An advanced alkaline slurry for barrier chemical mechanical planarization on patterned wafers*

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Abstract: We have developed an alkaline barrier slurry (named FA/O slurry) for barrier removal and evaluated its chemical mechanical planarization (CMP) performance through comparison with a commercially developed barrier slurry. The FA/O slurry consists of colloidal silica, which is a complexing and an oxidizing agent, and does not have any inhibitors. It was found that the surface roughness of copper blanket wafers polished by the FA/O slurry was lower than the commercial barrier slurry, demonstrating that it leads to a better surface quality. In addition, the dishing and electrical tests also showed that the patterned wafers have a lower dishing value and sheet resistance as compared to the commercial barrier slurry. By comparison, the FA/O slurry demonstrates good planarization performance and can be used for barrier CMP.

Key words: barrier CMP; alkaline barrier slurry; surface roughness; dishing
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1. Introduction

Chemical mechanical polishing (CMP) is an indispensable process step in semiconductor device fabrication, especially for Cu wiring and interconnects formation. To prevent Cu ion migration into interlayer dielectrics (ILD) films, a barrier film composed of Ta/TaN is used to isolate the Cu from the surrounding ILD film[1−4]. In the CMP process, one of the key issues is the development of slurries. Since TaN has mechanical and electrical properties that are vastly different from those of Cu, at this point, it seems essential to switch to a different polishing slurry to remove the hard and chemically inert barrier layer. The study and applications of Cu CMP have become more mature in recent years. However, studies on the CMP behavior of Ta and its nitrides are fewer than those of Cu[5, 6]. Most of the CMP process is performed in an acidic medium[7−10]. One of the drawbacks of the acidic slurry is the possible corrosion of copper wiring by the slurry. Most acidic slurries include a dissolution inhibitor to regulate excessive chemical etch and maintain good planarization efficiency. However, due to the introduction of inhibitors, such as the very effective benzotriazole (BTA), organic contamination has been increased. In the alkaline region, copper can be passivated and the passivation layer can be used to reduce the isotropic etching of recessed regions on an uneven surface and prevent the dissolution of Cu from those recessed regions[11−13]. Thus it may be unnecessary to add any inhibitors into the alkaline slurry. Currently, only limited information has been published about barrier removal during copper CMP processes using alkaline slurry and even less is known about using TaN. In this paper, an advanced alkaline slurry was developed for barrier CMP, and in order to demonstrate the polishing performance of the slurry, we have compared it with a commonly used barrier slurry. The comparison includes surface morphology and root mean square (RMS) roughness analyses. An electrical test was also performed to compare the sheet resistance of the pattern wafers polished by two different slurries respectively.

2. Experiment

The experiments were carried out on an Applied Materials Mirra Polisher with an end point detector. Post-CMP cleaning was performed using an OnTrak DSS 200 scrubber. The polish pads used were IC 1010$^{\text{TM}}$ and Suba IV, both pads were tested for Cu bulk removal as well as for Cu clearing. The Politex soft pad was used for barrier removal. Before the experiment began, all the pads were conditioned by a TBW diamond conditioner.

Two different types of slurries were used in this investigation, namely (a) FA/O slurry, which was prepared by us, and (b) a commercial commonly barrier slurry which was also prepared by us. In the present report, these two slurries will be referred to as slurry A and slurry B, respectively. Both of the slurries contained hydrogen peroxide as the oxidant. 200-mm copper blanket wafers and 200-mm MIT 454 pattern wafers were used, and the cross section view of the MIT 454 pattern wafers is shown in Fig. 1.

The polisher with end point detector used in the experiment was designed for a three-step copper CMP approach, which starts with high rate Cu bulk removal down to approximately 100 nm remaining Cu (step 1). The remaining copper was re-

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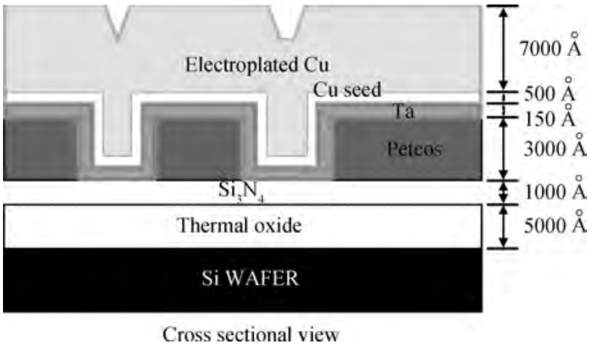

Fig. 1. Schematics of the MIT 454 patterned wafers used in the CMP experiments.

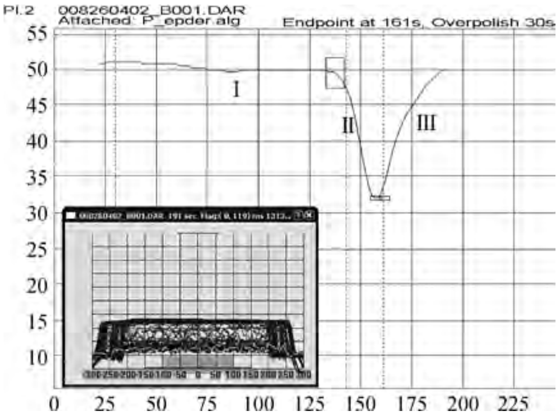

Fig. 2. Illustration of the CMP process in the experiment.

