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Generation Mechanism of Etching Damages on Low-k SiOCH Films and Development of Novel Damage Evaluation Technique

Masaru Hori

Nagoya Univ., Dept. of Electric Engineering and Computer Science
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
Phone: +81-52-789-4420 E-mail: hori@nuee.nagoya-u.ac.jp

1. Introduction

In ultra-large scale integrated circuits (ULSIs), high-speed operation to process large amount of information as well as complex functions and low power consumption is strongly required. In response, ULSIs today has advanced by shrinking device dimension and by high integration of semiconductor devices. The number of interlayer dielectrics in advanced logic devices has increased. ULSI is mostly occupied with interconnecting wiring metal whose length is several kilometer in one chip. The total delay in ULSIs is determined by the sum of the gate and interconnect delays. The gate delay decreased monotonously due to the reduction in gate length, while the interconnection delay has come to play a dominate role in determining the total signal delay in ULSIs rather than the gate delay. It is thus important to reduce the wiring resistance and parasitic capacitance for improving signal transmission rates. The improvement in chip performance will be greatest when Cu is combined with low dielectric constant (low-k) materials using multilevel interconnects. However, developing low-k dielectrics with required chemical, mechanical, electrical and thermal properties to be used in ULSI application is difficult. Several low-k materials with excellent properties as an alternative to conventional interlayer dielectric film of SiO_2 has been proposed [1-3].

The low-k films are damaged by the plasma during fabrications of via holes and trenches and removal of photoresist. The plasma damage induces the structural change on the surface of the films by irradiating ions, radicals and lights in plasmas and the increase in the dielectric constant of the low-k films. In order to realize the damage free plasma processes, it is indispensable to clarify the generation mechanism of the plasma damages by lights, radicals and ions in process plasmas.

In this study, the novel technique for evaluating plasma damages due to lights, radicals, and ions was developed. Using this technique, we have evaluated the plasma damage on the properties of the low-k films systematically.

2. Experiment

The dual frequency capacitively coupled plasma etching apparatus used in this study was shown in figure 1. The H_2 and N_2 mixture gas was used. The distance between the upper electrode and the sample was 50 mm.

In order to clarify the damages due to lights, radicals and ions from the plasmas separately, we have developed a novel sample setup technique. We call the technique a pallet for plasma evaluation (Pape). Figure 2 shows the schematic diagram of the Pape. The MgF_2 and quartz windows were put directly on the film to clarify the influences of vacuum ultraviolet (VUV) light and ultraviolet (UV) light from the plasmas (sample (a) and (b)), respectively. The MgF_2 and quartz windows transmit the light of wavelengths 115nm or more and 170 nm or more, respectively. Si plate was put 0.7 mm above the film surface to investigate the influence of radicals (sample (c)). In order to investigate the influence of the interaction of VUV and UV lights with radicals, the MgF_2 and quartz windows were put 0.7 mm above the film (sample (d) and (e)), respectively. To clarify all the influences of lights, radicals and ions, nothing was put on the film (sample (f)). The porous SiOCH film as the low-k films in this study was prepared. The value of the dielectric constant of the film was 2.2.

The refractive index of the films before and after plasma exposure was evaluated because the refractive index was proportional to square root of the dielectric constant. The refractive index and the film thickness were measured by a spectroscopic ellipsometer. Thermal desorption spectroscopy (TDS) was used to investigate the outgassing from the films.

Moreover, in order to measure the transmission spectra of the porous SiOCH films, the sample which the porous SiOCH film was deposited on the MgF_2 windows was employed. The thickness of the film deposited on the MgF_2 window was 50 nm. The sample was set between the chamber wall and the VUV monochromator. The optical emission through the sample from the etching plasma was measured and the transmission characteristics of the porous SiOCH films in real plasma condition were evaluated.

3. Results and discussions

Figure 3 shows the film thickness at various sample conditions. The experimental condition damaged was a VHF power of 500 W, a bias power of 500 W, a pressure of 5.3 Pa, and a gas flow rate ratio of 50%. The etching time was 2 minutes. The etching depth of sample (f) was about 25 nm. However, the samples from (a) to (e) were not etched.

Figure 4 shows the refractive index of the film at various sample conditions. The increase of the refractive index of the sample (f) was the largest. Thus, the damage due to ions was the largest. It was found that the damages on the low-k films were induced by VUV light, UV light and radicals. The damage due to VUV light was the largest among them. Moreover, the damage due to the interaction of the lights and radicals was larger than those due to the individual lights and radicals.

Figure 5 shows the TDS spectra of H_2O in the films after plasma exposure. The amount of outgassing from the sample (f) was the largest. The tendency of the TDS signal at the various sample conditions was corresponding to that of refractive index measurements.

