CMP Pad Design for Ultra-low K Compatible Cu CMP Process

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CMP is an enabling process technology for advanced sub-micron integration using copper damascene. Copper CMP process must meet increasingly stringent requirements for metal loss. ITRS 2005 suggests a total metal loss budget (at 10% of total metal) of 120 Å at 65 nm, which reduces to 60Å for the 32nm node[1]. ITRS roadmap also suggests potential simultaneous incorporation of low-k dielectric, which will likely be porous. Novel dielectrics and their stacking are susceptible to cohesive and adhesive failures, when processed under conditions, which are optimized for conventional dielectrics. Consequently, low-k process integration must include a planarization technology, which offers low mechanical impact to the target materials. Additionally, process must offer the ability to process wafers with minimal over-polish to achieve metal loss and defectivity targets.

While incorporation of porous low-k for sub 45nm technology nodes is one of the most demanding applications, planarization of all films used in advanced semiconductors and MEMS technologies requires processing in an optimized process regime along with the ability to control across-wafer removal profiles. As indicated in Table 1, CMP of conventional oxides for ILD and PMD at the 130 nm technology node is generally performed at higher down force and leverages high abrasive content slurries. In contrast, metal-polishing slurries have a greater chemical component to the removal and operate under more moderate down force conditions. Advanced metal dielectric CMP slurries for 45nm use low abrasive content and may be as low as sub-one percent abrasive content by weight.

Table 1: Evolution of Polish Down Force

Application	130 nm	45nm
Oxide	5-6 psi	
STI	3-4 psi	2-3 psi
Tungsten	5 psi	3 psi
Copper	3-5 psi	2 psi
Copper - Low k		< 2 psi

As CMP processes move to lower mechanical stress processes, an improvement in CMP equipment, slurries and pads is required to achieve required process performance.

Conventional pad technology includes a top-pad layer with or without an under-pad layer to provide a polishing surface[2-5]. Polishing pads provide local planarization due to inherent material hardness and global uniformity due to the flexing action of the polishing layer. While such pads have served the industry well, inherent coupling of key output parameter, planarization and WIWNU, limits the overall performance potential (Table 1). Conventional pad systems suffer from two primary limitations. Firstly, the continuous nature of the top polyurethane layer gives rise to an edge rebound effect as it passes under the wafer or in some cases, the (wafer) retaining ring. While retaining rings help mitigate the edge rebound effect, significant edge-related non-uniformity remains. Secondly, global compliance or with-in-wafer non-uniformity (WIWNU) considerations necessitate that the total stack has limited stiffness thus impacting within-die planarization. For example, a soft pad stack has a lower flex modulus and compression modulus, which enables good contact at low pressures. A hard pad stack, on the other hand, has a much higher flex modulus and compression modulus, hence, offers limited contact at lower pressures. This process leads to non-uniform contact at low pressures as well as variation in contact pressure leading to potential contact "Hot Spots".

Table 2: Pad Design and Performance Attributes

Performance Attribute	Conv. Pad	eSQ Pad
Planarization & Edge Profile	Coupled	Decoupled
Global Profile Control	Unavailable	**Enabled**
Planarization & Global Uniformity	Coupled	Decoupled

A novel CMP pad design platform is presented. As indicated in the table 2 above, there is a significant distinction in the approach of the eSQ technology compared to the conventional stacked-pad approach. The new pad design overcomes fundamental limitations associated with conventional pad technology. Among the various design elements, the eSQ Planarizer™ is specifically designed to enable low down force polishing, and to work with advanced consumables via a novel compression compliance mechanism. The compression compliance mechanism enables a highly uniform contact pressure across the entire wafer surface over a wide range of pressure conditions. Through a combination with additional design elements, this mechanism can be leveraged to provide removal profile control. The new pad design decouples various polish pad attributes, which in turn directly decouples specific performance characteristics. Through a simplified process of individual and direct optimization of process characteristics, significant improvement in overall polish process performance can be achieved.

