Chemical-Mechanical Planarization for Multilevel Interconnect, CMPMIC 2001, Santa Clara, CA, March 2001.

Modeling of Pattern Dependencies in Multi-Step Copper Chemical Mechanical Polishing Processes

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Executive Summary

Copper Chemical Mechanical Polishing (copper CMP) processes are recognized to suffer from pattern dependent problems such as dishing and erosion [1], which lead to increased line resistance and thickness non-uniformity. The amount of dishing and erosion can be reduced if a well designed multi-step copper CMP process is used [2]. In a multi-step process a different slurry, different pad, and different polish process settings (down force, table speed, etc.) may be used in each step. To help design an optimal multi-step process, a pattern dependent multi-step copper CMP model is urgently needed. We present a mathematical pattern dependent model that predicts the amount of dishing and erosion across a die for a given multi-step process, and we show preliminary comparisons between the model prediction and experimental data.

Extended Abstract

Typical multi-step processes used today have two or more polish steps. In a two step process, step one uses a slurry in combination with polish process settings that give a significantly higher blanket removal rate of copper compared to the blanket removal rates of the barrier and the dielectric. In the second step, on the other hand, a slurry in combination with polish process settings that give slightly higher barrier and dielectric blanket removal rates compared to the blanket copper removal rate is used. The first step is intended to remove the overburden copper rapidly without dishing the copper and eroding the dielectric significantly. The second step is intended to remove the barrier in the non-trench regions across the entire wafer. It could also be used to reduce any excessive thickness non-uniformity within the die that resulted after the first step.

A single step (single slurry and fixed polish process parameter settings) copper CMP process comprises of three intrinsic stages [3]. Stage one deals with the removal of the bulk or overburden copper, stage two deals with the removal of the barrier material, and stage three involves overpolishing. A multi-step copper CMP process can be thought of as a combination of separate single step CMP processes, each comprised of the three intrinsic stages just mentioned.

The model formulation involves construction of removal rate diagrams for all intrinsic stages. A removal rate diagram plots removal rate versus local step-height (or dishing). Figures 1-2 show the removal rate diagrams for intrinsic stages one and three of each step in a two step copper CMP process. The figures show that the removal rates vary linearly with local step-height (or dishing). This relationship is based on experimental data for CMP processes that are chemically-enhanced mechanical wear processes, including dielectric [4], tungsten [5] and copper CMP.

In intrinsic stage one (for both steps one and two) where we have single material CMP (i.e. we are polishing copper only), we see that when the local step height is very large, there is no removal of material in the down-area. As we polish, we reduce the local step height until we reach a critical step height, at which point we begin to remove material in the down-area. Below the critical step height, the removal rate of the down-area increases linearly while that of the up-area decreases linearly until a negligible or ideally zero step height is reached, at which point we polish at the blanket copper rate. The rationale here is that below the critical step height, the pad compresses sufficiently enough to press hard on the abrasives and exert a non-negligible pressure on the down-area. When the pressure exerted on the down area increases, the corresponding pressure on the up-area has to reduce because the average pressure exerted on a localized region is finite and constant.

In intrinsic stage three, the dielectric and copper removal rates are equal to their respective blanket removal rates when there is no dishing (i.e. when the surface is flat). In step one, because the blanket copper removal rate is higher than the blanket dielectric removal rate, as we polish, the copper level dips below the dielectric level. With this, the copper removal rate reduces linearly, and that of the dielectric increases linearly until we reach a steady-state at which the removal rate of the copper is equal to that of the dielectric. In step two on the other hand, because the blanket removal rate of the dielectric is higher than that of the copper, as we polish (starting from a flat surface) the dielectric level dips below the copper level. This makes the copper the up-area, and the dielectric the down area. Hence, the removal rate of the dielectric decreases with dishing (which is now negative) while that of the copper increases until steady state in reached, at which point the removal rates of the copper and dielectric are equal.

From the removal rate diagrams, we can formulate equations of removal rates in terms of step-height (or dishing) and other modeling parameters. We can then use these equations to solve for the dishing, erosion, and the time it takes to remove the overburden copper and the barrier material. The model needs to be calibrated before it can be used to predict dishing and erosion for arbitrary layouts, for a given process. We do this calibration by performing time split experiments with a specially designed test mask, and using the data to estimate the model parameters for the given process. The model parameters are described in table 1.

