Development and Mechanisms of Action of a Ceria-Based Slurry for Shallow Trench Isolation CMP

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Abstract

As the IC industry progresses through each successive technology node on the ITRS roadmap, to continually produce more demanding devices, new consumable materials are required to realize the high yields necessary for success. For the chemical mechanical planarization (CMP) process, silica-based slurries have traditionally been used at technology nodes of 90nm and higher, for both Shallow Trench Isolation (STI) and Inner Layer Dielectric (ILD) applications. At 65nm and below, cerium oxide-based slurries were introduced, since these slurries successfully address many of the issues resulting from the use of silica-based slurries.

At the 45nm technology node and below, the aspect ratio of the STI structures is increasing and the oxide deposition process has to change in order to achieve void-free gap-fill. The High Aspect Ratio Process (HARP) oxide is seen as replacing the HDP oxide used for the earlier nodes. Polishing this material requires a change in the CMP process and the current BKM involves the use of a two step process with a high selectivity ceria slurry being used in the first step and a fixed abrasive pad being used in the second step. This process has been shown to give excellent planarization and dishing, but there are still issues with high defectivity and cost of ownership.

This paper presents a viable alternative to the FA pad process and describes a slurry-only process which gives equivalent performance and superior defectivity compared to a FA pad process. Mechanistic aspects are also described, focusing on differences between slurries formulated with particles of positive and negative zeta potential.

Introduction

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 lithography[1], 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 Materials[2], 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 altogether[3]. 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 times[4]. This paper describes the impact of using such high selectivity slurries in the STI CMP process, along with their mechanism of action.

The difference in polishing mechanisms between slurries based on particles with different zeta potentials is what leads to the superior dishing through overpolish and defectivity of positive zeta potential slurries. It is this mechanism which leads to FA pad-like dishing performance.

Polishing Mechanisms: Nitride Suppression

Slurries based on polyacrylic acid chemistry generally show a lower oxide to nitride blanket wafer selectivity (~30:1) compared with slurries based on amino acid chemistry (>100:1). Selectivity is a more complex issue than is originally thought and a better understanding is required[5].

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Polyacrylic acid coats the particle, resulting in a negative zeta potential (ZP). Oxide polishes faster than nitride, but there is no self-stopping on nitride. The chemistry in the positive ZP (amino-acid based) slurries does not coat the particle, but interacts with the wafer surface, resulting in a positively charged particle and almost complete inhibition of nitride polishing.

Amino acid systems interact with the nitride layer, causing non-linear removal behavior with respect to time. When the linear oxide removal is combined with the non-linear nitride removal, blanket wafer selectivity does not remain constant over different polish times, as shown in figure 1. At sixty seconds, amino acid-based slurry selectivity is >100:1, but after twenty seconds, both amino acid and polyacrylate systems have 30:1 selectivity.

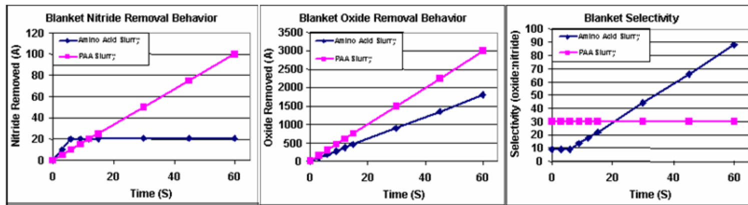

Figure 1. Blanket Selectivity Comparison

Pattern wafer selectivity is not modeled by blanket wafer data and all slurry systems experience lower selectivity than is predicted by blanket wafers. This reduction in selectivity is much more dramatic for amino acid systems than for polyacrylate systems. In amino acid systems, with such low removal of nitride on a pattern wafer, the oxide is also protected and is not eroded. The final result is low dishing, that is virtually independent of polishing time, enabling overpolish times up to 100% of endpoint time. Due to the strong suppression of nitride, feature dependency is low, which allows very low WIW and WID dishing values. Also, cost savings can be realized by decreasing nitride deposition thickness.

Polishing Mechanisms: Particle Surface Charge

Polyacrylic acid-based slurries have particles with negative surface charge and this creates a repulsive force between the particle and both wafer and pad, which have similar charges[6]. The particle must be mechanically forced to interact with the wafer surface to induce polishing, which can adversely affect defectivity. However the particles can be easily removed from the surface of the wafer after polishing, by these same repulsive forces. On pattern wafers, polishing induction periods, which can adversely affect throughput, result from transport phenomena relating to the similar surface charges[7].

In slurries that utilize amino acid type chemistry, 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 downforce pressures to be used, thereby minimizing defectivity. However, particle removal is more difficult. On pattern wafers, transport phenomena relating to the different surface charges, eliminates the polishing induction period. Due to these favorable transport phenomena, the positive ZP slurries behave somewhat like a fixed abrasive pad, 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.

The additive in the positive ZP slurries is very effective in suppressing nitride removal, since it's molecular structure is such that it bonds tightly to the nitride surface[8]. Several additives have been studied which show varying degrees of affinity for nitride and other inorganic surfaces[9]. These additives exhibit an 'on/off' behavior controlled by the pH and concentration. The additives in the positive ZP slurries show optimum efficiency at pH 4.

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 slurries for STI CMP based on amino acid chemistry, have been developed based on a complete understanding of both particle and chemistry characteristics and how these can be combined to produce the optimum slurry for hitting the required performance targets. By modifying selectivity through molecular engineering, it is possible to produce a slurry-only alternative to the fixed abrasive pad process currently being investigated for sub-45nm technologies.

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