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Low-k Film Damage-Resistant CO chemistry-based Ash Process for low-k/Cu Interconnection in Flash Memory Devices

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1. Introduction

Memory devices, such as Flash memories and dynamic random access memories (DRAMs), have rapidly increased their storage capacity by decreasing critical dimensions. On the other hand, the extreme shrinkage of critical dimensions increases parasitic capacitance between memory cells, which results in significant signal delay and power consumption. Therefore, low-k dielectric interlayer materials which reduce parasitic capacitance are considered as the inevitable in sub-40nm memory devices.

One of the big challenges is photo resist removal process on low-k materials using oxygen plasma. Generally ash processes are known to deteriorate the dielectric properties of low-k films through CH₃ loss and oxygen absorption such as O-H, H₂O and CO bonds [1][2]. These effects result in significant increase of dielectric constant. The needs of low-damage ash have consequently requested. Hydrogen containing chemistries (NH₃, H₂) have been reported to show good compatibility with low-k materials, but they have also critical problems [1][3][4].

In this paper, we suggest CO chemistry-based ash process conditions for 40nm node Flash memory integration using low-k materials. Ash processes with various chemistries in commercial ash process equipments were performed. Damages were characterized both on blanket and trench patterned materials. Diagnostic methods used for film analysis include Fourier transform infrared spectroscopy (FTIR), k-value measurements, and sidewall shrinking profile measurements through a cross-sectional scanning electron microscope (SEM) after filling trench with Cu.

2. Experimental

We have used 300 mm diameter silicon wafers coated with two types of low-k films of 250nm thickness for a comparative study. Each low-k films have k=3 after UV treatment and k=2.5 after UV treatment. The investigated ash chemistries are N₂, O₂, CO or their gas mixtures (CO/O₂ or N₂/O₂). NH₃ plasma was not used due to low removal rates for photo resist and the formation of the carbon-based residues. Ash processes were respectively performed on a triple frequency coupled-plasma equipment (TFCCP), inductively-coupled plasma (ICP) equipment, and reactive ion etcher (RIE). Blanket and trench patterned wafers were both pre-exposed to fluorocarbon chemistries for low-k materials etch. Plus

exposure time of ash plasmas corresponds to the enough time to ash photo resist (300nm thickness). After ash processes, film analysis include FTIR, k-value measurements, and analysis of side-wall profiles through a cross-sectional SEM after filling trench with Cu. Table I shows various ash conditions in this experiment.

Table I Ash Processes

Ash	Equipment Type	Condition
A	TFCCP	30mTorr, CO/O ₂
B	TFCCP	100mTorr, CO/O ₂
C	TFCCP	30mTorr, CO
D	TFCCP	3mTorr, O ₂
E	RIE	500mTorr, O ₂ /N ₂

3. Results and Discussion

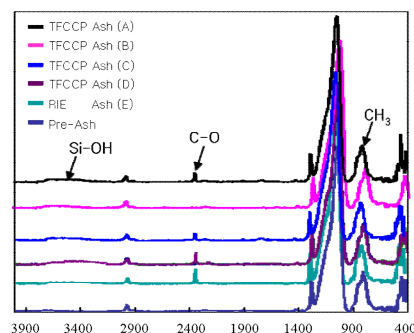


Fig.1 FTIR spectra of as-deposited low-k films and after ashes (A), (B), (C), (D), and (E)

Figure 1 illustrates the FTIR spectra on low-k films after plasma exposure with various process conditions. FTIR spectra show that the peaks in the region between 3000-3700 cm⁻¹, which were not obtained on as-deposited materials, are allotted at Si-OH. C-O bonds are located at 2400 cm⁻¹. As for the broad region between 700 and 900 cm⁻¹, the peaks are assigned to Si-CH₃ bonds. The low-k properties can be evaluated by calculating the Si-CH₃, Si-OH, and C-O bonds on the film from the FTIR spectra resulting from oxygen radicals. FTIR spectra show the noticeable changes of Si-OH and C-O with use of ashes (D) and (E), while no significant changes is seen for ashes (A), (B), and (C) with use of CO/O₂ gas mixture in TFCCP

etcher.

