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Evaluation of Dielectric Constant through Direct CMP of Porous Low-k Film

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1. Introduction

In current LSI devices, nanoporous low-k materials are often used for a dielectric film. However, their low dielectric constant (k-value) is altered during device fabrication such as dry processing, chemical mechanical planarization (CMP), and so on. It is reported that increase of k-value during CMP is up to 50% [1,2]. This increase is explained by moisture uptake and/or surfactant included in CMP slurry [1-4]. Moreover, the diffusion of surfactant depends on the structure of its molecule [4]. However, there is almost no report about the impact of nanoporous film types on k-value increase during CMP and the impact of total process damage including sputtering and dry processing. In this study, we analyzed three kinds of porous low-k materials that were exposed to CMP slurry, dry processing, and/or barrier sputtering.

2. Experiments

Three kinds of nanoporous methyl silsesquioxane (MSQ) film varying carbon content (about 15, 30, 45 atom%) with the same k-value (k≈2.5) were deposited on 300 mm diameter Si wafers. In addition, three types of CMP slurry A, B, and C, which contain different surfactant, were prepared. K-values were measured by Hg-probe. Some porous MSQ films were exposed to plasma treatment of dry processing and/or barrier (Ta) sputtering before CMP, or to annealing (350°C, 3min) after CMP. The film characteristics were examined by Fourier transfer-infrared spectroscopy (FT-IR), X-ray photoelectron spectroscopy (XPS), and thermal desorption spectroscopy (TDS).

3. Results and Discussions

Figure 1 shows the delta-k (percentage of k-value increase) values of the low-k film with lowest carbon content. It is easily found that high delta-k value is only observed with slurry A. This result can be attributed to the difference of surfactant in slurries. Thus, in the following investigation, we applied slurry A to reveal the influence of surfactant. Figure 2 shows the relation between delta-k and four kinds of low-k material including a nonporous low-k material (k≈2.9) as a reference. Although delta-k values of porous materials swelled with the increase of carbon content, that of the nonporous film is almost zero. The detail of this result will be discussed later. Figure 3 shows the delta-k values of different CMP process recipes. In standard condition, the normal recipe of polishing as well as cleaning and spin-rinse-drying were performed. It is clear that cleaning and drying conditions made almost no difference in the delta-k value. However, DIW polishing instead of the slurry and annealing after CMP were effective to avoid the increase of the k-value. This result reveals that the cause of delta-k is not moisture uptake but CMP slurry, which can be removed by annealing. In addition, FT-IR results (Fig.4) show that $-CH_2$ and C-H bonds attributed to the surfactant are appear with the nanoporous films polished by slurry A, and that no outstanding H_2O peak is observed. Figure 5 shows the depth profiles of C, O, and Si in the nanoporous film. The carbon concentration after CMP is uniformly increased by about 5 atom% through the film. This suggests that there is diffusion path of surfactant through the film. That is to say, the increase of k-value during CMP is explained by the absorption of the surfactant on sidewalls of continuous pores which were formed by desorption of porogen during the film deposition. Moreover, as shown in Fig.6, the higher the carbon contents in the films, the larger the increase of C concentration during CMP. This C increase during CMP is attributed to more absorption of surfactant, leading to the higher delta-k value after CMP.

Considering influence of dry and sputtering process, Fig.7 shows that k-values after these steps also increase although their amounts are lower than that after CMP only. The XPS depth analyses in Fig.8 suggest that the raise of k-value after plasma treatment is caused by the decrease of C, showing contrast with the case of CMP, and that C concentration is recovered after CMP. This indicates that the damaged layer containing less carbon was removed by CMP. It is also obvious that the sputtering step has almost no impact on k-value or XPS depth profile.

Figure 9 shows TDS results. Comparing CMP only with slurry A or slurry B, degassed amounts of surfactant were quite different each other, while those of H_2O were almost equal to that of the reference. Moreover, degassed amount of surfactant was decreased by 1/10 after annealing. These data also support that k-value increase is due to surfactant in this case. To the contrary, in the case of CMP after sputtering and plasma treatment, degassed amount of H_2O is highest. Therefore, the delta-k in this case is mainly caused by moisture uptake on the damaged surface, which has less carbon and more oxygen, increasing hydrophilicity.

4. Conclusions

We demonstrate that k-value increase during CMP is caused by diffusion of surfactant through the nanoporous film, depending on characteristics of porous film and surfactant. The diffusion is explained by absorption of surfactant on sidewalls of continuous pores formed by porogen desorption while it is easily released by annealing. To the contrary, the increase of k-value during CMP after dry processing can mainly be caused by moisture uptake.

References

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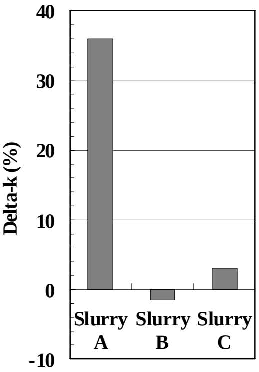


Fig.1 Delta-k dependence on CMP slurry.

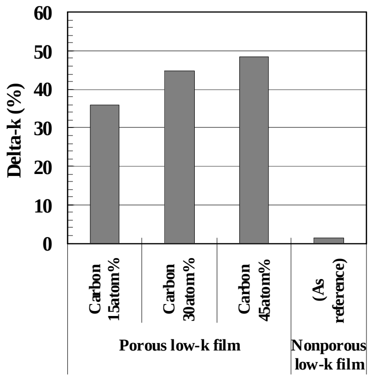


Fig.2 Delta-k dependence on low-k films.

