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LETTER

# Photoresist ashing technology using $N_2/O_2$ ferrite-core ICP in the dual damascene process

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The demand for faster devices has resulted in ever smaller design rules, and interconnects are becoming the limit factor for device speed. Accordingly, in order to improve the performance of ultralarge-scale integrated (ULSI) devices, there is a strong demand for using copper and low-$k$ intermetal dielectric materials ($k$ = 2.6–2.9). Dual damascene structures use these new materials and incorporate both lines and vias in one step, decreasing the number of process steps. One of the main problems when building the dual damascene structure is to remove the photoresist (PR) without damaging the low-$k$ dielectrics; The $O_2$ plasma used in the conventional PR ashing process oxidizes low-$k$ material and makes an $SiO_2$-like layer which is called the ''damage'' layer [1–5], causing the increase of the dielectric constant and the leakage current.

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In this paper, we have used the $N_2/O_2$ plasma and varied the $O_2/(N_2 + O_2)$ gas flow ratio in the range of 0.05–0.25 with respect to the PR ashing rate and low-$k$ materials ashing damage, optimizing the PR ashing process. By using the optimized process, we have investigated the characteristics of the PR ashing process with respect to the dual damascene structure in its low-$k$ materials scheme.

The equipment used in this study is an ICP-type etcher with a ferrite-core [6–8]. In our previous study, we have demonstrated the application of the ferrite-core ICP to the PR ashing process [9], in which the ferrite-core is expected to help to obtain a higher plasma density, compared to that of the conventional ICP. During the ashing process, the source power, the bias power, and the pressure were 6000 W (400 kHz), 400 W (13.56 MHz), and 1.1 Torr, respectively. For unpatterned blanket wafers, the Si substrates were coated with a 400 nm-thick layer of low-$k$ materials (SiOCH) with the dielectric constant of 2.8. For patterned wafers, Fig. 1a and b show the cross-sectional scanning electron microscopy (SEM) image and the corresponding schematic diagram, respectively, of the test dual damascene structure employed in this study. The first intermetal dielectric stack consisted of 90 nm barrier film (SiC; BLOk™) and 330 nm low-$k$ film deposited on top of Si substrate. After the via etching process, the via holes were filled with PR and subsequently the 60 nm $SiO_2$ layer was deposited. Layers of 260 nm low-$k$ film and 150 nm $SiO_2$ were then deposited as the second intermetal dielectric stack, followed by the trench etching process.

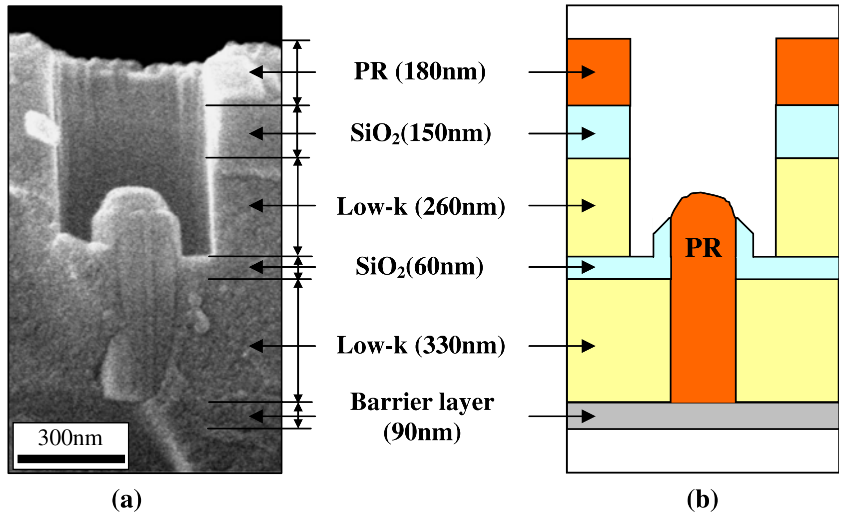


**Fig. 1** (**a**) Cross-sectional SEM image and (**b**) associated schematic diagram, respectively, of the test dual damascene structure prior to ashing process

We have evaluated the degradation of low-*k* materials by treating the ashed samples with 50% aqueous HF solution for 5 s. Immediately after the HF wet treatment, the samples were dipped and rinsed in deionized water. For blanket wafers, only a part of the ashed samples was soaked into the HF solution and α-step profilometer was used to measure the difference of film height between the soaked and the unsoaked regions. For patterned wafers, the whole samples were soaked and SEM was used to observe the dual damascene structure.

Figure 2 shows the variation of PR ashing rate and decreased thickness by the HF wet treatment, with varying the $O_2/(N_2 + O_2)$ gas flow ratio in the range of 0.05 to 0.25. Since the low-*k* materials etching rate during the PR ashing process was relatively small (less than 13 nm/min; not shown here), we have obtained the high enough PR to low-*k* material etch selectivity. It is noteworthy that the amount of removed material by the HF wet treatment, which is represented by the decreased thickness of low-*k* material film on blanket wafer, decreases with decreasing the $O_2/(N_2 + O_2)$ gas flow ratio in the previous ashing process.