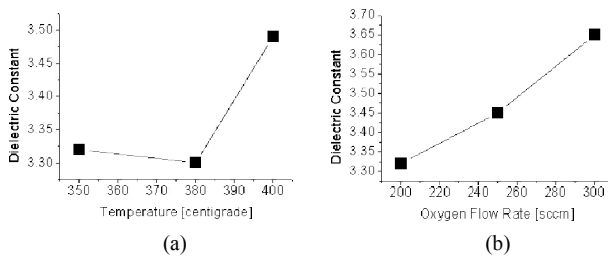


Fig. 2 Dielectric constant (k) shift in RIE plasma equipment (a) dielectric constant shift vs. temperature (b) dielectric constant shift vs. O₂ flow rate

The changes in film such as composition and film density all contribute to affect the film dielectric constant. Fig. 2 illustrates the shift of k-value according to oxygen flow rate and substrate temperature during ash process. Fig. 2 shows the high substrate temperature and oxygen flow rate result in substantial increases in k value. It represents the reaction of low-k films to oxygen radicals is critical to the dielectric constant change.

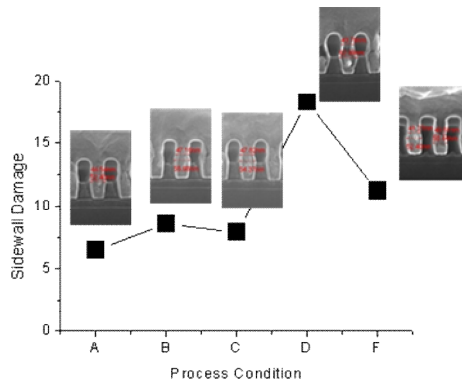


Fig. 4 Cross-sectional SEM images of the trench-patterned samples after ashes (A), (B), (C), (D), and (E).

Reducing sidewall shrinking profiles on low-k films, which results the significant RC delay, is also the key issue for application in sub-40nm Flash memory devices [5]. Sidewall shrinking profiles by ash processes were measured at cross sectional SEM. Fig. 4 shows oxygen radicals induce sidewall shrinking profiles in low-k/Cu interconnection during trench etching. Fig. 4 indicates the sidewall damage by ashes (A), (B), and (C) in TFCCP etcher is smaller than that of ashes (D) and (E) without use of CO chemistry. It was found that oxygen radicals and anisotropic etch are working as the most important factor. However, exposure of oxidative plasma is indispensable for photo resist removal on low-k film. NH₃, H₂, and N₂ chemistry-based processes have been reported on some papers but they induce serious carbon-rich residue in trench bottom area due to its low removal rate of carbon layer [1][3][4]. Therefore, CO chemistry-based ashes are strongly recommended. All measured parameters with use of the CO chemistry-based plasma showed little changes of dielectric

properties as well as undercut profile for low-k films. It shows that carbon radicals from CO plasma are helpful to reduce carbon depletion and moisture absorption.

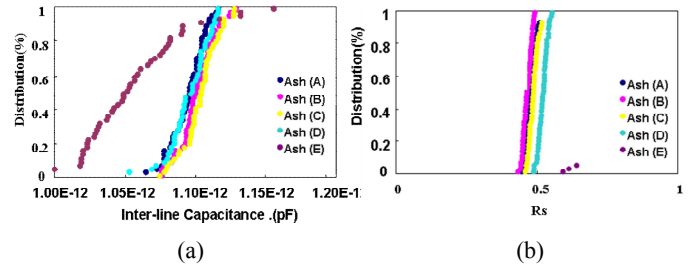


Fig. 5 Inter-line capacitance and metal resistance measured at 40nm node Flash memory devices. (a) Inter-line capacitance. (b) Metal resistance.

Fig. 5 presents results of electrical measurements on 40nm node Flash memory. As a result, Ashes (A), (B) and (C) using CO chemistry-based plasma show the good electrical measurement results, such as values of inter line capacitance and metal resistance. On the other hand, both ashes (D) and (E) without CO chemistry induced the degradation of electrical properties.

4. Conclusions

Dielectric properties were characterized both on blanket and trench patterned with low-k ($k=3.0$) materials using various ash conditions. All measured parameters, such as electrical characteristics, sidewall shrinking profile, and dielectric constant shift, proved that the ash chemistry was more crucial parameter than ash equipment type for determining of low-k damage. Especially, CO chemistries showed very prominent results for photo resist strip process with low-k integration.

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Appendix

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