Experimental Data versus Model Fits

Using a specially designed test mask, we performed single and two step time split copper CMP experiments on an IPEC 472 polisher. Using the dishing and erosion data for some of the test structures on the mask, we extracted the model parameters for both steps one and two. We then used the calibrated model to predict the dishing and erosion for the test structures not used in the calibration process. Comparisons between the model fits and the experimental data for two of these test structures are shown in figures 3 - 6. As shown in the figures, in the first polish step, dishing first increases and later saturates as overpolish time increases, while erosion increases with overpolish time. In the second polish step, dishing decreases with polish time because the dielectric blanket rate is now higher than the copper blanket rate. Erosion on the other hand continues to increase with polish time, in the second step. If we polish longer, we will reach steady state where the dishing will saturate close to zero, the recess caused by the first step will be eliminated, and the rate of erosion will almost be equal to the blanket dielectric rate

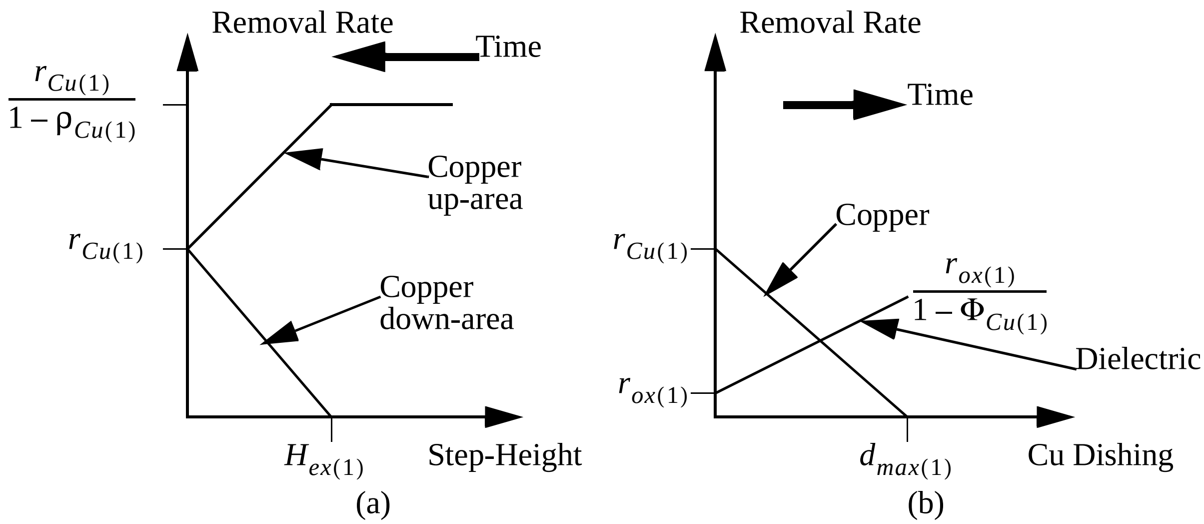

Figure 1: (a) Intrinsic stage one of polish step 1; (b) Intrinsic stage three of polish step one.

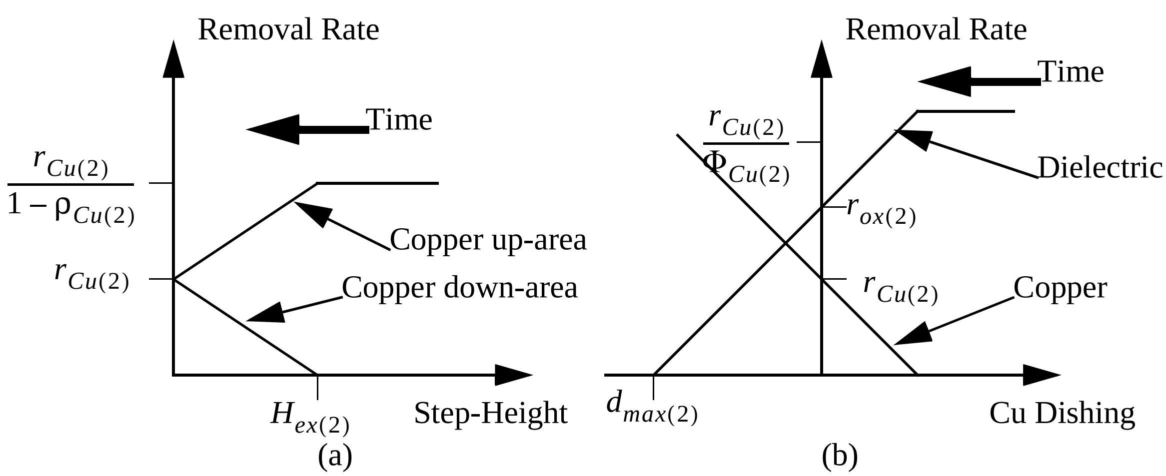

Figure 2: (a) Intrinsic stage one of polish step 2; (b) Intrinsic stage three of polish step two.