Table 1. Process conditions of CMP process.

CMP recipe	Platen speed (rpm)	Head speed (rpm)	Membrane pressure (psi)	Retaining ring (psi)	Inter tube (psi)
Pattern Cu wafer	35	29	2	2.5	2
Barrier layer	60	54	2	2.2	2
Blanket Cu wafer	43	37	2	2.5	2

moved during the clearing step (step 2), followed by barrier removal during an over-polishing step (step 3) the CMP process is shown in Fig. 2. The copper removal step has been studied extensively and is not discussed here. In this report, we focus on the comparison between slurry A and slurry B. Table 1 summarizes the CMP process conditions used in this experiment, which were supplied by ATDF fab in Autin, Texas, USA.

The surface roughness and topography of the copper blanket wafers that were polished using the two different slurries was analyzed by using a Schmit Micro Surface Roughness Tool (Veeco TMS 3000-W). Copper dishing was measured by Thermo Wave OptiProbe 6240 and sheet resistance measurements were performed using TEL P12XL probe with an Agilent 4073C tester.

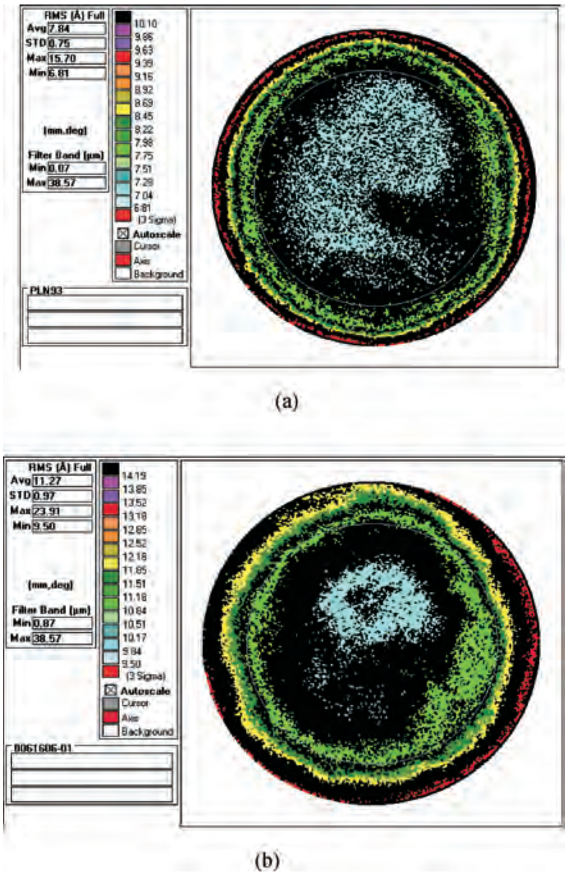

Fig. 3. Post CMP surface roughness maps on 200 mm copper blanket wafers. (a) After polishing using slurry A. (b) After polishing using slurry B.

Table 2. Post copper CMP surface roughness on 200 mm copper blanket wafers.

Slurry	RMS (Å)	Standard deviation (%)
Slurry A	7.84	0.75
Slurry B	11.3	0.96

3. Results and discussion

Table 2 compares the root mean square roughness of the copper blanket wafers polished by slurry A and slurry B under the same CMP process conditions. From the results we can see that the RMS roughness of the copper blanket wafers polished by slurry A has a good planarity value of 7.84 Å (< 1 nm), which is lower than the commercially developed barrier slurry (11.3 Å). The post-copper CMP surface roughness maps on 200 mm copper blanket wafers are depicted in Fig. 3. It can be seen that the disparity of the RMS roughness of the copper blanket is relevant to the different colours displayed in the maps: when the surface roughness is lower, then the colour present on the maps is lighter. On the contrary, if the surface roughness is too high, then the colour may be displayed as black. As compared in Fig. 3, the lighter colour area of the wafers polished by slurry A are much larger than that polished by slurry B. This indicates that the average RMS roughness of the former copper blanket wafers is lower than the latter. We can conclude that the copper blanket wafers polished by the

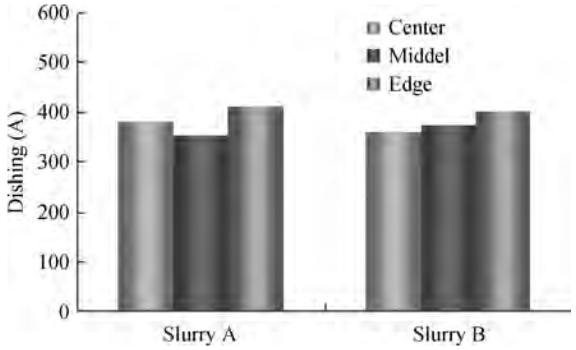

Fig. 4. Dishing values of copper at 100 μm pitch structures with 50% pattern density polished by two slurries at different positions of the wafer.