In this paper, we address two key requirements of a Cu-low k process which relate to performance benefits offered by the eSQ Planarizer^{TM}; low downforce process capability and edge profile control. A conventional best-known-method (BKM) pad and the eSQ Pad™ were tested across W and Cu applications. Screening DOEs was performed to establish removal rate and uniformity using blanket wafers to compare performance between the eSQ Planarizer™ and BKM pad. Removal rates and with-in-wafer non-uniformity (WIWNU) were determined based on diameter scans at 2mm and 4mm edge exclusion for tungsten and copper respectively. Normalized removal profiles are presented.

EXPERIMENTAL SETUP

All 200mm wafers were polished using Applied Materials Mirra polisher and 300mm wafers were polished using Applied Materials Reflexion polisher at Advanced Tool Development Facility (ATDF). Identical pad break-in procedure and process conditions were used for the BKM pad and eSQ planarizer^{TM}. Metal film thickness measurements were performed with a Philips Impulse 300B with a TM superscript, and not a Rudolph Metapulse. The topology mesurements were performed with a Veeco Vx 310 with the TM superscript after the Vx.

RESULTS AND DISCUSSION

Figure 1 shows the radial profiles for a 200 mm tungsten wafer process using a 45 nm node-capable tungsten slurry. Identical process parameters were used for both pads. While the overall WIWNU profiles (49-pt dia. scan, 2 mm EE) are comparable, the edge profiles are significantly different. These differences in performance are minimized via the 49-pt WIWNU statistic. For BKM pad, the classical edge rebound effect is evident, even though processed on a carrier head of the AMAT Mirra, which uses a differentially controlled retaining ring. The magnitude of the edge range characterizing the rebound effect is significantly lower for the eSQ planarizer^{TM}. On a normalized basis, the edge range for the eSQ planarizer^{TM} is approximately 50% lower than that of BKM pad.

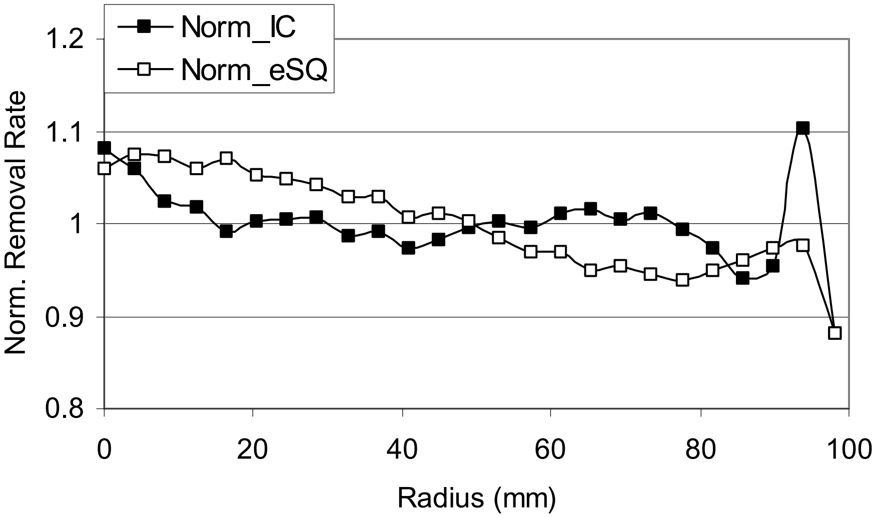

Figure 1: Radial Removal Profile Comparison for WCMP

Figure 2 displays the radial removal profiles (75-pt dia. scan, 4 mm EE) for wafers processed with the BKM pad for a 200 mm Cu process using slurry targeted for 45nm technology node. Note that the shape of removal profile changes as pressure is increased from 1 psi to 2 psi. The overall shape of the profile, however, remains the same when the pressure is increased from 2 psi to 3 psi.

