

Choices	MRR_{avg}	K_p
i	↑	↓
ii	↑	→
iii	↑	↑
iv	→	↓

Table 1. Four choices to improve the NU through Preston's Equation adjustment