Planarization Length: Concept and Determination in Dielectric CMP Process

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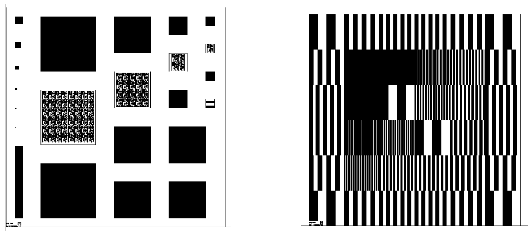
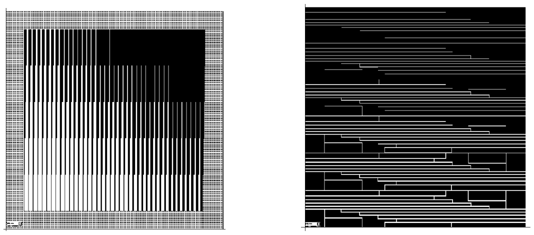
The purpose of this brief description is to explain the concept of “Planarization Length” without confusing details. Those who are interested in further information, please contact SKW Associates for references.

A set of 4 masks, as shown in Fig.1, was developed by MIT research group in 1996 under Prof. Duane Boning and Prof. James Chung to identify and quantify pattern effects in oxide chemical mechanical polishing (CMP). Each mask, with the die size of 12mm x 12mm, was designed to target different pattern factors: area, pitch, density, and perimeter over area. The area mask contains structures with varying size, the pitch mask contains varying pitch blocks at constant 50% pattern density, the density mask contains varying density blocks with constant pitch of 250μm, and the perimeter over area mask contains structures with the same area but with different x and y perimeters.



Area Mask **Pitch Mask**



Density Mask **Perimeter/Area**

Fig. 1: Original MIT CMP Characterization Mask Set

The experimental results from running a short-flow experimentation are summarized in Fig.2 where each graph shows polished oxide thickness vs. pattern in study. As seen in the graphs, there are no significant dependencies on the pattern of area, pitch, and perimeter/area, but a clear linear dependency is observed for pattern density. This study, along with various experiments with variants of this density mask and other improved masks, have shown so far to date that density is the key pattern factor that affects oxide polishing.

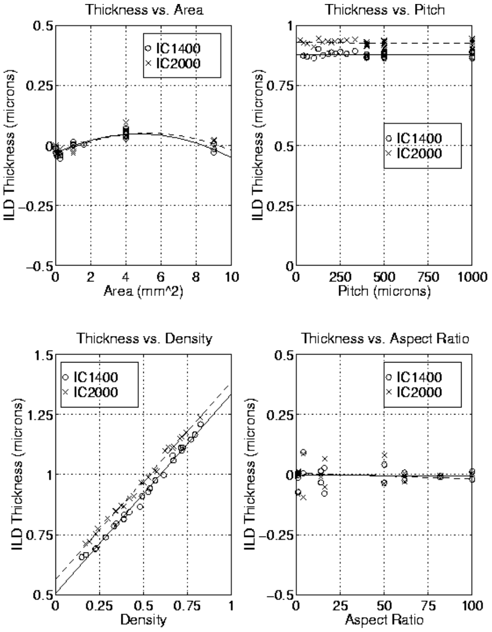
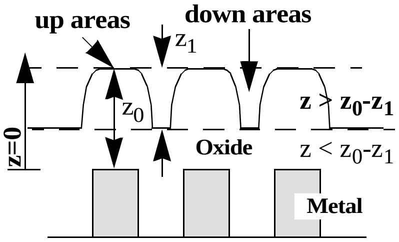


Fig. 2: Experimental Result. Density shows key dependency.

From this observation, an analytical model based on pattern density was formulated starting with the Preston’s equation (Eq. 1). The model states that the oxide polish rate at each point on a die is inversely proportional to the effective density, and the effective density at each point depends on the nearby topography and density. This effective density is determined by averaging density over a surrounding region and this region is determined by the planarization length which must be characterized for a given CMP process and consumables.

Shown in Fig.3 are the oxide deposition profile (assumed conformal) and the model formulation with parameter information. The model falls into 2 regimes: the first is the phase of removing up or raised areas (thus, need to calculate pattern density assuming conformal oxide deposition) before local regions become planar, and the second is the phase after the local planarity where oxide now polishes at blanket polish rate (i.e. density of 1 or 100%). This pattern density change over polish time is shown with Eq. 2. The final oxide thickness is shown in Eq. 3, and if enough polishing is done to remove all the up areas, the model states that the



Layout and Deposition Profile

z = final oxide thickness over metal features.
K = blanket oxide removal rate for die of interest.
t = polish time.
ρ_0 = local pattern density.