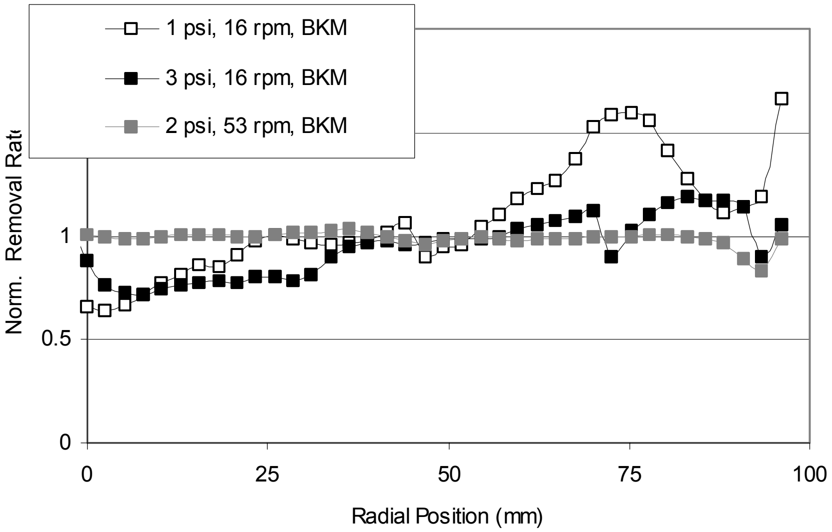

Figure 2: Radial Removal Profile evolution for low Pressure Copper CMP using BKM Pad

Figure 3 shows the corresponding removal profiles for wafers processed with the eSQ Planarizer™ for the same 200 mm Cu process. Note that the shape of the removal profile remains the same across the pressure range from 3 Psi down to 1 Psi, indicating a uniform contact across the entire wafer surface upto 1 Psi conditions.

The eSQ Planarizer™ was also evaluated on an advanced 300 mm platform. Figure 4 and 5 show the radial removal profiles (66-pt dia. scan, 3 mm EE) for wafers processed BKM pad and eSQ pad respectively. Profile change similar to the one observed at 200mm platform, is seen for wafers processed on the 300 mm platform. While wafers polished with BKM pad shows a removal profile transition as pressure is increased from 1 Psi to 2 Psi, wafers polished with eSQ planarizer show stable profiles. across the pressure range and have 50% lower WIWNU compared to the BKM pad (9 % @ 3 mm for SQ vs 17 % @ 3 mm for BKM).

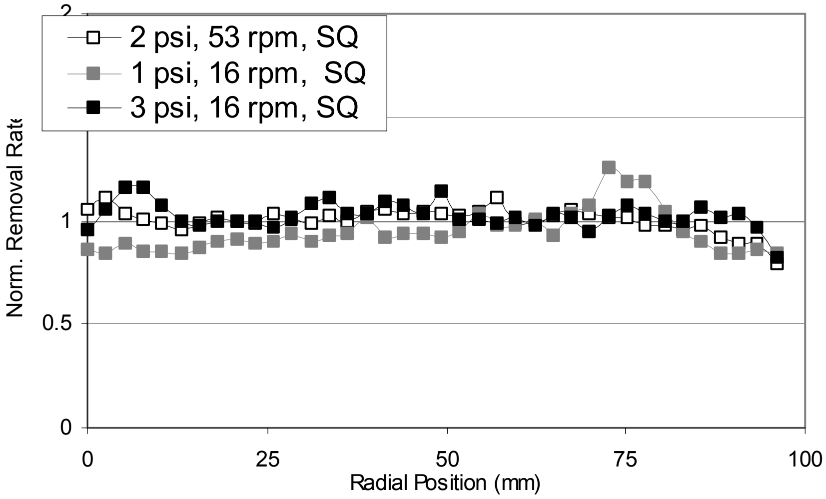

Figure 3: Radial Rem. Profile evolution for low Pressure 200mm Copper CMP using eSQ Planarizer™

