COPPER CMP MIMICKED WITH ATOMIC FORCE MICROSCOPY
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ABSTRACT
To optimize chemical mechanical polishing (CMP) process, one needs to get information on the interaction between the abrasive slurry particles and the surface being polished. To study such interactions, we used atomic force microscopy (AFM). An AFM tip was used to mimic a single abrasive silica particle typical of those used in CMP slurry. Studying copper CMP, we found that the AFM scanning removes the surface oxide layer in different rates depending on the depth of removal and the pH of the solution. Oxide removal happens considerably faster than the CMP copper removal. This is in agreement with generally accepted models of copper CMP. Both long-range and the friction forces acting between the AFM tip and surface during the polishing process were measured. The correlation between those forces and the removal rate is discussed.

INTRODUCTION
Chemical mechanical polishing (CMP) of copper is of great interest for microelectronics\(^1,2,3\). Because of its higher electromigration resistance and lower resistivity, copper is used as the interconnect metal in integrated circuits, replacing traditional aluminum. CMP is used to remove the excess of metal in the damascene processes for copper patterning. Indeed CMP seems to be the only effective technique to achieve both local and global planarization on the integrated circuits wafers used in modern manufacturing. To optimize the process of copper CMP, various chemicals, abrasives, polishing pads, etc. have been investigated\(^4,5,6,7,8,9,10,11,12\). To study such interactions, we used atomic force microscopy (AFM). An AFM tip was used to mimic a single abrasive silica particle typical of those used in CMP slurry.

METHODS
A Nanoscope™ IIIa Dimension 3100 AFM by Digital Instruments was used in this study. Standard integrated silicon nitride NP-S V-shaped AFM tips by Digital Instruments were utilized for the AFM scratching, “polishing”. Nanoprobe™ RTESP7 silicon rectangular cantilever tips were used for measurement of friction forces. Spring constants of both types of cantilevers were measured as described in refs.\(^13,14,15\). Friction coefficients were measured against 5 - 8 different load forces. Then, the coefficients was calculated as the averaged ratio of the friction force to the total vertical force, which include the load force and the force of adhesion. 6” copper on tantalum wafers were prepared by PVD method by Silicon International (used as received). Slurry solution used for copper oxidation was prepared as aqueous solutions of 5wt% peroxide (Pfaltz & Bauer) and 1wt% of glycine (J.T.Baker) in different pH of 3, 4, 5, 8, and 8.4. The pH of the slurry was adjusted with either HCl or KOH with 10 mM ionic strength. Oxidation of the copper wafer was done by placing ~2-3 cm diameter droplet of the slurry solution onto the copper surface for 10 or 15 minutes. The AFM scanning/scratching was done with no oxidizing agents, and taking place in aqueous solutions of HCl and KOH of 0.01 mol/L mixed to maintain the same pH as in the slurry solution.

The AFM scratching was done over 2µm x 2µm area with the load force of ca.20-30nN. This is about the estimated force for a single abrasive particle during CMP.

RESULTS AND DISCUSSION
We found that the AFM scanning removes the surface oxide layer in different rates depending on the depth of removal and the pH of the solution. Comparing the obtained qualitative behavior of the removal rates as a function of pH with the reported CMP data\(^16\), one can see definite correlation, Fig.1. For the qualitative comparison, we put the same rates for the pH of 3. Quantitative comparison reveals the following. Oxide removal with the AFM happens considerably faster than the CMP copper removal. This essentially confirms a generally accepted model of copper CMP\(^17\): originally corrugated/patterned copper surface is oxidized while immersed in the slurry solution. A fast rotating pad and the abrasive particles touch and remove the oxide layer from the top areas of the corrugated/patterned copper surface, because these areas are touched by the pad first. Because the rate of removal of the oxide layer is much higher then the actual CMP removal rate, the rate of oxidation must be much slower that the rate of oxide layer removal. If we are dealing with polishing rather than etching, the exposed pure copper is oxidized faster than the areas passivated by the oxide layer. If the area is still
high, the oxide layer is removed again, and the process repeats until the high area disappears, i.e., is polished away. This results in faster dissolution of higher areas than the lower ones, i.e., in the planarization.

![Graph](image)

**Fig.1.** Comparison of actual CMP removal rates and the AFM mimicked. Rates for pH3 are taken to be the same.

A serious advantage of the AFM technique is in its ability to measure all forces acting between the slurry particles and the polishing surfaces while polishing/scratching. Because it is plausible to expect direct correlation between the removal rate and the force of friction between the AFM tip and surface, we measure the friction force. Fig.2 shows the friction coefficient (normalized by the lateral spring constant of the cantilever).

![Graph](image)

**Fig.2.** Dependence of the friction on the slurry pH for copper and copper oxide layer.

As one see from Fig.2, the friction decreases as pH grows from 4 to 8, which confirms hypothesis that the removal rate directly correlates with the friction. However, the friction coefficient increases while the pH changes from 3 to 4. This happens even though the removal rate is higher for pH3, as seen in Fig.1. It is interesting to note that pH3 is a special case. As one can see from regular AFM topology images, the oxide is much rougher for the case of pH3 vs. the other considered pHs. Analyzing removal noise by the AFM, we can speculate that the oxide is being removed through grinding into nanosize particles of the oxide which are noticeably smaller than in the case of the other pHs. These particles, sliding between the AFM tip and polishing surface, effectively lubricate the tip-surface contact, and consequently, decrease friction.

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**REFERENCES**