Oxide CMP Model Formulation

- Removal rate inversely proportional to effective density (***Eq. 1***).

$$\frac{dz}{dt} = -k_p p v = -\frac{K}{\rho(x,y)}$$

- Density assumed constant (equal to layout pattern) until local step has been removed (***Eq. 2***).

$$r(x,y,z) = \begin{cases} \rho_0(x,y) & z > z_0 - z_1 \\ 1 & z < z_0 - z_1 \end{cases}$$

- Final oxide thickness linearly related to effective density (***Eq. 3***)

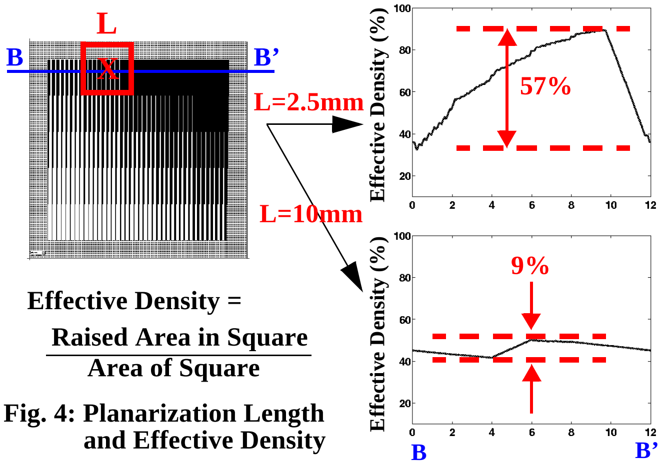
$$z = \begin{cases} z_0 - \left(\frac{Kt}{\rho_0(x,y)}\right) & Kt < \rho_0 z_1 \\ z_0 - z_1 - Kt + \rho_0(x,y) z_1 & Kt > \rho_0 z_1 \end{cases}$$

Evaluation of pattern density $\rho_0(x,y)$ is the key to model.

Fig. 3: MIT Pattern Density Oxide Model

polished thickness depends linearly on the effective pattern density with slope of initial step height.

Here is an example to illustrate the concept of effective density. As shown in Fig.4, we want to calculate the effective or the average density across B and B’ for the density mask. To obtain effective pattern density for each point along the line, for example the point X, we take the average (raised area in the square over the area of the square) of pattern density over the given square with size L. Two effective density profiles are shown for L of 2.5mm and 10mm. Because you are averaging over a larger area, the effective density range for L=10mm is a lot less (9%) than that for L=2.5mm (57%). We know that the final oxide thickness is linearly related to the effective density, thus higher the number L, more planar the final oxide thickness is going to be. This concept of the length scale L of polishing is what we refers to as planarization length (PL). The planarization length is unique to a given process and must be characterized for each process consumable set. Typically, it ranges in the order of 3-6mm with conventional CMP tools and consumables, and stiffer pads give longer PL.



Effective Density = $\dfrac{\text{Raised Area in Square}}{\text{Area of Square}}$

Fig. 4: Planarization Length and Effective Density

Thus, conceptually the planarization length determines a region over which we calculate the density, and physically it relates to the distance beyond which other features no longer affect the polishing rate of the feature of interest. Mathematically based on the model, the planarization length is determined by fitting experimental data with effective pattern density calculated for various PL and finding the best model fit which gives the associated PL.

The following figure, Fig.5, shows a sample data set and model fit for the effective density and also for spatial location along 10% and neighboring 90% density structure. The data is from using MIT’s latest ‘Dielectric CMP Characterization Mask’ which contains gradually and abruptly varying density structures as well as pitch structures. As seen, there is an excellent fit between the data and model.

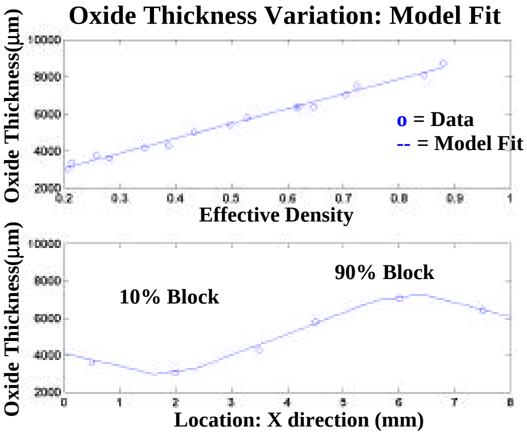


Fig. 5: Oxide CMP Data and Model Fit