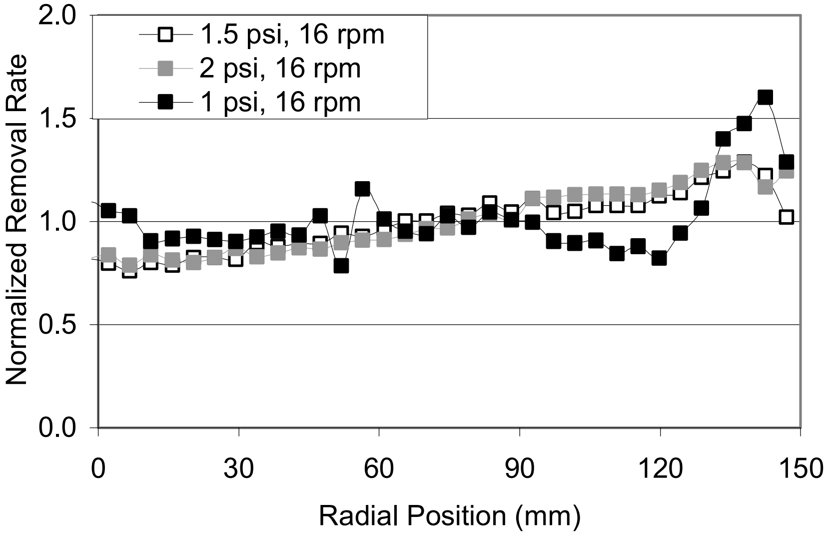

Figure 4: Radial Removal Profile evolution for low Pressure 300mm Copper CMP using BKM pad

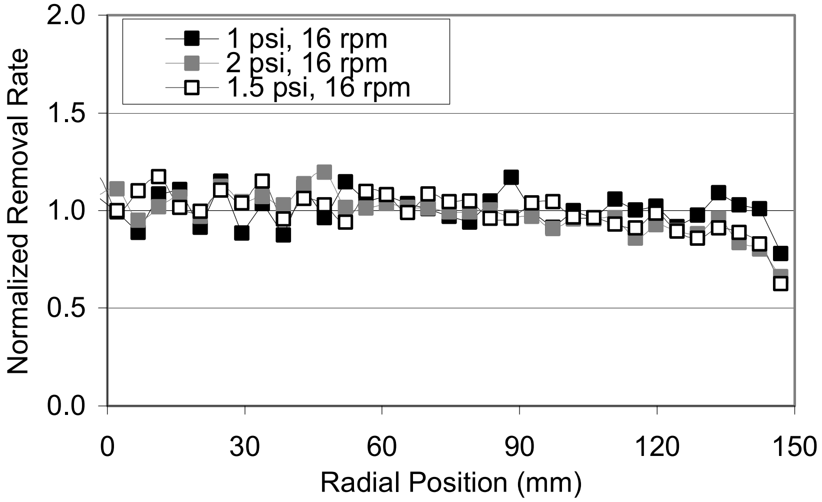

Figure 5: Radial Rem. Profile evolution for low Pressure 300mm Copper CMP using eSQ Planarizer™

A significant edge component is observed in removal profile of the wafers processed with BKM pad. The improvement in WIWNU is primarily driven by edge profile improvement. At 1 psi, the edge range for the BKM pad is approximately 3X that of the SQ pad (88 % for BKM vs 31 % for eSQ).

Patterned wafers were polished at optimized conditions to determine dishing, erosion and total metal loss performance (Figure 6 and Figure 7). A new test vehicle, using the next-generation integration test mask set (454AZ) and 854 mask set from the ATDF were used to compare process performance of the new pad vs. the existing BKM pad. The data presented here is for 854 mask set. Optical end point signal was used to complete polishing of wafers polished on BKM pad while wafers polished on the planarizer™ were polished by time. Single step polish process, developed for BKM pad, was used on both pads. Three dies located at center, mid-radius and at edge of the wafer were measured to establish

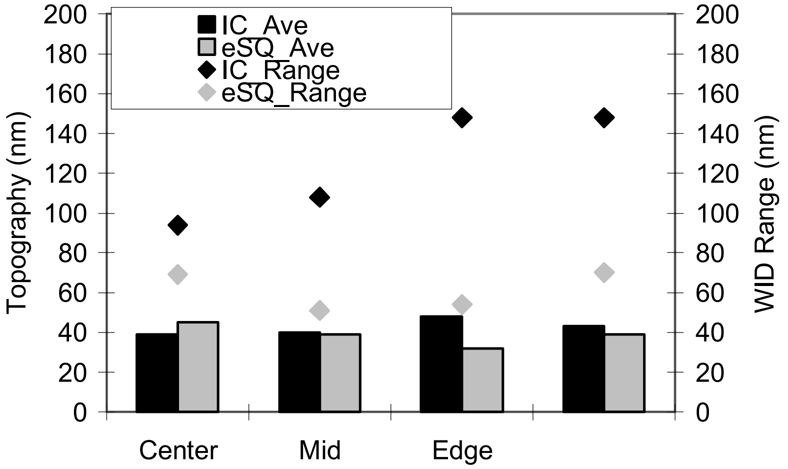

Figure 5: Average and Range of WID Dishing performance Across the Wafer (Arrays)