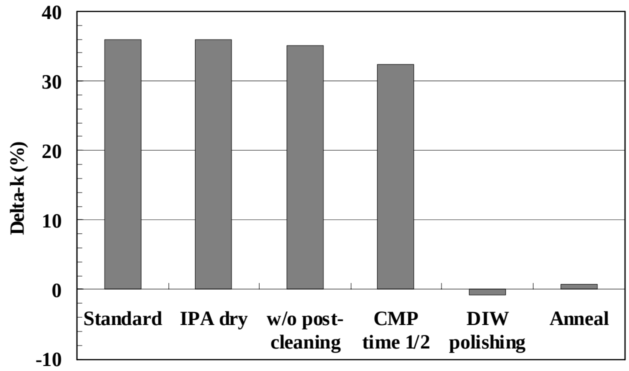
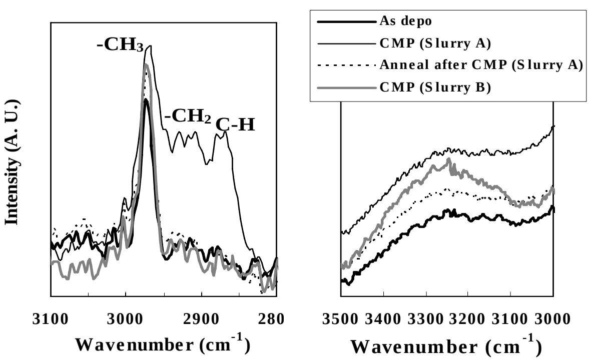
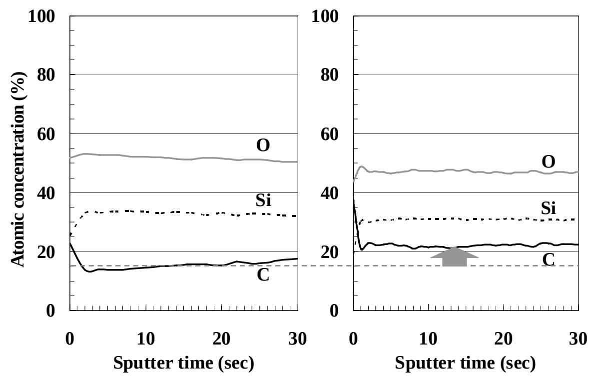


Fig.3 Delta-k dependence on CMP conditions



(a) Hydrocarbon **(b) Absorbed water**

Fig.4 FT-IR spectra.



(a) As deposited **(b) After CMP**

Fig.5 XPS spectra of porous low-k films.

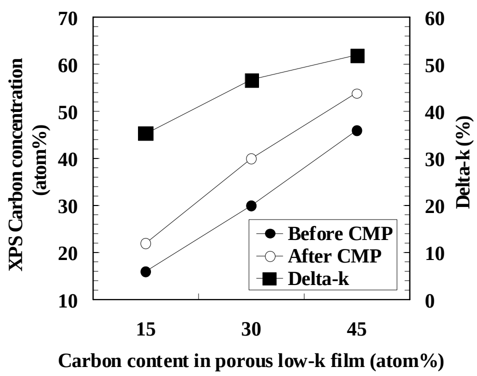


Fig.6 Relation between carbon content and delta-k.

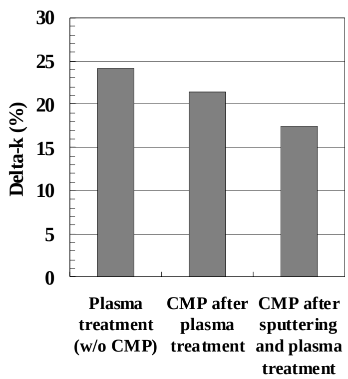
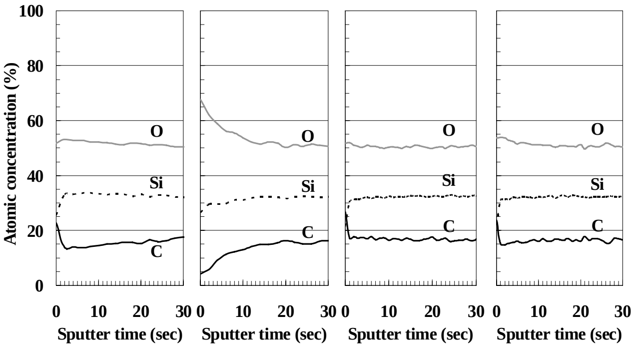


Fig.7 Delta-k dependence on various treatments.



(a) As deposited **(b) Plasma treatment (w/o CMP)** **(c) CMP after plasma treatment** **(d) CMP after sputtering and plasma treatments**

Fig.8 XPS depth analyses.

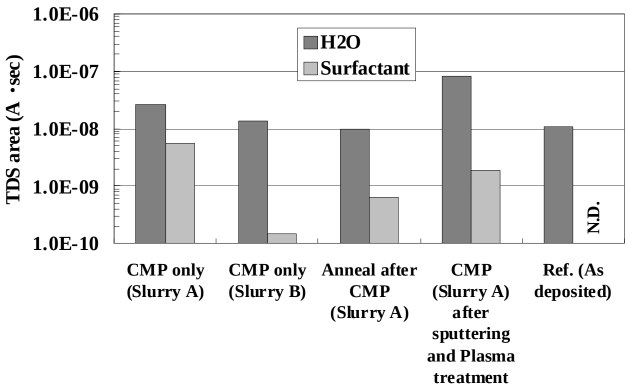


Fig.9 Degassed amount of H_2O and surfactant.