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Effects of CF_3I Plasma for Reducing UV Irradiation Damage in Dielectric Film Etching Processes

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1. Introduction

Plasma etching processes are one of the key technologies for microfabrication of MIS devices. However, plasma irradiation damage to MIS devices causes very serious problems, such as an increase in interface state density between SiO_2 and Si during the dielectric film etching process using perfluorocarbon gas chemistries. Previously, we reported that the increase in the interface state of MIS devices was caused by UV irradiation in the plasma process, and the interface state generation substantially reduced the performance of the sensor in devices such as charge coupled devices (CCDs). [1,2] The UV irradiation damage strongly depends on the kind of gas chemistry and the optimum gas chemistry must be selected for reducing UV irradiation damage. Additionally, the use of perfluorocompounds for the etching of silicon dioxide and silicon nitride is also considered problematic from an environmental standpoint. They can act as greenhouse gases and contribute to the warming of the earth's surface (global warming). To solve this problem, a new gas chemistry (CF_3I, C_2F_4) for high-performance dielectric patterning has recently been proposed. [3]

In this paper, the effects of CF_3I plasma for reducing the UV irradiation damage in dielectric film etching are discussed in comparison with C_4F_8 gas plasma. We found that CF_3I gas plasma was very effective for suppressing the UV irradiation from 250nm to 350nm, and eliminating the increase in the interface state density during the etching processes, as compared with the conventional fluorocarbon gas (C_4F_8) plasma.

2. Experiment

Figure 1 shows the experimental setup for the plasma irradiation. Applying 13.56 MHz of RF power to one turn antenna generates C_4F_8/O_2 and CF_3I/O_2 inductively coupled plasma under the conditions of continuous wave (CW) or pulse-time-modulated (TM) plasma. We used ultraviolet (UV) spectrometer to measure UV light intensity in CW plasma. The flow ratio of the fluorocarbon gas verses oxygen was fixed at 50 sccm/15 sccm under a gas pressure of 2.6 Pa. The electron density was fixed at 6×10^{10} cm^{-3} by varying the RF power of each gas. The interface states were evaluated by using metal-nitride-oxide-silicon (MNOS)-field effect transistor (FET) by the charge pumping method as a charge pumping current. Figure 2 shows the MNOS-FET for measurement of the charge pumping current.

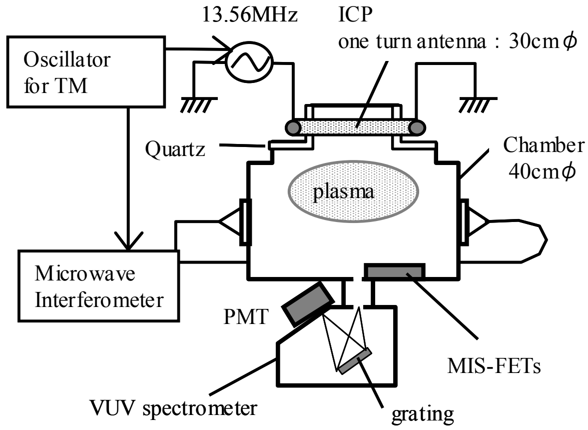

Fig.1. Experimental setup

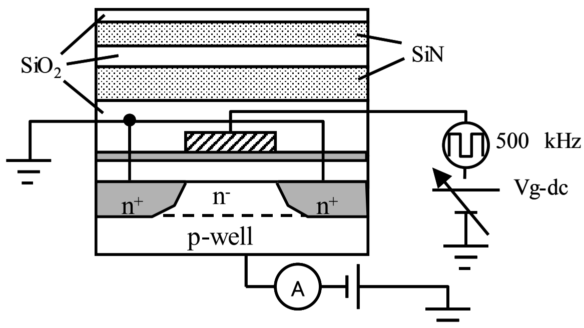

Fig. 2. MIS-FET for charge-pumping current

The gate structure of MNOS-FET was a poly-Si rectangular electrode measuring 20×28 μm and a gate insulation film of LP-CVD SiN (25 nm)/thermal SiO_2 (65 nm). This transistor was an n-channel type. Gate voltage from –6 V to 1 V was applied to the gate electrode. The pulse frequency applied to the gate electrode was 500 kHz and the wave height was 4V. SiO_2 films of 2 μm thickness in total and SiN films of 1μm thickness in total were formed on the transistor as shown in Fig. 2. When the CF_3I/O_2 and C_4F_8/O_2 plasmas were irradiated on the transistor, it appeared that only UV of more than 250nm penetrated to the interface between the gate SiO_2 and Si substrate. This was because the UV light of less than 250nm was almost all absorbed in the thick SiO_2 and Si_3N_4.

