

The Real Impact of Selectivity on CMP Performance

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Abstract

Slurry selectivity has become increasingly more important in the minds of CMP engineers over the last ten to fifteen years. In many ways, the improved natural selectivity properties of ceria drove the recent, and ongoing, conversion of oxide slurries from silica to ceria. However, selectivity is often defined as the ratio of oxide removal to nitride removal based on polishing blanket wafers for sixty seconds. This can be deceiving in many ways since blanket wafers are not always reliable models of pattern wafers that contain both topography and multiple materials in contact with the slurry at the same time.

By better characterizing both the blanket and pattern behavior of a slurry, it is possible to reveal critical characteristics of slurries hitherto unknown – or at least uncharacterized – in the larger CMP world. It is the purpose of this paper to summarize the experimental results that have led to this understanding and to discuss the impact that such knowledge has on slurry design and performance.

1. Introduction: Selectivity in STI CMP

As devices continue to shrink, control of the transistor dimensions becomes ever more critical. The Shallow Trench Isolation (STI) process allows much tighter packing of transistors, whilst minimizing current leakage and crosstalk. The STI process was developed to effectively isolate the active areas that form the transistor gates at the device level. It allows superior scalability and fulfils the planarity requirements for lithography¹, compared to earlier techniques.

One of the greatest challenges for the integration of STI structures in circuits is to develop a well-controlled planarization process using Chemical Mechanical Polishing (CMP). The CMP process is carried out following the formation of the isolation structures (trenches) by etching and the filling of the trenches with a dielectric material (traditionally HDP CVD oxide down to the 45nm technology node). After the oxide deposition, there is usually substantial topography across the structure, the result being that the oxide over the active areas is thicker than that over the field (trench) areas. CMP is used to reduce the topography down to the silicon nitride CMP-stop layer deposited over the active areas. An important aspect of the process is that it needs to produce minimal dishing in the trench oxide after an overpolish step, which is necessary to remove all of the active oxide from the active area nitride. The selection of the polishing slurry is therefore critical.

Apart from producing low dishing, other requirements of the slurry are that it must give: fast planarization (step height removal), high selectivity (oxide to nitride), and low defectivity. Traditionally, silica-based slurries have been used, but due to the increasingly stringent

requirements of the evolving technology, these can no longer provide the required performance for the finishing (stop on nitride) step. This is especially true for the next generation oxide, deposited by the High Aspect Ratio oxide Process (HARP) from Applied Materials², believed to be superior to HDP oxide for sub-45nm technology, where silica slurries show a much greater pattern dependency than the newer ceria-based slurries and have therefore been removed from the process altogether³. Ceria slurries are becoming dominant for sub-65nm node STI polishing for the finishing step, with silica slurries only being used for the first (bulk oxide removal) step. Other than decreased pattern dependency, ceria slurries show greater oxide to nitride selectivity, which limits the amount of nitride erosion.

Slurries with selectivities of >100:1 (as measured on blanket wafers) are now available, which limit nitride loss, but at the same time minimize dishing, even at extended overpolish times⁴. This paper describes the impact of using such high selectivity slurries in the STI CMP process, along with their mechanism of action. A comparison of blanket and pattern wafer selectivity is given and also an explanation of how both dishing and process-related rework can be minimized with respect to lower selectivity slurries.

2. Blanket vs Pattern Selectivity

In the STI CMP process, the main goal is to completely remove the oxide from the silicon nitride hardmask in the active areas of the transistors, whilst maintaining the desired field oxide height in the field (trench) areas (i.e. minimizing dishing in the trench). A major factor in evaluating the performance of a STI slurry is its oxide to nitride selectivity and this is commonly expressed as the 60 second blanket oxide wafer removal rate divided by the 60 second blanket nitride wafer removal rate. However, when pattern wafer selectivity is measured, it is observed to be lower than blanket selectivity (pattern wafer selectivity is defined as the rate of trench oxide removal rate divided by the active nitride removal rate). Suppression of the trench oxide removal rate by the nitride layer, and uneven clearing of active oxide contribute to this reduction in selectivity. High selectivity slurries (HSS) using amino acid chemistries can achieve greater than 100:1 selectivity, while older generation slurries that use polyacrylic acid (PAA) chemistries have selectivities around 40:1. Amino acid slurry systems have several key advantages when compared to PAA slurry systems. However, using the 60-second blanket wafer measure of selectivity can often mask these advantages.