within-die as well as total across-wafer performance. A total of 13 sites were measured in each die covering pattern density from 10% to 90% and feature size from 0.18 μm to 50 μm. Average and range of all dishing measurements in each die were computed. The average dishing number is indicative of WID metal loss, while range is indicative of the WID variation in metal loss. Figure 6 shows the WID average dishing and range of all features in arrays. As data shows, the average WID metal loss is similar for IC and eSQ planarizer$^{\text{TM}}$. The WID range shows a significantly higher range at the edge of the wafer when using BKM pad. ESQ planarizer$^{\text{TM}}$ shows a lower and same value across all dies. Figure 7 below shows the same data as figure 6 for isolated features. The trend for dishing in isolated features is identical to the one observed in arrays.

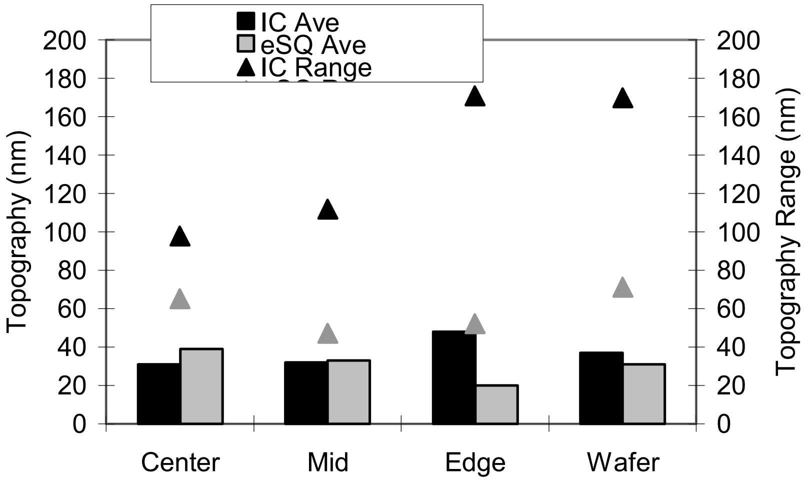

Figure 7: Average and Range of WID dishing performance across the wafer (Isolated features)

CONCLUSIONS

A new pad platform is presented. The unique design of eSQ planarizer $^{\text{TM}}$ effectively mitigates the pad rebound effect leading to more than 2X improvement in edge range and significant improvement in with-in wafer uniformity. New architecture enables more effective low-pressure contact leading to a > 3X improvement in edge range and 2X improvement in WIWNU performance at 1 Psi (and lower) down force. With in wafer (WIW) uniformity improvements directly translate to improvements in edge-die performance.

REFERENCES

1. International Technology Roadmap for Semiconductors, 2005 Edition, International SeMaTech
2. “Filled Polyurethane Pad for Chemical Mechanical Polishing”, G. Wu, et.al., CMP-MIC, Feb. 2005.
3. “Optimization of CMP Pad Groove Arrays for Improved Slurry Transport, Wafer Profile Correction and Defectivity Reduction”, G.P. Muldowney, et.al., CMP-MIC, Feb 2005.
4. “A Model for Wafer Scale Variation of Removal Rate in Chemical Mechanical Polishing Based on Elastic Pad Deformation”, G. Fu, A. Chandra, J. of Electronic Materials, Vol. 30, No. 4, 1 April 2001, pp. 400-408.
5. “Characterization and Modeling of Oxide Chemical-Mechanical Polishing Using Planarization Length and Pattern Density Concepts”, D. Ouma, et.al., IEEE Transactions on Semiconductor Manufacturing, Vol. 15, No. 2, May 2002.