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The Delamination Mechanism of Porous Low-k Film during the Cu-CMP Process

S. Kondo, T. Nasuno, S. Ogawa, S. Tokitou, B.U. Yoon, A. Namiki,[1] Y. Sone,[1] K. Misawa, T. Yoshie, K. Yoneda, M. Shimada, S. Sone, H.J. Shin, N. Ohashi, I. Matsumoto and N. Kobayashi

Semiconductor Leading Edge Technologies, Inc. (Selete)
16-1 Onogawa, Tsukuba, Ibaraki 305-8569, Japan
Phone: +81-29-849-1285, FAX: : +81-29-849-1186, E-mail: kondou3@selete.co.jp
[1]Novellus Systems Japan, Inc.
3-2-1 Sakado, Takatsu-ku, Kawasaki, Kanagawa 213-0021, Japan

1. Introduction

Low-k dielectrics have been extensively investigated as materials that can reduce parasitic capacitance. Porous low-k materials (k=1.8-2.5) are thought to be most promising for 65-nm technology nodes. Most porous low-k materials, however, have poor adhesion to cap-CVD film. This often results in film delamination during the Cu-CMP (chemical-mechanical polishing) process. To reduce mechanical stress on the porous low-k film, low-pressure CMP has been developed [1]. It is known that there exists strong correlation between CMP failure and Young's modulus of the low-k film [2]. However, mechanism for this correlation is not clear because the modulus is a bulk property of low-k materials and is not directly related with the adhesion between low-k film and cap-CVD film.

In this work, we investigated the relationship between the modulus and adhesion of the porous low-k film with the cap-CVD film and clarified delamination mechanism of the porous low-k film. Based on this mechanism, we have developed reliable high-modulus porous low-k process using low-pressure CMP.

2. Experimental

We used an orbital polishing tool (Novellus Systems, Momentum300) for CMP-induced delamination test. An abrasive-free slurry (Hitachi Chemical; HS-C430-TU) [3] was supplied through 137 small holes in the polishing pad (Rodel, IC1000). The standard polishing pressure was 10 kPa. The delamination test was carried out using a blanket low-k film with a 500-nm-thick electroplated copper film on a 300-mm wafer. The low-k film was a 250-nm-thick SOD (spin-on dielectrics) film, and a 50-nm-thick cap-SiO_2 film was deposited on the low-k film after He-plasma treatment. A 25-nm-thick TaN film was formed to promote adhesion of the Cu film to the cap-SiO_2 film. Several low-k films with various moduli were also compared. The delamination interface was observed by STEM (Hitachi HD-2000) at an acceleration voltage of 200 kV.

3. Results and Discussion

Figure 1 shows the delaminated low-k film area within the 300-mm wafer depending on the polishing time. The modulus of the films decreased as porosity was increased in the low-k materials, while the chemical composition remained unchanged. The delaminated area was measured every 15 s during the 10-kPa CMP by taking a picture of the wafer. All the films with a modulus lower than 3 GPa peeled off within one minute. In contrast, the low-k films with a modulus of more than 8 GPa passed a 1000-s (16.7 min) continuous CMP test without delamination [4].

The delamination interface of the low-k film sample, which has low modulus (1.6 GPa, k=1.8, porosity: 54%), was carefully observed by STEM. As shown in Fig. 2, a plasma-modified layer, about 30 nm thick, was observed under the cap-SiO_2 film, and the delamination interface was found to be just under the modified layer, not at the interface between the cap-SiO_2 film and the low-k film. The adhesion of the plasma-modified layer to the cap-SiO_2 film appeared to be quite strong because we could not find any interfacial delamination in all observed samples. Therefore, the type of delamination in the low-k film was cohesive, and not interfacial. This is thought to be the reason why CMP-induced delamination is related to the modulus, which is a bulk property of low-k materials.

The question then is, which type of delamination can be expected in a low-k film that has not been treated with He-plasma? A CMP delamination test was carried out using a plasma-treated porous low-k film and an untreated film (k=2.2, modulus: 4.5 GPa). As shown in Fig. 3, the delamination resistance improved by one order of magnitude as a result of the He-plasma treatment.

Next, we observed the delamination interface of the untreated sample. As shown in Fig. 4, there was a plasma-modified layer, but its thickness was thinner than that of the plasma-treated sample, and it was not uniform even in the small field of STEM vision. Though this non-uniformly modified layer is thought to have been formed in the initial stage of the CVD-SiO_2 deposition process, cohesive delamination also occurred just under the thin modified layer, and not at the interface between the cap-SiO_2 film and the low-k film. Therefore, not only high modulus, but He-plasma treatment is also effective in forming a uniformly modified layer that promotes adhesion of the porous low-k film to the cap-SiO_2 film.

Finally we successfully integrated a porous low-k film with high modulus of 10 GPa (k=2.3) in 2-level dual damascene structure. No changes in thickness, refractive index, k value or FT-IR spectra after the He-plasma treatment were observed. Other techniques such as SOD adhesion promoter (low-k film underlayer), dummy metal fill in the field area and low-pressure CMP were also optimized. As shown in Fig. 5, no delamination was observed after M2-layer CMP. The resistance and yield of 0.15 μm via chain was acceptable for 300-mm wafer manufacturing. Cross-sectional FIB-SEM image is also shown in the figure.