To more accurately predict slurry performance, time-based polish data must be evaluated. When looking at time-based removal data (Figure 1), two differences in behavior are noted. The first is that the blanket nitride removal of the amino acid slurry is not linear with respect to time. This is a critical behavior that leads to significant dishing and defectivity benefits. The second difference is that the amino acid slurry blanket oxide rate is less than that of some PAA slurry systems. While both systems can be modulated with respect to oxide rates, there are some advantages afforded by this protection of oxide that will be referenced later in this paper.

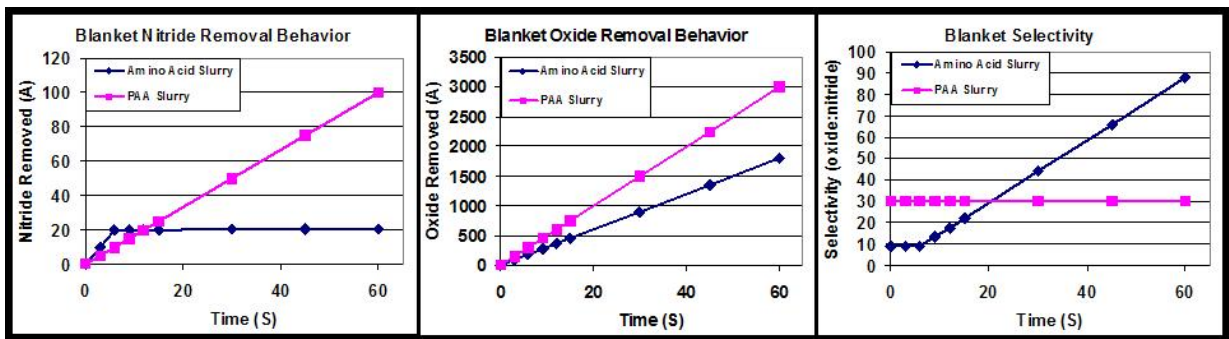


Figure 1: Blanket Removal Rate and Selectivity Comparison

The blanket nitride rate is high for the first five or six seconds, but after that the removal is almost 100% suppressed. This “induction” period is due to the time required for the amino acid suppressant chemistry to effectively bond to the nitride surface. At approximately 20 seconds polish time, both the amino acid slurry and the PAA slurry have a blanket selectivity of 30:1. However, from that point on, the amino acid slurry continuously increases in selectivity since blanket oxide removal continues while blanket nitride removal stops.

This non-linear behavior of amino acid slurries is also observed on the nitride layer of pattern wafers. However, here the amino acid slurries show a clear advantage over PAA slurries in their stopping behavior on trench oxide (see figure 2).

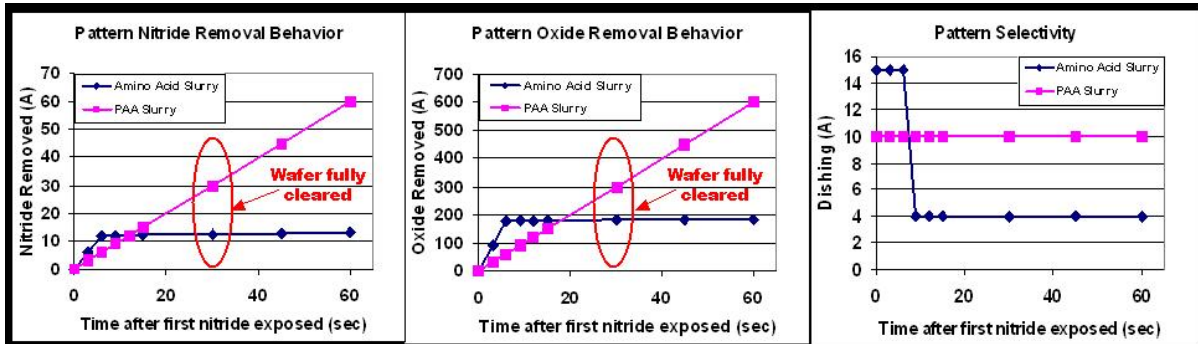


Figure 2: Pattern Removal Rate and Selectivity Comparison

Due to the incoming wafer deposition and within-die variety of features, the active oxide above nitride does not clear at the same time for all sites or at all locations on the wafer. Therefore, some features and wafer dies will be over-polished in order to clear all active oxide from the entire wafer. This unavoidable behavior leads to nitride being exposed locally in certain areas for some time prior to the end-point.

For PAA slurries, that local exposure of nitride results in a localized suppression of both nitride and oxide rates, but polishing still continues in a linear fashion. Therefore, by the time the wafer has fully cleared, a significant amount of nitride and trench oxide has been eroded in those areas where nitride was first exposed. This leads to within-wafer and within-die non-uniformity issues as well as high average dishing values. This can also lead to areas of higher defects due to the localized over-polishing that occurs.

