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Diagnostics of plasma induced damages on low-k SiOCH films

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1. Introduction

In the ultralarge scale integrated circuits (ULSI), the linewidth and space between metal interconnections become smaller with increasing the packing density. However, the influence of the resistance capacitance (RC) delay becomes the serious problem in the limitation for the device performance. For reducing the RC delay, the parasitic capacitance of interlayer dielectrics must be reduced. Therefore, the new insulating materials with a low dielectric constant (low-k) are being developed and introduced into ULSIs. However, the low-k films are susceptible to the damages from the process plasmas in the etching and ashing process. The plasma damages induce the increase of the dielectric constant of the low-k films. In this study, we propose a new technique for evaluating the damage caused by plasma; we call this technique pallet for plasma evaluation (PAPE).[1,2] Using the PAPE, we investigated the properties of the films exposed to the O_2 plasma. From these results, we discuss the mechanisms responsible for generating damage on the porous SiOCH due to exposure to radiation, radicals, and ions and also by synergies between radiation and radicals.

2. Experimental

The dual frequency capacitively coupled plasma (CCP) apparatus for 8 inch wafer processing was used in this study, as shown in Fig. 1. VHF (60MHz) power was applied to upper electrode and the bias power of 2MHz was supplied to the bottom electrode. The O_2 gas was introduced through the shower head on the upper electrode. The substrate temperature was maintained at 20 ^{o}C.

In order to distinguish the influence of radiation, radicals, and ions from the process plasmas, six different etching configurations were prepared. Figure 2 shows a schematic diagram of the PAPE. *Sample (a)*: A MgF_2 window was placed directly on the film surface to clarify the influence of the VUV radiation from the plasmas. *Sample (b)*: A quartz window was placed directly on the film surface to evaluate the influence of the UV radiation from the plasmas. The MgF_2 and quartz window transmit the radiation with wavelength over 115 nm and 170 nm, respectively. *Sample (c)* and *Sample (d)*: The MgF_2 and quartz windows were positioned 0.7 mm above the film to evaluate the effect of the interaction of VUV and UV radiation with radicals. *Sample (e)*: A Si plate was positioned 0.7 mm above the film to investigate the effect of radicals. *Sample (f)*: Nothing was placed above the film to clarify the combined effect of radiation, radicals, and ions. The film properties; refractive index and the film thickness, composition of chemical bonds were measured by using spectroscopic ellipsometry and fourier transform infrared (FTIR) spectroscopy, respectively.

3. Results and discussions

Figures 3 and 4 show the variations in film thickness and refractive index for the various sample conditions after plasma ashing. The experimental conditions were a VHF power of 500 W, a bias power of 500 W, a pressure of 5.3 Pa, and an O_2 gas flow rate of 200 sccm. The processing time was 2 min. The decrease of thickness and the increase of refractive index in the case of sample (c) and (d) were the largest compared with those of the other samples. In the O_2 plasma, the surface of SiOCH exposed to ions was immediately oxidized by the O atom because of dangling bonds generated by ion bombardment. Therefore, it is considered that the damage due to the influence of O atom with irradiation of VUV and UV radiations didn't affect the inside of porous SiOCH films. Figure 5 shows the refractive index changes of porous SiOCH film for the various samples in O_2 and H_2/N_2 CCPs. From these results, in the O_2 plasma, the damages induced by interaction of the VUV and UV radiations with radicals were large, although the damage due to ions was the largest in the H_2/N_2 plasma. However, optical emission intensities around VUV and UV region in O_2 CCP were lower than those in H_2/N_2 plasmas, as shown in Fig. 6. Therefore, it was considered that the influence of O atom with irradiation of VUV and UV radiation on the properties of low-k film was larger than that of H and N atom. Moreover, Si-O/Si-CH_3 ratio of sample (c) and (d) measured by FT-IR were large. (Fig. 7) Therefore, it was found that the influence of oxidation due to O atom assisted by irradiation of VUV and UV radiations induced the damage, which led to increase of dielectric constant of porous SiOCH films in the O_2 CCP.

4. Conclusions

We have developed the technique for evaluating the influences of the radiation, the radicals and the ions on the low-k films in the process plasma. The damages induced by the radiation, radicals, and ions on the porous SiOCH films in O_2 CCP were investigated using the technique. From the results, the influence of oxidation due to O atom assisted by irradiation of VUV and UV radiations induced the damage of porous SiOCH films.

References

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[2] S. Uchida, S. Takashima, M. Fukasawa, K. Ohshima, K. Nagahata, T. Tatsumi , and M. Hori, Jpn. J. Appl. Phys., 47 (2008) in press.

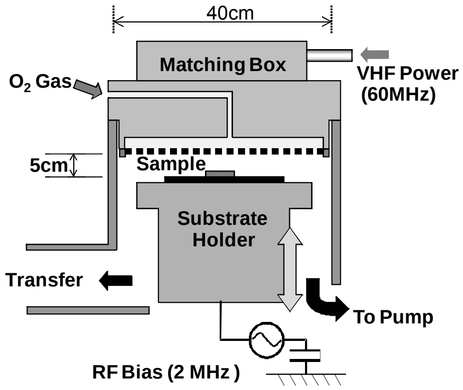

Fig.1. Dual frequency CCP apparatus for 8 inch wafer processing used in this study.