3. Results and Discussion

Figure 3 shows the UV spectrum in C_4F_8/O_2 and

CF_3I/O_2 plasmas. In this experiment, we mainly addressed UV intensity from 250 nm to 350 nm (corresponding to UV light from C_xF_y radicals) because this UV light causes an increase in the interface state density. The UV intensity in the C_4F_8/O_2 plasma is much higher than that in the CF_3I/O_2 plasma. Namely, a larger amount of higher molecular weight radicals was generated in the C_4F_8/O_2 plasma, as compared with the CF_3I/O_2 plasma. Figure 4 shows charge pumping current in the MNOS-FET after irradiating each gas plasma. The charge pumping current had a maximum value of about 2V under any conditions. The maximum value in the case of irradiating C_4F_8/O_2 plasma was 4.0E-11 (A) and that was 2.0 E-11 (A) when irradiating CF_3I/O_2 plasma. In other words, the damage in CF_3I/O_2 plasma was about half the damage in C_4F_8/O_2 plasma. Figure 5 shows the integration values of the UV light intensity for wavelengths from 100 nm to 250 nm and from 250 nm to 350 nm. Concerning the wavelengths from 100 nm to 250 nm, there was no difference between C_4F_8/O_2 plasma and CF_3I/O_2 plasma. Conversely, the integration value of UV from 250 nm to 350 nm in the CF_3I/O_2 plasma was limited to about 30% in C_4F_8/O_2 plasma. We reported that UV light from 250 nm to 350 nm could penetrate to the SiO_2/Si interface and drastically influence the device characteristics, because UV light of 5eV or more was almost all absorbed in the Si_3N_4 and UV light of 9eV or more was absorbed in the SiO_2. Consequently, the trend of charge pumping current in the MNOS-FET almost corresponded to the trend of integration value of UV from 250 nm to 350 nm.

Finally, the effect of TM plasma was investigated when using C_4F_8/O_2 and CF_3I/O_2. Figure 6 shows a comparison of charge pumping currents when using CW plasma and TM plasma. The CF_3I/O_2 TM plasma was more effective to reduce the increase in the charge pumping current, as compared with C_4F_8/O_2 TM plasma. This can be attributed to lower electron temperature and lower electron density during the pulse-off time in the CF_3I/O_2 TM plasma, due to the generation of a larger amount of negative ions.

4. Conclusion

Effects of CF_3I plasma, in comparison with C_4F_8 plasma, for reduction of UV irradiation damage during dielectric film etching were investigated using the charge pumping method and measurement of UV light intensity. We clarified that the charge-pumping current of the MNOS-FET after irradiating with CF_3I plasma was much lower than that after irradiating with C_4F_8 plasma. This was because the UV light intensity from 250 nm to 350 nm when using CF_3I was lower than that when using C_4F_8 plasma. Additionally, the CF_3I TM plasma was more effective to reduce the UV irradiation damage than C_4F_8 TM plasma. Based on these results, CF_3I gas plasma is a very promising candidate for future damage-free dielectric film etching.

Acknowledgement

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References

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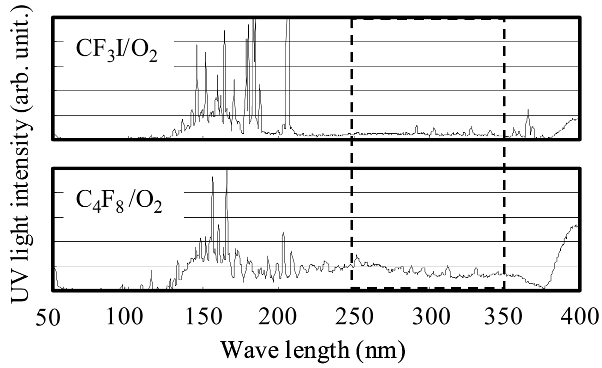

Fig. 3. Observed UV light spectra for each gas

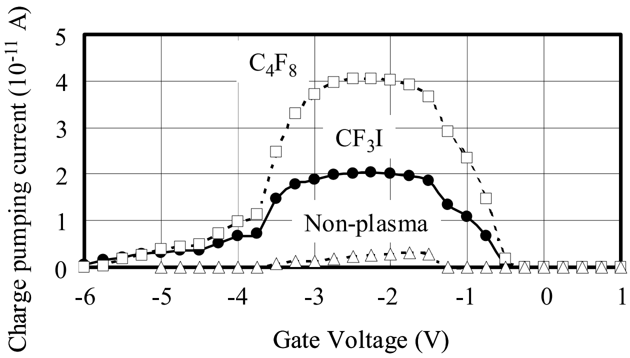

Fig. 4. Charge-pumping current after plasma irradiated

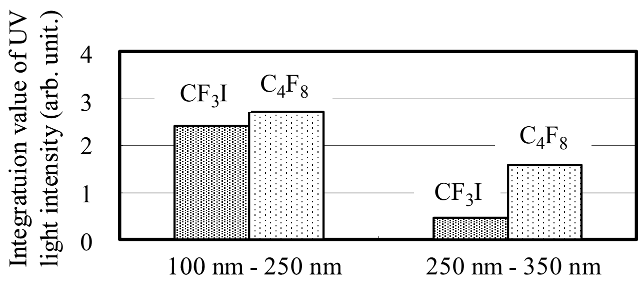

Fig. 5. Integration value of UV light intensity of C_4F_8 and CF_3I gas

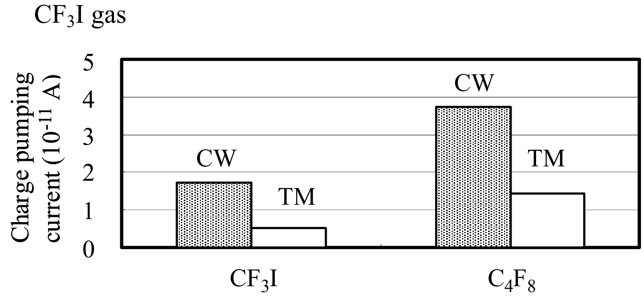

Fig. 6. Charge pumping current in the case of CW and TM of C_4F_8 and CF_3I gas