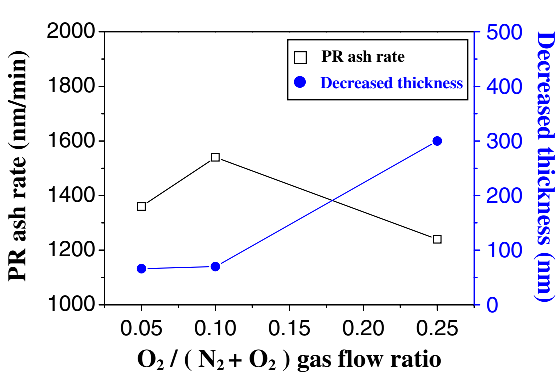


**Fig. 2** Variation of PR ashing rate and decreased thickness by the HF wet treatment, with varying the $O_2/(N_2 + O_2)$ gas flow ratio in the range of 0.05 to 0.25

The oxygen contributes to damaging the low-*k* material presumably by breaking the Si–$CH_3$ and C–H bonds and thus by changing the low-*k* dielectric layer to the $SiO_2$-like material, which can be easily removed by the HF solution. On the other hand, the role of nitrogen may be to dilute the effects of the oxygen species in the plasma and/or to generate the nitrogen containing layer which acts as a barrier against the ashing damage [10]. Therefore, the ashing damage to the low-*k* materials is close to the decreased thickness by the HF wet treatment [5,9]. In order to attain both high PR ashing rate and low ashing damage, we have chosen the PR ashing process with the $O_2/(N_2 + O_2)$ gas flow ratio of 0.1 to be the optimized condition. In the optimized condition, the PR ashing rate and the decreased thickness were 1540 nm/min and 70 nm, respectively.

Figure 3a and b show the cross-sectional SEM images of the dual damascene pattern after PR ashing, respectively, without and with the subsequent HF wet treatment. By comparing with Figs. 1, Fig. 3a reveals that not only the PR on the top $SiO_2$ layer but also the PR inside the via hole has been successfully removed, with the trench hole diameter and via hole diameter of 415 nm and 140 nm, respectively. Fig. 3b indicates that the average trench hole diameter and the via hole diameter after the HF wet treatment are 585 nm and 214 nm, respectively. Therefore, the diameter reduction of trench hole and via hole are approximately 170 nm and 74 nm, respectively, indicating that the estimated thicknesses of damaged layers on the sidewall of trench hole and via hole are approximately 85 nm and 37 nm, respectively. Accordingly, SEM images reveal that the via hole has a reduced thickness of damaged layer compared to the trench hole. While the inner surface of via hole have been exposed to $O_2$ in plasma for a limited period of time due to protection by the pre-filled PR, those of trench hole have been exposed all the time during the ashing process. Additionally, Fig. 3b suggests that

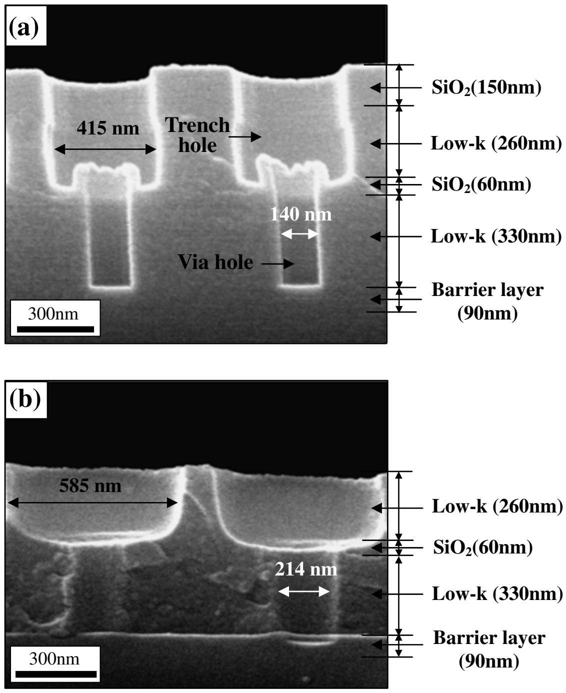


**Fig. 3** Cross-sectional SEM images of the dual damascene pattern after PR ashing, respectively, (**a**) without and (**b**) with the subsequent HF wet treatment

considerable amount of the low-k dielectric material has been preserved without being changed into the $SiO_2$-like material after the PR ashing process and thus employment of $N_2/O_2$ plasma with sufficiently low $O_2$ content may have promising application in the future Cu/low-*k* materials technology. Further study is underway.

In summary, we have investigated the effect of $O_2/(N_2 + O_2)$ gas flow ratio on the PR ashing rate and the ashing damage, optimizing the ashing process. We have employed the optimized process to remove the PR in the dual damascene test structure which comprises the low-*k* materials as interlayer dielectrics. The ashing process removes both PR on top of the structure and inside the via hole. By using the HF wet treatment, we have investigated the effect of ashing on the sidewall low-*k* materials of the dual damascene structure.

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## References

1. Chang TC, Liu PT, Mei YJ, Mor YS, Perng TH, Yang YL, Sze SM (1999) J Vac Sci Technol B 17:2325
2. Liu PT, Chang TC, Mor YS, Sze SM (1999) Jpn J Appl Phys 38:3482
3. Vitale SA, Sawin HH (2002) J Vac Sci Technol A 20:651
4. Kim YH, Kim HJ, Kim JY, Lee Y (2002) J Korean Phys Soc 40:94
5. Yonekura K, Sakamori S, Goto K, Matsuura M, Fujiwara N, Yoneda M (2004) J Vac Sci Technol B 22:548
6. Boyd EL (1968) J Appl Phys 39:1304
7. Hewitt FG (1969) J Appl Phys 40:1464
8. Takata K, Tomiyama F, Shiroishi Y (2004) J Magn Magn Mater 269:131
9. Kim HW, Myung JH, Kim NH, Yoo C-G, Suh KW, Kim SK, Choi D-K, Chung C-W, Kang C-J, Park WJ, Park S-G, Lee J-G (2005) J Mater Sci 40:3543
10. Chang TC, Mor YS, Liu PT, Tsai TM, Chen CW, Mei YJ, Sze SM (2001) Thin Solid Films 398–399:632