4. Conclusions

The delamination of the porous low-k film caused by CMP was found to be cohesive delamination that occurred just under the plasma-modified layer, and not interfacial delamination between the cap-SiO_2 film and the porous low-k film. Therefore, a higher modulus, which is a bulk property of low-k materials, is required to prevent low-k film delamination. He-plasma treatment was also effective in forming a uniformly modified-layer, which worked as an adhesion promoter. The 2-level dual damascene structure was successfully fabricated by using a high modulus (10 GPa) porous low-k film.

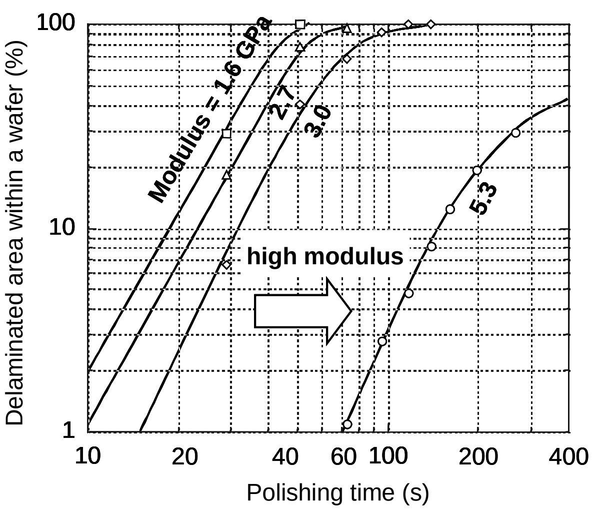

Fig. 1 Dependence of low-k film delaminated area within a wafer on polishing time. He-plasma treatment was carried out for all the low-k films.

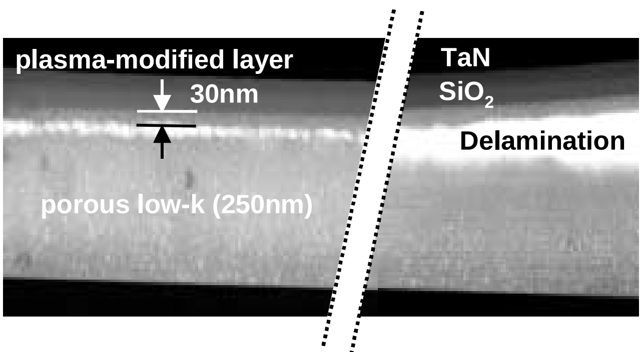

Fig. 2 STEM observation of CMP-induced delamination at the plasma-modified layer formed in the porous low-k film by the He-plasma treatment.

References

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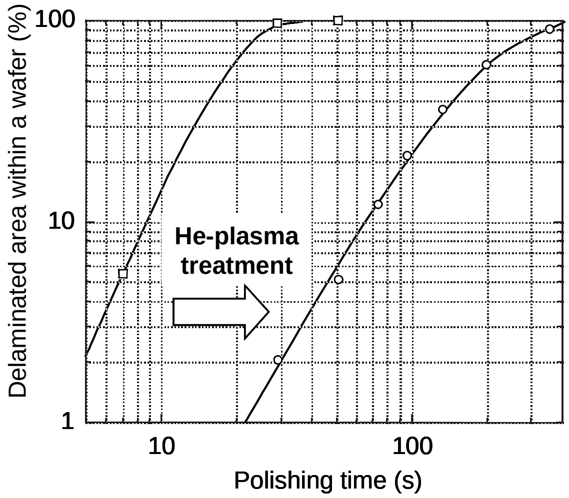

Fig. 3 Effect of He-plasma treatment on adhesion of the porous low-k film to the cap-SiO_2 film.

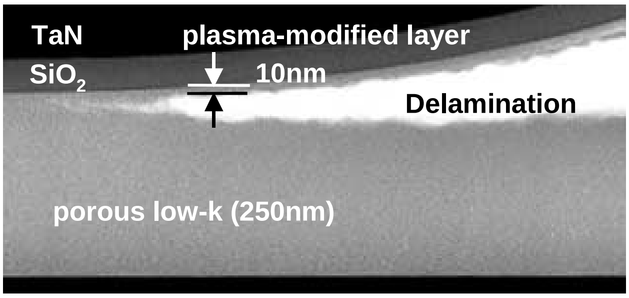

Fig. 4 STEM observation of CMP-induced delamination at the plasma-modified layer formed in the porous low-k film by the CVD deposition (w/o He-plasma treatment).

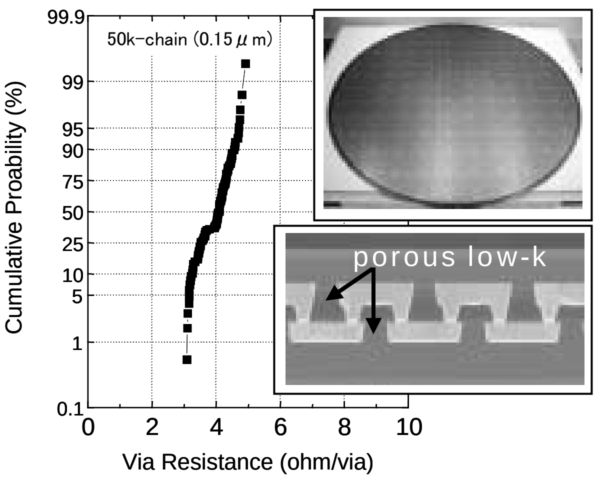

Fig. 5 Via resistance of two-level Cu metallization with porous low-k film (k=2.3). No delamination was observed after M2-layer CMP (10 kPa).