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Impact of Dry Process Damage on Chemical Mechanical Planarization with Cu/low-k Structure

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Abstract

We evaluated the impact of process damage caused by dry or sputtering on chemical mechanical planarization (CMP) with Cu/low-k structures. We revealed that dry process drastically decreased C-H/C-C bonding in low-k films, and CMP mechanism of the low-k film was completely different between with and without dry processing. Although CMP slurry for low-k films usually contains surfactant to promote CMP removal rate of hydrophobic low-k surface, the C-H/C-C decrease of the low-k film significantly changes the absorption model of the surfactant. Moreover, during fabrication of Cu wiring, carbon missing inhomogeneously occurs within the low-k film. Thus, slurry design considering C-H/C-C missing in low-k films is a clue for successful fabrication.

1. Introduction

In current CMOS devices, Cu/low-k structures are utilized. However, low-k materials are easily damaged by dry processing[1], moisture uptake[2], and CMP and post-CMP cleaning[3-7]. Although many papers discussing plasma damage with low-k materials have been published, there are few papers reporting total integration of Cu/low-k considering film property, dry etch, and CMP process simultaneously. We reported effect of surfactant in CMP slurry on k-value shift during CMP with various low-k films, and revealed that surfactant is able to penetrated into porous low-k materials inducing k-value shift[8]. In this paper, we discuss the impact and mechanism of dry process damage on CMP process.

2. Experiments

Two types of methylsilsesquioxane (MSQ) films were used for the evaluation; the k-value is 2.9 or 2.55, respectively. MSQ films of k=2.9 were treated with dry process, CMP, or surfactant dipping followed by DIW rinsing and drying. This surfactant is used in CMP slurry to suppress excess removal of MSQ films. The experimental split is shown in Table I. CMP removal rate was measured by spectroscopic ellipsometry. The film property was evaluated by X-ray photoelectron spectroscopy (XPS) with two different take off angles (TOA); 90 degree and 5 degree. Roughly speaking, XPS results with TOA=90 deg. provides us bulk information while that of 5 deg. does surface information of the MSQ film. Such surface information is fairly useful to understand the behavior of surfactant absorption on the low-k films.

In addition, same kind of evaluation was performed s with MSQ films of k=2.55. We also performed cross-sectional TEM/EELS observation and surface profile measurement after CMP with Cu/MSQ (k=2.55) structure.

Table I Experimental conditions of k=2.9

Sample	Dry process	CMP process
No. 1	With (W/)	W/O
No. 2	With (W/)	W/
No. 3	With (W/)	W/O; Surfactant dipping
No. 4	Without (W/O)	W/O
No. 5	Without (W/O)	W/
No. 6	Without (W/O)	W/O; Surfactant dipping

3. Results and Discussion

Figure 1 shows CMP removal rates with and without dry process. A huge increase of the removal rate by 40 times was observed after dry process. Figure 2 illustrated XPS results (TOA=90 deg.) of the MSQ films treated by the conditions in Table I. We had to remove the results of No. 2 from further discussion since almost all MSQ film was unintentionally eliminated by dry etch and CMP. C-C/C-H peaks at 285 eV (Fig. 2(a)) are drastically decreased. On the other hand, Si-O peaks at 104 eV and 532 eV (Fig. 2(b), (c)) were increased after dry process. Since slight increase of C-O, C=O bonding with CMP or surfactant dipped sample is observed in Fig. 2(a), these peaks are thought to originated from the slurry. The absorption of the surfactant is more clearly detected using TOA=5 deg. (Fig. 3). Much larger peaks of C-O, C=O are observed with W/O Dry sample (No. 6) than that with W/ Dry sample (No. 3). As shown in Fig. 4, concentrations of C-O, C=O bonding increase by 4.1 atom% between before and after surfactant dipping of W/O Dry samples. However, the increase of C-O, C=O bonding of W/ Dry samples remains only 0.5 atom%. These results indicate that the surfactant tends to absorb not on hydrophilic but on hydrophobic surface. This absorption is more evidently observed with MSQ (k=2.55) (Fig. 5).

TEM/electron energy-loss spectroscopy (EELS) images with 32 nm-pitch Cu/MSQ structure (Fig. 6) shows that inhomogeneous carbon missing occurs within the film. As a result, surface profile of a Cu/MSQ structure became rough (Fig. 7). Since plasma damage occurs along sidewalls and bottoms of wiring trenches, the surfactant in CMP slurry does not absorbed on the damaged portion, which leads to excess removal of MSQ (Fig. 8).

3. Conclusions

We have made clear that dry process damage and CMP performance are closely related. The behavior of surfactant in CMP slurry is a clue to control planarity.

.References

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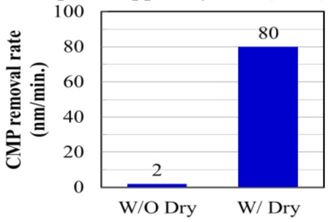

Fig. 1 CMP removal rate. Plasma treatment of MSQ surface to increase hydropilicity was performed before dry process.