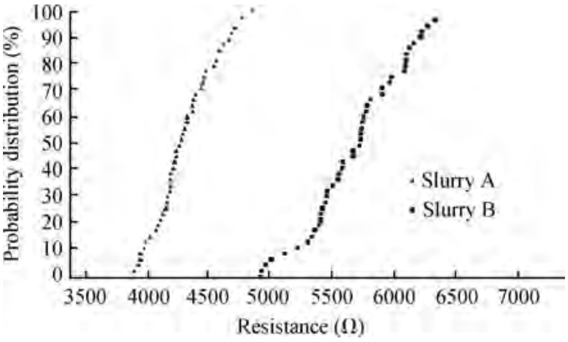

Fig. 5. Serpentine sheet resistance over 1 μm line width and 5 μm space polished using two different slurries.

FA/O slurry have a better surface topography.

A key feature of the alkaline barrier slurry used in the experiment is that it contains a novel chelating agent, it can be abbreviated as $(NH_2)_2R(NH_2)_2$. The chelating agent can effectively form a complex with a copper ion in the alkaline conditions. During the copper CMP process, the passivation layer mixture of Cu_2O and CuO is formed by the oxidizer. In the elevated regions, $(NH_2)_2R(NH_2)_2$ can react with the cupric ion, and then form a soluble new molecule. However, in the recessed regions the complex reaction does not occur and then the passivation prevents the recessed regions from direct dissolution. Finally, the continuous repetitive process achieves global planarization of the copper film.

A major requirement for the copper planarization process is simultaneously effectively polishing the Cu and barrier films with minimal dishing of the copper wiring. Dishing commonly occurs and signals a state where the Cu film in the wiring area has been over polished so that the central part thereof is concaved, and it is caused by the different removal rates of the Cu and the barrier film. The copper dishing measurement results are shown in Fig. 4 over a pitch test structure consisting mainly of 100 μm pitch structures with 50% pattern density polished by the two slurries at different positions on the wafer. It can be seen that the dishing values obtained by using slurry A is lower than slurry B, we can conclude that the pattern wafers polished by slurry A have good planarization and polishing selectivity TaN/Cu is better than the commercially developed barrier slurry. Electrical tests were used to further confirm the dishing results. The serpentine sheet resistance over a 1 μm line width and 5 μm space polished using two different slurries is shown in Fig. 5. In the figure, it is concluded that slurry A shows lower resistivity than that of slurry B. It can be concluded that the patterned wafers polished by the FA/O alkaline slurry produced less dishing than the commercially slurry. It is reconfirmed that the FA/O slurry has better TaN/Cu selectivity and topography than that of the common commercial slurry.

In order to minimize the dishing of copper lines, a slurry with selective removal of the barrier layer to copper is desired. As a solution, inhibitors are introduced to prevent etching of the low-lying features. BTA is an excellent inhibitor for various slurries. It forms a protective polymeric copper-BTA film, improves the planarization efficiency, and reduces copper-line dishing, but it may increase the burden of the post-CMP cleaning process. The FA/O slurry used in the experiment is absent of inhibitors and the mechanism for copper CMP is similar to the aforementioned. The excess copper is removed by the combined action of the chemicals and the abrasives, while the low-lying regions remain protected in the alkaline slurry due to the oxidation of copper.

For TaN CMP, previous authors have described TaN as a binary alloy[14] where the Ta and N sites of the composite selectively support different chemical effects. In the presence of H_2O_2, however, the CMP mechanism of TaN and Ta are very similar. The main steps of the TaN CMP process can be summarized as follows. In the high-pH (pH $\geqslant$10) environment, H_2O_2 breaks down, catalyzed by Ta_2O_5:

$$2H_2O_2 = H_2O + H^+(aq) + O_2 + OH^-. \qquad (1)$$

The H^+(aq) generated in this reaction diffuses back into the bulk solution (to eventually react with OH^-, and the OH^- from Eq. (1) tends to adsorb on Ta_2O_5 (forming a structure similar to tantalum oxyhydrate. This substantially increases the local pH at the Ta_2O_5 surface, which in turn activates the generation of soluble $(Ta_6O_{19})^{8-}$ (hexatantalate) ions[15]:

$$3Ta_2O_5 + 8OH^- = (Ta_6O_{19})^{8-} + 4H_2O. \qquad (2)$$

Therefore, using the FA/O alkaline slurry can achieve an excellent final surface quality with low dishing and surface roughness. It is also advantageous in the overpolishing step of the CMP for copper and tantalum nitride removal.

4. Conclusion

In this paper, we have proposed a novel alkaline slurry for the copper clearing step and barrier removal during the CMP process. The experiments show that the copper blanket wafers polished by the FA/O alkaline barrier slurry have a lower RMS roughness than those polished by commercially developed barrier slurry, and a lower dishing value and sheet resistance is still observed during CMP by using the slurry. We can conclude that the alkaline barrier slurry can achieve an excellent final surface quality and may be useful in barrier chemical mechanical planarization.

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