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Photoresist ashing in nitrogen gas using ferrite core inductively coupled plasmas

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Abstract

The characteristics of photoresist (PR) ashing using N_2 plasmas in a ferrite core inductively coupled plasma etcher have been studied and the effect of bias power and gas flow rate on PR ash rate and low-*k* material etch rate has been investigated. Fourier transform infrared spectroscopy revealed that the ashing process with N_2 gas produced less damage to the low-*k* material compared to the process with O_2 gas. The HF etch test was used to evaluate the ash damage to the low-*k* material.

Keywords: Plasma ashing; Low-*k* material; Ferrite core HF plasmas

1. Introduction

Changes in the interconnections are inevitable as the manufacturing technologies move beyond the 180 nm technology mode due to the decrease of dimensions and increase of the wiring density. Since resistance–capacitance delay in the metal interconnects becomes a serious problem at high clock frequencies, low dielectric constant (low-*k*) materials ($k = 2.6-2.9$) have been introduced.

However, since O_2 plasma oxidizes low-*k* material and makes an SiO_2-like layer which is called the "damage" layer [1–5], the O_2 plasma ashing process drastically degrades the electrical and mechanical characteristics of the low-*k* material, causing an increase in the dielectric constant and the leakage current.

In this paper, we report the characteristics of the ashing process using an N_2 gas. We have used an inductively coupled plasma (ICP) system with a ferrite core. Several researchers have studied the

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properties and applications of the ferrite core [6–8] and we expect that the ferrite core helps to increase the plasma density in the ashing process. We have investigated the ashing damage of the low-*k* material by an HF dipping technique and Fourier transform infrared (FTIR) spectroscopy.

2. Experiments

The equipment used in this study is an ICP-type etcher with a ferrite core (Fig. 1). Although the detailed study is not yet complete [9], the installed ferrite core is expected to help to obtain a higher plasma density, compared to that of the conventional ICP. The chamber was pumped down by a dry pump and a booster pump with a base pressure of 4 Pa. During the ashing process, the source power was 6000 W with a frequency of 400 kHz, and the pressure was 150 Pa. The bias power (13.56 MHz) and the gas flow rate, respectively, were in the range of 0–1000 W and 2–6 l/min. The samples were situated on the centre of the wafer, which was held on a mechanical chuck. The 13.56 MHz RF bias power supply was coupled to the electrode to extract ions from the plasma.

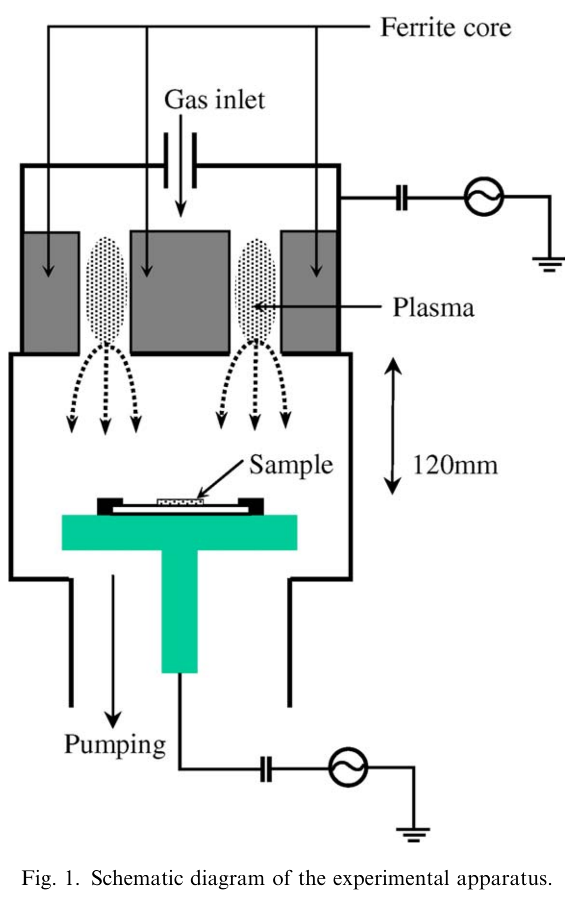

Fig. 1. Schematic diagram of the experimental apparatus.

The silicon substrates were coated with a 400 nm thick layer of low-*k* materials (SiOCH) with an as-deposited dielectric constant of 2.8, by the chemical vapour deposition method. The chemical bonds of the low-*k* material films after different ashing processes were investigated by FTIR spectroscopy (Bruker-IFS66V/S). In addition, film degradation was evaluated by treating with a 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 an alpha-step profilometer was used to measure the difference of film height between the soaked and the unsoaked regions.