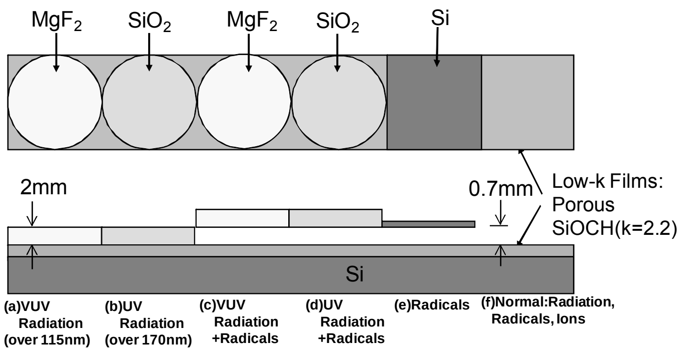

Fig. 2. Schematic diagram of PAPE.

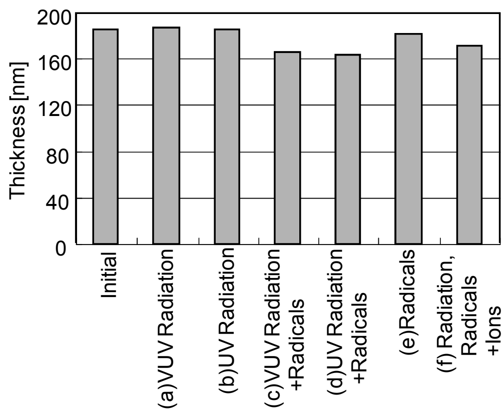

Fig. 3. Thickness of porous SiOCH films for the various samples.

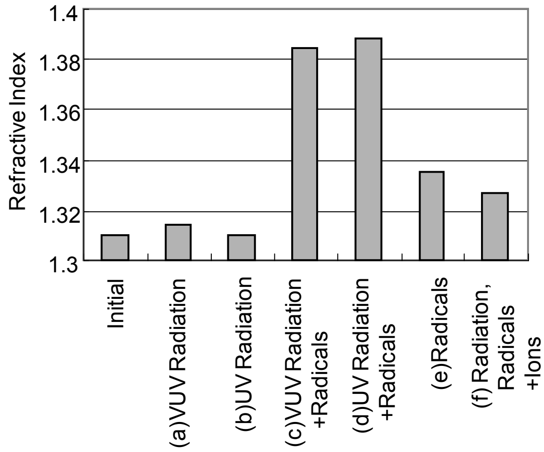

Fig. 4. Refractive index of porous SiOCH films for the various samples.

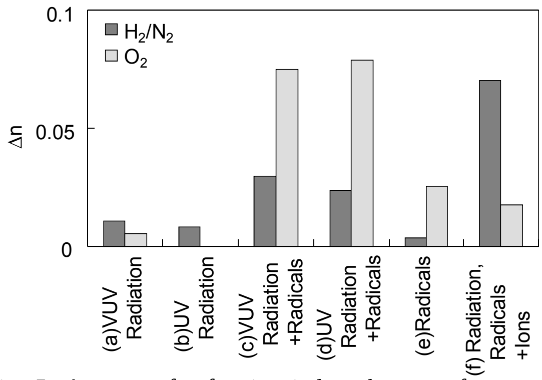

Fig. 5. Amount of refractive index changes of porous SiOCH films for the various samples in O_2 and H_2/N_2 CCPs.

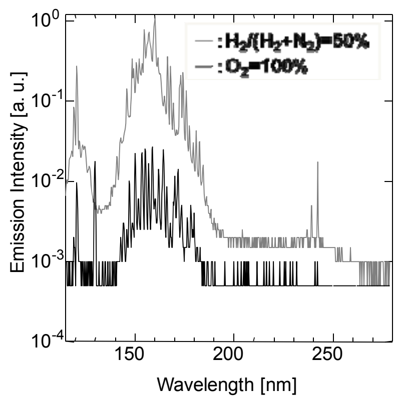

Fig. 6. Emission spectra in O_2 and H_2/N_2 CCPs in VUV and UV regions.

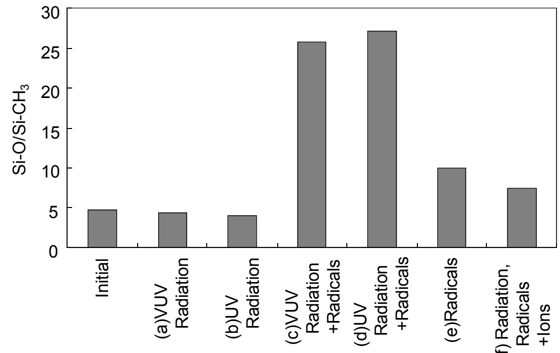

Fig. 7. Si–CH_3 / Si–O ratios for the various samples.