

Chemical-mechanical polishing of copper with a low K polymer interlevel dielectric

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Abstract

Chemical-mechanical polishing (CMP) of copper with a low dielectric constant polymer as interlevel dielectrics (ILD) has been demonstrated as a viable patterning approach for copper interconnect structures. This paper presents a study of the mechanisms involved in copper CMP when used with a low k ILD. A two-step model of copper CMP involves the mechanical abrasion of the copper surface followed by removal of the abraded material from the vicinity of the surface and has been optimized after rigorous CMP experiments with alternative slurries.

Introduction

As interconnect lines shrink and move closer together, the resistance of aluminum/copper and tungsten conductors and the capacitance of structures with SiO_2 -based dielectrics limit further increases in clock speed. Many semiconductor manufacturers envision switching to lower-resistance, electromigration-stable copper conductors and lower permittivity (low-k) organic dielectrics [1]. This revolutionary path is complicated by the absence of manufacturable processes and integration knowledge for copper and low-k dielectrics [2]. Etching of copper has been difficult mainly because of the lack of copper compounds with high vapor pressures at relatively low temperatures (preferably $< 100^\circ\text{C}$). Recently reported results on etching of copper indicate RIE etching at temperatures $> 200^\circ\text{C}$ and the stability of etch masks at such temperatures is an added concern [3]. One solution to the problems of patterning copper films into interconnects can be realized by develop-

ing a process to chem-mechanically polish back the copper film. Patterning can be accomplished by using an inlaid metal scheme in a three-step sequence. First, the pattern for the copper metallization is formed by etching via windows into the ILD layer. Second, a thin liner film is deposited followed by a thick, 1 to 3 μm , copper film. Finally, the copper film is polished back using a CMP process until copper is completely removed from the top of the ILD leaving copper only in the via regions originally etched into the ILD.

Experimental

Film deposition and ILD characterization.

A thin blanket layer of aluminum was evaporated on a 4" p-type silicon wafer and was used as the first level of metal. This was followed by the deposition of a fluorinated polyimide film (dielectric constant = 2.6) to act as the interlevel dielectric. This organic film required a trilayer process scheme for patterning, and called for a spin on glass layer to act

as an etch stop followed by a photo resist coating to serve as an imaging layer. The photo resist was exposed and developed and the spin on glass was etched in a CF_4 plasma. After the masking layer was defined, pattern transfer was carried out by use of an O_2 plasma to both strip the photo resist and pattern the ILD. A titanium nitride film was sputter deposited in an argon/nitrogen environment onto the fluorinated polyimide of which was 6000 Å thick. Titanium is known to be both an effective adhesion promoter and diffusion barrier for copper metallization and will therefore prevent the interdiffusion of the various films that were used. Following the deposition of the titanium nitride a copper film was also sputter deposited in an argon environment. The sputtering conditions to achieve a copper thickness of 3.5 μm involved a pressure of 5 mtorr, 2.5 kwatts of power, and a sputter time of 90 minutes. Initial film thickness measurements were taken using a Tencor profilometer.

Chemical preparation.

For this copper CMP process, dissolved NH_3 (from NH_4OH) was used in the slurry solutions to complex the copper and thereby increase the solubility of the copper in the slurry. The solubility of a copper ion is determined by the ability of the ammonia molecules to shield the charge on the ion from other copper ions in the solution. Three different polishing slurries were investigated, and different polish rates were encountered when the concentration of the ammonia in the slurries were varied. All three slurries utilized a .3 μm alumina abrasive dissolved in 400 ml of dionized water. Slurry 1 received 2 ml of NH_4OH which gave a pH of 10.25, slurry 2 received 6 ml

of NH_4OH which gave a pH of 12.2, and slurry 3 gave a pH of 11.8 when 4 ml of NH_4OH was added. Slurries 1 and 2 contained a .3 μm alumina abrasive which came already in a liquefied state, while the .3 μm alumina abrasive used in slurry 3 came in a powdered solid form.

Polisher setup.