Amino acid slurries experience a similar linear removal while the suppression chemistry is becoming active, but after that, both nitride and oxide structures are protected. This behavior acts to minimize dishing and defectivity. Beyond simply minimizing dishing, it also dramatically reduces the feature-dependent dishing behavior seen with PAA slurries.

3. High Selectivity Ceria-Based Slurry Mechanisms

The use of polyacrylic acid derivatives to achieve effective planarization can have other negative impacts. For example, depending on the molecular weight and other polymeric characteristics of the PAA used in the slurry, the interaction with the ceria particle can cause agglomeration and slurry instability that leads to limited pot-life⁴. Amino acid additives give superior planarization, but do so by interacting with the wafer surface and not with the particle,

leading to very long shelf- and pot-life. This can be clearly seen in Figure 3 where the zeta potential curves are shown for three slurries. The control slurry is a bare ceria particle in water. The fact that the amino acid slurry curve is almost identical to that of the bare ceria indicates virtually no impact of the amino acids on the particle surface chemistry.

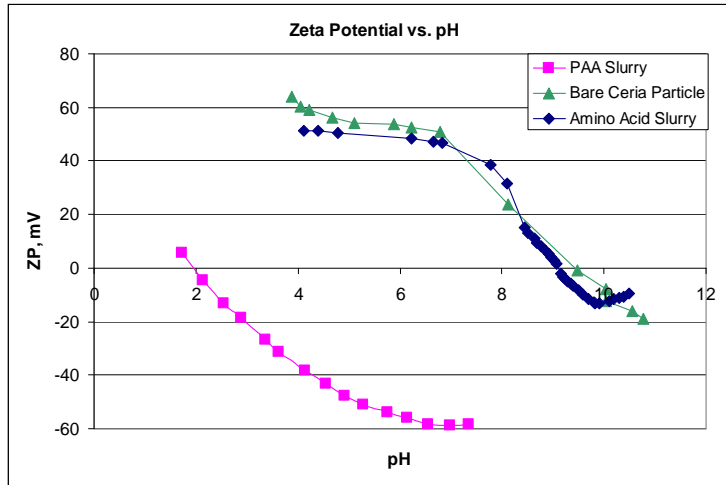


Figure 3: Zeta Potential Curves for PAA Slurry and Amino Acid Slurry

In the case of PAA slurries, the chemistry completely alters the surface charge and chemistry of the particles. This results in a negative surface charge and creates a repulsive force between the particle and both the wafer and the pad, which also have negative surface charges⁵. The particle coated by PAA must be mechanically forced via polishing pressure settings to interact with the wafer surface to induce polishing, which can adversely affect defectivity. However, the particles require little force to be removed from the surface of the wafer after polishing since the repulsive forces assist the transportation of particles away from the surface. On pattern wafers, polishing induction periods, which can adversely affect throughput, result from transport phenomena relating to the repulsion caused by the similar surface charges⁶.

In slurries that utilize amino acid chemistries, the particle has a high positive charge, which is attracted to the negatively-charged silica surface. This causes the particle to readily interact with the wafer surface to create a polishing event, allowing lower down-force pressures to be used, thereby minimizing defectivity. However, the repulsive forces no longer facilitate particle removal, so shear forces are required to facilitate the transport of particles away from the surface after polishing. On pattern wafers, these transport phenomena relating to the different surface charges, eliminates the polishing induction period. Due to these favorable transport phenomena, amino acid slurries perform similarly to a fixed abrasive pad with respect to planarization efficiency, in that particles in down oxide areas (i.e. trenches) do not experience enough shear force to be removed easily. These ‘old/used’ particles block ‘new/fresh’ particles from being introduced to those surfaces, which would otherwise be subjected to a continuation of polishing.

Amino acid additives are very effective in suppressing nitride removal, since its molecular structure is such that it bonds strongly to the nitride surface, with a moderate adsorption to oxide surfaces as well⁷. Several amino acid peptide chains have been studied, showing varying degrees of affinity for nitride, oxides, and other inorganic surfaces⁸. These peptide chains, meant to model amino acid functional groups, exhibit an ‘on/off’ behavior controlled by both the pH and peptide concentration. The amino acid currently being used in production quantities operates across a wide range of pH values, but has optimal behavior near a pH of 4.