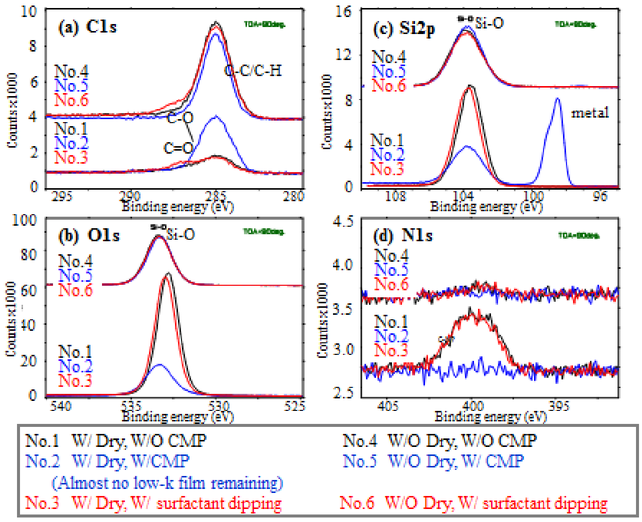

Fig. 2 XPS results with MSQ films (k-2.9). TOA=90 deg. Signals of No.2 are originated from the substrate.

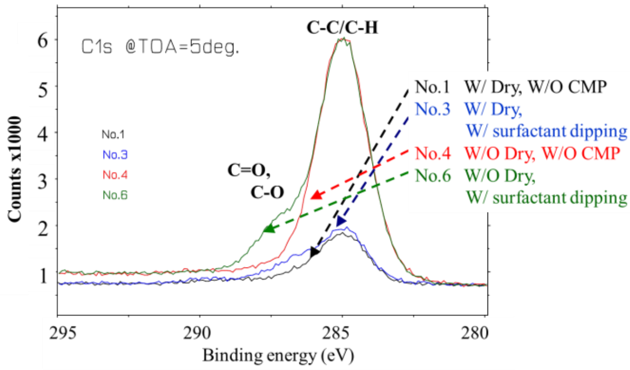

Fig. 3 C1s peaks of XPS with MSQ films (k-2.9). TOA=5 deg.

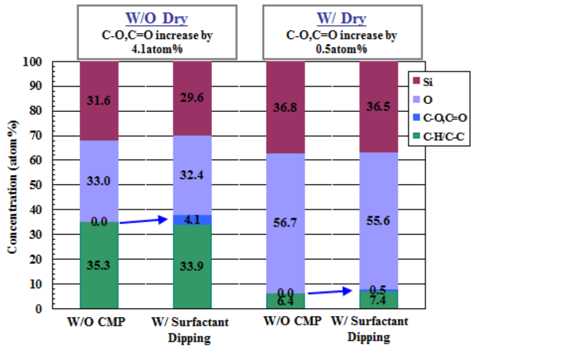

Fig. 4 Concentration of each bonding of XPS with MSQ films (k-2.9). TOA=5 deg.

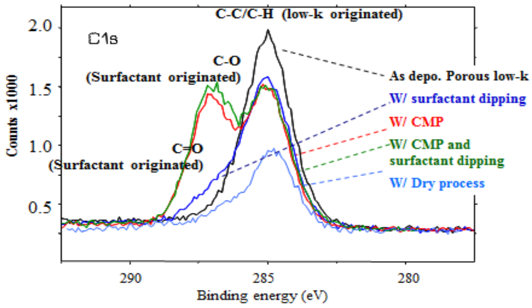

Fig. 5 C1s peaks of XPS with MSQ films (k-2.55). TOA=5 deg.

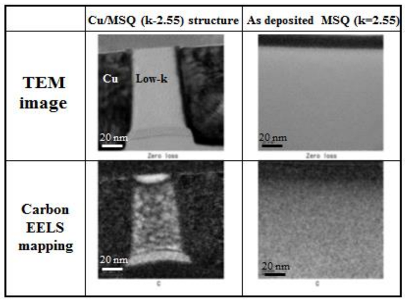

Fig. 6 TEM images and carbon EELS mapping with 32-nm pitch Cu/MSQ (k=2.55) structure and blanket as deposited MSQ.

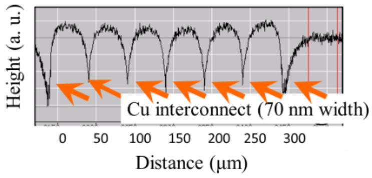

Fig. 7 Post-CMP profile of 70nm/50μm width Cu/MSQ structure.

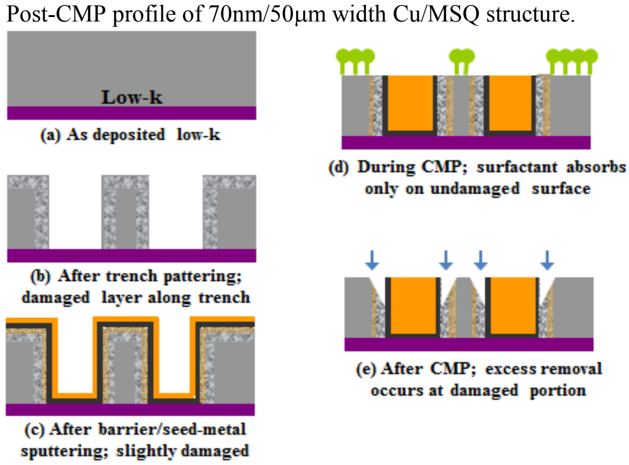

Fig. 8 Mechanism of dry process damage and CMP planarity.