The copper films were polished on a Leco AP-600 automatic polisher using a Rodel Suba IV pad as the polishing surface. Both the wafer carrier and the polishing table (with the Suba IV pad fixed to the table) were rotated with the same rotational velocity, nominally 65 rpm, and the pressure of the spindle holding the wafer to the polishing pad was optimized at 10 PSI. Only one polishing pad was available throughout the entire process, therefore continuous pad conditioning was necessary. Pad conditioning techniques are often used to redress the pad and return the pad to a fresh state before each wafer is polished. The conditioning of the polishing pad included (i) removing any used slurry left on the pad from the previous wafer, (ii) holding a straight razor against the pad and moving it along the diameter as the pad rotates. Without this procedure, the uniformity and polish rate of the copper film seemed to vary substantially.

Results and Discussion

After polishing was completed and evaluated, it was found that slurry 1 gave the lowest polish rate of 2,250 Å/min, slurry 2 gave a slightly higher polish rate of 2,500 Å/min, and slurry 3 showed a polish rate of 5,600 Å/min, which is more than twice of those observed in slurries 1 and 2. This suggests that the complexing action in the slurry with a greater con-

centration of ammonia offered a faster polishing rate. As for slurry 3 with a polish rate of 5,600 A/min,

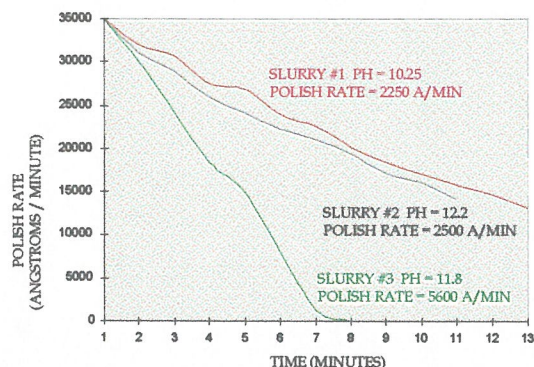


Figure 1. Copper polish rate in NH_4OH based slurry as function of concentration.

it should be safe to say that the alumina abrasive which came in the solid form was much more aggressive at abrading copper atoms away from its original surface, promoting an increased dissolution and an overall faster polish rate. Since NH_4OH does not etch copper during polishing, the CMP process was very mechanical in nature. In a highly mechanical polish the selectivity in the polish rates between copper and the polyimide arises because of the difference in mechanical hardness of the two films. Slurry 2 seemed to be the best behaved solution and was used for the final polishing of the copper film. Before polishing was carried out, the topology of the copper surface was determined by a profilometric measurement which is demonstrated below in figure 2.

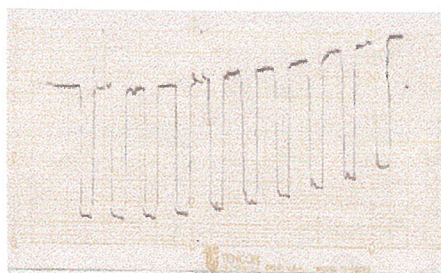


Figure 2

This profilometric measurement was performed on a 10,000 A scale and showed a copper step height of 6100 A. After polishing was performed, the surface topology of the copper was decreased to 500 A. This is demonstrated in figure 3 using the same measurement technique and the same 10,000 A scale.

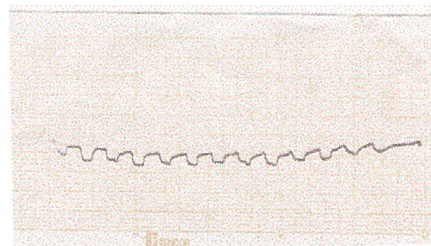


Figure 3

Complete global planarization was not achieved because of an overpolishing step which was required to insure complete copper removal across the entire wafer. The result was copper dishing in the via regions which is defined as the difference in height between the center of the copper fill, which is the lowest point of the dish, and the point where the copper levels off with the ILD, which is the highest point of the dish. Overall, the polishing of the copper was a success. After the copper was polished down to the interlevel dielectric level, a second layer of aluminum was deposited and patterned to complete the multilevel metalization scheme.

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