4. Performance Effects of Mechanisms: Minimization of Dishing and Defects

Because the active oxide deposited on different features and different wafer locations will not clear at the same time, some nitride will be exposed in localized areas earlier than in other areas. This occurs for both PAA and Amino Acid slurries. Because of this behavior, the areas within a die or wafer that have nitride exposed earliest will have to endure a certain amount of over-polishing while waiting for the rest of the wafer to fully clear. Due to the mechanisms described above, PAA systems continue to polish both nitride and trench oxide as a function of polishing pressure throughout this period of clearing the wafer. This localized over-polishing causes field oxide to be lost in the areas that clear first, resulting in varying degrees of dishing across the wafer at the time of clearing. In many cases, the wafer is further over-polished to make sure that all residual active oxide has been removed. This further exacerbates the dishing across the entire wafer and leads to increased scratching.

Due to incoming wafer variability, some small percentage of wafers often fall outside the acceptable process window for dishing, leading to yield loss and scrapped wafers. The CMP process is bounded by upper and lower limits and to prevent scrap due to dishing. Many FABs bias their process toward under-polishing wafers, then add a rework step or a third platen over-polishing step to insure that all oxide is removed. Furthermore, sophisticated end-point detection methods are being developed and used, which require significant financial and personnel resources to implement.

However, when using amino acid slurries, all of these process compensations can be minimized or eliminated. This is due to the ability of the Ferro slurry to overpolish for long periods without causing unacceptable dishing. The high level of protection for nitride and trench oxide also results in a much lower feature-dependency with regard to dishing and over-polish window. Even large trench oxide areas such as can be seen on a MIT 864 mask are protected against dishing (see Figure 4). Feedback from several 300mm FABs evaluating this slurry, is that the dishing performance is within their production baseline using the fixed abrasive pad process, but with superior defectivity. This robust over-polish window allows portions of the wafer that clear early to maintain good trench oxide and nitride thicknesses while the rest of the wafer continues to polish to the point of clearing. The polishing process can be simplified by using a fixed time polishing for all wafers, although throughput can be further optimized by the use of simple torque end-point detection. Therefore, the only reason for any rework to be necessary would be related to tool issues, not slurry issues.

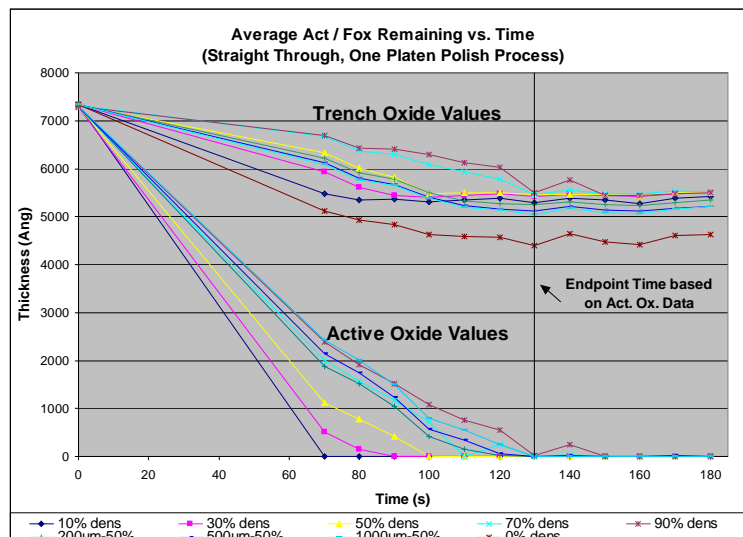


Figure 4: Amino Acid Slurry Over-Polish Behavior on a MIT 864 Mask

Protecting the wafer surface from the adverse particle effects while still facilitating acceptable removal rates is a break-through concept in CMP slurries. Not only can the wafer be protected from dishing throughout an extended over-polish window, but the wafer surface can also be shielded from micro-scratching via the same mechanisms described in the previous section. The combination of positive surface charge on the ceria particles and a physical protection layer afforded by the amino acid additives, can achieve much lower defectivity than competitive PAA slurry systems.

The most powerful indication of this fact is that dramatically increasing particle size will increase oxide removal rates, but will not increase nitride rates or scratch densities. Internal testing on blanket HDP wafers has confirmed that an increase of approximately 100% in particle top size can still achieve similar defect densities to those achieved by the standard particle currently used in commercially available amino acid slurries (see Figure 5). All polish processes and formulation levels were kept the same. Only the particle size distribution was changed.