Table 1: Description of Model Parameters shown in figures 1 - 2.

Parameter	Description
r_{Cu}	Blanket copper removal rate at location of die of interest.
r_{ox}	Blanket dielectric removal rate at location of die of interest.
H_{ex}	Critical local step-height below which we begin to polish the down-area.
d_{max}	Maximum dishing: depends on line width, line space and process.
ρ_{Cu}	Effective copper density: Computed from layout over appropriate length scale.
Φ_{Cu}	Copper pattern factor: Depends on short range layout density and line space.

because the blanket removal rates of the dielectric and the copper are very close in step two). We see this in figure 6, where as the second step polish time increases, the amounts of erosion for the 80% and the 33% density structures become identical, and the rate of erosion becomes approximately the blanket dielectric removal rate. From figures 3 - 6, we see that the model captures the trends in two-step copper CMP processes both qualitatively and quantitatively.

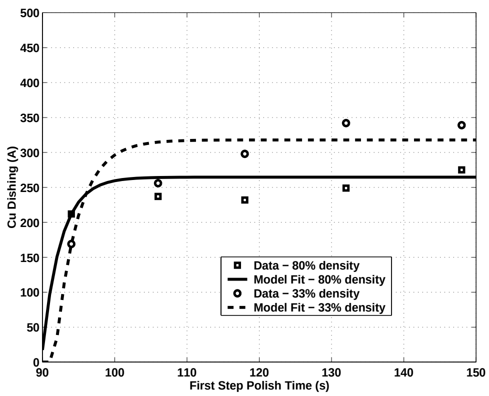

Fig 3: Dishing versus polish time for step one (blanket copper rate is 135 Å/s and blanket dielectric rate is 1.5 Å/s in step one).

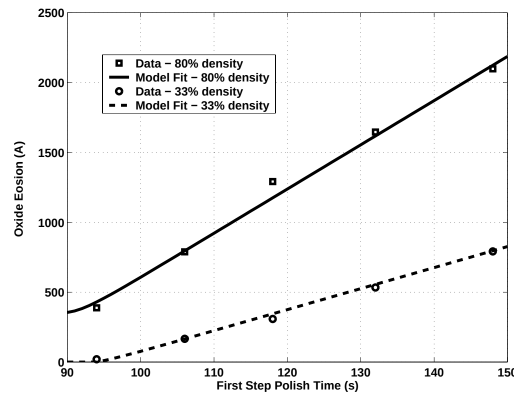

Fig 4: Erosion versus polish time for step one (blanket copper rate is 135 Å/s and blanket dielectric rate is 1.5 Å/s in step one).

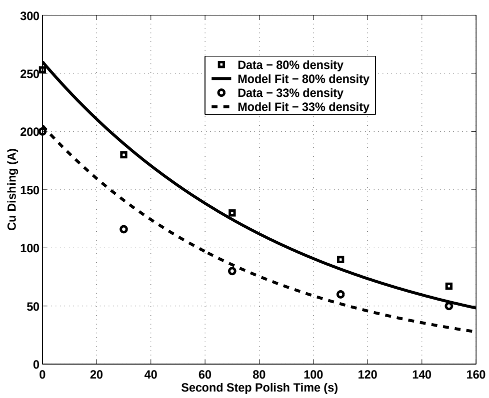

Fig. 5: Dishing versus second step polish time for two step CMP process (blanket copper and dielectric rates are 12 Å/s and 18 Å/s).

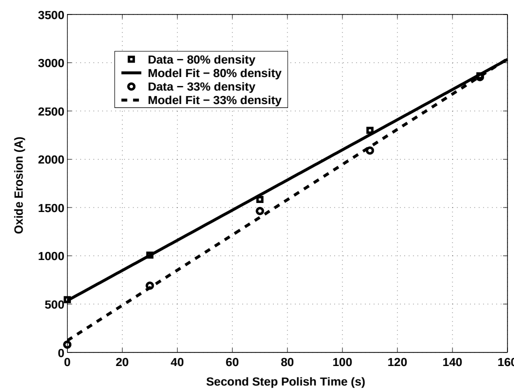

Fig. 6: Erosion versus second step polish time for two step CMP process (blanket copper and dielectric rates are 12 Å/s and 18 Å/s).

References

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