Application of N_2/Ar inductively coupled plasma to the photoresist ashing for low-*k* dielectrics

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As ultralarge-scale integrated (ULSI) circuits are reduced in size to deeper submicron dimension, signal propagation delay, crosstalk, and power consumption are greatly increased due to parasitic capacitance and resistance. Accordingly, in order to improve the performance of ULSI devices, there is a strong demand for low-*k* intermetal dielectric materials ($k =$ 2.6–2.9) instead of SiO_2 that has been conventionally used. However, in the process of moving toward the low-*k* materials scheme, manufacturers have identified new integration challenges. One significant challenge involves photoresist (PR) ashing process which normally uses the O_2 plasma. The O_2 plasma 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. In this paper, we report the characteristics of the PR ashing process using N_2/Ar plasma. We have investigated the ashing damage of low-*k* material by the HF-dipping technique. To the best of our knowledge, this is the first report on the application of N_2/Ar plasma to the PR ashing with respect to the low-*k* material scheme.

The equipment used in this study is an ICP-type etcher with a ferrite-core. Several researchers have studied the properties and applications of the ferrite-core [6–8]. Although the detailed study is underway [9], the installed ferrite-core is expected to help obtaining a higher plasma density by providing the magnetic field energy, compared to that of the conventional ICP. During the ashing process, the source power was 6000 W with a frequency of 400 kHz, the pressure was 1.1 Torr, and the bias power (13.56 MHz) was 400 W. The silicon substrates were coated with a 4000 Å-thick layer of low-*k* materials (SiOCH) with the as-deposited dielectric constant of 2.8, by the chemical vapor deposition method. The film degradation was evaluated by treating with 50% aqueous HF solution for 5 s. Immediately after the HF dipping, the samples were dipped and rinsed in deionized water. Only a part of the ashed samples was soaked into the HF solution and subsequently alpha-step profilometer was used to measure the difference of film height between the soaked and the unsoaked regions.

Fig. 1 shows the changes of photoresist (PR) ashing rate and low-*k* material etching rate with varying the $N_2/(N_2 + Ar)$ gas flow ratio in the range of 0–1, revealing that PR ashing rate increases with increasing the $N_2/(N_2 + Ar)$ gas flow ratio. Although we surmise that the reduction of the ashing rate by increasing the $Ar/(N_2 + Ar)$ gas flow ratio is due to chemical inertness of Ar with the PR mask, further systematic investigation is necessary. We observe that the etching rate of low-*k* material is less than 100 Å, regardless of the $N_2/(N_2 + Ar)$ gas flow ratio. Fig. 2 shows that the PR to low-*k* material etch selectivity increases with increasing the $N_2/(N_2 + Ar)$ gas flow ratio and the selectivity is higher than 10 at the $N_2/(N_2 + Ar)$ gas flow ratio in the range of 0.25–1.

Since the damaged layer is the region where the Si—CH_3 and C—H bonds have been broken and thus was changed to the SiO_2-like material, it is easily etched by the HF solution, while the original low-*k* material is not. Therefore, the decreased thickness by the HF dipping

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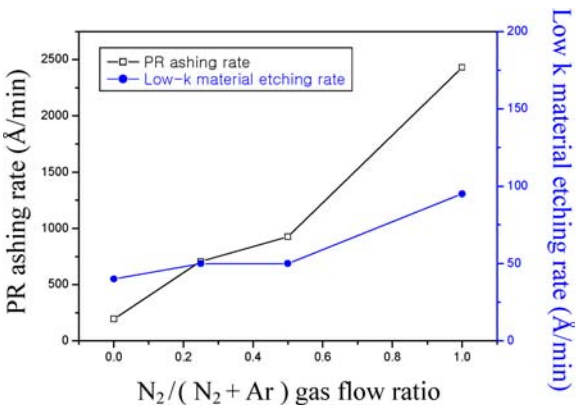

Figure 1 Variation of the PR ashing rate and the low-*k* material etching rate with varying $N_2/(N_2 + Ar)$ gas flow ratio.

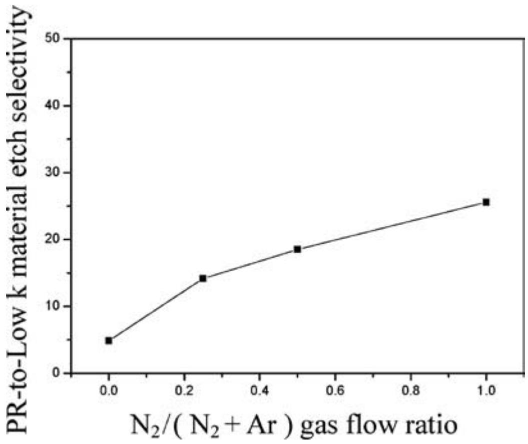

Figure 2 Variation of PR to low-*k* material etch selectivity with varying $N_2/(N_2 + Ar)$ gas flow ratio.

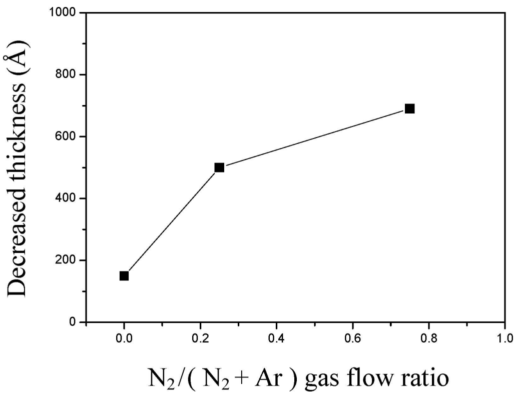

Figure 3 Decreased thicknesses of the low-*k* material films by the HF dipping treatment, depending on the previous ashing process with varying the $N_2/(N_2 + Ar)$ gas flow ratio.

is close to the thickness of the damaged layer [5].Fig. 3 shows the decreased thicknesses of the low-*k* material films by the HF-dipping treatment (i.e. the difference of low-*k* material film thickness before and after the HF dipping) depending on the previous ashing process with varying $N_2/(N_2 + Ar)$ gas flow ratio. The decreased thicknesses of the samples after the HF-dipping, which were previously ashed with the $N_2/(N_2 + Ar)$ gas flow ratio of 0, 0.25, and 0.75, respectively, are measured to be approximately 150, 500, and 690 Å. Accordingly, we surmise that the ashing damage decreases with increasing the $Ar/(N_2 + Ar)$ gas flow ratio. Although the N_2 plasma is known to generate the smaller degradation of the low-*k* film than the conventional O_2 plasma does [5], we reveal that the Ar plasma is even more effective in reducing the ashing damage, possibly due to the inertness of Ar species with regard to CH_3 groups in the low-*k* material.

In summary, we studied the PR ashing using N_2/Ar gas in an ICP. We reveal that both the PR ash rate and the PR to low-*k* material etch selectivity increase with the increasing $N_2/(N_2 + Ar)$ gas flow ratio. The HF-dipping treatment indicates that the ashing damage increases with the increasing $N_2/(N_2 + Ar)$ gas flow ratio. Therefore, we suggest that the $N_2/(N_2 + Ar)$ gas flow ratio in the ashing process should be optimized by considering both the ashing rate and the ashing damage.

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