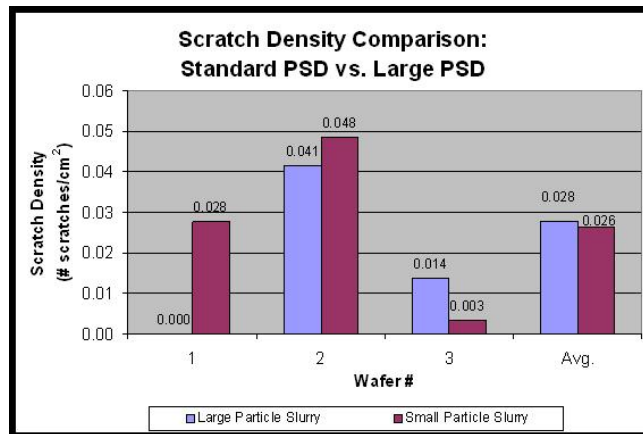


Figure 5: Comparison of Scratch Densities on Blanket Wafers for Small and Large PSD Slurries using Amino Acid Chemistry Package

Furthermore, the over-polish window is not compromised by increasing defects with the latest amino acid slurry, as compared to PAA slurries that show linear or even exponential increase in micro-scratching through the over-polish window. Customer-supplied data comparing the amino acid slurry system against their traditional process of record clearly shows that the amino acid additive is able to preserve the surface quality of the wafer despite extended polish times (see Figure 6).

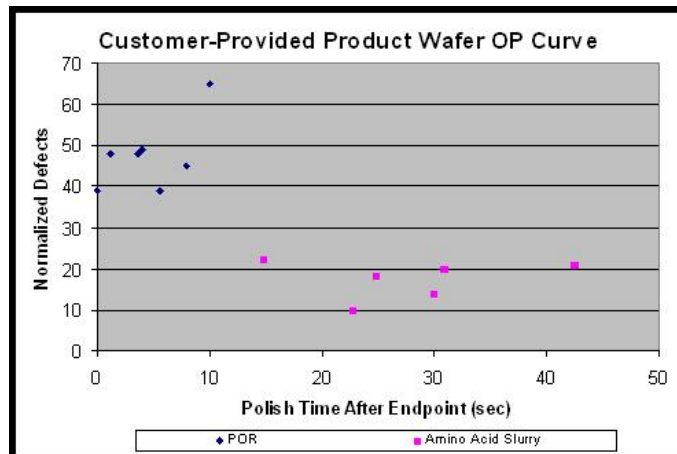


Figure 6: Customer Comparison of Normalized Defects vs. Over-Polish Time for Amino Acid Slurry and Standard Competitor

5. Conclusions

As integration schemes and materials become more complex, a fundamental understanding of slurry-additive-wafer interactions is needed in order to accelerate slurry development for future materials selection. The amino acid slurries for STI CMP designed by Ferro have been developed based on a sophisticated understanding of both particle and chemistry characteristics and how these can be combined to produce the optimum slurry for hitting the required performance targets. We believe that by modifying the selectivity through particle and wafer-level engineering, we have made a significant leap forward in STI CMP slurries. A leap forward that achieves performance beyond what can be accomplished through incremental improvements made to the older PAA slurry systems and polishing processes.

The result is a slurry system that is being used in production quantities and is being qualified by customers at an ever-increasing rate. This is due to the fact that our slurry system can achieve superior dishing, defectivity, and over-polish robustness than the competitive PAA systems. Further, it is the only slurry-only solution currently in mass production that can compete with the low dishing of the fixed abrasive pad process while achieving much lower defects.

6. References

1. S.Wolf, 'Silicon Processing for the VLSI Era volume 4 – Deep Sub-micron Processing Technology, Lattice Press, CA, pp433-474, 2002.
2. Liu, H., *et al.*, Proceedings of the ISTC, Shanghai, China, 2007, p81.
3. Liu, D-S., *et al.*, Proceedings of the ISTC, Shanghai, China, 2007, p249.
4. Merricks, D., Santora, B., Liu, H., Her, B., Kraft, B., Frink, S., Goodman, H., Hofmann, C., Zedwick, C., Proceedings of the ISTC, Shanghai, China, 2007, p332.
5. J-H Lim, *et al.*, Proceedings of the 9th CMP-MIC, Fremont, CA, 2005, p488.
6. J-W Lee, *et al.*, Proceedings of the 30th Korea CMP Users Group Conference, 2006.
7. US Patents 6627107 B2, 6468910 B1, 6491843 B1.
8. Willet, R.L., Baldwin, K.W., West, K.W., Pfeiffer, L.N., PNAS, 2005, 102(22), p7817.