

## CHAPTER 8

### SUGGESTIONS FOR FUTURE RESEARCH

Based on the analytical and experimental results presented in this thesis, future research on the CMP process may be directed toward the following areas.

- *Process Optimization*

In Chapters 2 to 5, several process optimization schemes were proposed to enhance the overall MRR and the wafer-, die-, and device-level uniformity in Cu CMP. Those schemes must be integrated to determine the optimal process windows.

First, at the wafer-level, as shown in Chapter 2, the optimal ratio of relative velocity to pressure can be determined by maintaining the process in the contact regime. In practice, however, the optimal pressure and velocity values are constrained by the machine capability, machine vibration associated with the high pressure application, the slurry transport, and the heat generation and dissipation in the system. As a result, the optimal pressure and velocity condition may deviate from the theoretical optimal point. Experiments can be designed and conducted to investigate these effects and determine the process recipes for optimal wafer-level polishing. Additionally, new methods of slurry dispensing, such as through the pad instead of outside the wafer/pad interface, may improve the continuity of slurry flow and enhance heat removal. Moreover, the overall MRR can also be enhanced by using larger abrasive particles in both planarization and polishing regimes, as shown in Chapter 3. Small, soft abrasives may be employed near the onset of endpoint to control surface roughness.

Second, at the die-level, retaining the planarity in Cu planarization stage and increasing the oxide to Cu selectivity in the polishing regime are the keys to maintain surface uniformity. A pad with a stiff surface layer may be employed to maintain surface planarity across patterns (subdie areas) of different area fraction. Chapter 4 presented the effects of elastic properties

of the pad on pad displacement. This will help select the pad properties so that the pad does not conform to the surface topography in a die and retain the surface planarity. As proposed in Chapter 5, the effects of particle hardness and size can be employed to increase the selectivity between Cu and the surrounding oxide.

- *Effect of Chemistry on Material Removal Rate*

Another line of research may focus on the effects of chemistry on the MRR and WIWNU. Based on the preliminary tests on blanket oxide polishing, the pH value greatly drastically affects the MRR of TEOS coating. With the pH value around 11 (Rodel 1501-50 slurry), the MRR increased by an order of magnitude, about 200 - 250 nm/min compared with 20 nm/min with neutral slurry. Similarly, the CMP literature suggests that the MRR increases with a slightly acidic slurry. It is hypothesized that the oxide in the basic slurry and Cu in acidic slurry form thin passive films on the surface by chemical reaction. The film is softer than the initial coating and thus more easily removed by particle abrasion. Many techniques, such as SEM, Auger spectroscopy, and AFM can examine the morphology and composition of the surface to verify the hypothesis. Additionally, micro-indentation tests can measure the hardness of the coating surface in slurries of different pH on Cu, oxide, and other coatings. The results can investigate the effects of chemistry on the material removal behavior by changing the mechanical properties of the coating surface.

- *Slurry Transfer Behavior*

Uniform slurry transfer to the interface is crucial to minimize WIWNU. The slurry flow may be retarded with increase of wafer size. It is necessary to investigate the effects of process parameters on the slurry flow. Based on the results of previous tests, the pressure applied on the retaining ring of the wafer carrier and the velocity-to-pressure ratio, which determines the interfacial contact condition, are important parameters to control for within-wafer uniformity. Experiments must characterize the effects of these parameters to determine the optimal process window for high MRR and acceptable WIWNU. Additionally, the slurry viscosity and the pad macro- (grooves or perforations) and micro-structure (porosity and interconnection of pores) affect the global and local slurry flow. It may be possible to model

the deformation of the porous structure and the local slurry transfer based on the mechanics of cellular solids and fluid dynamics. The model will explain the local slurry transport phenomenon and identify important design parameters for the pad to improve slurry transfer and the polishing uniformity.

- *In-Situ Sensing on Various Pattern Designs*

Chapter 6 reviewed both analytical and experimental results of reflectance sensing to characterize the surface condition of the wafer at different stages and to detect the process endpoint. The proposed process monitoring and endpoint detection schemes, however, must be validated by different mask designs. Experiments may be conducted on the patterned wafer with layout close to the commercial IC designs. Moreover, multi-level Cu oxide damascene structures must be examined with the existing sensing technique to investigate the effect of the underlying Cu interconnects on surface reflectance and the effectiveness of the detection schemes.

- *Integration of Low-k Dielectric in CMP*

As shown in the SIA roadmap in Table 1.1, materials with low dielectric constant (low-k) will be incorporated to fabricate ILD layers in the next-generation ICs. One of the challenges to low-k integration is its reliability and compatibility with the CMP process. MRR, surface nonuniformity, and CMP related defects, such as scratching, are still the main issues for throughput and yield of the process. For the immediate replacement of the present PECVD oxide ( $k = 4.1-4.3$ ), some silicon-based ceramics, such as silicon oxyfluoride ( $k = 3.4-4.1$ ), hydrogen silsesquioxane ( $k = 2.9$ ) and nanoporous silica ( $k = 2.5$  or less), seem to be the best candidates. Since their mechanical properties are close to silicon oxide, the models developed in this thesis may be employed to predict their outputs and optimize the process. Preliminary experiments can be quickly run on blanket wafers with these coatings to verify the models. On the other hand, for  $k$  values less than 3, some polymers, such as polyarylene ether (PAE,  $k = 2.6-2.8$ ), bis-benzocyclobutene (BCB,  $k = 2.6$ ) and polytetrafluoroethylene (PTFE,  $k = 1.9$ ), may be adopted as the dielectric materials in a long term. Because polymer polishing depends on molecular weight, the molecular structure, the orientation of the polymer and the cross-link

density, etc., experiments must be conducted to characterize these effects on polishing mechanisms. Additional chemicals may weaken the secondary bonds and enhance the removal rate.

Additionally, because polymers are generally softer than Cu, instead of Cu dishing the surrounding low-k features may easily dish and increase the nonuniformity. The contact mechanics model and the models for dishing and overpolishing, may still be applied to evaluate the pressure distribution and the evolution of patterns. However, the concept of hardness employed in metal or ceramic polishing needs to be modified to account for the viscoelastic behavior of the polymers. Moreover, some polymers may be highly reflective. Thus, the wavelength of the light source of the sensing system must be selected to increase the difference of the surface reflectances of Cu and the dielectric, and thus improve the effectiveness of endpoint detection.