3. Results and discussion

In order to investigate the ashing characteristics using N_2 gas, we varied the bias power and the gas flow ratio. Fig. 2(a) shows the changes of photoresist (PR) ash rate and low-*k* material etch rate on varying the bias power in the range 0–1000 W with a fixed gas flow rate of 4 l/min, revealing that the PR ash rate slightly increases with increasing bias power. With a bias power of 1000 W, the PR ash rate is about 248 nm/min. Fig. 2(b) shows the changes of PR ash rate and low-*k* material etch rate on varying the gas flow rate in the range 2–6 l/min with a fixed bias power of 400 W, revealing that the PR ash rate decreases with increasing gas flow rate. With a gas flow rate of 2 l/min, a PR ash rate of about 451 nm/min is attained. We surmise that the lower gas flow rate provides a longer residence time, resulting in a more efficient ashing process. We observe that the etch rate of a low-*k* material is measured to be below 8 nm/min, regardless of the bias power and gas flow rate. Therefore, a PR to low-*k* material etch selectivity of higher than 20 has been

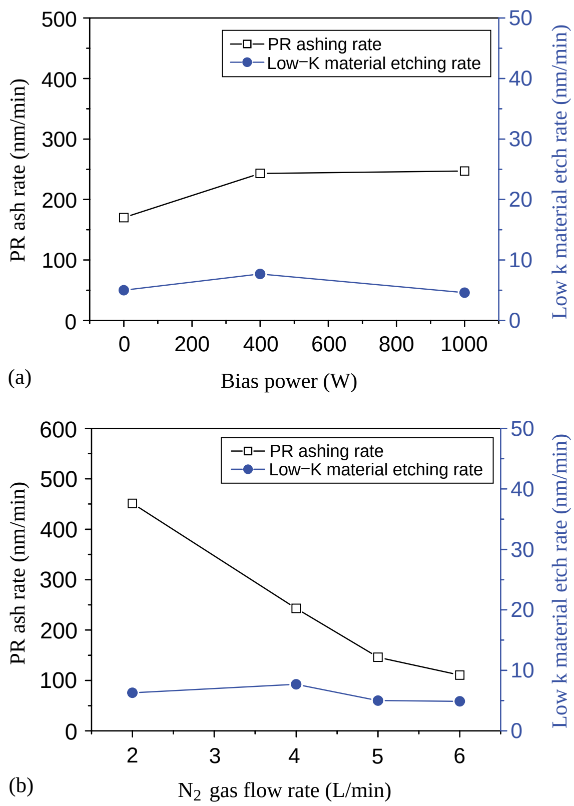

Fig. 2. Variation of the PR ash rate and the low-*k* material etch rate with varying (a) bias power at a fixed gas flow rate of 4 l/min and (b) N_2 gas flow rate at a fixed bias power of 400 W. The source power and the pressure were 6000 W and 150 Pa, respectively.

obtained, regardless of the bias power and gas flow rate. A high selectivity of about 72 is obtained at a bias power and gas flow rate of, respectively, 400 W and 2 l/min.

We have investigated the chemical bonding characteristics of the low-*k* material films using FTIR absorbance analysis. Fig. 3 shows the FTIR absorbance spectra of the low-*k* material films after the ashing process. The spectra exhibit Si–O, Si–CH_3, and C–H absorption peaks, respectively, centred at 1080, 1270, and 2970 cm^{-1}. Compared with the spectrum of the O_2-ashed films shown in Fig. 3(a) [10], we find that the spectrum of N_2-ashed films shows higher relative intensities of the C–H and Si–CH_3 peaks with respect to the Si–O peak, regardless of the bias power and gas flow rate (Figs. 3(b)–(e)). We surmise that during O_2 plasma ashing, the Si–CH_3 and C–H bonds in the films are readily attacked and broken by the active oxygen species of the plasma discharge, and subsequently replaced by Si–O bonds, resulting in a more SiO_2-like film with a high dielectric constant. On the other hand, the nitrogen is less

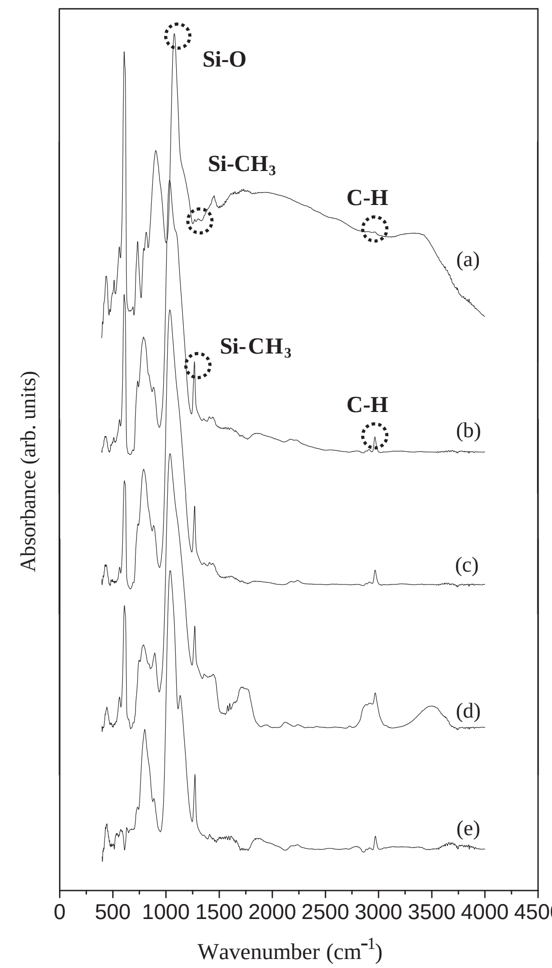

Fig. 3. FTIR absorbance spectra of the low-*k* material films after the ashing process with (a) O_2 gas flow and (b)–(e) N_2 gas flow. The bias power and the gas flow rate of the ashing process, respectively, are (a and b) 400 W and 4 l/min, (c) 1000 W and 4 l/min, (d) 400 W and 6 l/min, and (e) 400 W and 2 l/min. The source power and the pressure were 6000 W and 150 Pa, respectively.

reactive than oxygen and generates a nitrogen containing layer by doping which acts as a barrier against moisture or oxygen uptake [11]. Further study is necessary to establish the detailed mechanism.