In order to clarify the generation mechanism of the damage on the films due to VUV light, we measured the transmission spectra of porous SiOCH films deposited on the MgF_2 windows at the wavelengths from 115 nm to 200 nm. Figure 6 show the transmission spectra of the films. The plasma condition was a VHF power of 500 W, a bias power of 500 W, a pressure of 5.3 Pa, a gas flow rate ratio of 50 %. There was the big absorption at the wavelengths from 115 nm to 130nm. The small absorption was at the wavelengths from 130 nm to 160 nm. These results indicate that VUV lights were absorbed by porous SiOCH films and VUV lights broke the chemical bonds such as Si-C and Si-O because the energies (wavelengths) of the chemical bonds of Si-C and Si-O contained in the low-k films are 4.5 eV (273 nm) and 3.1 eV (397 nm), respectively. So the plasma damages on the low-k films were induced by VUV lights. The VUV light absorption coefficients of this SiOCH film at the wavelengths of 121 nm and 140 nm were 4.4×10^7 m^{-1} and 8.0×10^6 m^{-1}, respectively. Therefore, the lights at the wavelengths of 121 nm and 140 nm penetrate up to the depth of about 23 nm and 125 nm of this film, respectively.

4. Conclusions

We have developed the technique for evaluating the influences of lights, radicals, their synergies and ions from the plasmas on the low-k films in real process conditions. Using this technique, the systematical evaluation of the plasma damages due to lights, radicals and ions on low-k porous SiOCH films have been carried out. The damage due to the ions was the largest. Increase of the refractive index was caused by VUV lights, UV lights and radicals from the plasmas.

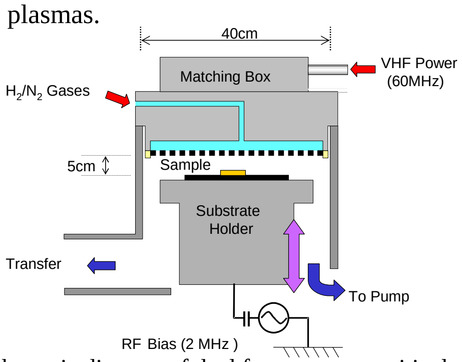

Fig. 1. Schematic diagram of dual frequency capacitively coupled plasma etching apparatus.

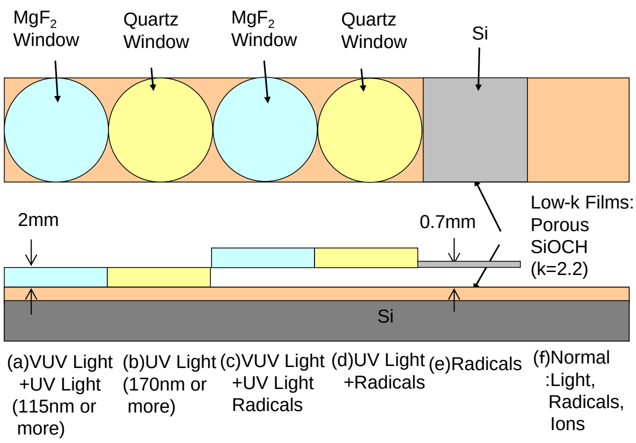

Fig. 2. Schematic diagram of pallet for plasma evaluation : Pape.

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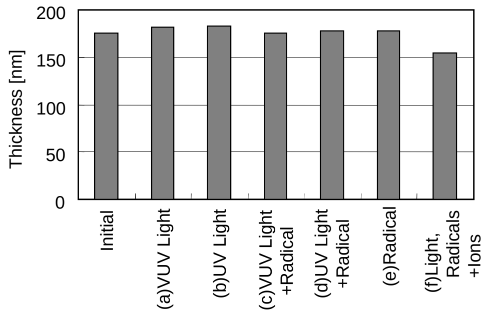

Fig. 3. Films thickness at various sample conditions.

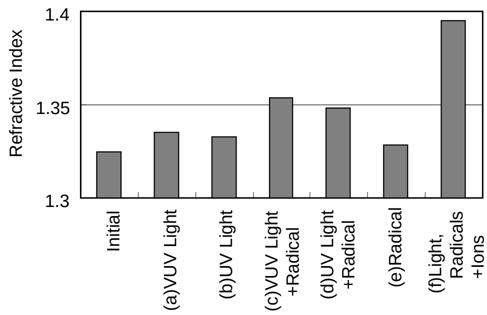

Fig. 4. Refractive index of films at various sample conditions.

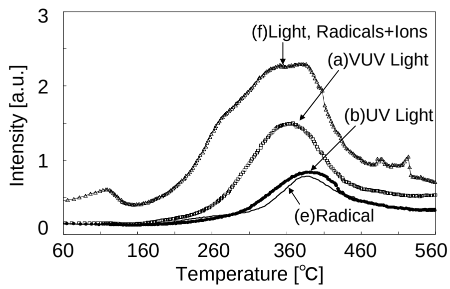

Fig. 5. TDS spectra of films at various sample conditions.

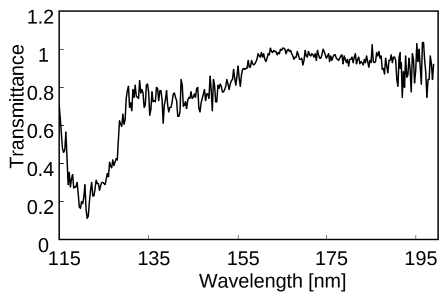

Fig. 6. Transmission spectra of porous SiOCH film at the wavelengths from 115 nm to 200nm.