Since there was no noticeable variation in the FTIR spectrum with varying bias power and gas flow rate in the N_2 ashing process, in order to evaluate the degree of degradation in the low-*k* material film, we applied the HF dipping test. Since the damaged layer is the region where the Si–CH_3 and C–H bonds have been broken (and thereby changed to a SiO_2-like material), it is easily etched by the HF solution, while the original low-*k* material is not. Therefore, the decrease in thickness caused by the HF dipping is close to the thickness of the damaged layer. Fig. 4(a) shows the decreased thicknesses of the low-*k* material films by the HF dipping treatment (i.e. the difference in low-*k* material film thickness before and after the HF dipping) depending on the previous N_2 plasma ashing process with varying bias power. The decreased thicknesses of the samples after the HF dipping, which were previously ashed with bias powers of 0, 400 and 1000 W, respectively, are measured to be 43, 57, and 27 nm. Although the difference in the decreased thickness between 0 W- and 400 W-ashed samples is within the statistical error, we observe that the amount of removed material by the HF dipping is noticeably reduced at a bias power of 1000 W. Based on previous experiments and analyses, we estimate that the plasma density slightly increases with increasing bias power and does not significantly change with varying N_2 gas flow rate in our experimental regime. Since the self-bias voltage increases with increasing bias power in our experimental regime (not shown here), we surmise that the nitrogen ions have a relatively higher energy in the 1000 W-ashed process, efficiently forming a nitrogen-containing passivation layer on the low-*k* material films. On the other hand, the decreased thicknesses of the samples after the HF dipping, which were previously ashed with gas flow rates of 2, 4, 5, and 6 l/min are measured to be 45, 57, 48, and 41 nm, respectively, revealing that the amount of material removed by the HF dipping is not significantly dependent on the gas flow rate.

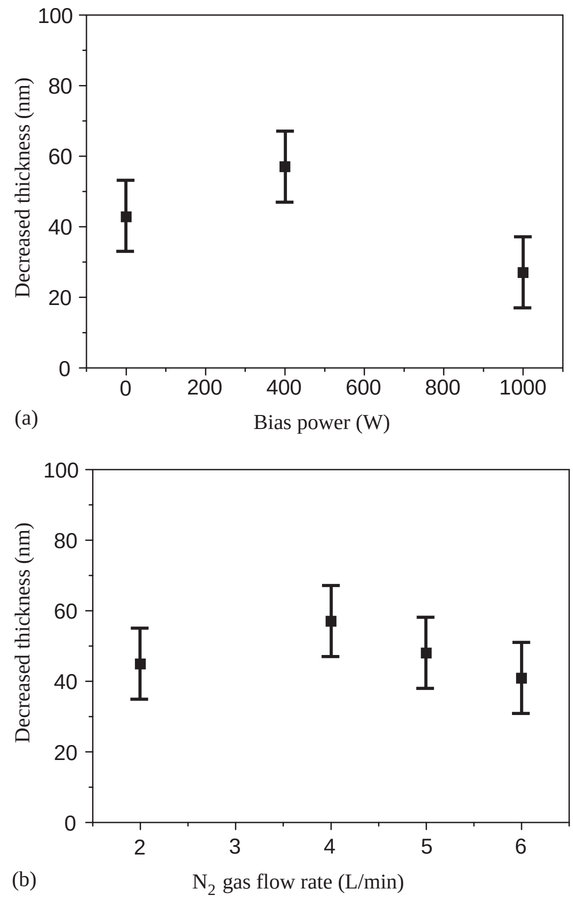

Fig. 4. Decreased thicknesses of the low-*k* material films by the HF dipping treatment, depending on the previous ashing process with varying (a) bias power at a fixed gas flow rate of 4 l/min and (b) N_2 gas flow rate at a fixed bias power of 400 W. The source power and the pressure were 6000 W and 150 Pa, respectively.

4. Conclusion

We have studied the PR ashing using N_2 gas with a ferrite core ICP. We have shown that the PR ash rate is dependent on the bias power and increases with decreasing N_2 gas flow rate. Etch rate of the low-*k* material is less than 8 nm/min. Compared with the FTIR spectrum of O_2-ashed films, we found that N_2-ashed films show higher relative intensities of C–H and Si–CH_3 peaks with respect to the Si–O peak. In order to further evaluate the ash damage to the low-*k* material, we have measured the decreased thickness after HF treatment for varying bias power and N_2 gas flow rate.

Acknowledgements

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